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# Environmental Conditions in San Martin Lake: Effects of Eutrophication in an Estuary Associated with the Laguna Madre

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# ENVIRONMENTAL CONDITIONS IN SAN MARTIN LAKE: EFFECTS OF EUTROPHICATION IN AN ESUTARY ASSOCIATED WITH THE LAGUNA MADRE

A Thesis

by

WENDY L ROGERS

Submitted to the Graduate College of
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August 2018

# ABSTRACT

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San Martin Lake is a shallow water Estuary in the lower Laguna Madre off the Port of Brownsville Shipping channel. It is influenced both by incoming tides and waste water runoff both from local farms and the Brownsville water treatment plants. The resulting mixture of eutrophic water and incoming sea water creates the perfect mix for a potential algal bloom. This study looks at the nutrient levels and environmental conditions in the main basin of the estuary to establish baseline levels and to observe the rate of nutrient clearing being accomplished in this environment. As sport recreation in the area increases, changes the landscape of the estuary are occurring and, as the population of Brownsville increases the amount of nutrients being released into the estuarial system will continue to increase. It is believed that if not monitored and kept in check this will have detrimental effects on the area. This study looks at the conditions in the lake and attempts to predict what effects changes to the system may have in the future.

# ACKNOWLEDGEMENTS

I would like to thank Dr. Hudson DeYoe, my thesis committee chairman for his mentorship, advice and support throughout this project. From research design to document editing he has provided invaluable advice and experience in this process. I would also like to thank my thesis committee, Dr. Frank Dirrigl and Dr. Robert Dearth for their assistance and input to the project and comments and recommendations on the thesis.

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# CHAPTER I

# INTRODUCTION

## Eutrophication of Estuaries

Estuaries are some of the most unique ecosystems; they consist of areas where ocean waters and fresh water meet and mix creating a range of intermediate salinities which are usually protected by surrounding lands. This protecting land can often restrict the water flow out of the estuary often leading to hypersaline or brackish water depending on the current patterns. Estuaries can range in form from bays and lagoons to marshes and swamps. Because of their unique role of transitioning from freshwater to saltwater, they often have highly productive ecosystems serving both freshwater and marine species as well as species unique to estuaries. Their uniquely intermediate conditions and protected areas serve as effective nesting and breeding grounds or nurseries for the young of many species. Humans also find that estuaries are in highly desirable locations for recreational sports like fishing and increasingly popular coastal living. Coastal development has caused a loss or damage to large portions of coastal habitats worldwide. The greater the human usage of the estuary or nearby areas, the more pressure from human activities is placed on these coastal ecosystems.

One of the most common and harmful human effects on estuarial ecosystems is eutrophication. Eutrophication is an increase in the amount of nutrients flowing into an estuarial system; often this increase can be extreme. As more of the human population chooses to live on coast often in or near estuaries, there is an increase in the usage of the surrounding land for construction, farming or gardening which means runoff of excess nutrients from eroded topsoil and fertilizer usage. This runoff can also lead to an increase in harmful chemicals like heavy metals and pesticides being added to the estuarial ecosystem. An increase in nearby human activity can also mean an increase in sewage and wastewater discharging into the rivers and streams which flow into estuarial systems providing further sources for the excess nutrients entering in the estuary. The high level of nutrients flowing into such estuaries, combined with poor outflow can lead to high levels of nutrients in the water column and sediment (McComb, 1995).

In many eutrophic systems, the primary concern is the dissolved inorganic nitrogen, and phosphorus levels as these alter the photosynthetic species at the base of the food chain most drastically (McComb, 1995). In estuaries that receive input from water treatment plants or livestock runoff, organic nitrogen and phosphorous become of concern as excessive nutrient loading can have significant detrimental impact on estuarine ecosystems.

Besides nutrients, heavy metals and toxins released at allowable levels in the estuary watersheds, have been shown to accumulate to high levels in the sediment of an estuary in some parts of the world (McComb, 1995). The accumulation of such toxins could have detrimental effects to the ecosystems such as bioaccumulation of the metals in the species present.

The shallowness of many estuarial systems along with wind and wave action can lead to high turbidity increasing the amount of oxygen dissolved in the water and resuspending the sediments with the potential to increase the nutrient levels in the water column. The turbidity and sediment disruption are also affected by sport fishers boating into shallow sections of the estuary and disrupting the sediment. The poor tidal exchange affects the salinity levels within the estuary, sometimes leading to freshwater areas and other times to hypersaline areas.

Each of the above alterations to the estuaries leads to an unbalanced ecosystem which will adjust to the environmental stressor. This can lead to the loss of native flora and fauna and can have harmful effects on the humans that use the area as well.

## Harmful Algal Blooms and Eutrophic Estuaries

Past studies indicate that red tide algae (dinoflagellates) and blue-green algae (cyanobacteria) take advantage of eutrophic estuaries (McComb, 1995). When exposed to high nutrient loads, they can multiply rapidly causing an algal bloom, i.e. high microalgal density and can dominate the phytoplankton community.  High algal density can lead to severe changes in dissolved oxygen sometimes leading to fish kills. Algal blooms dissipate once an essential resource becomes limiting such as light or nutrients. A bloom die-off can lead to very low dissolved oxygen levels and toxic or noxious gas being released by the decaying algae (McComb, 1995).   One red tide microalga that is known to bloom in the Gulf of Mexico is *Karenia (Gymnodinium) brevis*.  First identified in Japan in the 1930s, *K. brevis* has more recently been identified as the source of most Florida and Gulf of Mexico red tide events including those along the South Texas coast (Wilson, 1967; Vargo et al. 2008, Vargo, 2009; Steidinger, 2009; Lightfoot,2011; Brand et al., 2012).

Species of the *Kareiniaceae* family were difficult to distinguish via toxicology and microscopic observations leading to the same species being labeled with several different names (Brand et al., 2012).   In 2000, Hansen et al., conducted an in-depth molecular and physiological study of the family which led to the current classification of the twelve species within the family, *Kareniaceae* (Hansen et al. 2000; Brand et al. 2012).  *Kareniaceae sp.* are unicellular, unarmored dinoflagellates lacking peridinin and utilizing the accessory pigment fucoxanthin which makes them able to photosynthesize at a wide range of light levels and especially well adapted for low light conditions found in the turbid estuarial waters (Hansen et al. 2000, Vargo et al. 2008; Brand et al., 2012). All members of this family produce toxins most of which kill fish, cause NSP and form aerosols which cause respiratory problems (Lekan and Tomas, 2010; Errera and Campbell 2011; Abraham et al. 2006). These toxins are known to be harmful or cause death in mammals, birds, invertebrates, and turtles. It is also believed that *Karenia brevis* also produces allelopathic toxins which allow it to outcompete other species of unicellular alga (Hargraves, 2011).

The *Karenia* genus is characterized by its lack of a cell wall plate and has been observed in sizes ranging from 20-90μm (Wilson, 1967). The lack of a theca and size variability allows it to adapt its body structure to the environmental conditions and survive and photosynthesize in areas that are not favorable to other dinoflagellates. *Karenia brevis* have two flagella, a cingulum and trailing flagellum, for mobility and dividing the cell into a smaller, upper epicone and a larger hypocone with an apical groove dividing the epicone into left and right halves with the concavity of the cell identifying the dorsal and ventral orientation (Figure 1) (Vargo, et al.

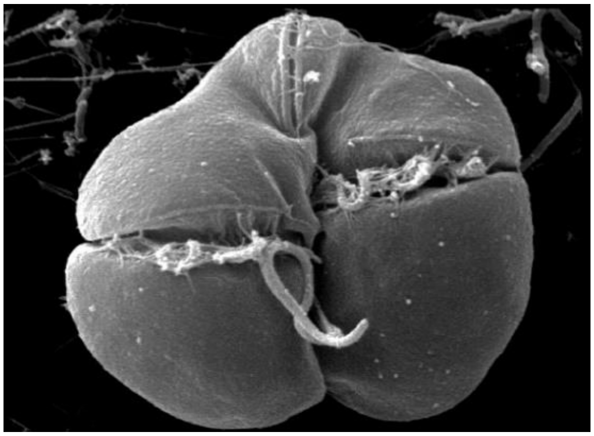

Figure 1: *Karenia brevis* scanning electron micrograph. Source: Fish and Wildlife photostream:https://www.flickr.com/photos/myfwc/5807661111/

Figure 2: *Karenia brevis:* micrography. Arrow indicates the nucleus. Photo courtesy of Florida Fish & Wildlife Conservation via Smithsonian Marine Station Commission http://www.sms.si.edu/irlspec/images/Kareni_brevis_2.jpg

2009; Hargraves, 2011). It typically has a nucleus in the lower left quadrant of the cell, (Figure 2), (Steidinger 2009; Vargo et al. 2009; Hargraves 2011).

*K. brevis* generally reproduces by binary fission every two to ten days, primarily at night, but are believed to be able to reproduce sexually via conjugation and possibly has a resting stage. The toxin levels of individual cells and the toxicity of bloom events are variable but generally correlated with the cell density and environmental conditions like salinity (Tester et al., 2008; Lekan and Tomas, 2010, Errera and Campbell 2011, Maier-Brown et al., 2006). Studies have established preferred ranges of salinity (31-37), temperature ranges (4-33°C) with ideal growth being at temperatures from 22-28°C (Vargo et al., 2009). Many trace metals have been shown to enhance the growth rate of cells in the lab and are still thought to be a possible trigger of blooms (Vargo et al., 2009). Nutrient and temperature stress have also been hypothesized as a trigger for toxin production, but it appears that neither has a significant impact on toxin levels (Lekan and Tomas, 2010). Nitrogen and phosphorus limited stress did reproductive impact rates, potentially leading to rapid cell production needed for blooms of this generally slowly reproducing alga (Lekan and Tomas, 2010). *Karenia brevis* is known to be able to survive on very low levels of inorganic nitrogen, 1 uM, and phosphorous, 0.48uM, and can also utilize organic sources of nitrogen favoring urea, glycine, leucine and aspartic acid; however, growth rates were similar whether organic or inorganic nitrogen sources were used (Vargo et al., 2009; Vargo et al. 2008). Ammonia is thought to be the primary source of N for and is generally considered the limiting (Vargo et al., 2008).

## Texas Coastal Estuaries and San Martin Lake

The Texas coastline has multiple river inputs and barrier islands associated with the Gulf of Mexico which means much of the coast of the of Texas would be classified as estuarial. Like elsewhere in the world, the coastal regions of Texas host several large cities and the popularity of coastal living is increasing. The warm waters of the Gulf of Mexico coupled with the nutrient runoff from watersheds make the estuaries of Texas susceptible to eutrophication and occurrence of algal bloom events, of which red tide is the most common. The southernmost of the Texas estuarial systems is those associated with the Rio Grande and the Laguna Madre. In this area, tidal flow would flood the land and recede with the tides providing small pockets of interconnected shallow natural estuaries where mangroves and/or salt marshes developed. As development into the area increased, the wetlands began to be cut off and isolated into small estuarial lakes. The largest change happened in 1933 and 1948 by the construction of the Port of Brownsville shipping channel and Highway 43 respectively (Breuer, 1974). In the late 1990s, plans were discussed to restore the wetlands by the construction of several channels from the bay through the wetlands; however, this has not yet been accomplished and appears to have been an abandoned task.

One of the small estuaries formed was San Martin Lake. San Martin Lake is used primarily for sports fishing. There is a paddle trail currently in use through the lake primarily for bird watchers, and sport fishing (TPWD, 2018). The estuary is surrounded by salt marsh and mangroves. The shallow middle basin is used by flocks of wading birds of many species. In the past, it has been a nesting and breeding site for the white pelican. While it still hosts large wintering flocks, they no longer breed at the location. There are a series of eastern oyster (*Crassostrea virginca*) beds primarily along the southwestern edge of the estuary. If it is found that the lake is associated with *K. brevis, oysters* could serve as a natural monitoring species. Being filter feeders, they are known to retain brevotoxins from suspension feeding of red tide cells (Echevarria, 2012; Plakas, 2008; Leverone et al., 2007; Plakas, 2004).

San Martin Lake might be a eutrophic shallow water estuary, but this area has not previously been studied to quantify the nutrient levels in the estuary. It is a series of three shallow water estuarial basins, basin C, that on the most southern and eastern basin is most closely associated with the tidal flow of the Brownsville shipping channel and in the northwestern end is a semidry basin that floods with rains, basin A (Figure 3). Between these two areas is a basin that is associated with water from a drainage system for the City of Brownsville, basin B. The Brownsville drainage system is fed with urban and rural land runoff and water treatment plants effluents from Brownsville and a desalinization plant. San Martin Lake has variable salinities that are associated with tides and flow from the drainage system. In the largest basin, C, of San Martin Lake there is variable levels of water exchange depending on the strength of the daily tide and freshwater inflow. During extremely low tides it is not unusual for large portions of the shoreline sediment to be exposed. In the two smaller basins, A and B, there is restricted tidal exchange, suggesting these would be most impacted by nutrient loading.

Figure 3: San Martin Lake: Source Google Earth Screen Capture. Three basins: A- primarily dry basin fills with heavy rains. B- shallow primarily freshwater basin. It is often heavily populated with wading birds, C- Primary site of research in this study which is the largest of the three basins and connected to the Brownsville Ship Channel by a channel on the east edge.

One study indicated that in San Martin Lake there are including copper, arsenic, and lead in the water column and high readings in some of the sediments samples (Contreras et al., 2013). The levels varied seasonally possibly due to shipping traffic in the Port of Brownsville (Contreras et al., 2013).

Early stages of local red tide events have been associated with San Martin Lake and nearby areas of the Port of Brownsville shipping channel (Lightfoot, 2011). This estuary has characteristics suggestive of a possible location for the incubation and proliferation of the harmful marine algae *Karenia brevis,* which is responsible for red tide blooms in the Gulf of Mexico associated with neurotoxic shellfish poisoning. Establishment of baseline water quality and nutrient conditions of the estuary will increase the ecological knowledge of the area and may assist in determining triggers of future red tide events in the area.

San Martin Lake, the site for this study appears to be set under conditions for which it is at risk of eutrophication. It might meet the ideal conditions to support a rapidly growing algal population like *K. brevis* and thus become an initiation site for local red tide algal blooms. The purpose of this project is to establish baseline nutrient levels of the shallow marine estuary, San Martin Lake in Cameron County, Texas.

# CHAPTER II

# METHODOLOGY

## The Study Site

This study took place from August of 2012 to July of 2013 at San Martin Lake, Cameron County, Brownsville Texas (Lat. 26.008098°, Long -97.323648°). Seven sampling sites were sampled, each site was chosen along a central transect where the tidal flow of water and depth was greatest (Table 1, Figure2). The source of effluence is located at the top of the smaller basin B; however, this basin was not accessible therefore sample site BW1 is most closely associated with the effluence source. The channel leading from basin B to basin C is bordered by salt flats and mangroves site CT1 is located at the end of this narrow channel and is characterized by mangroves. Site CW1 and CW2 are centrally located on the western half of the lake along the path of tidal flow. CW1 is parallel to the end of the largest mangrove stand in this area of the lake and just before several large oyster beds. Sites CE1 and CE2 were on the eastern half of the lake. Site CE2 is located at the largest oyster bed on this area of the lake and site CE1 is at the end of the oyster beds just before the channel that leads to the Port of Brownsville Shipping Channel, there is also a small stand of mangrove around CE1. Each of these sites was sampled once a month and were timed to be close to high tide to make sure that all sites were accessible for collection.

Table 1. San Martin Lake Sampling Location and Site Notations. The location is described by GPS coordinate and distance is measured along the boat path between sites (River meters).

| Site Notation | River meters(m) | GPS N Coordinate | GPS W Coordinate |
|---|---|---|---|
| BW1 | 5402.93 | 25.99563 | 97.33868 |
| CT1 | 4064.31 | 26.00486 | 97.33009 |
| CW2 | 3830.25 | 26.00695 | 97.32977 |
| CW1 | 2793.24 | 26.00819 | 97.3195 |
| CE2 | 1806.97 | 26.00555 | 97.31011 |
| CE1 | 785.96 | 26.0056 | 97.3005 |
| SC | 0 | 25.99809 | 97.2944 |

Figure 4: San Martin Lake sampling site locations. Source: Google Earth Screen capture or San Martin Lake and the Port of Brownsville Ship Channel. Site notations labeled by GPS coordinates using Google maps.

## Field Methods

During monthly sampling trips, each site was located by GPS coordinates. Using a calibrated Hydrolab Quanta, field measurements included water temperature, specific conductivity, dissolved oxygen, pH, salinity, and turbidity as well as water depth. Two 250 mL brown collection bottles were rinsed twice and filled with water and then stored on ice. At site CE2 five oysters were collected and stored on ice for future analysis or in the case of a red tide algal bloom during the study. All water samples were transported on ice and processed within 24 hours of collection. The 250 mL and 1 L water samples were filtered by a vacuum pump through a 47 mm GF/C filter. For each site, triplicate filters from each site with a known volume of filtered water were folded, wrapped in foil, labeled, and frozen for chlorophyll analysis within 30 days. Water samples from each brown 250 mL collection bottle were stored in plastic tubes and frozen until nutrient analysis. For a planned bioassay study, two 1 L white or clear bottles were rinsed twice and then filled with water and kept on ice. The 1 L bottles were also filtered, and the collection bottles were washed, and the filtered water was returned to each bottle and frozen for a planned but not completed bioassay study.

## Laboratory Analysis Methods

The frozen filter papers were analyzed for chlorophyll a level from each site. Each filter was ground in 90% acetone and placed in 12 mL plastic tubes and then allowed to extract in the refrigerator overnight to complete the chlorophyll extraction. The tubes were then kept in the dark and centrifuged, diluted as necessary and an aliquot was placed in a Tuner Designs Model 10 fluorometer then fluorescence recorded. Each extract was then acidified with 0.1 N HCl to estimate phaeophytin, and the fluorescence read again. This differential was used to calculate the amount of chlorophyll in the water.

Frozen filtered water samples were analyzed for nutrients utilizing colorimetric assays from APHA Standard Methods of Water Analysis (Clesceri et al. 1995). Dissolved phosphate was analyzed utilizing ammonia molybdate and reaction with ascorbic acid (Clesceri et al., 1995 p.146-147). Ammonia levels were quantified using the phenate colorimetric analysis (Clesceri et al., 1995. p.109-110). Nitrate levels were determined by cadmium reduction followed by colorimetric readings (Clesceri et al., 1995. p.114-118).

# CHAPTER III

# RESULTS AND DISCUSSION

## Environmental Conditions

The environmental conditions found in San Martin Lake were measured to help characterize the estuary. The following conditions were similar across the estuary with the variations that appeared to be changed consistently in association with weather patterns (See Appendix A). Water depth at the sampling locations ranged from <0.1m to >2.5m. with the sites more centrally located, near the boating channel, being the deepest. The depth of the estuary varies widely with the daily tides, with much of the area away from the boating lane being exposed at low tide. Water temperature ranged from 15°C in winter to 30°C in the summer months but also varied with the depth of the site(Figure 5). Dissolved oxygen was consistently high and ranged from 2.6 mg/L to 14.3mg/L. The basin was slightly alkaline with pH's ranging from 7.8 to 8.8. The turbidity was also consistently high ranging from 21 NTU to 323 NTU.

Salinity was the one environmental condition to show a consistent spatial trend (Figure 6). As would be expected, the sites closest to the Brownsville shipping channel had the highest salinity ranging from 33.46 to 38.77, whereas the ship channel salinity ranged from 22.5 to 38.94. The salinity tended to be just slightly higher inside the cut to the east side of the lake than in the shipping channel suggesting some evaporative effect on the salinity. Equally predictable, the sampling locations farthest from the ship channel had the lowest salinities. The sampling site closest to the freshwater drainage source, site BW1, measured between 5.3 to 21.6, it was usually slightly brackish, but at times was fresh. The sites between the two extremes were generally brackish.

## Nutrients

The nutrients in San Martin Lake are highest in sites furthest the to the west and generally lowest nearest the ship channel to the east. Ammonia concentration for one sampling date at site CE1 was extremely high. It was omitted from the calculation of the average since it was suspected of being contaminated. Average nutrient levels at the exit of basin B, site BW1, were consistently high, $NH_4$ =62.5 µM, $NO_3$ =25.9 µM, and $PO_4$ =9.5 µM. This would be the location closest to the drainage input to the estuary. At the ship channel site, nutrient levels were considerably lower likely due to dilution with averages being $NH_4$ =5.8 µM, $NO_3$ =3.1 µM, and $PO_4$ =0.11 µM. Even though there is a drop in nutrient levels as water flows through the estuary, ammonia concentration remained high enough to support algal bloom initiation even at the exit of the estuary. Nitrogen is generally thought to be the limiting nutrient for algal blooms in marine systems. There were sufficient levels of nitrogen and phosphorous year-round to support algal blooms in basins C and in basin B. Evidence of green algal blooms were observed on several sampling dates in basin B as there were bright green algal mats floating in the water. This basin is difficult to access due to its shallow depth so was sampled at its exit into basin C, site BW1. It is likely that nutrient levels would be consistently higher in this location Figure 7, Table 2).

## Chlorophyll

Water column chlorophyll levels were measured to estimate phytoplankton abundance in the water column at each sampling site. Microalgal abundance followed the general trend of the nutrient concentrations. The highest chlorophyll averaging 197.31 µg/L with the highest recorded value of 442.21 µg/L at site BW1 closest to the freshwater drainage source. The average chlorophyll present declines steadily across the estuary with the largest amount never appearing to exit basin B (Table 3).

The drop in chlorophyll values between site CW1 and CE1 (middle of the estuary) is of interest as this decline may be related to the oyster beds in this region (Table 4). While oyster beds are found at various locations in the estuary, sites CW1 and CE1 bracket the largest oyster bed. A third sampling site CE2 is near the middle of the bed at the largest oyster clump. It was suggested that these chlorophyll levels before and after the oyster beds would show the impact of their filtering capacity. Comparing these sites on an outgoing tide, chlorophyll level is cut in half near this oyster bed, as the current flows past. On an incoming tide, no filtering is observed, and the chlorophyll level is twelve times higher to the west of the oyster bed. If we average all sampling days for this region, then as the water flows to the ship channel, the chlorophyll is reduced by about a third. The oysters are filtering out a large quantity of phytoplankton (chlorophyll) that make it into basin C from the system, but they are not eliminating it.

In south Texas, red tide events commonly occur in late summer or early fall. The nitrate and ammonia levels coming from San Martin Lake are high during this period and could enhance the initiation of a red tide. No red tide event occurred in this vicinity during the study (Table 5).

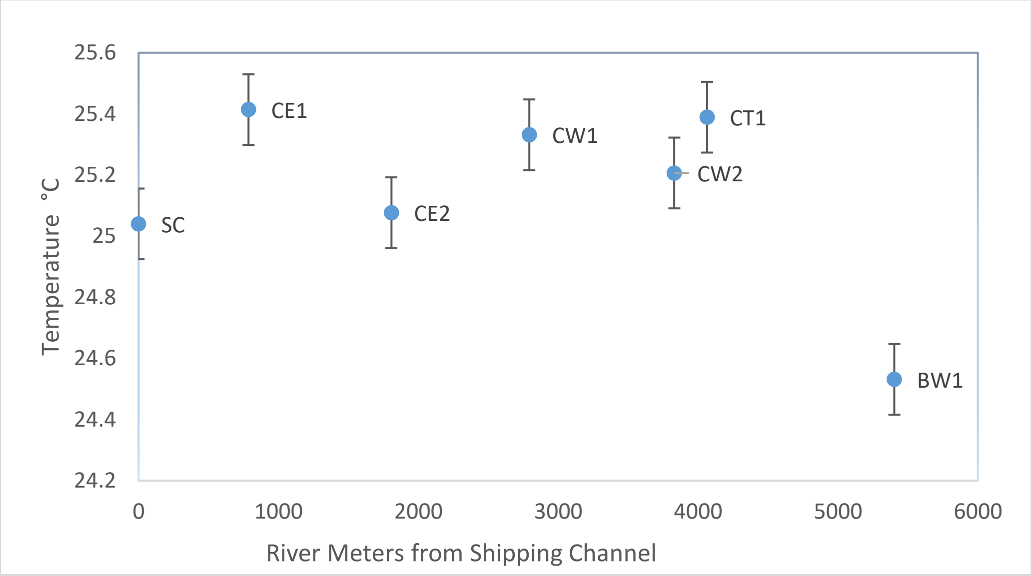

Figure 5: Water temperatures: Average temperature and ranges over one year. Distance is as the current would travel through the estuary.

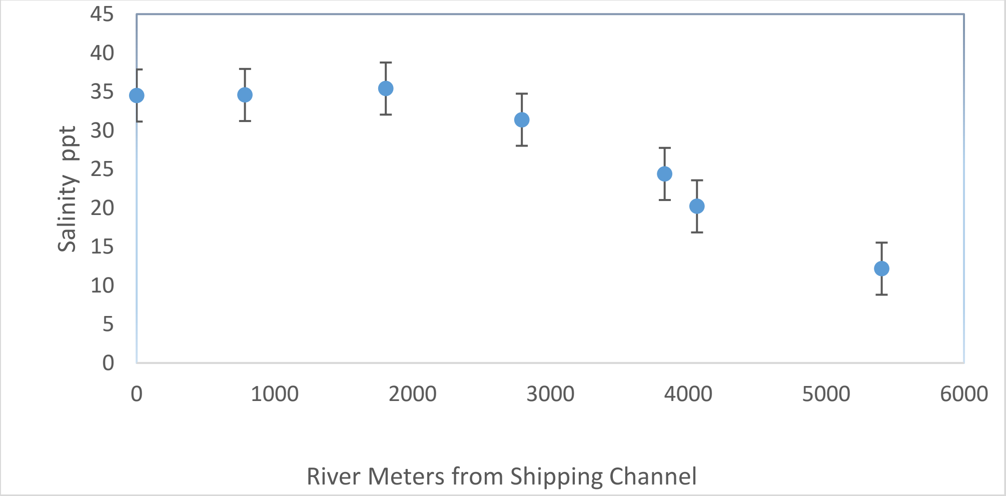

Figure 6: Salinity: Average salinity and ranges over one year. Distance is as the current would travel through the estuary.

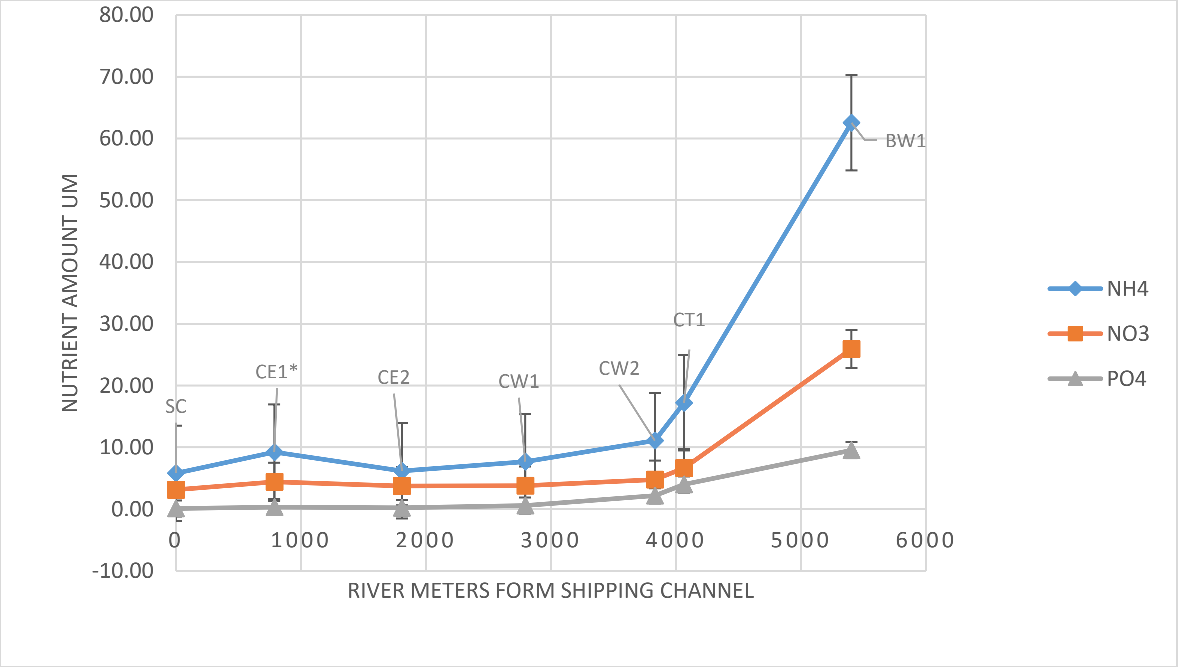

Figure 7: Nutrients: Average ammonia, nitrate-nitrite and phosphate levels in San Martin Lake. (micro-molar). Distance is as the current travels through the estuary * At CE1 has one data point omitted due to probable contamination.

Table 2: Nutrient levels: Annual average nutrient concentrations per sampling site in San Martin Lake. All nutrient levels are recorded in µM. *One data point was omitted due to excessively high value (479 µM).

| Sampling Location | NH4 (uM) | NO3 (uM) | PO4(uM) |
|---|---|---|---|
| BW1 | 62.57 | 25.95 | 9.54 |
| CT1 | 17.22 | 6.65 | 3.99 |
| CW2 | 11.09 | 4.77 | 2.22 |
| CW1 | 7.71 | 3.81 | 0.59 |
| CE2 | 6.21 | 3.73 | 0.21 |
| CE1 | 9.25* | 4.43 | 0.36 |
| SC | 5.82 | 3.15 | 0.11 |

| Site | Average chlorophyll ug/L | Std deviation |
|---|---|---|
| BW1 | 197.31 | 171.3 |
| CT1 | 68.71 | 44.3 |
| CW2 | 44.10 | 32.96 |
| CW1 | 16.45 | 15.07 |
| CE2 | 5.47 | 3.90 |
| CE1 | 5.12 | 5.98 |
| SC | 7.87 | 8.62 |

Table 3. Average annual water column chlorophyll levels (µg/L).

| Site | Chlorophyll (avg) (µg/L) | Std dev | Tide |
|---|---|---|---|
| CE1 | 2.44 | 1.34 | incoming |
| CE2 | 4.74 | 2.87 | incoming |
| Cw1 | 26.81 | 23.58 | incoming |
| CE1 | 6.02 | 6.71 | outgoing |
| CE2 | 5.71 | 4.32 | outgoing |
| Cw1 | 12.99 | 10.94 | outgoing |
| CE1 | 5.12 | 5.98 | All tides |
| CE2 | 5.47 | 3.91 | All tides |
| Cw1 | 16.45 | 15.07 | All tides |

Table 4. Oyster filtering. These site averages were based on three sample dates that occurred on an incoming tide and nine that occurred on an outgoing tide.

Table 5. Seasonal nutrient and chlorophyll averages in San Martin Lake during the study period. Seasons are based on the most likely months for red tide occurrences. *One data point omitted for probable contamination.

| Season | Average PO4 ± std (µM) | Average NO3 ± std (µM) | Average NH4 ± std (µM) | Average chlorophyll ± std (µg/L) |
|---|---|---|---|---|
| June -October | 1.32±2.37 | 6.94±12.00 | 7.51±8.20* | 28.06±31.82 |
| November - May | 3.19 ±5.53 | 7.87±17.07 | 23.67±43.09 | 63.72±115.07 |

## Discussion

San Martin Lake exhibited behavior typical for a small, shallow water estuary. Water temperature followed seasonal trends. The estuary is slightly alkali, highly turbid, and typically high in dissolved oxygen levels. Salinity demonstrated a consistent spatial pattern with lowest salinities furthest from the ship channel, the seawater source. Salinity further upstream was more variable likely due to changes in freshwater inflow and seasonal tidal changes.

Nutrient concentration (ammonia, nitrate-nitrite, and phosphate) of the estuary were routinely high with the highest levels nearest the freshwater input from the Brownsville watershed. Ammonia levels were generally higher than the nitrate levels. Dissolved phosphate levels were occasionally high. The high levels of nutrients suggest classifying the estuary as eutrophic with the bulk of nutrients coming most likely from urban and rural runoff and wastewater treatment plants. Besides inorganic nutrients being fed into the estuary, a recent study has shown that there are high levels of organic nitrogen in the freshwater inflow to San Martin Lake (DeYoe et al. 2016; DeYoe unpublished data). This study did not look at organic nutrients, but it is likely that they are also making their way into the estuary. While oysters are adept at water filtration and removing a large portion of the nutrients and particulate material, they are not removing them all.

Proper management of estuaries with significant treated wastewater input is possible. In Tolo Harbor (Hong Kong) with adept management, it was possible to restore the ecosystem (McComb, 1995). Such an approach might be desirable for San Martin Lake.

The nutrient, salinity, pH and dissolved oxygen conditions in this estuary appear like those found in Shenzen Bay in the South China Sea (McComb, 1995). This estuary has similar runoff from both urban and rural sources with high levels of dissolved nitrogen consistently present and fluctuating high and low levels of phosphorous (McComb, 1995). In Shenzen bay, however, the levels of eutrophication are much higher reaching up to 800 µM at times and staying consistently above 200 µM for during some months (McComb, 1995). Phosphorous likewise varies more in the Shenzen estuary from near zero to 200 µM (McComb, 1995). While the level of eutrophication is higher in the Shenzen Bay, the effects are similar. At times there are phytoplankton blooms which changed with the nutrient levels and was affecting the presence of normal ecosystem members, but while it met the criteria for a eutrophic estuary, it was not yet considered severely polluted (McComb, 1995). This estuary was being more frequently associated with red tide blooms and suspected of declining water quality. (McComb, 1995).

The chlorophyll levels in San Martin Lake give us some indication of the current level of algal growth in the basin. At each sampling date, the water around basin B had very high levels of chlorophyll. On at least one sampling date, a green algal bloom with sulfurous odors was noticeable in basin B just above the sampling site. Excessive algal growth and decomposition may have caused the situation.  Abundant wading birds in basin B suggest a very productive but perhaps unstable system.  As noted earlier, green algal blooms were noted in this basin.

The chlorophyll and nutrient levels currently are being reduced by the oysters and perhaps mangroves along the fringes of the estuary, but they are not removing all of them.

The eutrophication and the similarity to the Shenzen Bay estuary leads to several areas of concern for the continued future use of San Martin Lake.  First, ecotourism and fishing are actively being promoted in an area that is known to have a high nutrient load and a questionable water source.  At this time, little is being done to manage nutrient and pollution levels in San Martin Lake, and this could lead to a public safety issue.   Monitoring and management of the water quality in this area is key to ensuring the health of the estuary and maintaining it as a public resource.  Second, as one major source of water for San Martin Lake is from Brownsville, and Brownsville is one of the fastest growing cities in the nation, so how will this impact future nutrient loads in San Martin Lake?  Third, it is possible that nutrients are stored in the sediment in basin B.  If so, significant rainfall events may push stored nutrients downstream to the estuary.  Fourth, high nutrient levels of the estuary potentially create an area ripe for the promotion of red tides.  If the right conditions exist in the estuary at the right time, rapid algal growth may occur.  The inflow of San Martin Lake water into the ship channel should be a routine red tide monitoring site in the future.

# REFERENCES

Abraham, A., Plakas, S.M., Wang, Z., Jester, E.L.E., El Said, K.R., Granade, H. R., Henry, M.S., Blum, P. C., Pierce, R. H., and Dickey, R. W. 2006. Characterization of polar brevetoxin derivatives isolated from *Karenia brevis* cultures and natural blooms. Toxicon v. 48: 104-115.

Brand, L. E., Campbell, L. and Bresnan E. 2012. *Karenia*: The biology and ecology of a toxic genus. Harmful Algae, v. 12: 156-178.

Breuer J. 1974. Ecological Survey of the Brownsville Ship Channel 1971-1972.Coastal Fisheries 94-145.

Clesceri, L.S., Greenberg, A.E., Eaton, A.D., Standard Methods for the Examination of Water and Wastewater 20th ed., 1998.

Contreras, Mara, Law, Joshuah D., Delgado, Bianca, Heise, Elizabeth A. Analysis of Metal Pollutants in San Martin Lake. Geological Society of America Abstracts with Programs Vol. 45, No. 7, p593, 2013. https://gsa.confex.com/gsa/2013AM/webprogram/Paper223631.html

DeYoe, H., Pulich, W., Fernando, N. Modeled Inflow Validation & Nutrient Loading Estimation in two Subwatersheds of the Lower Laguna Madre. Texas.gov. http://www.glo.texas.gov/coastal-grants/_documents/grant-project/14-085-final-rpt.pdf. 2016. Accessed 7/1/18.

Echevarria, M.E., Narr, J.P., Tomas, C. and Pawlik J.R. 2012. Effects of *Karenia brevis* on clearance rates and bioaccumulation of brevetoxins in benthic suspension feeding invertebrates. Aquatic Toxicology. V. 106-107: 85-94.

Errera, R. M. & Campbell, L. 2011. Osmotic stress triggers toxin production by the dinoflagellate *Karenia brevis*. PNAS. v. 108 (26): 10597-10601.

Hansen, G., Moestrup, O., & Roberst, K. 2000. Light and electron microscopical observations on the type of species *Gymnodinium, G. fuscum* (Dinophyceae). Phycologia 39(5): 365-376.

Hargraves, P. E. 2011. Indian River Lagoon Species Inventory. Smithsonian Marine Station at Force Pierce Website. http://www.sms.si.edu/irlspec/Kareni_brevis.htm

Lekan, D. E., and Tomas, C. 2010. The brevetoxin and brevenal composition of three *Karenia brevis* clones at different salinities and nutrient conditions. Harmful Algae. v. 9: 39-47.

Leverone, J. R., Shumway, S.E., Blake, N.J., 2007. Comparative effects of the toxic dinoflagellate *Karenia brevis* on clearance rates in juveniles of four bivalve mollusks. Toxicon. v. 49: 634-645.

Lightfoot, S. 2011. Red tide confirmed along Upper, Lower Texas Coast. TPWD Media Links. Retrieved from: http://www.tpwd.state.tx.us/newsmedia/releases/?req=20110923b

Maier-Brown, A.F., Dortch, Q., Van Dolah, F.M, Leighfield, T. A., Morrison, W., Thessen, A.E., Steidinger, K., Richardson, B., Moncreiff, C.A., and Pennock, J.R., 2006. Effect of Salinity on the distribution, growth, and toxicity of *Karenia spp*. Harmful Algae v. 5: 199-212

McComb, A.J., Eutrophic Shallow Water Estuaries and Lagoons. CRC Press. Boca Raton. 1995.

Plakas, S.M., Jester, E.L.E., El Said, K. R., Granade, H. R., Abraham, A., Dickey, R. W., Scott, P.S., Flewelling, L. J., Henry, M., Blum, P. and Pierce, R. 2008. Monitoring of brevetoxins in *Karenia brevis* bloom-exposed Eastern oyster (Crassostrea virginica). Toxicon. V. 52:32-38.

Plakas, S.M., Wang, Z., El Said, K.R., Jester, E.L.E., Granade, H. R., Flewelling, L. Scott, P., and Dickey, R. W., 2004. Brevetoxin metabolism and elimination in the Eastern oyster (Crassostrea virginica) after controlled exposures to *Karenia brevis*. Toxicon. v. 44: 677-685.

Steidinger, Karen. 2009. Historical perspective on *Karenia brevis* red tide research in the Gulf of Mexico. Harmful Algae. v. 8: 549-561.

Tester, P. A, Shea, D., Kibler, S.R., Varnam, S. M., Black, M.D., and Litaker, R. W., 2008. Relationships among water column toxins, cell abundance and chlorophyll concentrations during Karenia *brevis* blooms. Science Direct. V. 28: 59-72.
Texas Parks and Wildlife. " Texas Paddling Trail." Paddle Padre. https://tpwd.texas.gov/fishboat/boat/paddlingtrails/coastal/south_bay/ . Accessed 6/15/2018.

Vargo, G. A. 2009. A brief summary of the physiology and ecology of *Karenia brevis* Davis (G. Hansen and Moestrup comb. Nov.) red tides on the West Florida Shelf and of hypotheses posed for their initiation, growth, maintenance, and termination. Harmful Algae, v. 8: 573-584.

Vargo, G.A., Heil, C.A., Fanning, K.A., Dixon, K., Neely, M.B., Lester, K., Ault, D., Murasko, S., Havens, J., Walsh, J., and Bell, S. 2008. Nutrient availability in support of *Karenia brevis* blooms on the central West Florida Shelf: What keeps *Karenia* blooming? Continental Shelf Research. V. 28: 73-98.

Wilson, W.B., 1967. Forms of the dinoflagellate *Gymnodinium breve* Davis in cultures. Contrib. Mar. Sci. v.12: 120–134.

# APPENDIX A

# APPENDIX A

## ANNUAL AVERAGES

Annual averages of all measurements taken during the study by sampling location.

| Location | Temperature °C | Conductivity | Dissolved Oxygen | pH | Salinity ppt | DO % avg. | Turbidity |
|---|---|---|---|---|---|---|---|
| BW1 | 24.53 | 21.93 | 8.02 | 8.22 | 13.33 | 103.43 | 215.74 |
| CE1 | 25.41 | 53.54 | 5.93 | 7.97 | 35.55 | 95.61 | 71.46 |
| CE2 | 25.08 | 53.87 | 6.43 | 8.01 | 35.55 | 99.33 | 52.33 |
| CT1 | 25.39 | 33.73 | 7.49 | 8.37 | 21.33 | 105.61 | 157.69 |
| CW1 | 25.33 | 49.33 | 6.32 | 8.27 | 33.48 | 95.91 | 152.97 |
| CW2 | 25.21 | 39.87 | 6.71 | 8.27 | 25.57 | 98.16 | 203.38 |
| SC | 25.04 | 53.64 | 11.78 | 8.03 | 35.26 | 106.11 | 37.12 |

| Location | Chlorophyll ug/L | NH4 µM | NO3 µM | PO4 µM |
|---|---|---|---|---|
| BW1 | 197.31 | 62.57 | 25.95 | 9.54 |
| CE1 | 5.12 | 143.55 | 4.43 | 0.36 |
| CE2 | 5.47 | 6.21 | 3.73 | 0.21 |
| CT1 | 68.71 | 17.22 | 6.65 | 3.99 |
| CW1 | 16.45 | 7.71 | 3.81 | 0.59 |
| CW2 | 44.10 | 11.09 | 4.77 | 2.22 |
| SC | 7.87 | 5.82 | 3.15 | 0.11 |

# BIOGRAPHICAL SKETCH

Wendy Rogers is a Rio Grande Valley native. She received her Bachelor of Science from Davidson College in May of 1998 and returned to the valley to pursue a career in education. She has taught various secondary grade levels and sciences in the valley for the last eighteen years. In May of 2007 she completed an Associates of Science in Chemistry at South Texas College and in August of 2018 she completed a Master of Science in Biology from the University of Texas Rio Grande Valley. Ms. Rogers' personal email is wlrogers98@hotmail.com.