The Effects of a Red Tide, *Karenia brevis* Episode on the Benthic Macroinvertebrate Communities of South Padre Island, Texas

by

Liana Lerma

A Thesis Presented to the Graduate Faculty of the University of Texas at Brownsville in Partial Fulfillment of the Requirements for the Degree of

Master of Science

in The Field of Biology

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ABSTRACT

South Padre Island, Texas has experienced increasing frequency of harmful algal blooms (Karenia brevis) since the 1900’s, many of which resulted in massive fishes kills. In addition, shorebirds and other terrestrial wildlife deaths have been linked to K. brevis blooms prompting investigations of potential pathways by which brevetoxins may be transmitted to higher trophic levels. The benthic macrofaunal community inhabiting the swash zone of sandy beaches consists primarily of filter feeding invertebrates which may serve as toxin bioaccumulators to secondary consumers of both marine and terrestrial food webs. The first reported mass mortality of swash zone benthic macrofauna on the south Texas coast associated with a harmful algal bloom, occurred on the shoreline of Boca Chica beach in 2005. In September 2011, South Padre Island was impacted by a four month long red tide event, killing a total of 4.4 million fishes. The effects of K. brevis on benthic communities are largely undocumented and the few studies that have been conducted often produce conflicting results. Thus, the purpose of this study was to assess the effects of K. brevis on the benthic macroinvertebrate community following the 2011 harmful algal bloom. Sampling was conducted from six 400 m stretches of beach prior to and after a prolonged period (4 month) of high red tide cell count concentrations. Species identification, abundances, and biomass were obtained from each sample. A one-way ANOSIM indicated that the pre and post bloom community structures were significantly different in terms of both abundance and biomass. Pre and post harmful algal bloom assemblages were 68.5% and 67.0% similar with respects to species relative abundances and biomass. The differences in communities were contributed to greater abundances and biomass of Scolelepis squamata in the pre-bloom samples and greater abundances of Donax variabilis and Ancinusus depressus in the post-bloom samples. Multi-dimensional scaling analyses also indicated a distinct separation of the before and after red tide communities in both abundances and biomass. However, when compared with data from a previous study, the variation among pre and post bloom communities was similar suggesting that seasonal variation rather than the effects of K. brevis may account for the differences between pre and post bloom communities. Though there is speculation that secondary effects of blooms, specifically anoxia, may be the underlying cause for mortalities in benthic invertebrates, other potential alternatives such as different Karenia spp. and levels of toxicity may be associated as well. Nevertheless, the results of this study pose a question of why two red tide events, 2005 and 2011, similar to an extent, resulted in two very different outcomes with regards to the benthic macrofauna community.
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Harmful algal blooms (HAB’s), commonly referred to as ‘red or brown tides’ are caused by different organisms, primarily dinoflagellates. One of the main culprits associated with red tides is the free-living dinoflagellate, *Karenia brevis* (Davis, 1948), which has been documented along the Gulf of Mexico shoreline of South Texas since the 1900’s (Magaña et al., 2003). Although red tide outbreaks have not been as frequent as reported from the west coast of Florida, which occur almost annually, Texas events result in similar massive fishes kills (Buskey et al., 1996; Magaña et al., 2003). The first documented event in South Texas, including South Padre Island, occurred in 1935 (Magaña et al., 2003) and the most recent in 2011. Among the many blooms South Texas has endured, there have been a few that remain memorable because of their severe impacts to fish communities. In 1986, Texas was hit hard with the harshest red tide bloom to date, killing 22 million fishes (Trebatoski, 1988). For decades, *K. brevis* has been infamous for consistently causing mass mortalities in fish and higher trophic vertebrates such as marine mammals, birds, and sea turtles (Gunter et al., 1947; Gunter et al., 1948; Landsberg, 2002; Steidinger et al., 2008a; Landsberg et al., 2009), while impacts to invertebrate communities have been reported to occur more randomly, with no definite explanation (Brand et al., 2012).

Simon and Dauer (1972) were the first to provide quantitative data on the effects of *K. brevis* on the infaunal invertebrate community in Tampa Bay, Florida (Steidinger et al., 1973; Smith, 1975a, 1975b, 1976). In 1978, Tiffany and Heyl’s study supported that *K. brevis* was the direct cause of many benthic invertebrate mortalities in Turtle Beach,
Florida. Both studies identified the invertebrate species affected by the red tide bloom, some of which are current beach residents of South Padre Island such as *Acanthohaustorius* spp. (Bousfield, 1965), *Scolelepis squamata* (O.F. Muller, 1806), *Donax variabilis* (Say, 1822), and *Emerita talpoida* (Say, 1817).

The first reported mass mortality of swash zone benthic macrofauna on the South Texas coast associated with a red tide event, occurred on the shoreline of Boca Chica Beach in 2005 (T Reisinger 2013, pers. comm., 16 April). According to Texas Parks and Wildlife Department (TPWD), *K. brevis* cell counts during the outbreak at this location were at a maximum and high concentration of 5490 cells/ml and persisted from mid-September through the end of November 2005 (TPWD unpublished data). Among the species that were killed were polychaetes, bivalves, mole crabs, ghost shrimp, and hermit crabs (Buzan, 2005). Since this incident, South Padre Island has experienced three other red tide blooms in 2006, 2009, and 2011 none however, displaying the mass mortalities of benthic invertebrates stranded on the beach as in 2005.

According to TPWD, HAB coordinator, Meridith Byrd, early September 2011 marked the beginning of one of the largest red tide blooms to impact South Texas in over a decade (Powell, 2012). Sightings of stressed fishes and discolored water were reported along the Brownsville Ship Channel on September 10th (NOAA HAB Bulletin, 15 September 2011). On September 14th, officials received confirmation of high concentrations (27,500 cells/mL) of *K. brevis* cells found in water samples from the ship channel. The following day, the fishes killed had begun to spread to the Lower Laguna Madre, South Bay, and Boca Chica Beach (Powell, 2012). The *K. brevis* bloom began to develop at low cell count concentrations along the southern end of South Padre Island.
On September 30\textsuperscript{th}, moderate and low concentrations (11-37 \textit{K. brevis} cells/ml) had been detected near the Galveston Island region (NOAA HAB Bulletin, 3 October 2011). \textit{Karenia brevis} cells found at the north and south ends of the Texas coast, separated by hundreds of kilometers, forecasted a bizarre pattern from the usual red tide blooms which evolves and expands from one location (Powell 2012). With opposite sides of the Texas coast simultaneously experiencing the development of a red tide bloom, it was anticipated that the mid-coast (i.e. Aransas and Matagorda Islands) would also be affected. By October 2011, a range of very low to high cell concentrations (1-100,000 cells/ml) had been observed along these mid-coast regions, including South Padre Island (NOAA HAB Bulletin, 11 October 2011). This island was affected by the harmful algal bloom from mid-September through late December of 2011. High cell concentrations (>1,000 cells/ml) however, were present from mid-October till early December (TPWD, unpublished data). Cell counts began to decrease after December 6\textsuperscript{th} until there was no presence of \textit{K. brevis} cells on the first of January 2012 (TPWD unpublished data). The maximum \textit{K. brevis} cell count at South Padre Island was 100,000 cells/ml (TPWD unpublished data), resulting in fishes kills and irritating aerosols, but no visible evidence of macroinvertebrate kills on the beach. The entire event extended from the Lower Laguna Madre to Galveston and killed 4.4 million fishes (Powell, 2012).

The swash zone community of Texas beaches consists primarily of benthic macroinvertebrate species such as polychaetes, mole crabs, amphipods, isopods, and bivalves, in which the majority are suspension feeders (Hicks, 2010). Organisms inhabiting the swash zone serve an important role within both marine and terrestrial food webs. For example, the active suspension feeder, \textit{E. talpoida}, a mole crab predominantly
found on the Texas coast, is preyed upon secondary consumers (e.g. fishes and crustaceans) which in turn attract tertiary consumers (e.g. shorebirds), thus linking the trophic levels that lead to the terrestrial food cycle. Fish kills have been observed as early as 1648 in the Gulf of Mexico (Steidinger, 2009), while occurrences of neurotoxic shellfish poisoning (NSP) and human respiratory irritations since 1880 (Rounsefell & Nelson, 1966) however, it was not until 1946 that *K. brevis* was linked to these incidences (Davis, 1948; Woodcock, 1948). More recent studies have focused on bioaccumulation of the brevetoxin produced by *K. brevis* and its potential for transfer to higher trophic levels such as fishes, marine mammals, shorebirds, and humans (Tester et al., 2000; Kröger et al., 2006; Naar et al., 2007; Landsberg et al., 2009; Sotka et al., 2009; Bricelj et al., 2012; Echevarria et al., 2012). In fact, Flewelling et al., (2005) identified the cause of bottlenose dolphin mortalities along the Florida panhandle as a result of brevetoxin biomagnification through the consumption of contaminated prey. Though there are no studies that suggest direct brevetoxin biomagnification through the consumption of swash zone benthic invertebrate prey, the bioaccumulation that occurs within this community may eventually attribute to indirect biomagnification of the toxin in higher trophic predators. Despite the intensity of *K. brevis* research, there is still limited information on how harmful algal blooms affect benthic macroinvertebrate communities (Simon & Dauer, 1972; Summerson & Peterson, 1990; Pierce et al., 2004a). During a bloom which affected Sarasota Bay, Florida in February 2005, a study was conducted to assess whether the benthic invertebrate community was the target of brevetoxin transfer. Benthic samples collected showed the presence of the brevetoxin in all taxonomic groups (polychaetes, bivalves, gastropods, and crustaceans) but was most
accumulated in the tissues of filter feeding bivalves and carnivorous and scavenging gastropods (Bricelj et al., 2012). Because NSP impacts the health of the human population, the accumulation of brevetoxins by suspension-feeding molluscs, with emphasis on commercial valued bivalves (e.g. edible oysters, mussels, cockles), have been well researched in controlled laboratory studies. Of the seven bivalve species collected in Florida waters, D. variabilis, also a resident of the South Texas coast, attained the highest brevetoxin concentration of 550 MU/g (reviewed by Landsberg et al., 2009). On the west coast of Florida (Tampa Bay), Sotka et al. (2009) focused on the effects of brevetoxin on the amphipod Ampithoe longimana (Smith, 1873), a common herbivore found in sea grass beds. The objective of the study was to assess whether K. brevis brevetoxin altered the feeding rate, survivorship, and growth of the amphipod. Ampithoe longimana was exposed to both a sea grass “test food” coated with purified brevetoxins and a control food that was not treated with the toxin. After a 10 day treatment period, results indicated that not only in some instances did the amphipod prefer the contaminated test food over the control, but also showed no alteration in the feeding behavior, survivorship, and growth of the benthic herbivore. Collectively, these two studies indicate that species from the benthic macrofaunal community are able to ingest and accumulate brevetoxin without mortality, while still playing a role in the food web, thus may be serving as a brevetoxin vector to higher trophic levels.

The frequency of K. brevis blooms along the Texas coast has more than doubled in recent years. Since 1986, South Texas has experienced eleven red tide events, killing a total of 75 million fishes, as compared to only five blooms during the preceding fifty-one year period (1935-1985) (Magaña et al., 2003). Even though red tide episodes have been
more common in Texas, there has been no published research, particularly on the effects it has on the benthic community. In addition, the majority of the studies cited in red tide literature were conducted in the eastern Gulf of Mexico (Florida) with research focusing on benthic macroinvertebrates limited to bay systems, rather than open-gulf shoreline communities where *K. brevis* cells are first encountered. It has also been suggested that the limited information known on mortality of benthic macrofauna during *K. brevis* blooms, is due to the lack of sampling (Echevarria et al., 2012). Thus, the objective of this study was to evaluate the effects of *K. brevis* on the benthic macroinvertebrate community inhabiting the swash zone of South Padre Island by comparing species diversity and assemblages for differences in abundances and biomass before and after the bloom in 2011. To assess the effects of this particular red tide bloom on the swash zone benthic community, the following null hypotheses were tested:

(1) Pre and post *K. brevis* bloom benthic invertebrate samples will not differ in species abundances.

(2) Benthic macroinvertebrate species biomass will remain similar between pre and post bloom samples.

(3) No differences in species richness, diversity, and evenness will result among the benthic swash zone macrofauna between pre and post bloom samples.
II. MATERIALS AND METHODS

Study Area

This study was performed on the shorelines of South Padre Island, located at the southern tip of Texas. The island extends 55 km along the Gulf of Mexico and is separated from the mainland by the Lower Laguna Madre. South Padre Island is bordered by the Port Mansfield Channel to the north and the Brazos Santiago Pass to the south (Figure 1).

Experimental Design

The southern portion of the island served as the study location which was further divided into three study sites, south, middle, and north (Figure 1). Pre and post bloom sampling was conducted at all three gulf-facing beach sites, each approximately 0.8 km (0.5 mi) in length. The purpose of having three sites was to provide spatial replication within the study. The southern site was 1.4 km (0.9 mi) apart from the mid-beach site while the northern site was located approximately 3.4 km (2.1 mi) north from the mid-beach site. Sampling was conducted twice during the course of this study. The pre bloom sampling took place in the Spring (April 2011), seven months prior to the red tide event, whereas the post bloom sampling occurred in the Fall (December 2011) during decreasing and low concentration cell counts (50 – 100 cells/ml) of the ongoing red tide bloom. Each beach site was divided into 20 linearly spaced 40 m (0.025 mi) intervals in which five were randomly selected to serve as the sampling location (i.e., stratified random sampling). Within each selected interval, a 5 m line was positioned parallel to the
shoreline and central to the swash zone, while a 4 m line lay perpendicular to this line forming a 5x4 m rectangular plot, thus establishing a grid of 20 1 m$^2$ subplots. Four sediment core samples (10 cm depth, 8 cm diameter) were collected from each corner of every m$^2$ subplot and placed into a single 500 μm mesh collecting bag (constructed from Nitex Bolting cloth) and sieved on site to remove excess sediment. This process was repeated at 1 m intervals across the length of the 5 m shoreline and down the 4 m seaward transect lines, thus yielding 80 corners and 20 sub-samples per plot. After samples were sieved, they were labeled and secured with a zip-tie, then placed into a reservoir filled with sea water. Samples were then preserved in a 10% formalin and seawater solution and stained with Rose Bengal for a minimum of 24 h. The total number of specimens of each species within every sample were enumerated and identified to the lowest taxonomic level possible then preserved into a 70% isopropyl solution. Biomass of each major taxonomic group was determined after drying specimens at 65°C for a 72 h period then weighing them on an analytical balance (Mettler Toledo B-S/PH model) to the nearest 0.0001g.

**Red Tide Cell Counts**

Cell concentrations were determined by counting *K. brevis* cells from water samples collected along the coast of South Padre Island by a local organization of trained personnel (Red Tide Rangers) which responds to and monitors HAB’s in Cameron County. Water samples of 50 ml were collected at 30.48 cm (12 inches) from the surface and preserved with Lugol’s iodine solution, thereafter taken to the lab for *K. brevis* cell counts using a Sedgewick Rafter (1801-G20 gridded model) counting chamber. Water
sample and *K. brevis* analyses was performed on a daily basis at designated sites throughout the course of the bloom. Once data was collected, it was submitted to TPWD and the National Oceanic and Atmospheric Administration (NOAA) to be shared with natural resource managers and the public. Aside from determining cell count densities, field observations (aerosols, water discoloration, wind speed/direction, fishes and invertebrate deaths) and water parameters (temperature and salinity) were also recorded.

**Statistical Analyses**

Abundances and biomass were summed over the 20 sub-samples for each plot in each sampling interval. Taxa comprising less than 2% of the total abundances were removed in order to prevent an interpretable outcome resulting from the presence of species that may largely be due to chance (Clark & Warwick, 2001). A square root transformation was applied to all the data for the purpose of down-weighing those species with extremely high abundances therefore allowing mid-range and rare species to contribute to similarity calculations among and between the bloom communities (Clarke & Warwick, 2001). Differences in community structure of the benthic macrofauna between pre and post bloom were analyzed using PRIMER V.6 software (Plymouth Routines in Multivariate Ecological Research; Field et al.,1982; Clarke, 1993; Clarke & Warwick, 1994). The *a priori* null hypothesis of no assemblage/biomass differences among pre and post bloom communities (abundance/biomass) was tested at α=0.05 via a one-way analysis of similarity (ANOSIM). ANOSIM (Clarke, 1993) is an approximate analogue of the factorial ANOVA (Clarke and Warwick, 1994) that compares resemblance matrices (abundance or biomass) among factors (e.g., pre vs. post bloom or
site) via the test statistic, R (analogous to F in ANOVA). The value of the test statistic, R, ranges from 0 to 1 where an R-value of 0 indicates no differences between pre and post bloom communities and a value near 1 suggests very different community structure among the two.

Non-metric Multidimensional Scaling (MDS) was used to configure pre and post bloom samples based upon their similarities in species abundance and biomass within and across samples. Hierarchical cluster analysis (CLUSTER) was performed to identify \textit{a posteriori} groupings (statistically significant) of sample plots based on a 70% similarity level. A SIMPROF test was applied to identify statistically significant groups among pre and post bloom sample plots (Clark & Warwick, 2001). Taxonomic groups contributing differences between the communities were determined by using the similarity percentages routine (SIMPER). All multivariate analyses (ANOSIM, MDS, and CLUSTER) were based upon Bray-Curtis similarity matrices (Bray & Curtis, 1957). In addition, univariate diversity indices (DIVERSE) including Shannon’s diversity ($H'$ \[\log_{10}\]), species richness ($S'$) and evenness ($J'$) were computed from species abundances (individuals/m$^2$) and compared across pre and post sampling intervals by an independent samples t-test.
III. RESULTS

Of the 17 different macroinvertebrate species identified throughout the course of the study, only seven taxa represented at least 2% of the total abundance in all samples and were therefore used in statistical analyses, excluding only 101 individuals of the 25,120 specimens (pre HAB: 13,409, post HAB:11,711) collected.

Comparison of Pre and Post Bloom Communities: Abundances

Molluscs accounted for 57.5% of the 13,367 specimens collected during the pre-bloom sampling, followed by polychaetes (29.1%), and crustaceans (13.4%). The dominant species within each taxon were the bivalve, *D. variabilis* (57.5%), polychaete, *S. squamata* (29.0%), and the amphipod, *Haustorius* spp. (6.4%), all of which were the most abundant species in the pre bloom abundances. Average densities for the pre bloom macrobenthic community was therefore highest for *D. variabilis* (635±80/m$^2$) followed by *S. squamata* (321±52/m$^2$), *Haustorius* spp. (71±8/m$^2$), *Acanthohaustorius* spp. (41±10/m$^2$), *E. talpoida* (31±3/m$^2$), *Ancinus depressus* (3±1/m$^2$), and *Lumbrineris* spp. (Blainville, 1828) (1±0/m$^2$).

Of the 11,652 individuals collected during the post bloom sampling, molluscs continued to be the most dominant group (79.9%), followed by crustaceans (15.9%), and polychaetes (4.2%). The most abundant species were *D. variabilis* (79.9%), isopod *A. depressus* (6.0%), and amphipod *Haustorius* spp. (4.4%) with corresponding densities of 769±68/m$^2$, 58±8/m$^2$, and 43±5/m$^2$. Average densities for the remaining swash zone were *S. squamata* (30±3/m$^2$), *Emerita talpoida* (29±3/m$^2$), *Acanthohaustorius* spp. (21±3/m$^2$), and *Lumbrineris* spp. (10±1/m$^2$).
Therefore, following the red tide event, abundances of *A. depressus* and *Lumbrineris* spp. increased by 19 and 60 fold respectively, *D. variabilis* and *E. talpoida* increased by 0.7 and 0.9 times respectively, while *Haustorius* spp., *Acanthohaustorius* spp., and *S. squamata* decreased by 39.6%, 47%, and 90.5% accordingly.

Species richness (S), diversity (H’), (Shannon diversity index) and evenness (J’), (equitability index) were calculated for each plot and compared by an independent samples t-test between pre and post bloom communities. Species richness (*t*0.05(58) = 9.17, *P* < 0.001) was significantly lower (Figure 2c), while species evenness (*t*0.05(58) = 4.691, *P* < 0.001) was significantly higher in the pre bloom abundances (Figure 2d). Species diversity did not differ (*t*0.05(58) = 0.910, *P* = 0.367) among between pre and post bloom swash zone communities (Figure 2b).

Benthic macroinvertebrate communities were significantly different between pre and post bloom samples (ANOSIM: Global R=0.612, *P*=0.01). Multidimensional Scaling ordination similarly indicated a distinct separation of the before and after red tide event communities (Figure 3, 2D stress = 0.13). Pre and post bloom samples formed two distinct clusters at a 71.9% similarity (SIMPROF: *π*=1.18, *P*=0.001). Two other minor clusters were observed consisting of two and five sample plots at similarities of 56.5% (SIMPROF: *π*=1.69, *P*=0.001) and 65.8% (SIMPROF: *π*=1.32, *P*=0.001) respectively (Figure 7). Furthermore, CLUSTER analysis revealed an additional minor grouping of two samples from the pre bloom abundances which arranged together with the post bloom samples (56.5% similarity; SIMPROF: *π*=1.69, *P*=0.001) (Figure 7). An exceptionally large abundance of the polychaete, *S. squamata* (321 individuals/m²), not observed in other samples, explains this grouping.
Results from similarity percentage analysis, SIMPER revealed a dissimilarity of 31.5% (68.5% similar) between the samples of pre and post bloom communities. The species driving the difference among sampling periods were *S. squamata* whose abundance was greater before, and *D. variabilis* and *A. depressus* whose abundances were greater after the red tide event (Table 1).

**Comparison of Pre and Post Bloom Communities: Biomass**

Community biomass before the *K. brevis* bloom was dominated by *D. variabilis* which contributed 81.3% followed by *E. talpoida* (13%) and *S. squamata* (4.1%). In comparison, the majority of the biomass from the post bloom community continued to comprise of *D. variabilis* and *E. talpoida* with 77.4% and 13.4%, respectively, as well as *Lumbrineris* spp. (2.5%) and the mole crab *Lepidopa benedicti* (Schmitt, 1935) (5.7%).

Differences in biomass of both pre and post bloom infaunal communities were significant (ANOSIM: Global R=0.568, P=0.01). This difference in community biomass was visually apparent on the 2d ordination plot (Figure 4, 2D stress = 0.13). Cluster analysis further supported two main groups distinguishing pre and post bloom communities at a similarity of 71.7% (SIMPROF: $\pi=1.38$, $P=0.001$) (Figure 8). Three additional minor clusters composed of two, three, and four samples were the only exceptions to the clear separation of both communities. Of these clusters, one was significantly similar at 82.8% (SIMPROF: $\pi = 0.82$, $P = 0.045$) (Figure 8), which was due to a greater biomass resulting from the presence of larger adult sized mole crabs, *E. talpoida*, which all four samples shared in common.
Similarity percentage analysis (SIMPER) indicated a 32.0% dissimilarity (68.0% similarity) between the biomass of the pre and post bloom communities. The species contributing the most to this difference were *D. variabilis*, *E. talpoida*, and *S. squamata* which all decreased in biomass by 42.5%, 40.8%, and 94.5% following the red tide event, respectively. *Haustorius* spp. and *Acanthohaustorius* spp. had 5.6 and 4.3 times less population biomass while *Lumbrineris* spp., *Ancinus depressus*, and *L. benedicti* increased their population’s biomass by 52, 6, and 5 times post bloom, respectively.
IV. DISCUSSION

Swash zone macrobenthic invertebrate community structures were clearly and significantly different in terms of both abundance and biomass before and after the *K. brevis* bloom which occurred on South Padre Island, Texas in 2011. These findings were supported by ANOSIM, MDS, and CLUSTER analyses (Figures 3-8), which all gave congruent results.

The observed invertebrate mortalities associated with the 2005 red tide event were massive and included members of all typical swash zone taxa. Assuming the 2005 mortalities were a direct effect of the red tide, the 2011 pre and post bloom communities, despite a relatively high global R (abundance $R = 0.612$, biomass $R = 0.568$) (ANOSIM) and a statistical significance ($P < 0.05$), would be expected to be considerably less similar than the observed 68.5% and 67.5% for abundance and biomass respectively. To determine whether the dissimilarities between 2011 pre and post bloom assemblages were a result of the *K. brevis* bloom, data from this study were compared with a previous study conducted in 2010 on the same location and benthic community. McWhorter (2012) studied the effects of a beach re-nourishment event on the swash zone community of South Padre Island. The results demonstrated that nourished and reference beach communities were highly similar before, one month, and three months after, indicating no consequences to the swash zone invertebrate community from deposited sediment. Thus, the abundance and biomass data from the McWhorter (2012) study, served as a temporal reference for comparing community variation between pre and post bloom samples in this study. When community temporal variation in the previous 2010 study were compared to
the present study by multi-dimensional scaling (MDS) analyses, samples from December, March, and June of 2010 were arranged spatially similar to those from pre and post bloom (abundance and biomass) samples suggesting seasonal variation, rather than the effects of *K. brevis*, attributed to the discrimination between the communities (Figure 5, MDS stress = 0.15 abundance; Figure 6, MDS stress = 0.15 biomass). Further supporting the influence that seasonal variation may have had on the swash zone benthic community before and after the red tide bloom was the observation that the June 2010 samples displayed a closer relationship to pre bloom community collected in April 2011 versus the post bloom samples which were taken in December 2011 (Figure 5). Similarly, the December 2010 sample was similar to the post bloom samples taken one year later in December 2011 (Figure 5). Thus, the similarities shared between the benthic invertebrate communities are linked to the time of year in which samples were collected.

The harmful algal bloom which occurred along the beaches of Boca Chica and South Padre Island in 2005 and 2011 respectively appeared to have had very different effects on the benthic swash zone community. While a maximum average *K. brevis* concentration of 2,933 cells/ml in 2005 coincided with mass mortalities in the benthic macrofaunal community at Boca Chica Beach, a considerably higher average of 33,570 cells/ml at South Padre Island in 2011 did not. Coincidentally, both red tide events began in mid-September of their respective year although the 2005 bloom came to an end in November while the 2011 bloom persisted until January 2012 (TPWD unpublished data). However, the 2005 red tide at Boca Chica consisted of more frequent cell count concentrations exceeding 1,000 cells/ml (13 days in which nine were consecutive), compared to the 2011 event which experienced only half the number of days, throughout
a longer time period. In comparison, the 2011 red tide event was characterized as having higher cell concentrations of *K. brevis* and enduring two months longer than the 2005 bloom. These facts pose a question of why two events, similar to an extent, resulted in two very different outcomes with regards to the benthic macrofauna community.

The Brazos Santiago Pass jetties, located on the south end of South Padre Island and north end of Boca Chica Beach may explain why in 2005 a mass abundance of swash zone benthic invertebrates were gathered at the north region of Boca Chica. Where as a result of long shore currents from the south, sand, seaweed, debris, and all other beach drift accumulates at the north of Boca Chica where the shore meets the jetties. While there were no reports of invertebrate mortalities on the beaches of South Padre Island, it is unknown whether dead invertebrates may have drifted north and similarly collected at the Port Mansfield jetties as may have occurred at Boca Chica Beach. According to the 2011 red tide data, water samples and concurrent field observations were taken on two accounts at the south Port Mansfield jetties (north of South Padre Island) during the beginning weeks of the bloom when concentrations were considered low (1-5 cells/ml) and no benthic mortalities were reported. No samples were taken in the months that followed when the *K. brevis* bloom had progressed and reached high concentration levels, leaving a possibility for accumulation of dead benthic invertebrates at the north end of South Padre Island unknown.

Past studies have shown that the density of *K. brevis* cells during a HAB is not the only factor that determines the toxicity of the bloom. Physical processes such as wind and wave action also play a role as the two can impact the toxicity effects of a *K. brevis* bloom (Hetland & Campbell, 2007). For instance, the toxicity of a bloom may increase
with the release of brevetoxin from lysed *K. brevis* cells caused by harsh winds and turbulent waters (Brand et al., 2012). Leverone et al., (2007) reported the survival of hard clam, *Mercenaria mercenaria* (Linnaeus, 1758) and *Crassostrea virginica* (Gmelin, 1791) significantly decreased when 3-day-old larvae were exposed to lysed versus whole cultures of 1,000 cells/ml. Another study revealed that although no mortalities were observed when planktivorous striped mullet (*Mugil cephalus*) ingested intact *K. brevis* cells at low concentrations, sudden death of these fish occurred when exposed to lysed cells (Naar et al., 2007). These findings may explain why the 2005 and not the 2011 bloom which reached greater *K. brevis* cell densities, influenced the survival of the benthic macroinvertebrate community, especially because the 2005 bloom co-occurred with hurricane Rita which affected South Texas on September 24th, only six days prior to the observation of dead benthic invertebrates on the shoreline. Thus, the close encounter of the hurricane with the red tide event could have impacted the toxicity of the bloom with lysing of *K. brevis* cells.

Red tide toxicity can also be affected by various *Karenia* species and not solely *K. brevis*. Though *K. brevis* and its brevetoxin is the dominating species during red tide blooms in the Gulf of Mexico, other *Karenia* species which produces different toxins and compounds may also be present (Brand et al., 2012). *Karenia brevis* in particular, may be composed of two different strains of brevetoxin which vary in potency, depending on the toxin’s chemical backbone structure (Furey et al., 2007; Ramsdell, 2008; Steidinger et al., 2008b). In addition, the ratios of the two parent brevetoxin compounds will also differ and change especially when exposed to environmental changes, such as entering water, air, and the food web (Errera et al., 2010; Lekan & Tomas, 2010). Thus, *K. brevis*
blooms regardless of low or high cell concentrations may not always give consistent levels of toxicity and as a result, will affect surrounding communities differently each time.

Among the reports of incidences where benthic invertebrates were killed as a result of a red tide event, there is reoccurring mention of secondary effects such as anoxia conditions responsible for invertebrate mortalities rather than the brevetoxin alone. Anoxia is suspected because available oxygen is consumed by K. brevis during high cell densities which can be exacerbated by mass amounts of decaying fishes. For instance, it was inferred that the cause for the benthic reef invertebrate mortalities off the coast of Sarasota, Florida during a red tide bloom in 1971, was likely due to a depletion of oxygen (Smith, 1975b). Though the absence of oxygen could explain benthic macrofaunal deaths in gulf and bay benthic habitats, where levels of oxygen are highly variable due to stratification and nutrient input (Diaz & Rosenberg, 2008), the invertebrates killed in 2005 occurred on the swash zone where constant wave action may aid to counteract levels of low dissolved oxygen (Tiffany & Heyl, 1978).

Aside from the results of this study which gave perspective to the 2005 red tide event, other occurrences unique to the 2011 bloom were present. For instance, despite a 21.1% increase in D. variabilis abundances, biomass results for this species displayed a 45.2% decrease from pre to post bloom samples, indicating a recent recruitment due to a considerably smaller size of bivalves post bloom. Because the D. variabilis population extends from the Mississippi Delta to Campeche, Mexico (Vega & Tunnel, 1987), recruitment during the post bloom sampling may have resulted due to prevailing currents from the south of Texas. According to a two year study done on the reproduction cycle
and recruitment patterns of *D. variabilis* residing along the Florida Coast, low densities of recruitment continuously occurred in the summer and fall even after the peak spawning and recruitment period, which occurred in early spring (Cobb et al., 2011). More similar with the South Texas location of this study, Vega and Tunnel (1987) sampled *D. variabilis* on the sandy beaches of Mustang and North Padre islands for 14 months to determine the population density, growth rates, and spawning periods of the species. The study revealed a recruitment of young *D. variabilis* present at both study sites during December and large (>10 mm) individuals absent or scarce from November through March, which could explain why post bloom samples, collected in December 2011, consisted of a greater abundance of juveniles and fewer adults. The indication of a *D. variabilis* recruitment during a red tide event also suggests that the developmental stages prior to a juvenile bivalve are not affected by the toxicity from *K. brevis* cells.

Leverone et al. (2007) examined survival and development of three species of bivalve, hard clam (*M. mercenaria*), eastern oyster (*C. virginica*) and bay scallop (*Argopecten irradians*) (Lamarck, 1819). Three-day-old larvae of each species were exposed to whole and lysed cultures of *K. brevis* cells at concentrations of 10, 100, and 1,000 cells/ml. Results showed that after a 72 h exposure of all treatments, *A. irradians* larvae had a survival of > 90%, with 80% reaching the final developmental larval stage. In addition, survival for *M. mercenaria* and *C. virginica* was > 88%, and 94% to 75% respectively, in all treatments with the majority to some reaching the final developmental stage (Leverone et al., 2007). Furthermore, observations off the west coast of Florida during a red tide bloom documented toxic amounts of 820 cells/ml contained by *D. variabilis* collected from the surf zone, without resulting in mortalities (Cummins et al., 1971). These
findings may explain why despite *K. brevis* concentrations at an average of 703 cells/ml during post bloom sampling days, juvenile *D. variabilis* were present and abundant in the swash zone.

Overall, this study assessed the effects of a *K. brevis* bloom on a community that is at times overlooked during a HAB. South Texas is a location that has experienced several red tide events and will most likely continue to do so more frequently in the future. While there has been some focus on the effects of *K. brevis* on the benthic community along the Florida coast and bay systems, it is important to study and document the effects in South Texas as benthic macrofauna communities vary among different locations. Finally, this study provided data that may serve as a baseline for further studies on *K. brevis* effects along the South Texas coast and can help to identify species that can potentially bioaccumulate and transfer toxins to higher trophic communities in both the marine and terrestrial food webs.
V. LITERATURE CITED


Tiffany III, W. J., & Heyl, M. G. (1978). Invertebrate mass mortality induced by a 
Gymnodinium breve red tide in Gulf of Mexico waters at Sarasota, Florida. 

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Austin, Texas, 48pp.


behavior of Donax (Donacidae: Bivalvia) on Mustang and northern Padre Island, 

Woodcock, A.H. (1948). Note concerning human respiratory irritation associated with 
high concentrations of plankton and mass mortality of marine organisms. Journal 
of Marine Research, 7, 56–62.
VI. TABLES

**Table 1**: Similarity percentages (SIMPER) of benthic macroinvertebrate species abundances (√transformed) between pre and post bloom swash zone communities at South Padre Island, Texas in 2011.

**Group Pre**

Average similarity: 77.10

<table>
<thead>
<tr>
<th>Species</th>
<th>Av.Abund</th>
<th>Av.Sim</th>
<th>Sim/SD</th>
<th>Contrib%</th>
<th>Cum.%</th>
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**Group Post**

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**Groups Pre & Post**

Average dissimilarity = 31.48

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Table 2: Similarity percentages (SIMPER) of benthic macroinvertebrate species biomass (√ transformed) between pre and post bloom swash zone communities at South Padre Island, Texas in 2011.

Group Pre
Average similarity: 77.16

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Group Post
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Groups Pre & Post
Average dissimilarity = 31.97

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Table 3: Estimated densities (individuals/m²) of swash zone benthic macrofauna at South Padre Island, Texas based on species abundances before and after the 2011 *K. brevis* bloom.

<table>
<thead>
<tr>
<th></th>
<th>Scolelepis squamata</th>
<th>Lumbrineris spp.</th>
<th>Haustorius spp.</th>
<th>Acanthohaustorius spp.</th>
<th>Ancinus depressus</th>
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<td>71</td>
<td>41</td>
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<td>30</td>
<td>10</td>
<td>43</td>
<td>21</td>
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Figure 1: South Padre Island, Texas and location of benthic sampling sites for South (lat 26.097505, lon -97.160621), Mid (lat 26.119271, lon -97.163645), and North (lat 26.153655, lon -97.169423) beaches before and during the red tide event in 2011. (Modified from Google Earth)
Figure 2: Pre and post bloom community indices based on A) mean species total (individuals/m²), B) diversity (H’), (Shannon diversity index), C) species richness (S), and D) evenness (J’), (equitability index). An asterisk (*) denotes significant difference (P<0.05).
Figure 3: Multi-dimensional scaling (MDS) plot (from Bray-Curtis similarities) of pre and post bloom samples of swash zone macrobenthic invertebrate species abundances at South Padre Island, Texas in 2011.
Figure 4: Multi-dimensional scaling (MDS) plot (from Bray-Curtis similarities) of pre and post bloom samples of macrobenthic invertebrate species biomass at South Padre Island, Texas in 2011.
Figure 5: Multi-dimensional scaling (MDS) plot (from Bray-Curtis similarities) of benthic macroinvertebrate species abundances between pre and post bloom samples from the swash zone community at South Padre Island, Texas in 2011 compared with long term data set from 2010 (McWhorter, 2012).
Figure 6: Multi-dimensional scaling (MDS) configuration (from Bray-Curtis similarities) of benthic macroinvertebrate species biomass between pre and post bloom samples from the swash zone community at South Padre Island, Texas in 2011 compared with long term data from 2010 (McWhorter, 2012).
Figure 7: CLUSTER dendrogram of pre and post bloom sample plots of benthic macrofauna at South Padre Island, Texas in 2011, using group-average clustering from Bray-Curtis similarities on √ transformed abundance data. Dashed line denotes a 70% similarity threshold.
Figure 8: CLUSTER dendrogram of pre and post bloom sample plots of benthic macrofauna at South Padre Island, Texas in 2011, using group-average clustering from Bray-Curtis similarities on √ transformed biomass data. Dashed line denotes a 70% similarity threshold.