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Swan Lake: Pilot Study Site Utilizing Processed Industrial Wastewater to Manage Salinity in Lower Galveston Bay.

Antonietta S. Quigg (Ph.D.)
Rachel Windham, Zheng Zhang, Rebecca Fleur Swartz
Ayal Anis (Ph.D.) and Sammy Ray (Ph.D.)

Texas A&M University at Galveston
Department of Marine Biology
Galveston, TX, 77553

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1. Abstract

In estuaries along the northern coast of the Gulf of Mexico, the eastern oyster, *Crassostrea virginica*, is highly valued for both its ecological and economic role. Following the devastation of the upper Texas coast by hurricanes in 2005 and 2008, there is renewed interest in restoration and creation of reefs. In many cases, progress may be hampered by the lack of suitable substrate. Swan Lake and the Virginia Point Shoreline (Galveston Bay, Texas) have a real potential to act as a new oyster reef whilst the oysters would provide shoreline protection and reduce erosion in this area. The present study analyzed spatio-temporal variation in growth and condition of market-sized oysters of *C. virginica* as well as recruitment in spat from 2009 to 2010 within the study area and a control site (Sportsmans Road). We also examined changes in phytoplankton community composition and production at the locations in which the oysters were growing. We found oyster recruitment was higher in Swan Lake relative to along the Virginia Point Shoreline; possibly because of (not significantly) lower overall salinities in the area. We did not find significant differences in Dermo (*Perkinsus marinus*) intensities between sampling locations but did find that at < than 25°C, Dermo intensities were significantly lower in 2010 than in 2009. This result is important because water temperatures were similar both years but there were overall lower salinities in 2010 than in 2009. Salinity is known to be one of the important forcing factors (higher salinities; higher Dermo intensities); the other is temperature. Hence, if freshwater is released into the Swan Lake and along the Virginia Point Shoreline, our findings suggest oysters in this area are likely to experience less stress as a result of this protozoan parasite. The dominant food source for the oysters in this area was diatoms, based on microscopic analysis and HPLC. Secondarily, cyanobacteria and "green" algae were important at different times based on HPLC analysis; these two groups are however difficult to examine microscopically. Food supply was similar at all stations and varied as a function of temperature primarily, and then other biotic and abiotic factors which did not investigate in detail.

2. Background

The eastern oyster, *Crassostrea virginica,* is the main shellfish found in the Gulf of Mexico. Since the late 1950's, Galveston Bay has produced about 80% of the oysters harvested in Texas bays (Lester and Gonzalez 2011). South of Houston (Texas), the Galveston Bay system (Fig. 1) is ideally suited for oysters – it has good water circulation and suitable water temperature and salinity conditions. This partly explains why the Galveston Bay oyster fishery has been an important commercial species for over one hundred years (Lester and Gonzalez 2011). Galveston Bay had 7,526 acres of surveyed oyster reefs in 1976, the majority of which were located in Galveston and East Bays. A 1994 study indicated nearly twice that area, 14,210 acres (not including West Bay). This increase can be attributed to several factors; however, it is more likely that better technology allowing more extensive mapping has resulted in better documentation, rather than more reefs. Between 1997 and 2001, the annual commercial harvest of oysters from Galveston Bay averaged 4.6 million pounds. For the same period, the annual, ex-vessel value of oysters caught in Galveston Bay averaged more than ten million dollars (Culbertson et al. 2004). More recently (September 2008), Hurricane Ike destroyed or damaged more than half of Galveston Bay's oyster reefs by burying them in sediment that eroded during the storm surge. Ike dealt its biggest blow to the East Galveston Bay, where nearly 80% of all oyster reefs were destroyed (Lester and Gonzalez 2011). Scientists and resource managers working in Galveston Bay are currently concerned by the impact of a depleted oyster population on environmental water quality in the bay and the status of the fishery during the rebuilding process.

2.1 *Crassostrea virginica*

In addition to being commercially valuable, oysters serve an important ecological role in the bay system. They stabilize the sediment, reduce turbidity by filtering particles, and provide a distinct habitat for reef associated organisms. A large, healthy oyster population can filter large volumes of water and influence water clarity throughout the Bay. At the same time, their habitat is utilized by a variety of other organisms including mussels, clams, serpulid worms, barnacles, crabs, finfish and birds. In Texas estuaries including Galveston Bay,

oyster reef habitat is created by the dominant species, *C. virginica*. Unlike a coral reef ecosystem, which can lose several species of coral and still survive, the oyster reef ecosystem will collapse without a healthy population of oysters. The health and well being of shellfish areas is dependent on a combination of several interacting extrinsic (biotic and abiotic) and intrinsic (genetic, physiological, immunological) factors.

One vital component of oyster habitat is the salinity of the water in which the reef is located. Oysters do well in salinities of l0 - 20 (All salinities in this report are presented on the practical salinity scale and thus unit less), which explains why they thrive in the middle of Galveston Bay for example (Espey et al. 2009). Salinities ranging from 17 - 24 are favorable for spat setting while waters below 8 have poor spat survival. Mature oysters often die when salinities fall below 5 for extended periods. Prolonged flooding occasionally causes oyster mortality in Galveston, Trinity and East Bays (Espey et al. 2009). Temperature is a factor during periods of low salinities as oysters have higher survival rates during lower temperatures than during high temperatures. While salinity and temperature can explain 50% of observations relating to oyster health, the other 50% is unexplained, but likely related to oyster diet.

2.2 Oyster diseases and predators

Not only are salinity and temperature important in maintaining good populations of oysters, they are also important factors for oyster diseases and predators. *Perkinsus marinus* (= *Dermocistidium* or Dermo) is an apicomplexan protozoan parasite that has had devastating effects on Atlantic and Gulf coast eastern oysters, *Crassostrea virginica*, since the 1950's. *P. marinus* is deleterious to oysters because of its ability to destroy connective tissues of the oyster; it affects larger oysters more than smaller ones. Parasites are spread by live oysters, decomposing tissues of dead oysters and by the excretions of scavengers that feed on the dead oysters. *P. marinus* activity and distribution levels are heavily affected by temperature (growth stops below 20°C) and salinity (>21 – 25) and are possibly linked to the reduction of freshwater inflow in estuaries and bays from developing areas along the Atlantic and Gulf coasts (Ewart & Ford 1993; Culbertson 2008). Eutrophication, due to

human population growth, may also regulate activity and distribution but there is limited research on the subject with respect to oyster populations, their diseases and predators.

P. marinus is a serious problem to Texas oysters, but unlike the Atlantic coast infections there has been no complete decimation of oyster populations. There may be differences in the virulence of the *P. marinus* strain on the Atlantic coast and the Gulf coast, or Texas oysters maybe more resistant to this "home-grown" threat (Bushek & Allen 1996). Alternatively, growth rates of oysters may explain differences between Gulf and east coast reefs. Oysters in Texas are harvested in approximately 1.5 to 2 years while east coast oysters can take anywhere from 3-4 years to reach market size of 3 inches (7.6 cm). Shorter growth time natural to Texas oysters limits exposure to infectious agents. Despite it being a lethal disease caused by a protozoan on the oysters, Dermo disease is harmless to humans.

The southern oyster drill (*Stramonita haemastoma*) is a predatory snail that drills into oyster shells to eat soft oyster tissue. The oyster drill is probably the most serious predator of oysters, and like Dermo, prefers a higher saline environment, exceeding 15. It is more prevalent on Half Moon Reef and other high-salinity reefs along the ship channel in Galveston Bay (Espey et al. 2009). One desirable effect of periodic freshwater flushing is to create conditions inhospitable to these organisms (see La Peyre et al. 2003; Turner 2006; Culbertson 2008; Buzan et al. 2009; La Peyre et al. 2009).

In Louisiana, most oyster production actually occurs between 5 and 15 because of excessive mortality due to *P. marinus* infections (Mackin 1962; Craig et al. 1989; Turner 1985) and predation from oyster drills at salinities above 15 (Galtsoff 1964). Because of this, short-term decreases in salinity (i.e., freshet events) have been suggested numerous times as a means to maintain productive and healthy oyster beds (Soniat and Gauthier 1989; Soniat and Kortright 1998; La Peyre et al. 2003, 2009).

2.3 Galveston Bay

Galveston Bay (Fig. 1) hydrology is driven by river inflow and saltwater exchange through passes to the Gulf. The Trinity River provides more than half of the freshwater inflow, supplemented by inflows from the San Jacinto River and numerous smaller streams and bayous around the system. Bolivar Roads Pass (Galveston entrance to the Bay) is the major source of salt-water exchange from Gulf to Bay, influencing Galveston and Trinity Bay, and parts of East and West Bays. San Luis Pass provides exchange for West, Chocolate, Bastrop, and Christmas Bays. Rollover Pass, when open, influenced upper East Bay. The Texas City Dike restricts freshwater inflow circulation to West Bay.

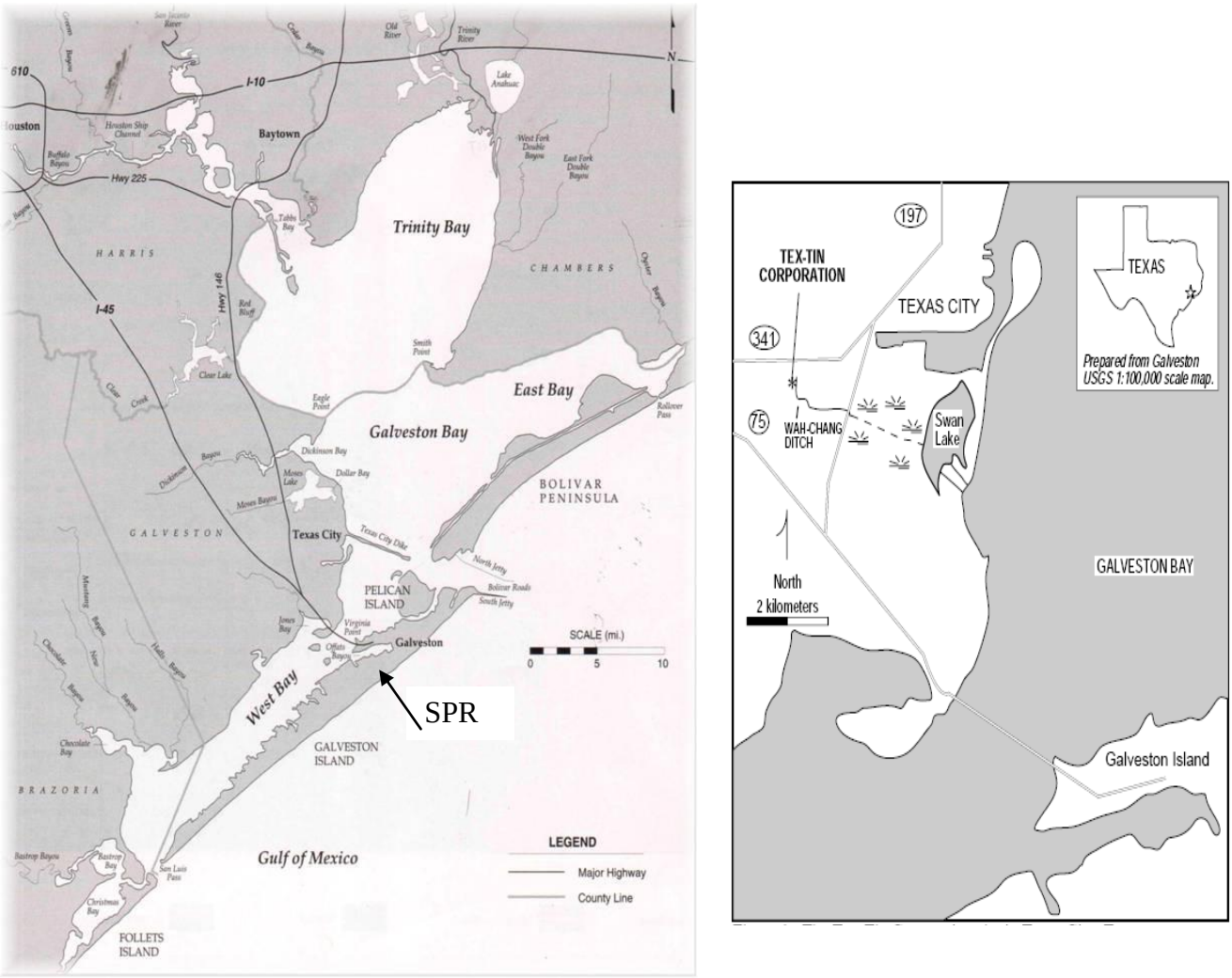

Figure 1 *Galveston Bay (left) and the study site showing Swan Lake (right). Virginia Point Shoreline runs below Swan Lake towards Virginia Point and Galveston Island. A high salinity control site was located on Galveston Island, at Sportsman Road (SPR).*

The oyster reefs of Galveston Bay can be divided into naturally occurring reefs that have existed over historic time and reefs that have been created as a result of human influences. Reefs created through human influences include those associated with:

(i) placement of dredged material;
(ii) oil and gas development;
(iii) oyster leases; and
(iv) modifications in current flow.

The reef types resulting from human activity account for a substantial fraction of all of the present reefs in Galveston Bay. In many areas of the bay, they account for 80 to 100 percent of the entire reef area (Diener 1975; Powell et al. 2003).

In the past, reefs were largely undisturbed by human influence and generations upon generations of oysters settled on previous reef occupants. Historically, the height and areal extent of the reefs in the bay were considerably greater (see pictures in Lester and Gonzalez, 2011). Oyster reefs were a major hydrological feature of Galveston Bay at the time of European colonization. Figure 7.13 in Lester and Gonzalez (2011) shows the emergent character of Redfish Bar which extended from Eagle Point to Smith Point and severely restricted water movement between the upper and lower bay. The abundance and distribution of oyster shell were significantly reduced by commercial shell dredging.

Prior to the 1900's Swan Lake was a very productive wetland and bay margin ecosystem. Since that time, three actions have greatly reduced its ecological value:

(i) large scale ground water pumping has caused 3-5 feet of subsidence,
(ii) many of the islands (see Fig. 1) have eroded away that once provided protection to its shoreline from the open bay forces; and
(iii) the area is part of a TexTin superfund site (Appendix A).

There is widespread concurrence that a major restoration effort is needed. Several factors have converged to provide a unique opportunity to help with the restoration. The TexTin settlement agreement has provided $6 million to be used in the creation of 93 acres of marsh and the extension of the protective breakwater, and dredge material from the Shoal Point

Container Terminal development will be used as part of a comprehensive beneficial uses of dredge material program in the region.

Erosion rates along the Virginia Point Shoreline – a 10,000 feet stretch of shoreline in Galveston Bay (Fig. 1) - range from 4.5 to 9 feet per year (Texas Bureau of Economic Geology). Breakwater extensions along Swan Lake, which is adjacent and to the north of the Virginia Point Shoreline, have recently been completed by the EPA (1987), in cooperation with US Army Corps of Engineers, as part of TexTin settlement. Options for protection and habitat restoration of the Virginia Point Shoreline are presently under investigation and URS corporation has recently (May 2007) prepared a technical memorandum summarizing bathymetric surveys and initial modeling results of waves and currents in the area of interest. Here, we conducted a cooperative project with Scenic Galveston, Inc. and Gulf Coast Waste Disposal Authority designed to increase oyster populations and facilitate shoreline protection in Galveston Bay.

2.4 Rationale for study

The approach to shoreline protection and habitat restoration proposed here is based on preliminary studies carried out by Dr. S. Ray (TAMUG) in Swan Lake at the request of Scenic Galveston. A limited study in Swan Lake and along the Virginia Point Shoreline was initiated in 2005. The results indicated that oysters (*C. virginica*) in this area were subjected, on average, to elevated salinity regimes, as indicated by:

(a) sparseness of live oysters,

(a) heavy shell pest (boring sponge, boring clams, and boring worms) infestations, and

(b) Dermo (*Perkinsus marinus*) disease intensity.

Areas such as Swan Lake and the Virginia Point Shoreline support high populations of the southern oyster drill. Unlike the rest of the oysters in along the southern most stretch of Virginia Point Shoreline, those in the northern most end, adjacent to Swan Lake, exhibited little evidence of shell pests. Laboratory analysis also showed these oysters also had lower levels of Dermo. These preliminary findings indicated that oysters in this vicinity were

receiving more freshwater (possibly through the Last Chance Ditch, via seepage, and the Wa Chang Ditch, via direct flow), making the conditions more favorable for them, and less so for their parasites.

These initial results stimulated the idea of potentially diverting treated wastewater from Gulf Coast Waste Disposal Authority into Swan Lake (10–12 million gallons of treated wastewater per day) to reduce water salinity to levels favorable for oysters. Healthy oyster reef systems accrete at rates of 1-2 inches per year and may thus provide a viable, and natural, shoreline protection system while at the same time increase oyster populations. A study, combining monitoring of hydrodynamics, oyster parameters, and phytoplankton populations (oyster food) was conducted to determine the most favorable sites for oyster recruitment and growing grounds and the release of available treated water.

2.5 Planned Project Benefits

- The project measurements provide accurate spatial and temporal information on the hydrographic conditions and surface-wave climate in the Swan Lake and the Virginia Point Shoreline, thus allowing researchers/ restoration ecologists to choose optimal locations for the oyster reefs.
- The study will determine the most favorable site/s for releasing treated water from Gulf Coast Waste Disposal Authority into the Swan Lake and the Virginia Point Shoreline area to improve oyster recruitment and their accretion potential.
- Optimization of oyster reef growth will provide: 1) a natural way, with no damage to the environment, of absorbing and dissipating wave energy, thus, facilitating shore protection and restoration; 2) increasing oyster populations in the general area.
- This project will provide new information (CMP goal 8) which will allow determination of the most favorable site/s for releasing treated water in the Swan Lake and the Virginia Point Shoreline area to improve oyster recruitment and their accretion potential. Optimization of oyster reef growth will provide: 1) a natural way, with no damage to the environment, of absorbing and dissipating wave energy, thus, facilitating shore protection and restoration (CMP goals 1, 5) ; 2) increasing oyster populations in the general area (CMP goals 2, 5).

When initially funded, the PI's expected that this pilot study - by showing the feasibility of using treated water to enhance oyster growth conditions - would act as a model for development of this method as a means of reducing salinity to more favorable levels in circumscribed estuarine areas. However, during the course of the program, the water was not released by the appropriate authorities, and hence we were not able to examine the influence of this direct freshwater inflow to the system. Nonetheless, we have been able to, and will continue to, collect baseline data which provides details on the current oyster populations in the Swan Lake and the Virginia Point Shoreline area and their response to hydrographic changes in their environment. If funded, and if water is released, future programs will address the original proposal goals. We are working with both the funding agencies and the water suppliers in order to achieve our initial goal.

3. Materials and methods

3.1 Study site and sampling design

The study was carried out in Swan Lake and along the Virginia Point Shoreline at the ten stations shown on the right (Fig. 2), located on the lower western coastline of Galveston Bay (Fig. 1). This intertidal area (630 acres = 259 hectares) includes no current oyster leasing grounds and few if any, natural oyster reefs. Not all stations were visited on all sampling trips due to constraints imposed by weather, boat issues and/or other unforeseeable circumstances. In 2008, we sampled in May and September, then lost most oyster spat collecting bags as a result of Hurricane Ike after our second sampling trip. Furthermore, no native oysters or spat were collected at Station 9 as it is too deep. The physicochemical conditions and oysters examined as part of this study are therefore those investigated from March 2009 to November 2010.

Figure 2. *Sampling stations in Swan Lake and along the Virginia Point shoreline.*

A control site was located at Sportsman Road on the nearby Galveston Island (see Fig. 1), which is not influenced by freshwater,

In November 2007, an initial sample of 10 oysters (*Crassostrea virginica*) was taken to establish pre-deployment conditions by measuring water quality characteristics (temperature, salinity, chlorophyll), the oyster condition index and *P. marinus* infection intensity (Dermo disease). Natural oysters were collected from each station (except Station 9). Natural spat (young oysters) were reared off-bottom in culture bags retained in milk crates. Each crate was stocked with five bags containing 30 shells each to collect spat; two crates were placed at each station (except Station 9). Thirty bags of 30 shells each were placed in reef balls at the west end of Sportsman Road. The shell heights (length) of all spat in the crates and natural oysters deployed at each site were measured using a caliper (Scienceware, Bel-Art Products, Pequannock, NJ, USA) at the time of deployment and bimonthly thereafter through November 2010. On several occasions the oyster crates had to be reinstalled (e.g., after Hurricane Ike) due to losses or vandalism. These crates in oyster stocks were considered in the data analysis.

3.2 Field conditions

At the ten sites, we established continuous data recorders. Hydrodynamic parameters were collected at all stations in Swan Lake and along the Virginia Point Shoreline (Fig. 2) to provide detailed time-series of salinity, temperature, and sea-surface elevation. Water currents were measured using a boat-mounted high resolution Acoustic Doppler Current Profiler (ADCP) during monthly surveys throughout the seasons as well as during various meteorological conditions. In addition, surface-waves were monitored. Background surface meteorological conditions were measured continuously from a full suite of meteorological sensors mounted at an on-shore station. The meteorological, surface-wave, currents, and sea-surface elevation data may also allow the calibration of wave and circulation models that can be used as predictive tools of the physical forces affecting erosion in this area.

3.3 Oysters (*Crassostrea virginica*) – biological measurements

Oyster recruitment, using "spat" collectors, and Dermo disease were monitored on a bimonthly basis at the same stations where the hydrodynamical time-series was collected. At each site, oyster growth and health was monitored by removing 10 native oysters from

surrounding reefs and 10 to 20 spat oysters from the two bags deployed. Oysters were kept in a cooler until they could be returned back to the laboratory for examination, usually the same day.

In the laboratory, oysters were cleaned of mud, scraped to remove any attached epifauna, and weighed to the nearest 0.01 g to determine whole weight (WW). Shell length (SL) was measured to the nearest 1.0 mm using a vernier caliper. Whole weight (WW) was measured by weighing the whole oyster, shell intact, and wet meat weight (WMW) was derived by weighing the contents of the shell. Meat index (MI) was calculated according to Baird and Drinnan (1957):

$$\mathrm{MI} = \frac{\mathrm{WMW}}{\mathrm{WW}} \times 100$$

3.4 Dermo (*Perkinsus marinus*) disease intensity

At every sampling date, 10 individuals per site were used for microscopic histological examination. Sections (approximately 5 by 10 mm) from oysters mantles were cut behind the labial palps and were cultured in Ray's fluid thioglycollate medium – RFTM (Ray 1952, 1966). Each individual was classified into distinct phases of Dermo disease based on microscopic analysis. Dermo intensity and prevalence (percent of oysters infected) were determined according to Abbe and Albright (2003) and Craig et al. 1989). The Mackin Values scale: 0 = no observable infection; 1 = slight infection; 3 = moderate infection; and 5 = heavily infected. The intensity of the Dermo infection is calculated as the density number of parasites in mantle tissue according to Mackin Scale/ number of infected individual oysters per site (Ray 1966). The incidence of Dermo is calculated as the density number of parasites in mantle tissue according to Mackin Scale/ total oysters examined per site (see Table 2). Mackin values between 0-1 were highlighted in green, those > 1 and < 2 were highlighted in yellow, while all those > 2 were highlighted in red. Despite the RFTM method and the Mackin scales being developed more than 50 years ago, they continue to be the methods of choice even to this day.

TABLE 2. Values used in statistical analysis for the infection intensities recorded (after Mackin 1962). Independent trials indicated values above 0 that were >0.5 apart varied more in infection intensity than the precision of the assay.

Level of *Perkinsus* Infection	Assigned Numerical Values
Negative	0.0
Very light	0.33
Light	0.67, 1.0, 1.33
Light to moderate	1.67, 2.0, 2.33
Moderate	2.67, 3.0, 3.33
Moderate to heavy	3.67, 4.0, 4.33
Heavy	4.67, 5.0

Table 1. Scaling system used to record infection intensities. Source: Craig et al. (1989).

3.5 Phytoplankton collection and identification

Phytoplankton community composition was determined qualitatively rather than quantitatively in this study. Phytoplankton collection involved towing a 67 □ m net in the water for no less than five minutes. This was used to concentrate plankton into a 50 mL sample which was preserved in an acid cleaned HDPE rectangular bottle (125 mL; Nalgene) using Glutaraldehyde (final 5%). Samples were examined microscopically for genera and species identification with the assistance of taxonomic guide of Tomas (1997). Digital photographs of representatives of each species were recorded along with the magnification, sizes and any other distinguishing detail. Cell counts were performed in triplicate.

3.6 Phytoplankton community structure

The relative abundance of microalgal groups in mixed species assemblages can also be assessed using the diversity and phylogenetic association of specific photosynthetic accessory pigments (chlorophylls and carotenoids). Microalgal photopigments provide reliable measures of the relative abundance of characteristic algal groups (Millie et al. 1993; Claustre 1994; Jeffrey et al. 1997). Photopigment composition is also significantly (linearly)

correlated with species cell counts (Jeffrey et al. 1997). In Table 2, the seven most common diagnostic pigments are listed along with the phytoplankton groups they are considered to represent. Mackey et al. (1996) have developed a factor analysis algorithm (CHEMTAX) for calculating algal class abundances (both in terms of relative and absolute numbers) based on biomarker photopigments.

Table 1. Diagnostic accessory pigments used to characterize the main phytoplankton groups in the ocean.

Diagnostic pigment	References	Phytoplankton group
Fucoxanthin	Jeffrey 1980	Diatoms
Peridinin	Jeffrey 1980	Dinoflagellates
19′-HF and 19′-BF*	Wright and Jeffrey 1987	Nanoflagellates†
Chlorophyll *b*‡	Jeffrey 1980	Green flagellates
Alloxanthin	Gieskes and Kraay 1983	Cryptophytes
Zeaxanthin	Guillard et al. 1985	Cyanobacteria
Zeaxanthin, divinyl-chlorophyll *b*‡	Goericke and Repeta 1992	Prochlorophytes§

* 19′-HF: 19′-hexanoyloxyfucoxanthin; 19′-BF: 19′-butanoyloxyfucoxanthin.
† The term nanoflagellates refers essentially to chrysophytes and prymnesiophytes which are characterized by 19′-BF and 19′-HF, respectively.
‡ Chlorophyll *b* and divinyl-chlorophyll *b* are regrouped as "Chl *b*" in this study as they coelute on reverse-phase HPLC.
§ Zeaxanthin is an accessory pigment in surface prochlorophytes while divinyl-chlorophyll *b* is an accessory pigment in deeper populations (Morel et al. 1993).

Table 2. The seven diagnostic accessory pigments for characterizing phytoplankton groups. Source: Claustre 1994.

High performance liquid chromatography (HPLC), which provides rapid and accurate quantification of chlorophylls and carotenoids, was used for photopigment-based chemosystematic characterization of microalgae (Millie et al. 1993; Jeffrey et al. 1997; Pinckney et al. 1998). Water collected (0.3 to 1.0 L) from the sampling stations (Fig. 2) were filtered under a gentle vacuum (<50 kPa) onto 2.5 cm diameter glass fiber filters (Whatman GF/F), immediately frozen, and stored at -80° C. Frozen filters were then placed in 100% acetone (3 mL), sonicated, and extracted at -20° C for 12 - 20 h. Filtered extracts (200 µL) were injected into a Spectra-Physics HPLC equipped with a single monomeric (Rainin Microsorb-MV, 0.46 x 10 cm, 3 µm) and two polymeric (Vydac 201TP, 0.46 x 25 cm, 5 µm) reverse-phase C_{18} columns in series. This column configuration was devised to enhance the

separation of structurally similar photopigments and degradation products. Monomeric columns provide strong retention and high efficiency, while polymeric columns select for similar compounds with minor differences in molecular structure and shape (Van Heukelem et al. 1994; Jeffrey et al. 1997). A nonlinear binary gradient, adapted from Van Heukelem et al. (1994), was used for pigment separations (Pinckney et al. 1998). Solvent A consists of 80% methanol: 20% ammonium acetate (0.5 M adjusted to pH 7.2) and solvent B is 80% methanol: 20% acetone. Absorption spectra and chromatograms (440 nm) were acquired using a Shimadzu SPD-M10av photodiode array detector. Pigment peaks were identified by comparison of retention times and absorption spectra with pure crystalline standards, including chlorophylls *a*, *b,* β-carotene (Sigma Chemical Company), fucoxanthin, and zeaxanthin (Hoffman-LaRoche and Company). Other pigments were identified by comparison to extracts from phytoplankton cultures and quantified using the appropriate extinction coefficients (Jeffrey et al. 1997). Chlorophyll *a* can also be used as a proxy for phytoplankton community total biomass.

3.7 Phytoplankton Pulse - Amplitude Modulated Fluorometer (PHYTO-PAM)

The pulse-amplitude-modulation (PAM) measuring principle is based on selective amplification of a fluorescence signal which is measured in the presence of intense, but very short (µsec) pulses of actinic light. In the PHYTO-PAM, light pulses are generated by an array of light-emitting diodes featuring 4 different wavelengths: blue (470 nm), green (520 nm), light red (645 nm) and dark red (665 nm). This feature is very useful for distinguishing algae with different types of photosynthetic accessory pigments of freshwater and marine algae (Jakob et al. 2005). Green algae (Chlorophytes and Prasinophytes) can be distinguished from Bacillariophyta (diatoms) plus Dinophytes and Cyanophyta respectively.

Further, valuable information on the photosynthetic performance and light saturation characteristics of a phytoplankton community can be obtained by measuring the relative electron transport rate (*rel*ETR). Light response curves were generated by measuring the change in quantum yield (Y) with increasing PAR. These resemble the photosynthesis-irradiance curves known from gas exchange and C14-fixation measurements. The advantage

of the PHYTO-PAM technique was that it can be done in minutes, is non-invasive and requires no isotopes. Gas-exchange techniques and C14-fixation require hours to a day, isotopes for the latter technique and so restrict the total number of samples which can be examined. The PHYTO-PAM approach promises to be particularly suited to monitoring programs designed to assess inter-annual variability in phytoplankton community composition, productivity and biomass. It is sensitive to 0.1 μg chlorophyll L^{-1} (Nicklisch and Köhler 2001) and allows for statistically robust experimental design given many samples can be examined within a short period of time.

The PHYTO-PAM was used to determine the content of *active* chlorophyll in water samples collected from the sampling stations shown in Fig. 2. Water samples were collected in acid-washed dark bottles and stored in a cooler at ambient temperatures. After dark acclimation, they were processed using the PHYTO-PAM. The minimal fluorescence of dark-adapted samples (F) was recorded as it provided an estimate of the chlorophyll content of the water samples and the proportions of the different types of algal groups given that all 4 wavelengths were used. Light response curves were generated for each sample so that photosynthetic performance and light saturation characteristics of the phytoplankton community could be deconvoluted.

3.8 Statistical analysis

Significant differences between measured parameters were examined using SPSS Version 15.

4. Results

4.1 Temperature and Salinity Observations

During each research trip, temperature and conductivity profiles were taken at the stations (see Fig. 2) using a mini-CTD (RBR XR-620), and were used to compute the salinities. Both the temperature and salinity were then averaged over the depth of the profiles at each station (see Appendix B for a summary of all temperature and salinity values and average stations depths).

Temperature (lower panel; Fig. 3) differences between the stations were generally not more than ~2^{O}C throughout the study period. Factors contributing to these differences were (1) the time differences at which measurements were taken and (2) water depth differences at the stations. The observed range of temperatures was 12-32^{O}C, with temperatures higher by about ~2 ^{O}C in summer 2010 than in 2009.

Observed salinities (upper panel; Fig. 3) ranged from 16-33. A rather striking difference was observed between the salinities at all stations in summers of 2009 and 2010, with salinities in the latter summer being lower, on average by about 10 PSU from January to August. While spring and summer salinities were very similar at all stations; marked differences were observed between stations during the fall and winter; typically the higher freshwater inflow and rainfall periods. Stations inside Swan Lake (1-5, 9) exhibited salinities approximately 5 PSU lower in comparison to stations outside the lake (6-8, 10), and along the Virginian Point Shoreline. Salinities at Station 3 in Swan Lake were consistently lower than other stations inside the lake. Station 3 is at the mouth of Wachang Ditch and it probably receives more fresh water directly than any other station in the Swan Lake study. Differences between the stations were largest between Feb-Aug 2010 (Fig. 3).

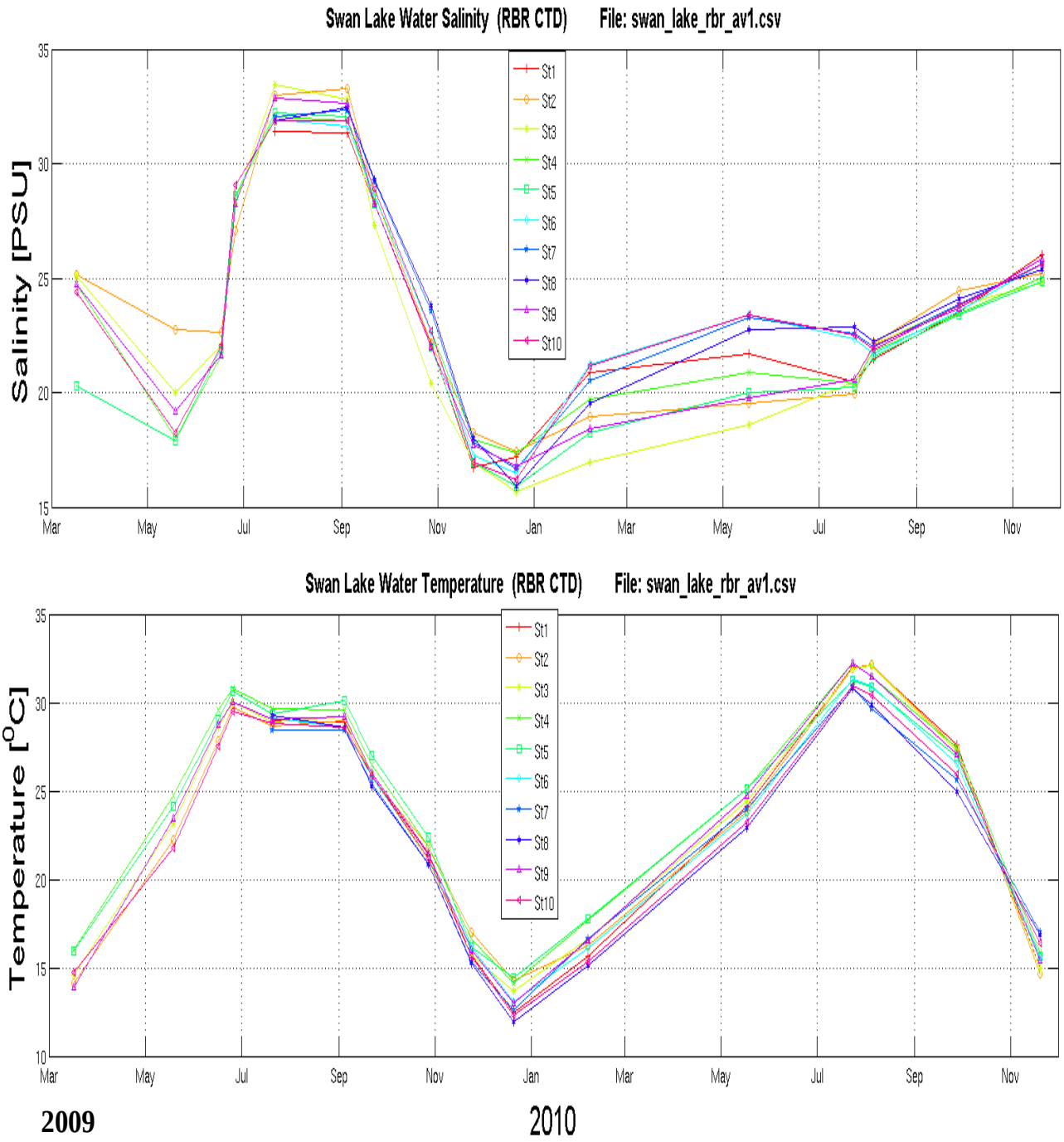

Figure 3. *Salinity (A; top) and temperature profiles (B: bottom) measured at Swan Lake and along the Virginia Point Shoreline from March 2009 to November 2010. Profiles at each station were averaged and a single data point included. For more specific information, details are presented in Appendix B.*

4.2 Wave Modeling

Wave model simulations were carried out using the SWAN model, a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters (Booij et al., 1999). SWAN is a spectral model in which the physical processes governing wave generation (source) and dissipation are implemented into implicit numerical codes. The model does not require prior knowledge of the wave spectra, and the source and dissipation terms included in the model are: wind-generation, triad and quadruplet wave-wave interactions (non-linear interactions) and dissipation due to breaking, white capping, and bottom friction. A general description of the major physical models implemented in SWAN can be found in the SWAN User's Manual (SWAN, 2006.)

Model Setup

The SWAN model was implemented in the unsteady mode in a computational domain with spatial resolution of x = 100 m and y = 100 m for simulation in the general Galveston Bay domain, and a high resolution domain of x = 10 m and y = 10 m for simulations in Swan Lake. Wind data obtained from a nearby NOAA meteorological station at Pleasure Pier, Galveston, was used to force the model and was assumed homogenous for Galveston Bay and the Swan Lake region. Bathymetry data for the model were taken from the National Ocean Service (NOS) archive at a spatial resolution of 100 m for Galveston Bay (Fig. 4) and 10 m for the Swan Lake domain (Fig. 5). We note that only the 10 m grid resolves the bathymetry for Swan Lake.

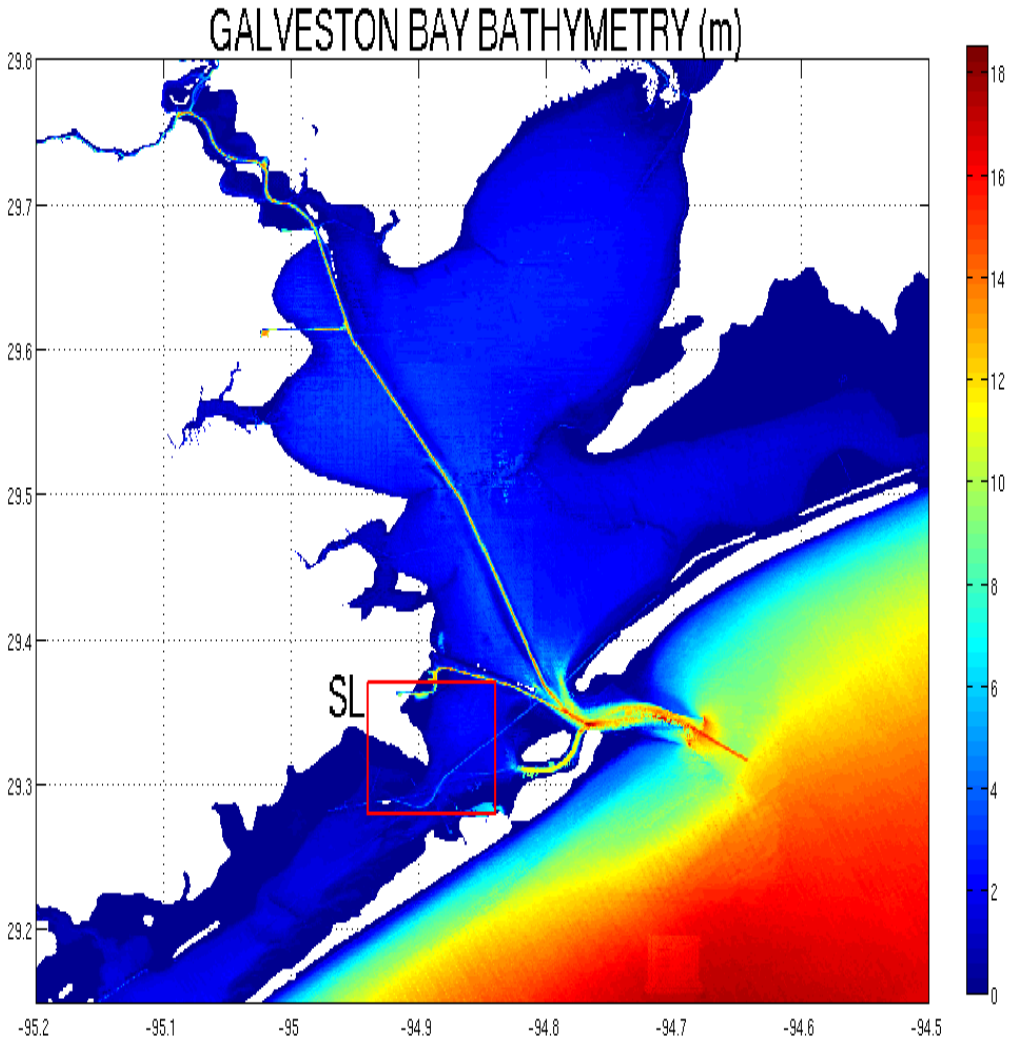

Figure 4. *Galveston Bay bathymetry [m], along with the Swan Lake domain present in the red box. The wave model domain for the coarse (100 m grid) is the same as the bathymetric domain shown in this plot.*

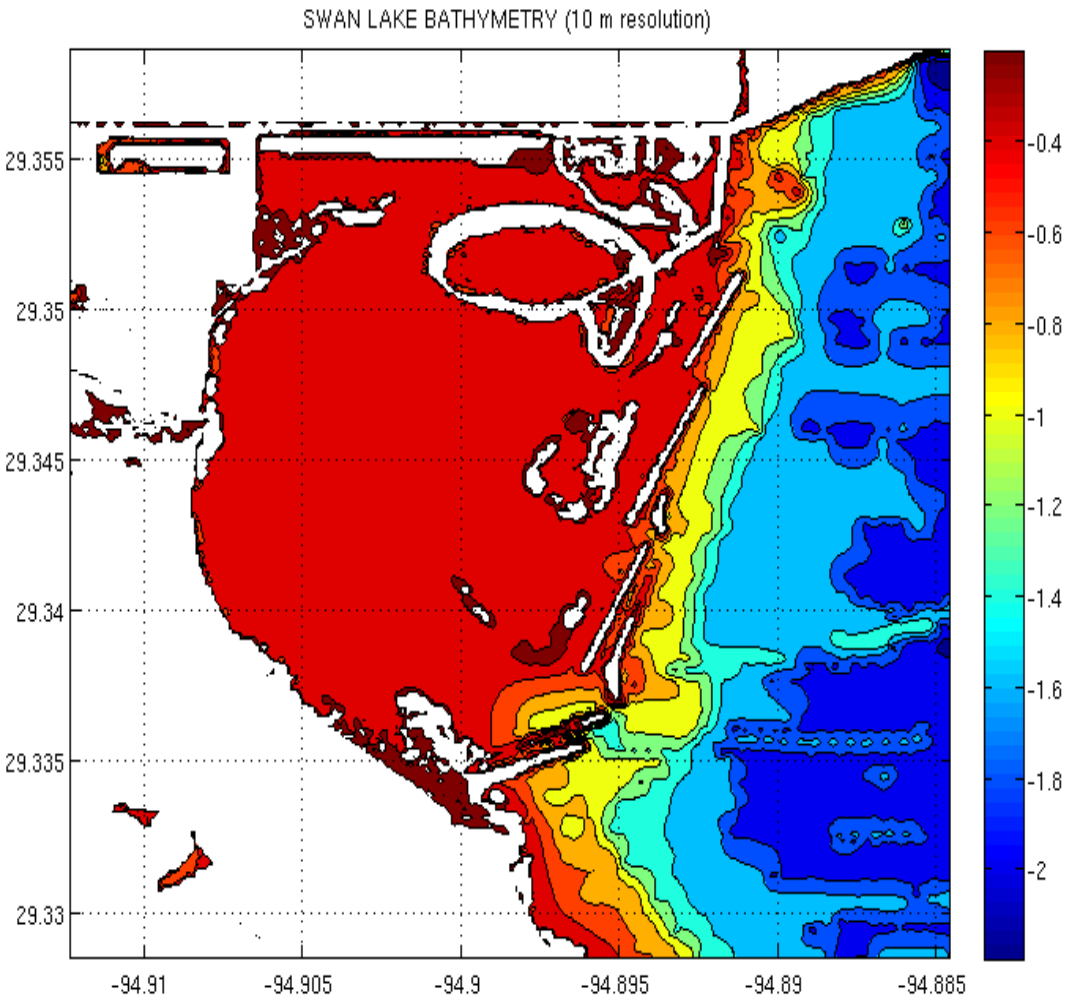

Figure 5. *Swan Lake bathymetry (10 m grid) used for the high resolution simulations. Mean depths in Swan Lake are ~0.6 m. Note the barrier islands at the eastern side of the lake.*

Summary of Model Simulation Results

Model simulations were run for two different grids. The first grid (100 m horizontal resolution; Fig. 4) was used for simulations covering the general Galveston Bay domain. Results of these simulations are presented in Figs. 6 and 7 for 10 m/s (~20 knots) winds blowing from N, E, S, and W. In general, the largest significant wave heights and peak periods do not exceed 1 m and 3.5 sec in the bay, respectively for these winds.

In the vicinity of Swan Lake, near its eastern boundary and breakwaters, significant heights are less than 0.3 m (Fig. 8) and peak periods are ~2-3 sec. A simulation with 20 m/s winds (~40 knots; not shown) resulted in significant heights of 0.4-0.5 m at the eastern boundary of Swan Lake, for easterly winds.

High resolution simulations (10 m horizontal resolution; Fig. 5) focused on Swan Lake and its nearby boundaries (total area roughly 3 x 3 km). Since the lake itself is relatively small, there is only a small fetch length for waves to develop. The average wave height corresponding to 20 m/s is ~0.2 - 0.25 m in the center of the lake (Fig. 9). Significant wave heights are fairly similar for all the runs since the wind speed was set to 20 m/s, with variations being in the wave propagation direction depending upon the wind direction. Peak wave periods are mostly ~1-1.5 sec inside the lake (Fig. 10), with variations more prominent right outside the lake.

Also, the barrier islands to the east block most of the wave energy that may have otherwise (partly) entered the lake from Galveston Bay. The limited wave penetration patterns seen through these breakwater gaps are akin to the classic wave refraction-diffraction patterns through breakwater gaps (Figs. 9 and 11).

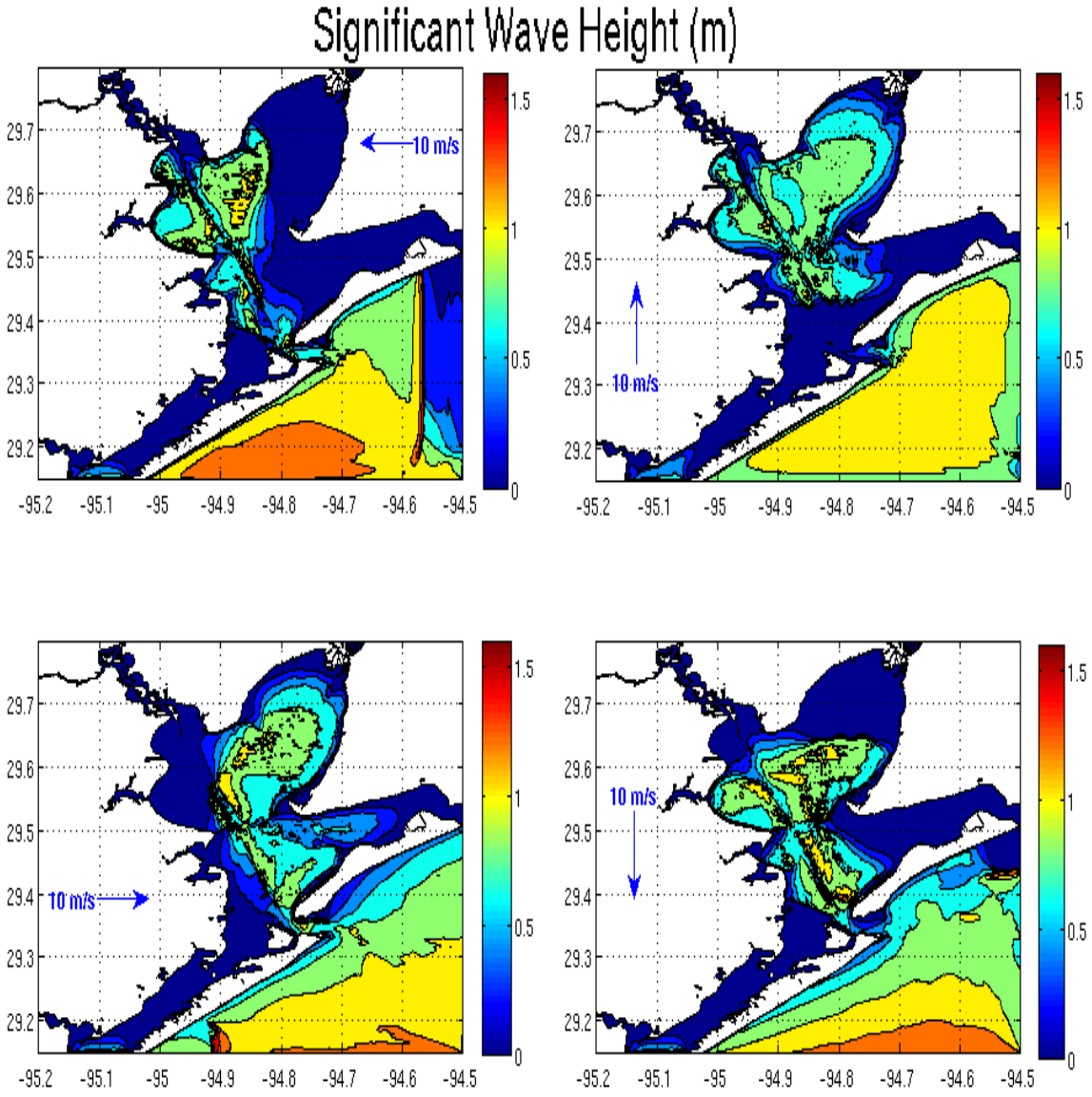

Figure 6 *Significant wave heights [m] for the coarse (100 m) simulations. The four subplots show four simulations with same wind speed of 10 m/s but different directions (easterly, southerly, northerly, and westerly winds, clockwise starting form upper left panel). The wind vector shown in each panel represents the wind direction.*

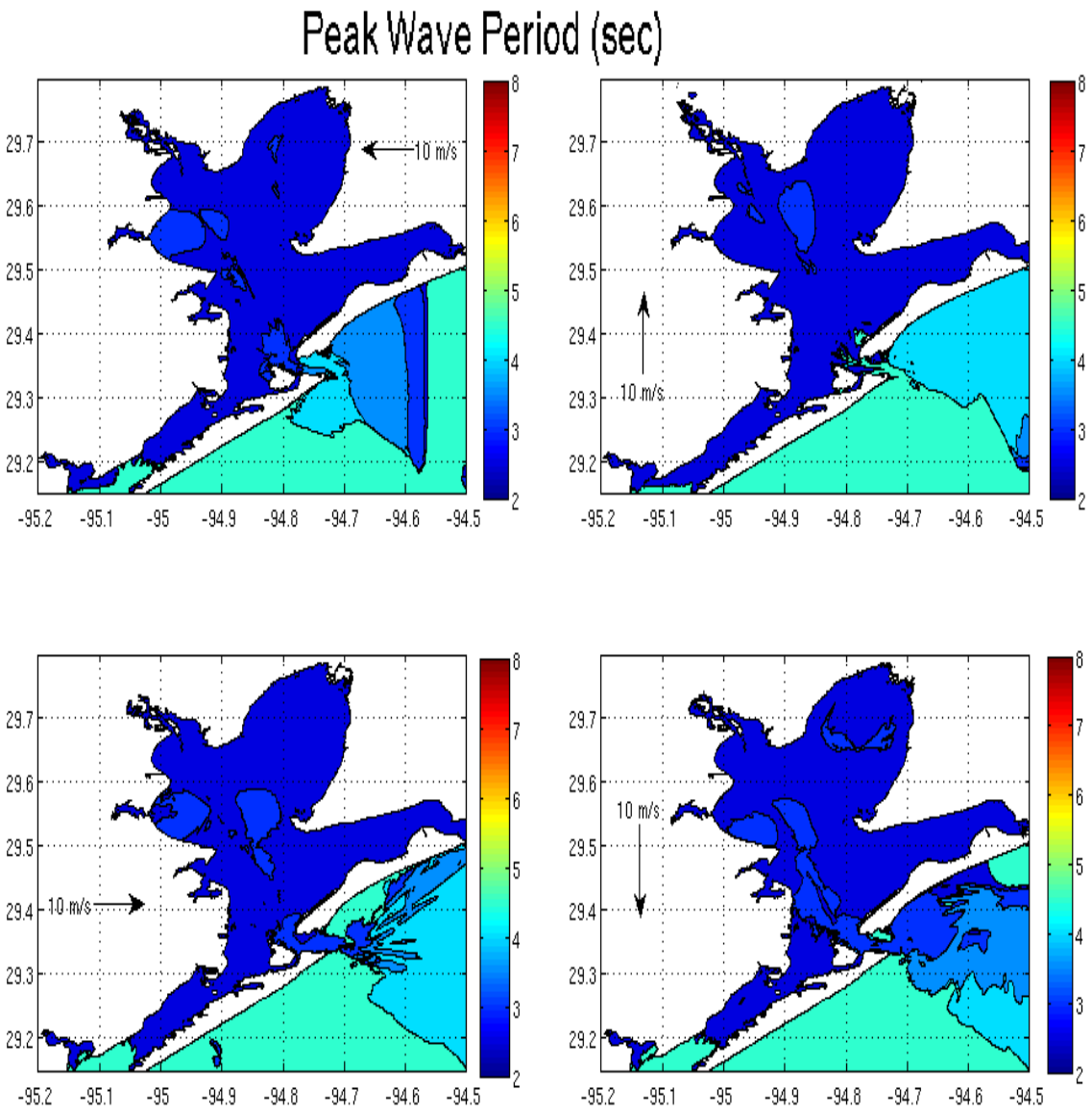

Figure 7 *Similar to Fig. 6 but for peak wave periods [s].*

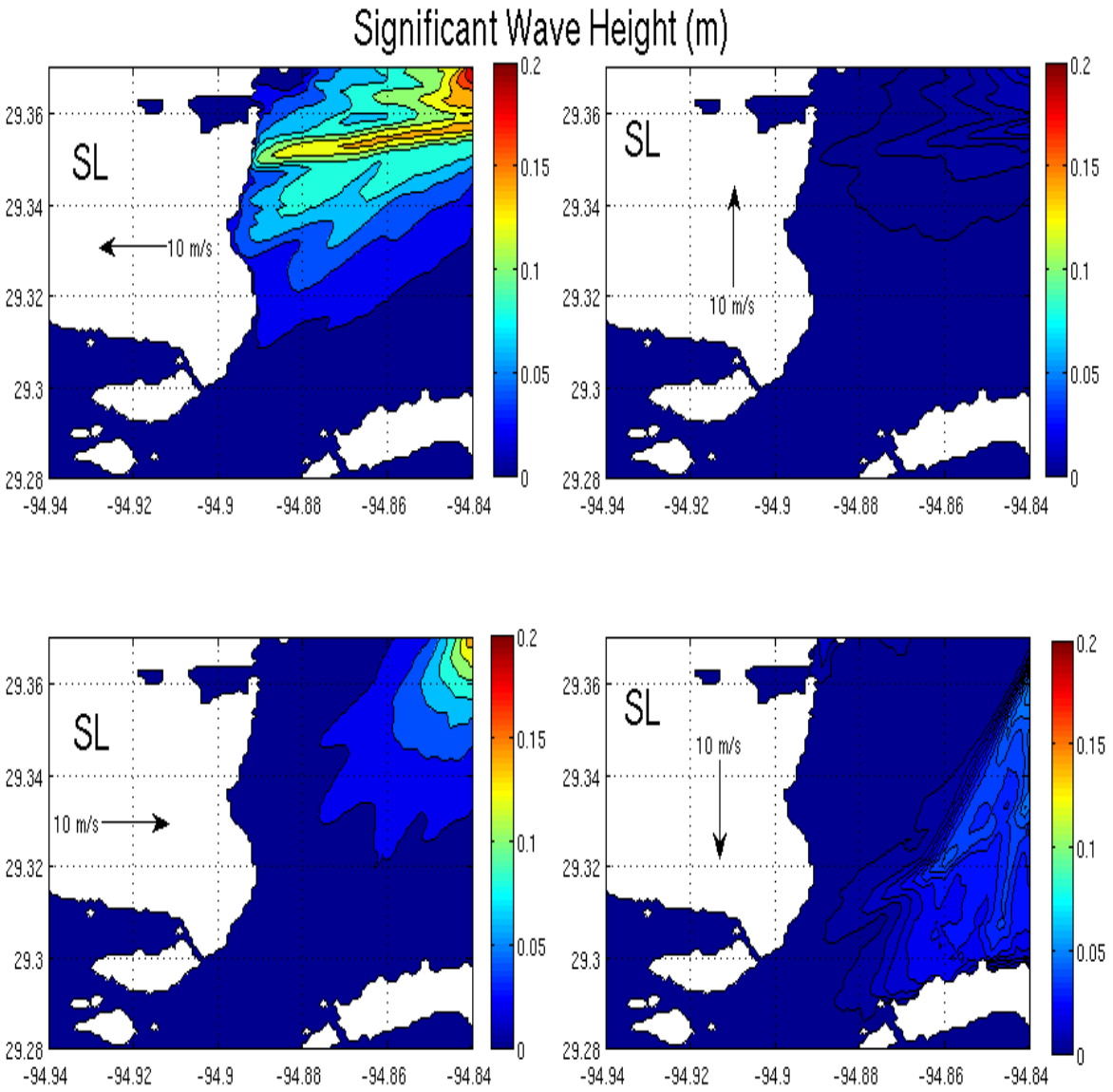

Figure 8. *Significant wave heights for Swan Lake domain (-94.94 W to 94.84 W; 28.28N to 28.37 N).*

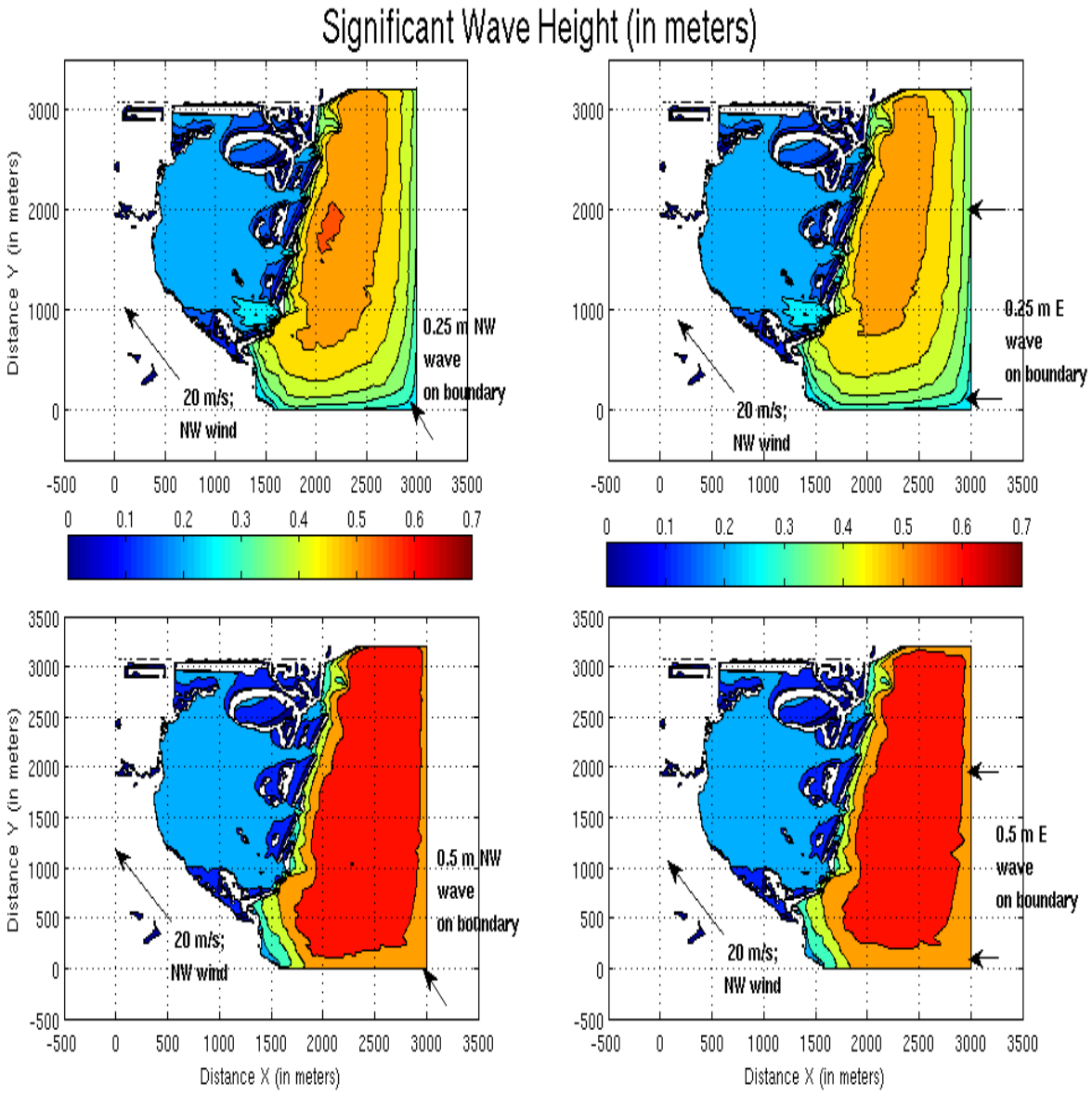

Figure 9. Comparison of significant wave heights [m] for a 20 m/s wind blowing from SE, with different boundary conditions on the open boundary (east side of the lake): 0.25 m waves from SE (upper left), 0.25 m waves from E (upper right), 0.5 m waves from E (lower right), and 0.5 m from SE (lower left).

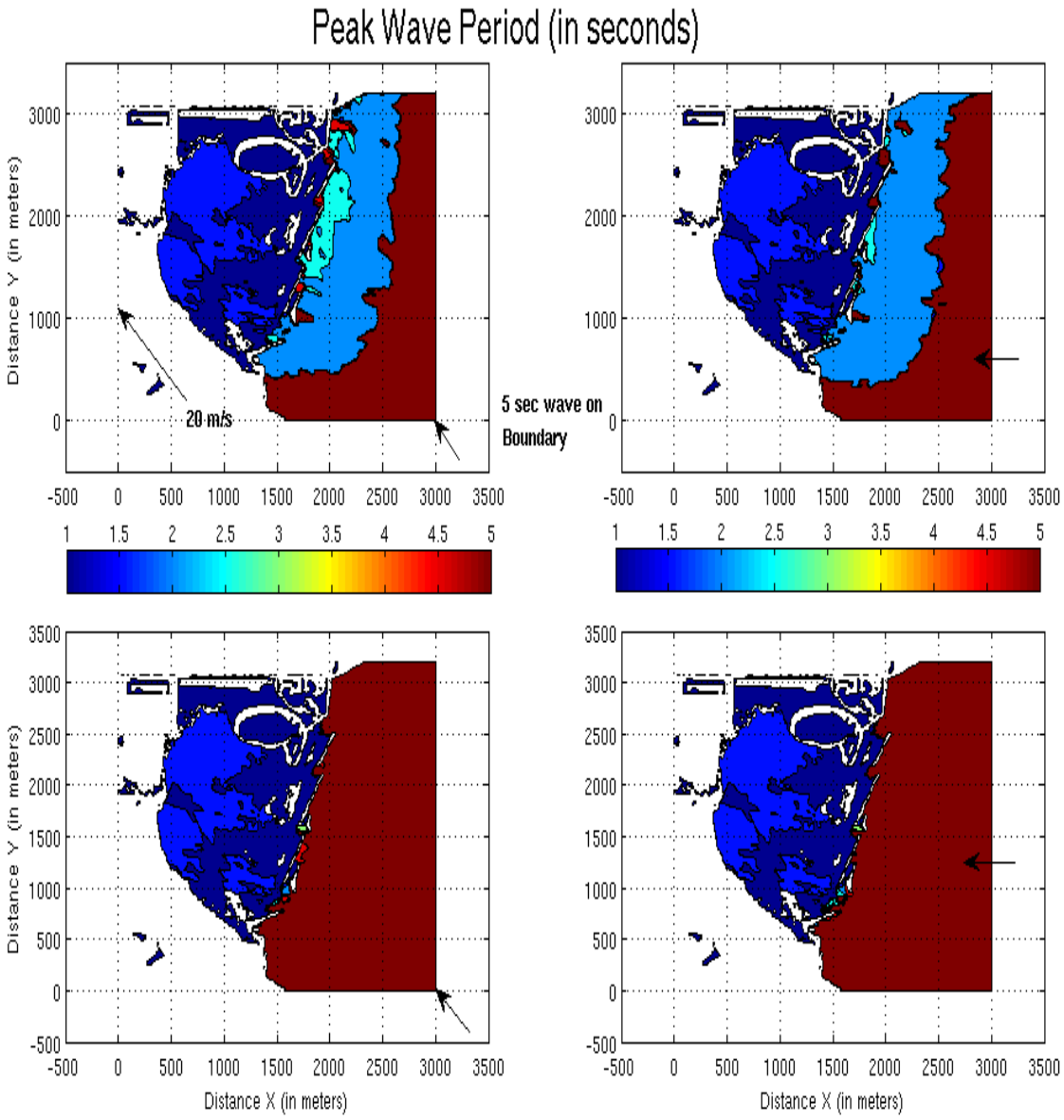

Figure 10. *Similar to Fig. 9 but for peak wave periods [s].*

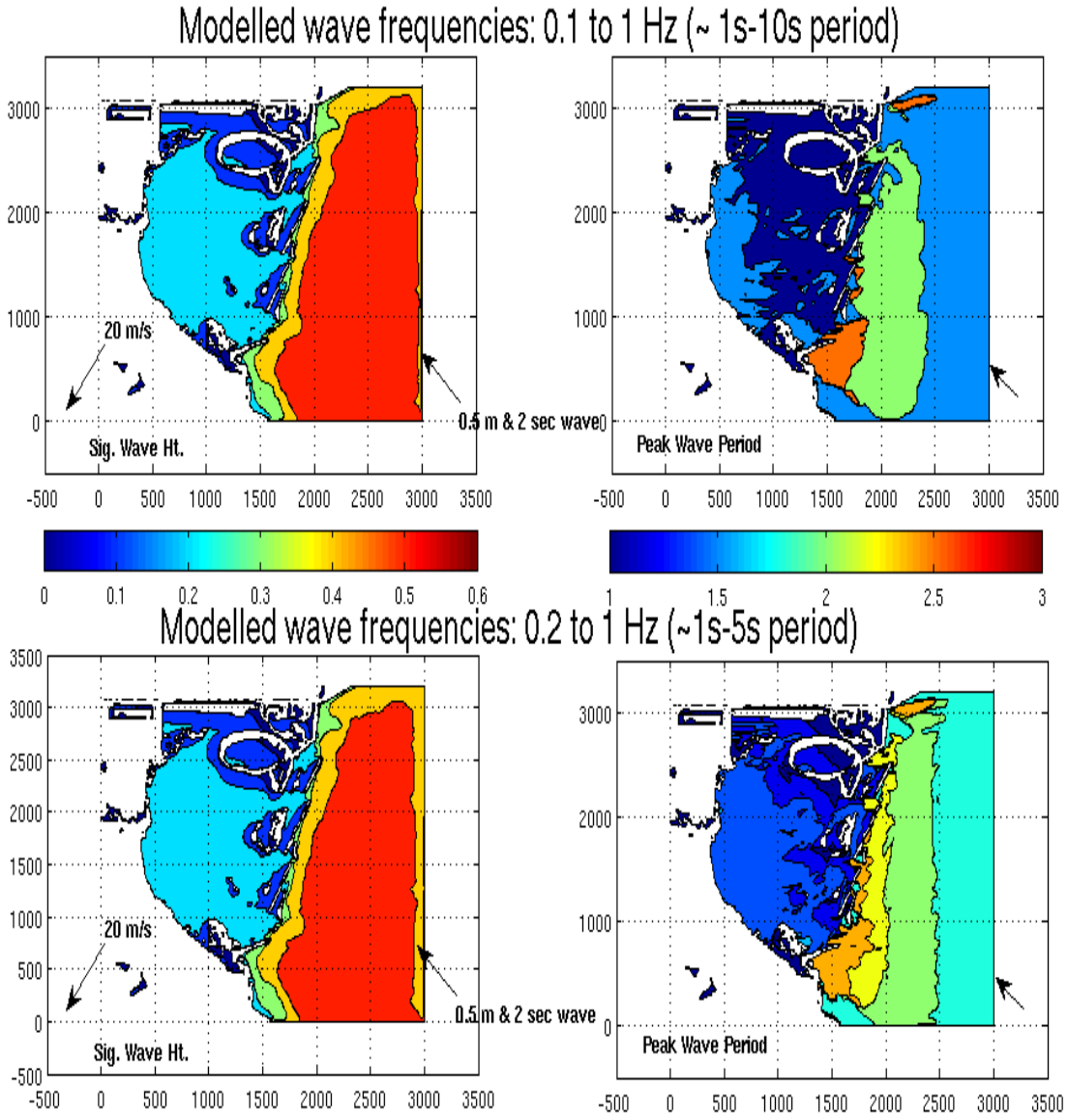

Figure 11. *Comparison of significant wave heights and peak periods for simulations forced with a 20 m/s wind, blowing from NE, and 0.5 m waves from SE on the open boundary (east side of the lake). The left two panels show the significant wave heights, while the right two panels show the wave peak periods. Two different model simulations were conducted: one in which output wave frequencies were limited to a range of 0.1- 1 Hz (upper panels) and one in which frequencies were limited to a range of 0.2 - 1 Hz (lower panels). The latter, i.e. a range of 0.2-1 Hz, is more representative of surface waves conditions in Galveston Bay (e.g. see Fig. 3) due to the limited fetches available for different wind directions and the lack of swell penetration from Galveston Bay and the Gulf of Mexico into the lake.*

4.3 Oysters

At the time of writing this report, the oyster data available spanned the period from March 2009 to July 2010 (although oysters were collected thru to November 2010). A detailed summary of the data collected during each sampling campaign is included in Appendix C below. Oysters examined during this period were selected on the basis of their shell size in order to ensure that they were of similar level of age and maturity. In all cases, oysters were market size, with shell lengths between 75 and 134 mm (Fig. 12A). There was no significant difference (p<0.05) in the range of shell sizes between 2009 and 2010.

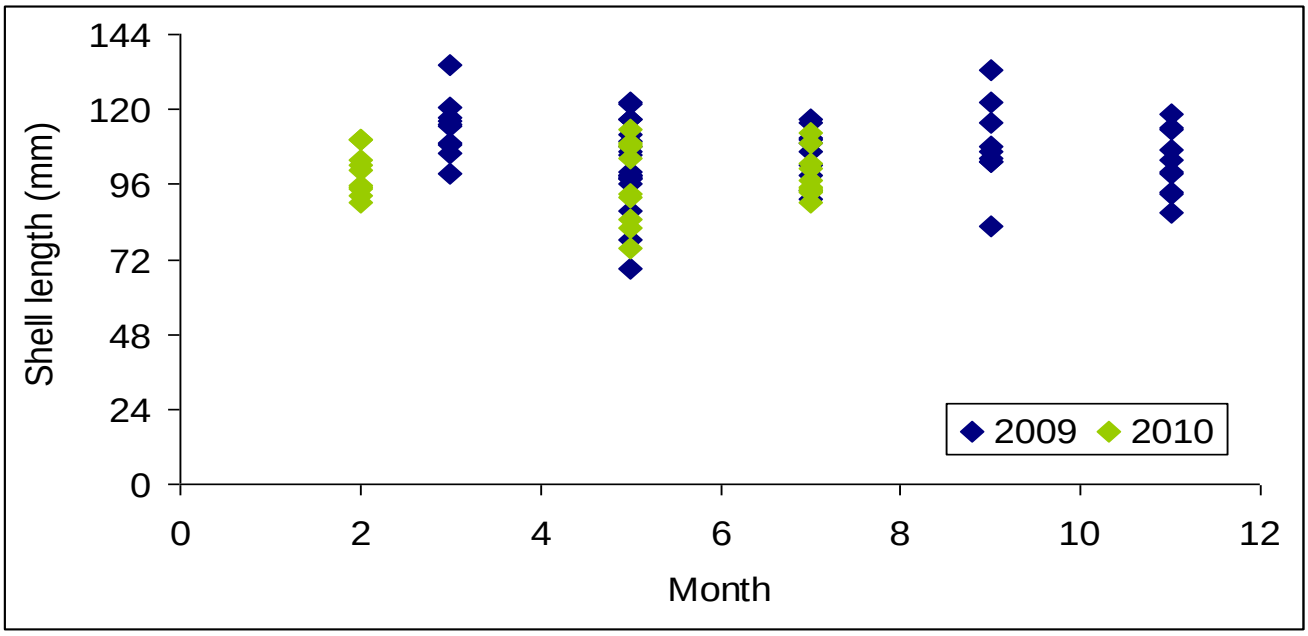

Figure 12 *Oyster shell length (mm) measured during sampling trips in 2009 (green diamonds) and 2010 (blue diamonds).*

"Spat collectors", that is, oyster shells in plastic mesh bags were deployed at each study site (see Fig. 2) to determine oyster recruitment (average number of spat per shell). Given that there was no significant difference between recruitment on a monthly basis between 2009 and 2010, we pooled the data sets to examine monthly trends. We found that oyster recruitment was greatest in the summer relative to fall and spring (Fig. 13). Unlike shell length (Fig. 12), we did find differences in recruitment between sites located within Swan Lake relative to those along the Virginia Point Shoreline. There was generally more

recruitment taking place on oysters in Swan Lake in the spring while more recruitment occurred on oysters along the Virginia Point Shoreline in the summer. These differences are however, not statistically significant. In addition, in all cases, oyster recruitment was lowest at the high salinity control site (Sportsman Road) with the number of spat per shell on average about 1 (range 0.10-3.14) which was significantly lower (p<0.05) than those measured at Swan Lake and along the Virginia Point Shoreline (Fig. 13).

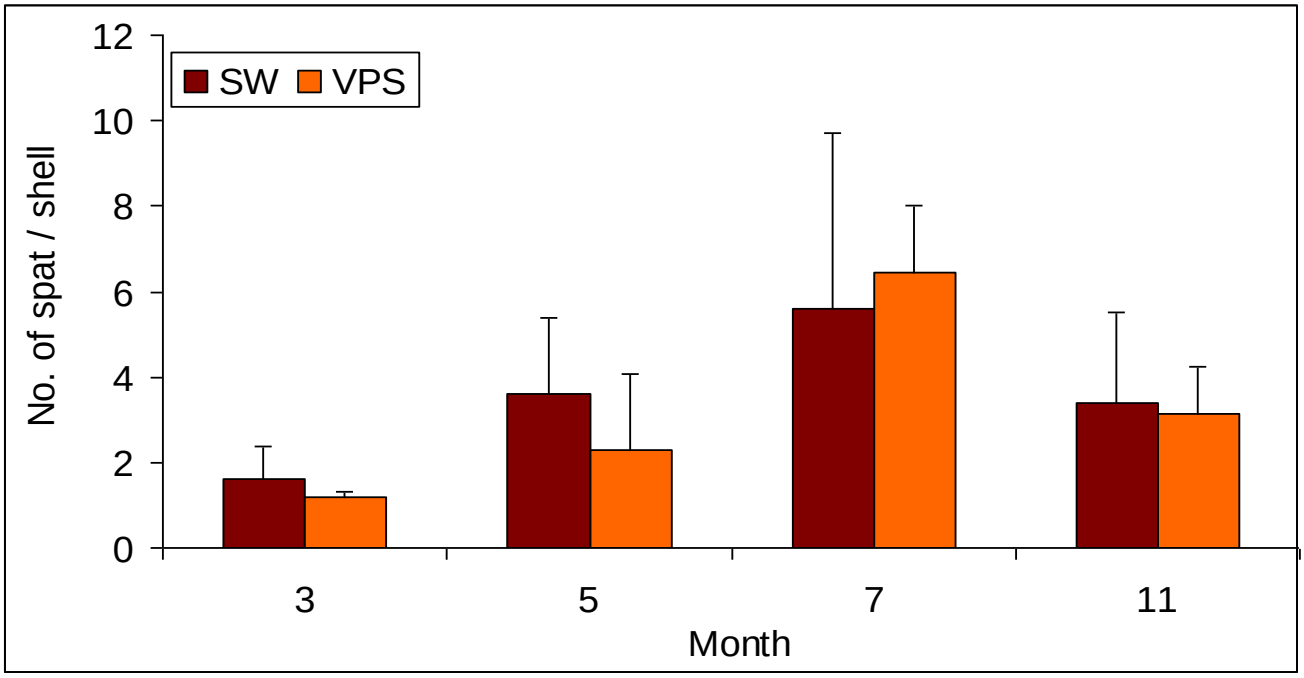

Figure 13 *Oyster recruitment was examined by counting the no. of spat per oyster shell at each site during the spat settling seasons. SW = Swan Lake and VPS = Virginia Point Shoreline*

Spat were most often present between salinities of 15 and 25 (Fig. 14A) and at temperatures between 16 and 32 (Fig. 14B). This was not dependent on the site at which oysters were collected but did depend to a degree on the salinities and temperatures present in 2009 relative to 2010. During 2009, spat recruited across a broad range of salinities and temperatures while in 2010 the major of spat recruited at the upper ranges of those recorded in 2009. However, this may also reflect that few samples were examined overall in 2010 in the preparation of this report. Additional samples not yet included in the analysis may result in the ranges being similar for both years.

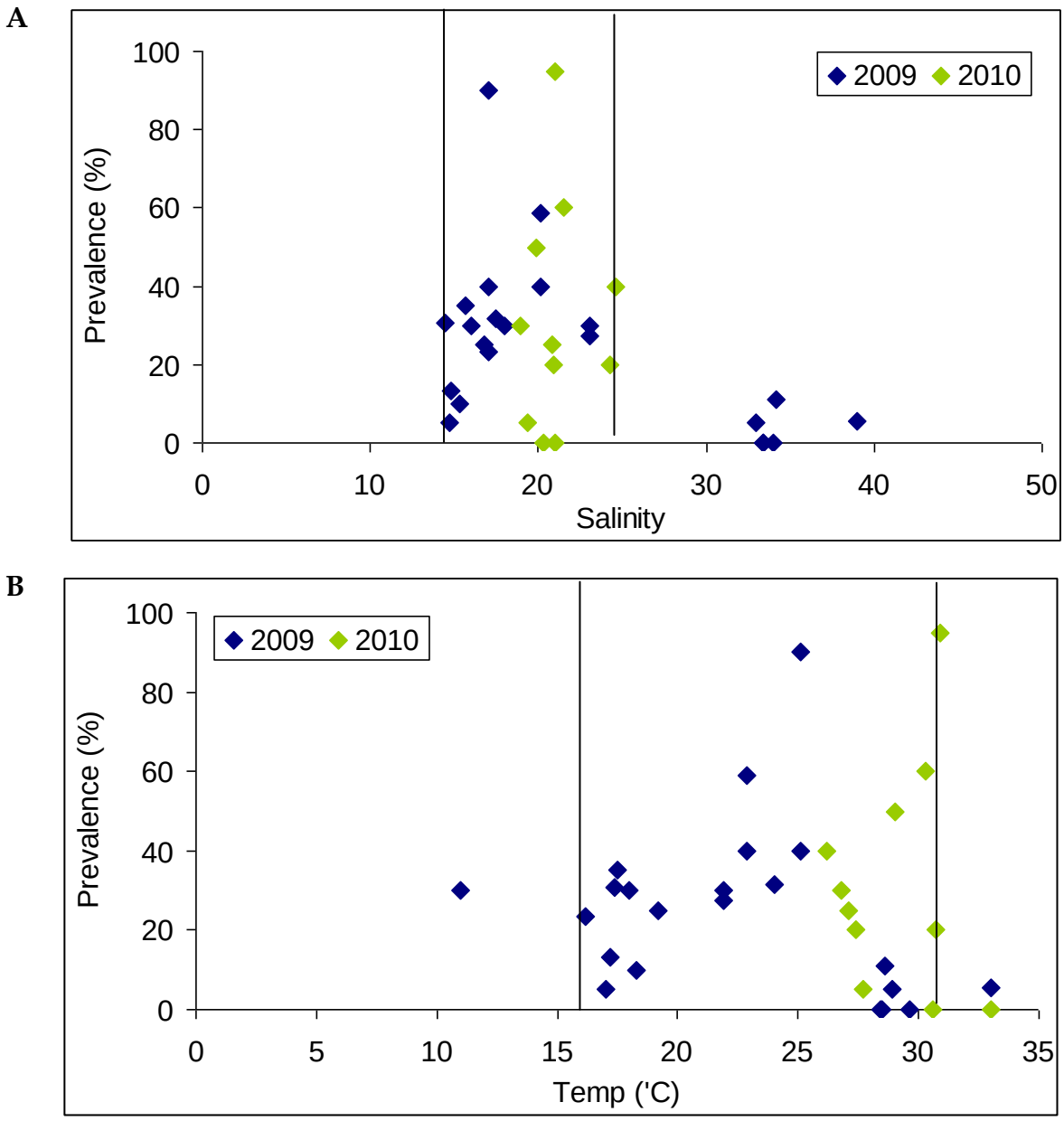

Figure 14. *Prevalence of oyster spat varied as a function of (A)salinity and (B) temperature (°C) on oysters collected from all sites during the two sampling years.*

The Ray Fluid Thioglycollate culture method was used to determine Dermo disease levels in oysters to be consistent with historical collections at the control site (Oyster Sentinel website; http://www.oystersentinel.org/); Ray and Soniat 2007) over more than 10 years. The overall findings were not significantly different when comparing trends between the control site (Sportsman Road), Swan Lake and the Virginia Point Shoreline and so the data was

pooled. We found that Dermo disease varied on seasonal scales with the highest Dermo intensities measured in July and August (Fig. 15A) and lowest intensities measured in the cooler months, especially February. Dermo intensity was generally higher in 2009 relative to 2010 (Fig. 15A).

Given Dermo disease intensity is known to vary as a function of temperature and salinity, we examined its intensity relative to these two hydrographic parameters (Fig. 15B and 15C respectively). At temperatures less than 25°C, we found significantly lower Dermo intensities (<1) in 2010 (Fig. 15B) than in 2009, in which case the Dermo intensity ranged from 1.3 - 2.57. On the Mackin scale (see Materials and Methods), Dermo intensities would be in the green range at < 25°C in 2010 but in the yellow to red range in 2009 (see Appendix B for details). At temperatures greater than 25°C, Dermo intensities were generally higher (>1).

This was particularly the case in 2009 relative to 2010. Given temperatures were not significantly (p<0.05) different between sites in 2009 and 2010 (Fig. 3B), then salinity was clearly an important factor in determining Dermo intensity differences between the two years.

At salinities greater than 25 which were recorded only in 2009, Dermo intensities were highest of all measured, usually between 1.37 and 3.23 (Fig. 15C). Lowered Dermo intensities appear to be associated with the lower overall salinities in 2010 (Fig. 15C and 3A). Despite some overlap with 2009 data, Dermo intensities were generally greater than 1 on the Malkin scale (yellow and red) in 2010.

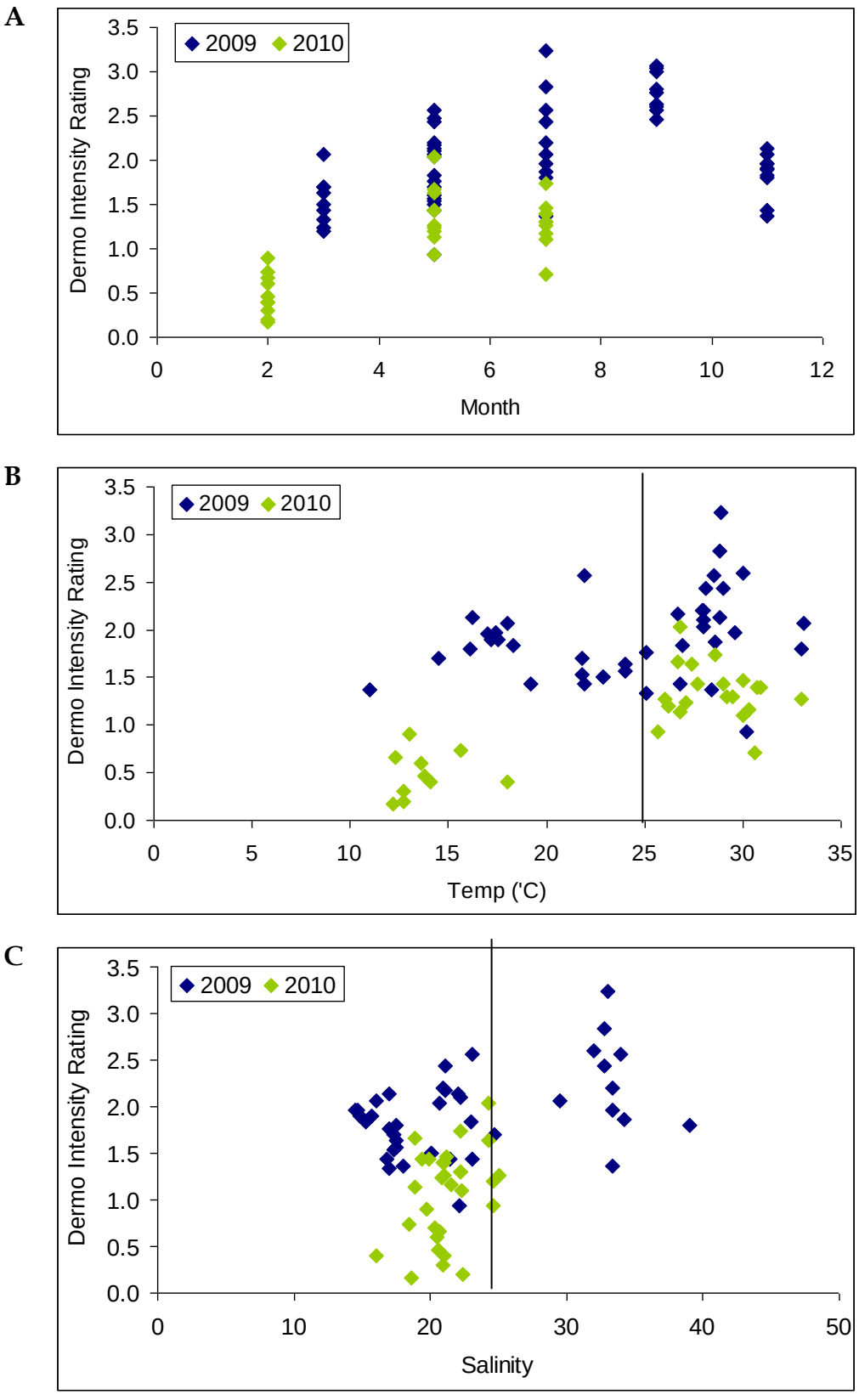

Figure 15. *Dermo Intensity Rating varied as a function of (A) month, (B) temperature (°C) and (C) salinity in oysters collected from all sites during the two sampling years.*

Consistent with these findings on Dermo intensity, we report here measurements of the prevalence of Dermo (% of oysters infected) as well as measurements of weighted prevalence (Fig. 16). In 2009, prevalence varied between 75 and 100%, with oysters examined in July 2009 having 100% prevalence (and so only one point can be seen in Fig. 16A), that is, 100% of the oysters were infected with Dermo. During 2010, the prevalence was more variable, and ranged from 50 to 100%. The weighted prevalence of Dermo in oysters also varied seasonally with more oysters infected (> prevalence) during the warmer months and fewer (< prevalence) in the cooler months (Fig. 16B). Again, differences were observed between 2009 and 2010. Typically the weighted prevalence was greater in any month during 2010 than during 2009.

In addition to these traditional measures of oyster health, as part of this study we also examined changes in the Meat Index (see Materials and Methods) as well as the ratio of Meat to Spawning Condition. There was no significant difference (p<0.05) when looking at these parameters between 2009 and 2010 (Fig. 17) ruling out temperature and salinity as primary controlling factors. During both years, despite natural variability, the Meat Index varied between 9.5 and 16.5 (Fig. 17A). The changes in the ratio of Meat to Spawning Condition were driven by changes in spawning (see also Figure 13) with highest ratios measured in the late spring and early summer with generally lower ratios in the cooler months. We did not find significant differences between the ratio of Meat to Spawning Condition in oysters growing in Swan Lake relative to those along the Virginia Point Shoreline.

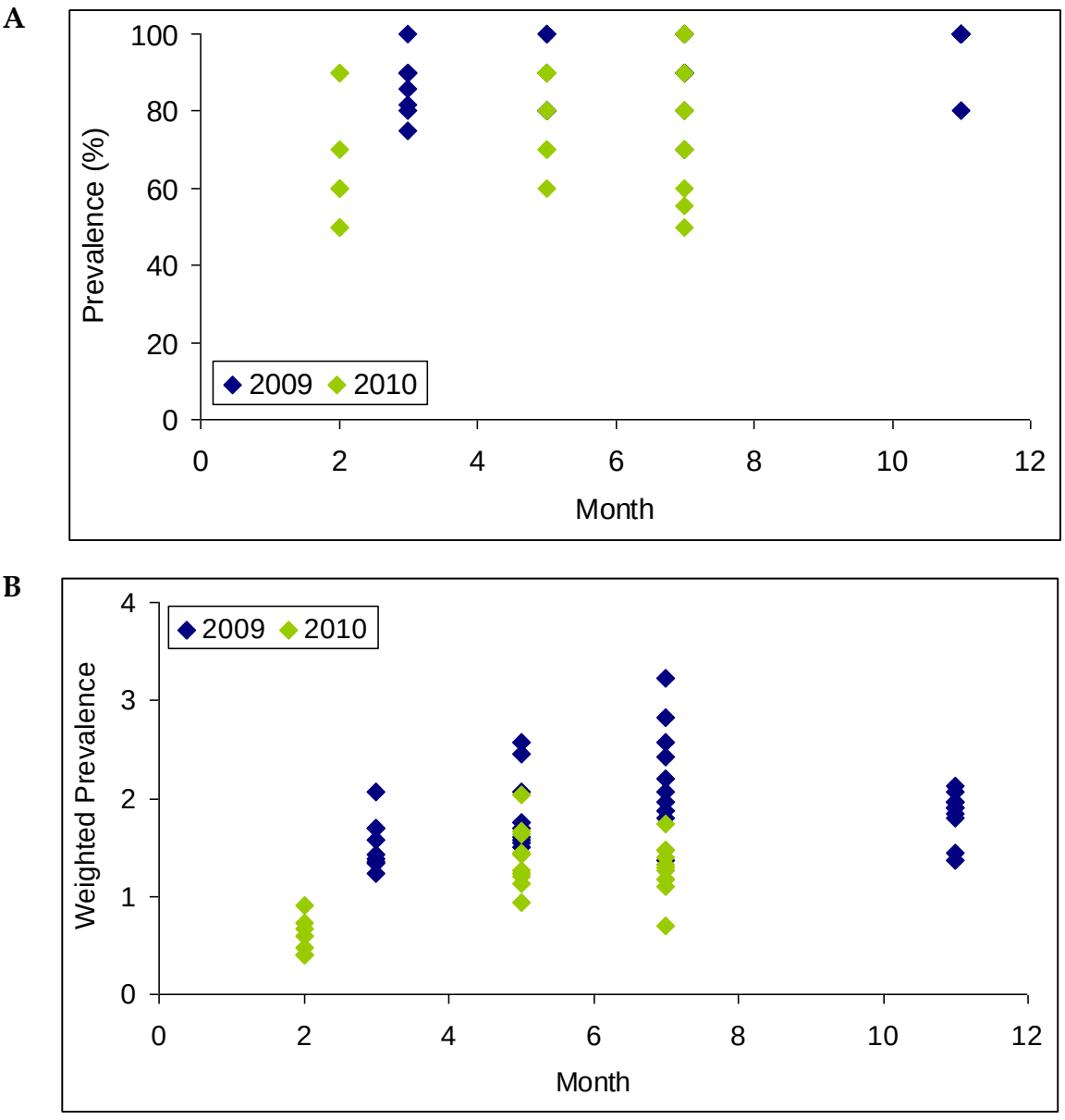

Figure 16. *Dermo l**evels were measured as prevalence (%)** A) and as weighted prevalence B) in oyster tissues collected from all sites during the two sampling years. Results were pooled for oysters examined from Swan Lake and Virginia Point Shoreline.*

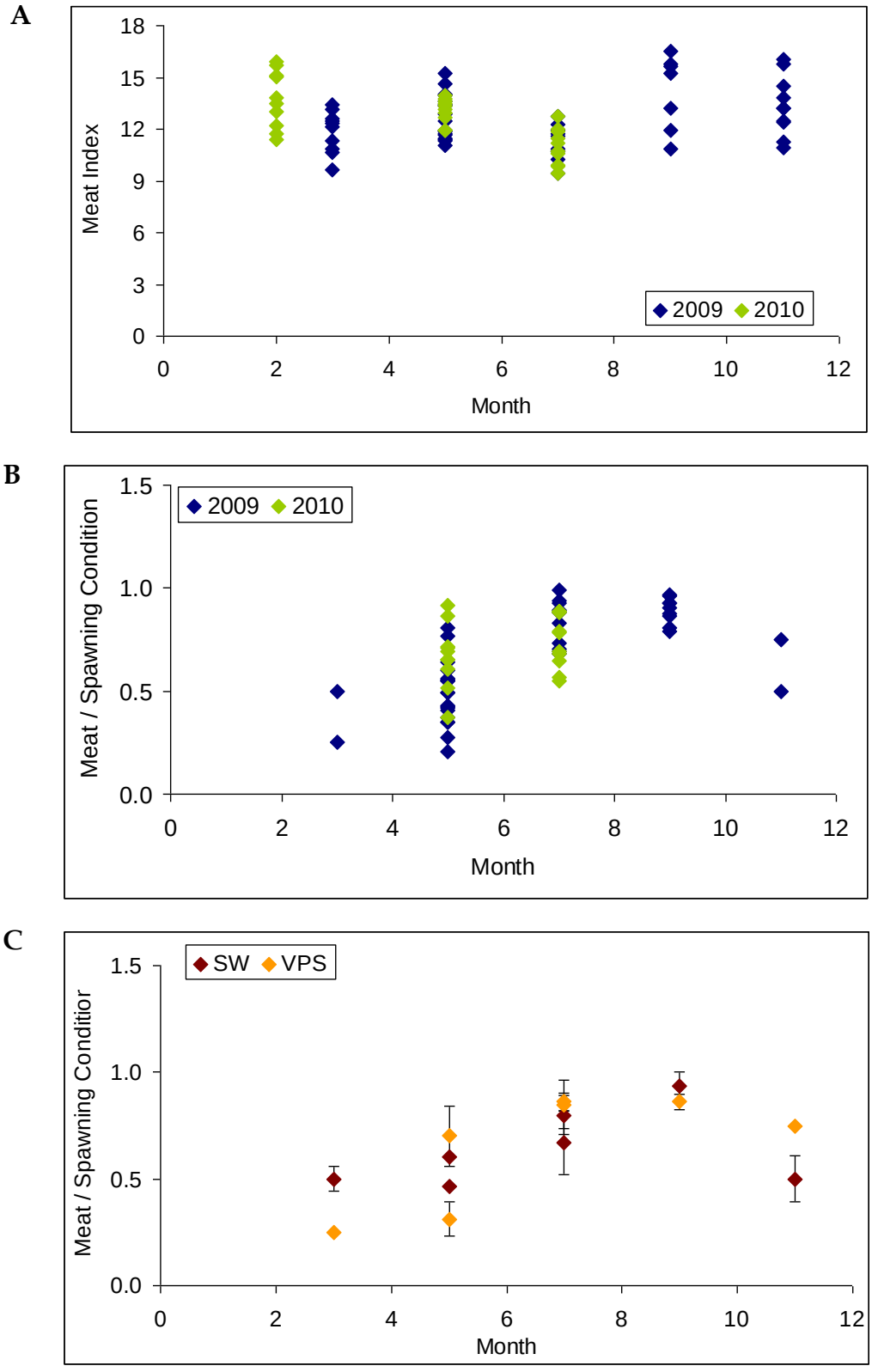

Figure 17. *Meat Index (A) and the ratio of Meat to Spawning Condition (B) in oysters collected from all sites during the two sampling years. Differences in the ratio of Meat to Spawning Condition between Swan Lake (SW) and Virginia Point Shoreline (VPS (C).*

4.4 Phytoplankton

The relative abundance of phytoplankton genera at each station was examined microscopically. Because of the phytoplankton net used (67 μm mesh size), the difficulty with resolving microorganisms which are < 5-8 μm sufficiently to be able to identify them and the large number of "small green coccoid" objects which are < 5 μm, the list in Table 3 is not comprehensive. Rather, it represents the most common identifiable genera – we were not able to clearly identify species in many cases. We found minor differences between sampling stations and so grouped the data from all stations into one Table. Sportsman Road (high salinity control site) samples were similar in composition (that is, similar species present) but those phytoplankton present, were often present in different proportions. A single star (*) was used to show if a particular genera was present in a given set of samples (see Table 3), while ** indicated that a genera was 'abundant', that is, representing >50% of all the phytoplankton present in a sample. In cases were no stars are shown, that genera was absent from all samples at all sites for that month.

Of the 35 genera of phytoplankton identified, 27 were diatoms. This partly reflects the ease of preservation and identification of this group. It also partly reflects that this group is a significant component of the phytoplankton assemblage in these areas. Of the diatoms identified, thirteen were characterized as being abundant at some time but most frequently in the spring (March, April, May) or fall (September, October, November). *Chaetoceros*, *Pseudo-nitzchia, Rhizosolenia and Skeletonema* were abundant in the spring of 2009, with *Skeletonema* only being abundant again in spring 2010 along with *Rhizosolenia*. *Coscinodiscus* and *Navicula* were abundant in the summer (June, July, August) of 2009, but only *Coscinodiscus* was again abundant in summer 2010 (Table 3). We found *Coscinodiscus, Ditylum and Rhizosolenia* to be abundant in the fall of both 2009 and 2010 but *Skeletonema* to only be abundant in fall 2009 (Table 3). Rather, in the fall of 2010, *Chaetoceros* and *Odentella* appeared as the abundant genera in Swan Lake and Virginia Point Shoreline. In the winter between 2009 and 2010 (December, January, February), we found *Bacillaria, Chaetoceros, Ditylum, Hemialus, Lioloma,* and *Rhizosolenia* were abundant in this area.

		2008	2009									2010				
Taxa	**Genus**	**Sep**	**Mar**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Feb**	**May**	**Jul**	**Sep**	**Nov**
Diatoms	*Asterionellopsis*											*	*	*		
	Bacillaria				*				*	*	**	*	*	*		
	Bacteriastrum									*			*	*	*	*
	Cerataulina			*												
	Chaetoceros		**	*		*			*	*	*	**	*	*	*	**
	Coscinodiscus	**				**	*	*	**	**	*	*	*	*	**	**
	Cylindrotheca			*						*			*	*		
	Ditylum		*	*					*	**	**	*	*	*	*	**
	Fragilaria				*											
	Gramatophora				*											
	Guinardia	*			*					*	*					
	Hemialus		*	*								**				
	Leptocylindrus			**	*											
	Licomophora											*				
	Lioloma											**	*			
	Melosira				*											
	Navicula			*		**			*	*	*					
	Nitzschia			*	*	*	*	*	*	*	*	*				
	Odontella		*	*				*	*	*		*	*		**	**
	Pleurosigma		*	*	*	*	*		*	*	*		*	*		
	Pseudo-nitzchia		**	*		*			*	*	*	*			*	*
	Rhizosolenia	*	**	*					**	*	*	**	*	*	**	*
	Skeletonema		*	**	*				*	**	**	*	**	*		*
	Stephanopyxis				*					*	*	*		*		
	Striatella			*												
	Thalassiosira											*		*		
	Thalassionema		*						*	*	*					*
Dinoflagellates	*Prorocentrum*					*					*					
	Protoperidinium									*		*				
	Unknown dinoflagellate													*		
Cyanobacteria	*Microcystis*				**											
General	Unknown Species A				**											
	Euglenoid like										*					
	UK colonial organism										*					
	Oxyphysis											*				
Other	*Roperia* (see snails)			**	*											
	Amoeboid objects										**					

Table 3. *List of major phytoplankton genera identified in Swan Lake, along the Virginia Point Shoreline and Sportsman Road, Galveston during 2009 and 2010. * = present; ** = abundant; ie., representing >50% of all the phytoplankton present in a sample.*

In summer 2009, we observed a *Microcystis* (cyanobacteria) bloom which dominated samples particularly close to Virginia Point. While various dinoflagellates were present at different times of year, usually in the fall to spring, they were never present in significant quantities. We can speculate that fall and winter in 2009 was windy and thus the water column well mixed as there were many benthic diatoms in our plankton tows – these include *Nitzchia, Navicula, Pseudonitizchia, Licomophora* and *Lioloma*, amongst others.

Another way of examining mixed phytoplankton assemblages involves using the diversity and phylogenetic association of specific photosynthetic accessory pigments which provide reliable measures of the relative abundance of characteristic algal groups (see Materials and Methods above). The output was further simplified so that we only considered the major groups: cyanobacteria, browns (includes diatoms, dinoflagellates, haptophytes and any other chl *c*-containing groups), greens (includes chlorophytes, euglenoids and any other chl *b*-containing groups) and cryptophytes. In order to be consistent with the phytoplankton analysis above, we again grouped all sampling sites.

In Fig. 18 below we can see that the "browns" typically dominate the water column in Swan Lake and Virginia Point Shoreline for most the year, both years. This grouping includes diatoms, dinoflagellates, haptophytes and any other chl *c*-containing groups. Hence, these findings are consistent with the patterns observed in Table 3. Highest concentrations of "browns" were typically measured in the spring and fall while lowest concentrations were measured in the summer. The opposite pattern was observed for the cyanobacteria, which were generally present in highest concentrations during the summer months. The "greens" which include Chlorophytes and Euglenoids are difficult to identify microscopically. We did note a Euglenoid like phytoplankton (Table 3) but only recorded it when it was present in high numbers. Many chlorophytes appear as green coccoid cells which are too small to identify. Hence, this technique allows us to determine the abundance of this group which we are not able to identify microscopically. Clearly, they are important, typically accounting for between 20 and 25% of the biomass, but up to 45% of the biomass in August and September of 2009.

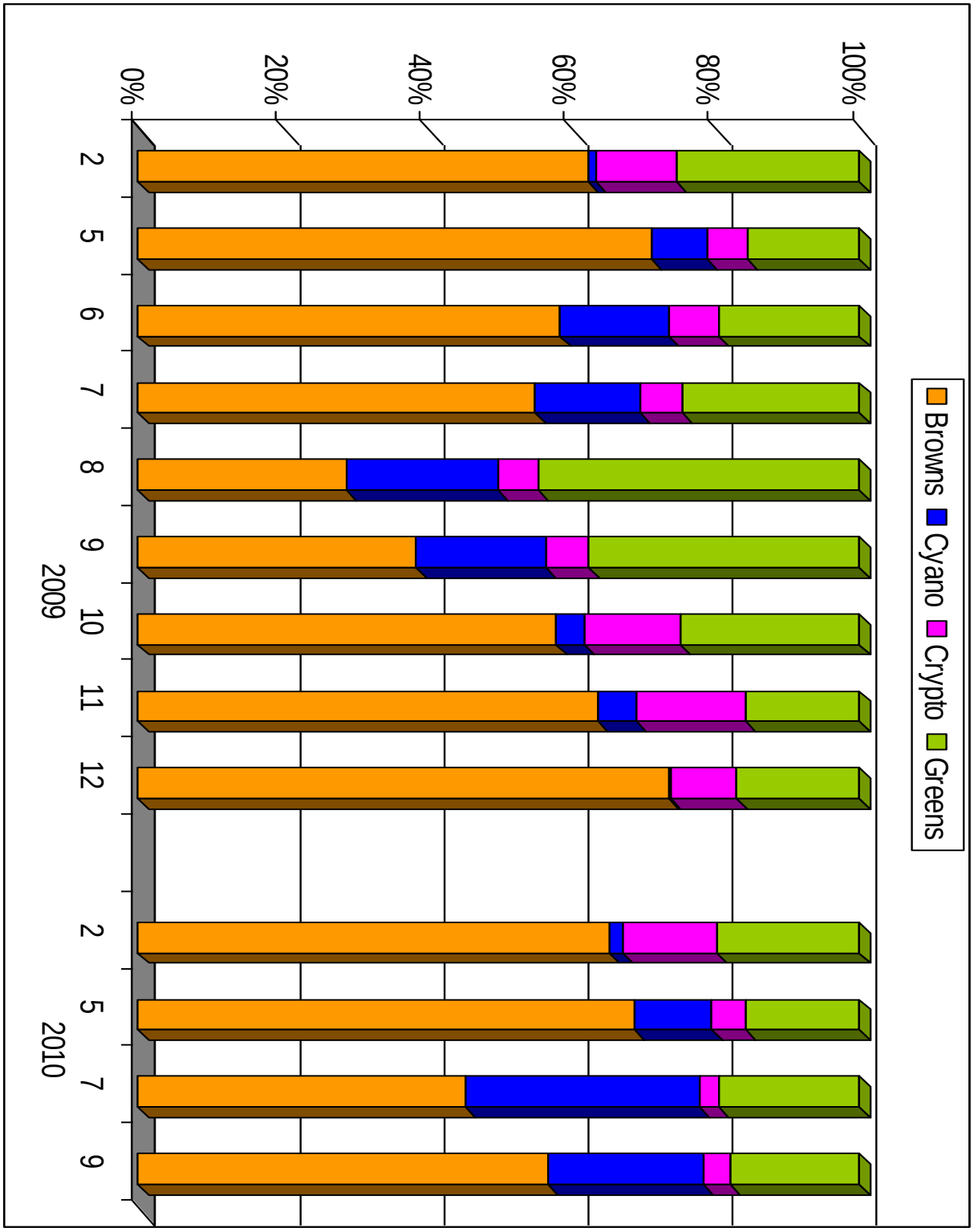

Figure 18. *Major phytoplankton groupings in Swan Lake, along the Virginia Point Shoreline and Sportsman Road, Galveston during 2009 and 2010.*

Given that blooms of crytophytes may lead to "pink oysters" we examined the presence of this group in the study area. In general, we found between 3 and 15% of the sample contained cyptophytes based on pigment analysis. Again, these are difficult to identify microscopically and so would have been missed if we had not also conducted this assessment.

While the above two methods provide important information on the phytoplankton community composition, it was also important to know the amount of phytoplankton biomass present and available for the oysters as a food source. We measured chlorophyll a (mg m^{-3}) as a proxy for phytoplankton biomass. In general, there was more biomass present between May and July than during the cooler months, from October to February of both years as seen in Fig. 19. We found we had insufficient data to distinguish between 2009 and 2010.

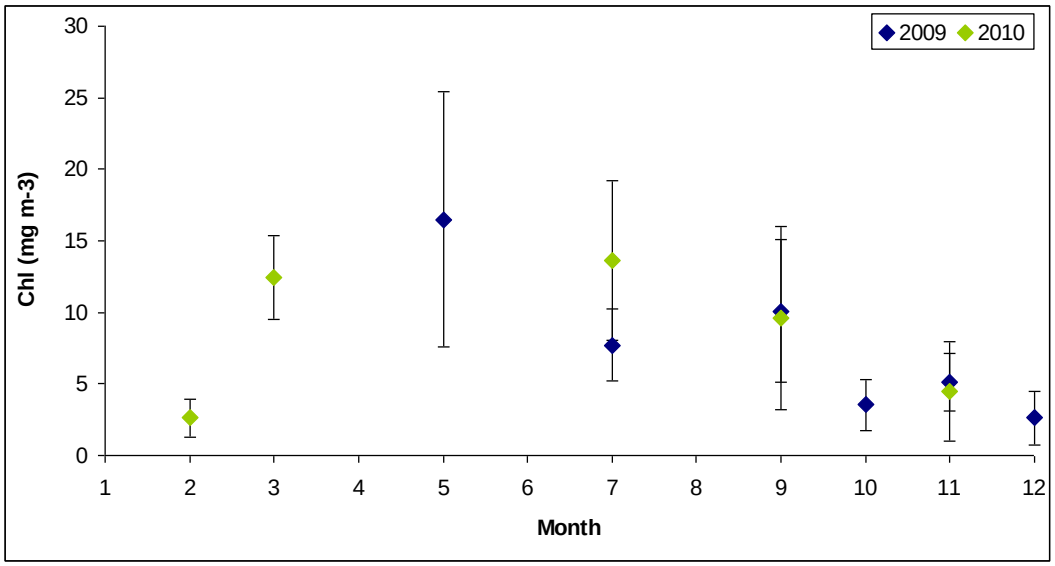

Figure 19. *Chlorophyll a (biomass proxy) in Swan Lake, along the Virginia Point Shoreline and Sportsman Road, Galveston during 2009 and 2010.*

Further, it is interesting to know how "active" the phytoplankton maybe under the conditions found at the sampling sites. Primary productivity is difficult to measure simultaneously using traditional methods (e.g., light – dark bottle) at 10 sites even in a relatively small area such as Swan Lake/Virginia Point Shoreline. Using the PHYTO-PAM (see Materials and Methods), we can use the relative electron transport rate (ETR) as a proxy for productivity but only to measure that going on for the cyanobacteria and the "browns" which in this case is the diatoms plus dinoflagellates (because different measuring principals to the HPLC which can capture more groups).

Given we found interesting patterns for ETR's measured in cyanobacteria and "browns" using the PHYTO-PAM as a function of salinity and temperature (Fig. 20), we will discuss the results in this context. We found that cyanobacteria had ETR's between 40 and 230 μmol electron m^{-2} s^{-1} in 2009, but a five-fold larger range in 2010 (Fig. 12 top left). On the other hand, "browns" had ETR's between 15 and 420 μmol electron m^{-2} s^{-1} in 2009 and 2010 (Fig. 20 bottom left). In both cyanobacteria and "brown", ETR's did not appear to vary as a function of salinity or temperature (there is insufficient data in 2010 to really argue the case for cyanobacteria), that is, a range of ETR's values were measured under the range of hydrographic conditions present. The variability in the ETR's reflects partly the different members of the phytoplankton community present at different times of the year (Table 3) as well as their response to other biotic and abiotic factors (e.g., nutrients, light) which we did not measure.

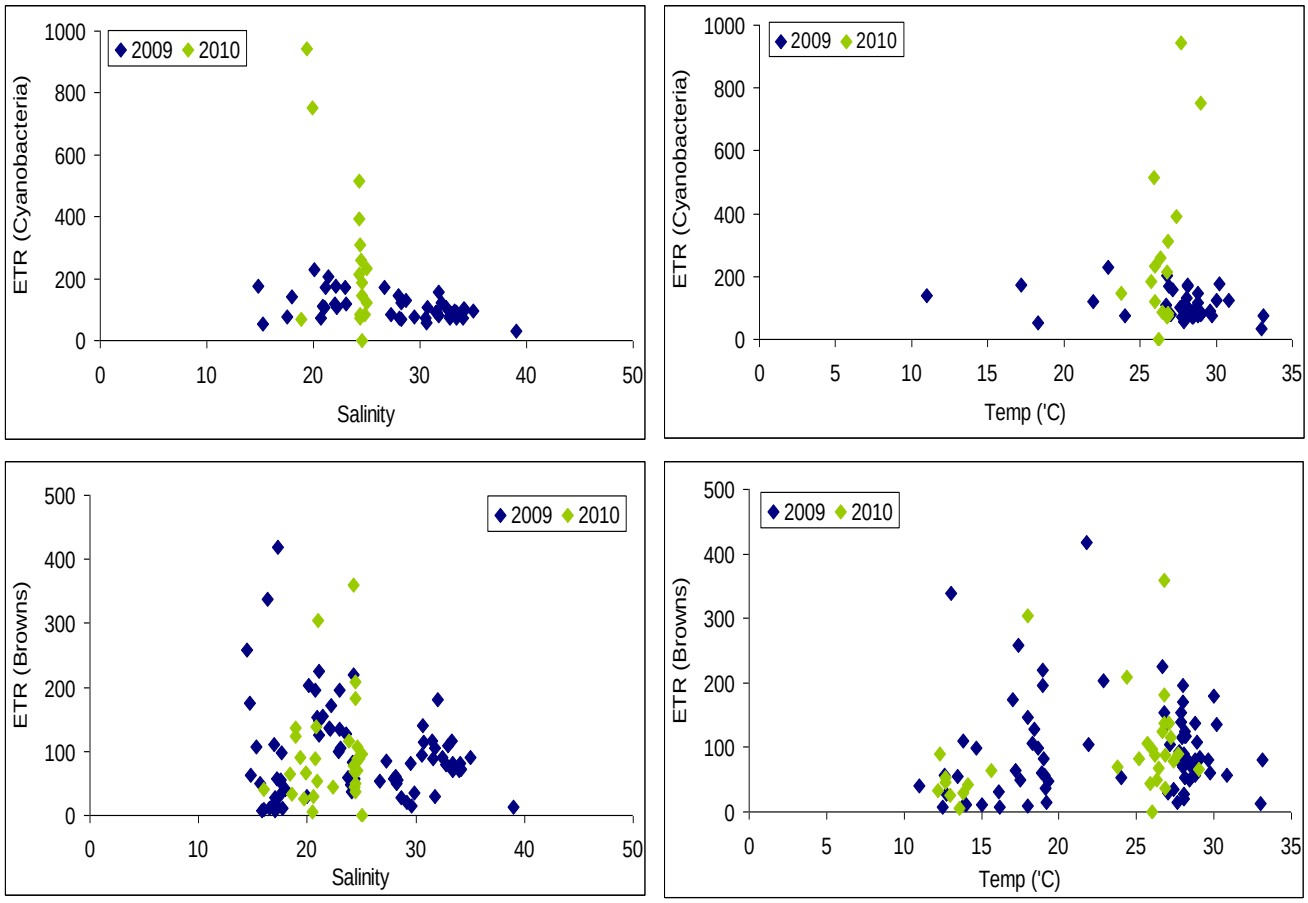

Figure 20. *The relative electron transport rate (ETR) measured as a proxy for productivity in cyanobacteria and the "browns" in Swan Lake, along the Virginia Point Shoreline and Sportsman Road, Galveston during 2009 and 2010.*

5. Discussion

The approach to shoreline protection and habitat restoration proposed herein is based on preliminary studies carried out by Dr. Sammy Ray (TAMUG) at the request of Scenic Galveston in Swan Lake along the Virginia Point Shoreline (Fig. 1 and 2). He found that live oysters along the Virginia Point Shoreline, when present, are heavily infested with shell pests (boring sponge, boring clams, and boring worms) and show high levels of Dermo disease (a lethal disease caused by a protozoan that is harmless to humans). Further, these areas also support large populations of the southern oyster drill, a serious predator of oysters. In contrast, oysters in the north end of Swan Lake exhibited little evidence of shell pests and had lower levels of Dermo. The only reasonable explanation for this was that oysters in Swan Lake were receiving more freshwater (possibly through the Last Chance Ditch, via seepage, and the Wa Chang Ditch, via direct flow) than those growing along the Virginia Point Shoreline. These initial results lead to the idea of diverting treated wastewater from Gulf Coast Waste Disposal Authority into Swan Lake to reduce water salinity to levels favorable for oysters. Healthy oyster reef systems accrete at rates of 1-2 inches per year and may thus provide a viable, and natural, shoreline protection system and at the same time increase oyster populations. Hence, in the first year of this proposal we planned to monitor the background (or baseline) conditions and in year two, follow the changes in the biological and hydrological parameters as a result of the release of freshwater. However, due to circumstances beyond our control, the freshwater was not released during the project period. Hence, in turn, we now have two years of baseline conditions in Swan Lake along the Virginia Point Shoreline which provides us with an understanding of the interactions between the biological and hydrological components. Further, as in year two, despite temperatures being similar, salinities were generally lower, particularly in Swan Lake relative to the Virginia Point Shoreline, we have some been given some insights into the potential benefits of lowered salinities to oyster health.

The exact causal mechanisms that determine the relationships between freshwater inflow, salinity, and oyster production are complex and not completely understood (e.g., see La Peyre et al. 2003; Turner 2006; Culbertson 2008; Buzan et al. 2009; La Peyre et al. 2009).

Periods of high freshwater inflows have a role in controlling the levels of parasites and predators on the reefs (Ray 1987; La Peyre et al. 2003, 2009), but there is disagreement on the relationship between freshwater inflow and productivity. Turner (2006) published an evaluation of the potential impact of a freshwater diversion in Louisiana on oyster harvests. Using historical harvest data from Galveston Bay, he concluded that high freshwater inflows in the estuaries are correlated with low oyster landings. This paper generated a response from biologists in Texas, who used the TPWD fishery independent data on oyster catch per unit effort (CPUE). Buzan et al. (2009) concluded that there is a linear relationship (R^2= 0.29) between market oyster CPUE and annual freshwater discharge two years before oyster samples are collected. In Texas, it takes approximately 18 to 24 months for oysters to reach market size. The final oyster is a product of the various abiotic and biotic changes that have taken place over this period. Hence, Buzan et al. (2009) appreciated the value of antecedent conditions in defining overall oyster growth rates and health, and hence the requirements for freshwater inflows over the life cycle of the oyster.

Wilson-Ormand et al. (1997) concluded that water flow rate is most likely a greater limiting factor than food concentration in determining oyster population densities. Supporting this finding, Montagna and Kalke (1995) found that only Texas bays with high rates of freshwater inflow can support a productive shellfish industry. While specific water flow requirements for Texas oysters have not been determined (Quast et al. 1988), together these results are consistent with the findings that Galveston Bay is far more productive in terms of oyster production that bays further south which generally receive less freshwater inflows (see Table 1 in Thronson and Quigg, 2008).

While oysters are typically found in areas where long-term salinity ranges between 10 and 30, salinity effects on the population depend largely on the range of fluctuation and rate of change (Quast et al. 1988). Data from 23 years of reef sampling indicated the best spat sets (corresponding, in commercial terms, to an oyster "crop") occurred when spring salinity ranged between 17 and 24. The poorest sets occurred when salinity dropped below 8 (Hofsetter 1977). We did indeed find that the best oyster recruitment (number of spat per

shell) did occur at these intermediate salinities (Fig. 13) and that oyster recruitment was better in Swan Lake than along the along the Virginia Point Shoreline. In addition, we found that oyster recruitment was lowest at the high salinity control site (Sportsman Road), likely a function of the semi-continuous high (>25) salinities at this site. We also examined the prevalence of spat and found they occurred most often between salinities of 15 and 25 and at temperatures between 16 and 32°; consistent with earlier literature.

One of the most important biological stresses to oysters in Galveston Bay is infection by "Dermo" (*Perkinsus marinus*), which thrives in warm waters of relatively high salinity (Powell et al. 2003). The Oyster Sentinel website (http://www.oystersentinel.org/; Ray and Soniat 2007) is one tool in the effort to manage Dermo in Galveston Bay. The web site provides a continuous record of the incidence of this parasite at specific reefs in the Galveston Bay system since 1998. Data collected from the current project has been (will be) added to the Oyster Sentinel website (see Appendix B for details). We found Dermo intensities, prevalence (%) and weighted prevalence varied seasonally in both 2009 and 2010; consistent with other studies examining the prevalence of this parasite on eastern oysters, regardless of the area in which the study was done (e.g., see Bushek et al 1994 and Bushek and Allen 1996 which examined oysters growing in the Northeast coast of the US or Craig et al. 1989 in Galveston Bay, Texas).

We also did not find significant differences between locations in the study area in terms of Dermo intensities but did find that at less than 25°C, Dermo intensities were significantly lower in 2010 than in 2009. This result is important because water temperatures were similar both years but there were overall lower salinities in 2010 than in 2009. Salinity is known to be one of the important forcing factors (higher salinities; higher Dermo intensities) leading to Dermo; the other is temperature. Further, in 2009, prevalence of Dermo in oyster tissues was greater (75 - 100%) than during 2010 in which case it was more variable, and ranged from 50 to 100%. Typically the weighted prevalence was greater in any month during 2010 than during 2009. Reinstated, 75-100% of oysters were impacted by Dermo in 2009 while fewer, between 50-100% of oysters were impacted in 2010. Hence, if freshwater is released

into the Swan Lake and along the Virginia Point Shoreline, our findings are consistent with the contention that oysters in this area are likely to experience reduced stress as a result of this protozoan parasite. Also, given mortality of market oysters in Galveston Bay resulting from this parasite can range from 10 percent to 50 percent annually (see Lester and Gonzalez, 2011); strategies to increase the availability of freshwater to oysters such as that proposed by Dr. Ray and Scenic Galveston in this case, clearly are worthy of serious consideration. Previous studies have also reported that a short term lowering of salinity (less than 5 psu for two weeks) is beneficial to oysters because it reduces infection levels by *Perkinsus* (Powell et al. 2003; Culbertson 2008; La Peyre et al. 2003, 2009). The challenge is defining the quantity and timing of suitable freshwater inflows because salinity directly affects mortality due to predators and mortality or morbidity due to parasite infection.

During both years, despite natural variability, the Oyster Meat Index varied between 9.5 and 16.5 (Fig. 17A). Royer et al. (2007) classified oysters with an index > 10.5 as "special", that is, those oysters belong to the best commercial category. Such a high index is only measured in bays which are classified as being highly productive (see references in Royer et al. 2007 for systems around the world); this should arguably include Galveston Bay, Texas. The changes in the ratio of Meat to Spawning Condition were driven by changes in spawning (see also Figure 13) with highest ratios measured in the late spring and early summer with generally lower ratios in the cooler months. Therefore, the increase of meat weight in ''adult'' oysters in contrast to the increase in spat may be attributable to a higher production of reproductive tissue rather than investment in growth. This is supported by the relatively small change in shell length over the study (see Appendix c). Previous studies have also shown that both prevalence and infection (Dermo) intensity were correlated with condition index and salinity (Craig et al. 1989); while we found this was indeed the case of salinity, in the current study, there was no direct correlation with the index of oyster condition measured. Craig et al. (1989) also reported that neither prevalence nor infection intensity of *P. marinus* were significantly correlated with temperature or mean length consistent with findings in the current study. While we did find a correlation with salinity, this was not the case for condition index.

Unfortunately, Galveston Bay oysters are not uniquely pressured by Dermo disease. *Perkinsus marinus* has caused extensive oyster mortalities along the Atlantic and Gulf coasts of North America for at least 60 years and continues to be a serious problem. Worldwide, there are also reports of Dermo impacts of oyster populations (e.g. *Crassostrea gigas* in France; Royer et al. 2007). Earliest studies in the Gulf of Mexico states (primarily Louisiana and Texas) to identify the issues were those of Ray (1952, 1954, 1966, 1987), Mackin et al. (1950) and Mackin (1962). Since then much research has been done. One of the best resources available to track the prevalence of this disease at least in the Gulf States is the Oyster Sentinel website (http://www.oystersentinel.org/) which dates back to 1998. This web page includes information on the number of oysters impacted by Dermo (prevalence) seasonally as well as annually at locations where important reefs are located. While it cannot be eradicated, research efforts need to continue towards finding suitable conditions for oysters to grow whilst balancing ecosystem services.

Surface wave climate simulations in Swan Lake suggest that the largest significant wave heights and peak periods will occur in the vicinity of the lake's eastern boundary and breakwaters, during easterly winds. However, even for rather strong winds (~20 m/s) significant heights do not exceed ~0.4 m. Inside the lake's center, under similar wind conditions, heights are only about 0.2 m with periods of ~1.5 s. Thus, oyster reefs are expected to be the least susceptible to mechanical damage resulting from surface waves if they are located away from the eastern boundary and breakwaters.

Temperature and salinity are generally held to be the dominant environmental factors controlling both the survival and growth of oysters and *P. marinus* independently, and it is likely that they influence the host parasite interaction (e.g., Soniat & Gauthier 1989). But what else is important? Other factors including water quality (Ray 1966; Royer et al. 2007), pollution (Turner 1985; Royer et al. 2007), agriculture (Craig et al. 1989) and the role of freshets (La Peyre et al. 2003; 2009) have been identified as possibly influencing *P. marinus* impacts on oysters and investigate. The role of food source is less studied *in situ* despite

many laboratory studies but it is known for example that food supply is the major environmental parameter determining gonad proliferation in oysters (Kang et al. 2000, Enriquez-Diaz 2004 in Royer et al. 2007; Wilson-Ormand et al. 1997). Wetz et al. (2002) found oysters preferentially ate diatoms and phototrophic nanoflagellates but were less interested in cyanobacteria and heterotrophic nanoflagellates. Here, we investigated if there were major differences in the food supply at different stations in the study area.

Annual variability was observed in the seasonal patterns of chl *a* in 2009 and 2010, although chl *a* concentrations peaked in May of both years as a result of the spring diatom bloom (Fig. 18 and 19; Table 3). Thirty-five genera (and many more species) of phytoplankton were identified in samples collected from Swan Lake, along the Virginia Point Shoreline and at the control site on Galveston Island, Sportsman Road. Of these, twenty-seven genera were diatoms (Bacillariophyta). As mentioned above, this partly reflects the ease of preservation and identification of this group but also reflects that this group actually is a significant component of the phytoplankton assemblage in these areas (see Fig. 18 HPLC findings) and so oyster diet. Of the diatoms identified, *Bacillaria, Chaetoceros*, *Ditylum, Hemialus, Lioloma, Navicula, Odentella, Pseudo-nitzschia, Rhizosolenia*, and *Skeletonema* appeared often as the abundant genera in Swan Lake and Virginia Point Shoreline (Table 3). All these diatoms are known to Galveston Bay (R. Windham, pers. obs.) but not all of them have been previously reported (Quigg et al. 2009). We can speculate that fall and winter in 2009 was windy and thus the water column well mixed as there were many benthic diatoms in our plankton tows; these included *Licomophora, Lioloma*, *Navicula, Nitzschia,* and *Pseudo-nitzschia* amongst others. In a recent study published by Quigg and Roehrborn (2008), diatoms were also found to be the most abundant group in the nearby Offatts Bayou which is located on Galveston Island. Quigg and Roehrborn (2008) also observed seasonal oscillations in the diatom community and found the dominant diatom genera in Offatts Bayou to be C*haetoceros, Ditylum, Rhizosolenia, Coscinodiscus, Guinardia, Dactyliosolen, Odontella* and *Lithodesmium*. Interestingly, all these species were also observed in Swan Lake and along the Virginia Point Shoreline as might be anticipated, except in the present study we did not

observe *Guinardia, Dactyliosolen* and *Lithodesmium*. This reflects difference in the hydrographic conditions between the two systems.

The second most important group was arguably the cyanobacteria. These are near impossible to identify microscopically because of their small size so that our understanding of cyanobacterial populations comes mostly from HPLC analysis. As with studies done in Galveston Bay, cyanobacterial abundance peaks in the warmer months and is lowest in the cooler months (Quigg et al. 2007, 2009). In summer 2009, we identified a *Microcystis* bloom in samples particularly close to Virginia Point. Previous studies, also conducted in Offatts Bayou, have reported blooms of this species, occurring only when certain hydrographic conditions persist in the summer which include warmer waters with high salinities, and a calm and stratified water column (McInnes and Quigg, 2010). Under these conditions, *Microcystis* blooms may also lead to fish kills. McInnes and Quigg (2010) found this was the case in 2005 but not in 2006 thereby allowing them to narrow down the likely contributing factors which lead to a fish kill event in which > 10,000 *Brevoortia partonus* (Gulf Menhaden) perished. Hydrographic and physical conditions were certainly different in both years (Figs. 3 – 11) and may explain why a bloom was observed in 2009 but not in 2010.

While it is known that oysters are substantial grazers of planktonic organisms, particularly phytoplankton, information is still lacking on oyster dietary preferences in nature and the regulatory mechanisms behind their feeding activity. Our results suggest that oysters in Swan Lake and along the Virginia Point Shoreline have a diet rich in diatoms. However, the role of flagellates (photosynthetic and heterotrophic) in this system can not be resolved with current methodology and available technology; but we do know that in other systems oysters do show a strong preference for flagellates and can affect phytoplankton biomass, emphasizing their role in regulating microbial food web structure and primary productivity where oysters are prominent components of the benthic macrofauna (Wetz et al. 2002).

6. Conclusions

Commercial oyster production in Texas, second to Louisiana, comprised 20% of the nation's harvest from 2000 to 2005 (NOAA 2007). In addition to being commercially valuable, oysters serve an important ecological role in the bay system. They stabilize the sediment, reduce turbidity by filtering particles, and provide a distinct habitat for reef associated organisms. This study was stimulated by the idea of using oyster reefs to stabilize sediment for erosion prevention and turbidity reduction in a recovering habitat. In addition, the study, if able to take advantage of freshwater inflows, would provide details on the role of freshwater inflows to oysters and their diet. The clearly observed differences in salinities between years 2009 and 2010, with significantly lower values in the latter year, are consistent with the *higher* Dermo levels and *lower* weighted prevalence (number of oysters impacted) observed in 2009 (note that the observed temperature values were not significantly different in 2009 and 2010). This conclusion, reinforces the notion that oysters may indeed benefit once treated water is redirected and allowed to flow into Swan Lake.

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Appendix A:

Tex-Tin Corporation (Texas City, Texas)
Region 6 (TXD062113329)

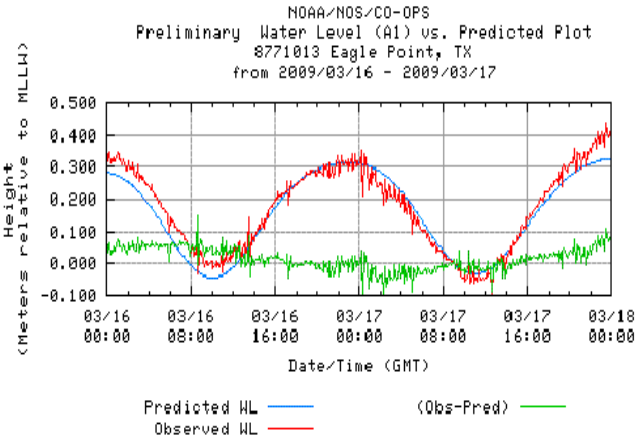
The Tex-Tin site is an active tin smelter operating in an industrial area of Texas City, Texas (Fig. 1). The facility was constructed by the U.S. Government during World War II. Wah Chang Corporation purchased the facility after the war and sold it in 1970 to Gulf Chemical and Metallurgical Company, which changed the name to Tex-Tin Corporation in 1985. In 1985, EPA issued an Administrative Order under the Clean Water Act charging Tex-Tin with violating a permit issued under the National Pollutant Discharge Elimination System (EPA 1987). The site occupies 52 hectares of flat land and consists of numerous buildings, five wastewater treatment ponds, a slurry pond, open and closed acid ponds, three inactive (EPA 1987). Surface waters of interest include the Wah Chang Ditch, which receives treated effluent from the facility (EPA 1987). This ditch runs south along the eastern side of the site and discharges into an unnamed intermittent stream. This stream flows for 3 km through a coastal wetland and into Swan Lake. Swan Lake empties directly into Galveston Bay, 5 km from the site. The groundwater is shallow and flows south toward the bay area. Contaminant migration pathways of concern include surface water runoff and groundwater flow to Swan Lake and Galveston Bay.

Appendix B:

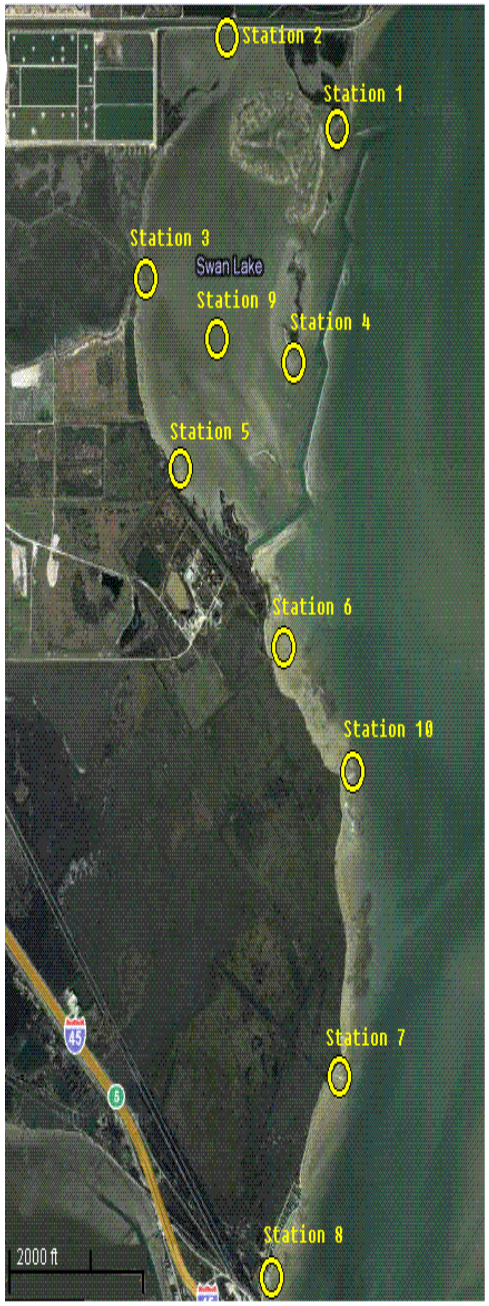
The following appendix summarizes the hydrographic conditions for the research trips conducted during this project.

Date	No. of stations visited	Hydrographic Data	Wave height	Comments
2008				
May	9	Y	Y	Not included in analysis
September	10	Y	Y	Not included in analysis
2009				
March	10	Y	Y	
May	10	6/10	Y	
June - 16	10	Y	Y	
June - 25				
July	10	Y	Y	
September – 4	10	Y	Y	Counted as an August sampling event
September - 21	10	Y	Y	
October	10	Y	Y	
November	10	Y	Y	
December				
2010				
February	10	Y	Y	
May 14, 18 & 20	10	Y	Y	Instrument issues
July	10	Y	Y	
September	10	Y	Y	
November	10	Y	Y	

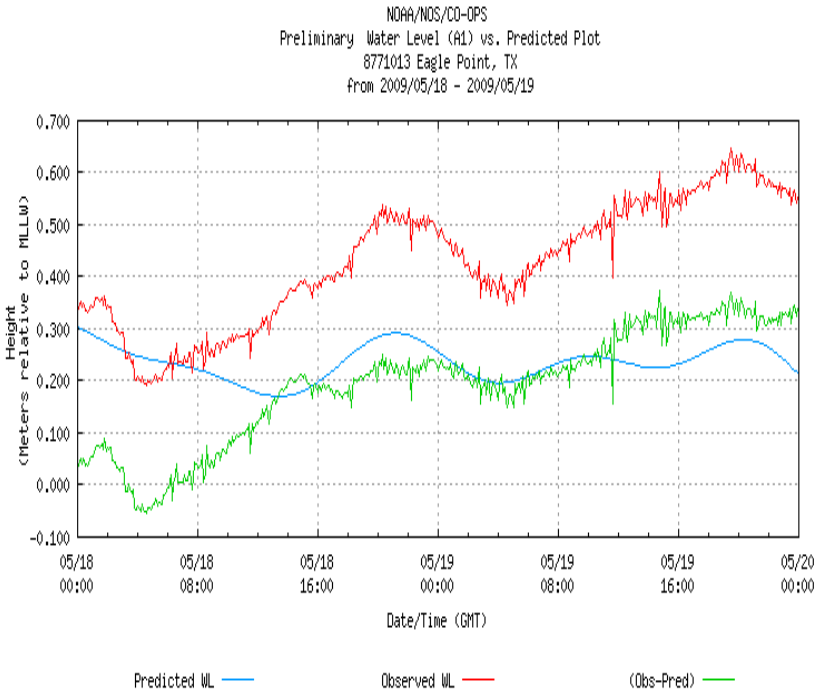
Swan Lake March 16th 2009 Data Summary



Station	Latitude (N)	Longitude (W)	Time (GMT)	Depth [m]	Salinity	Temp [C]
1	29 21.106	94 53.513	16:06	0.45	24.94	15.68
2	29 21.355	94 54.040	16:35	0.65	25.07	14.18
3	29 20.769	94 54.466	17:00	0.5	25.07	14.63
4	29 20.701	94 54.150	17:27	0.51	24.96	15.92
5	29 20.283	94 54.281	17:44	0.33	20.42	15.98
6	29 19.826	94 53.827	15:42	0.27	24.69	14.53
7	29 18.742	94 53.595	15:09	0.5	24.79	13.84
8	29 19.294	94 53.890	14:42	0.52	24.78	13.95
9	29 20.710	94 54.148	17:16	0.9	24.61	14.7
10	29 19.469	94 53.516	15:30	0.41	24.48	14.33

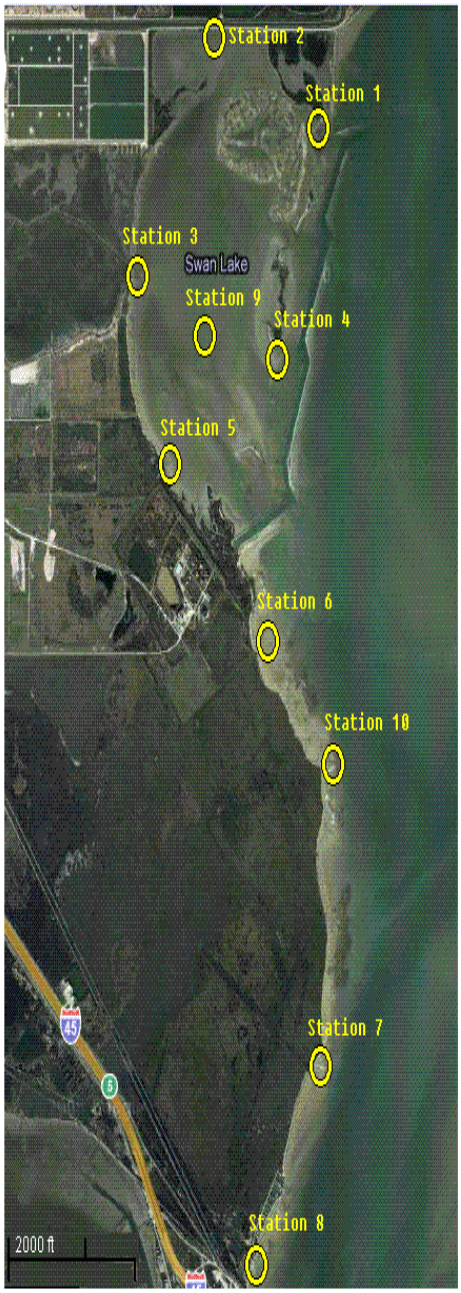


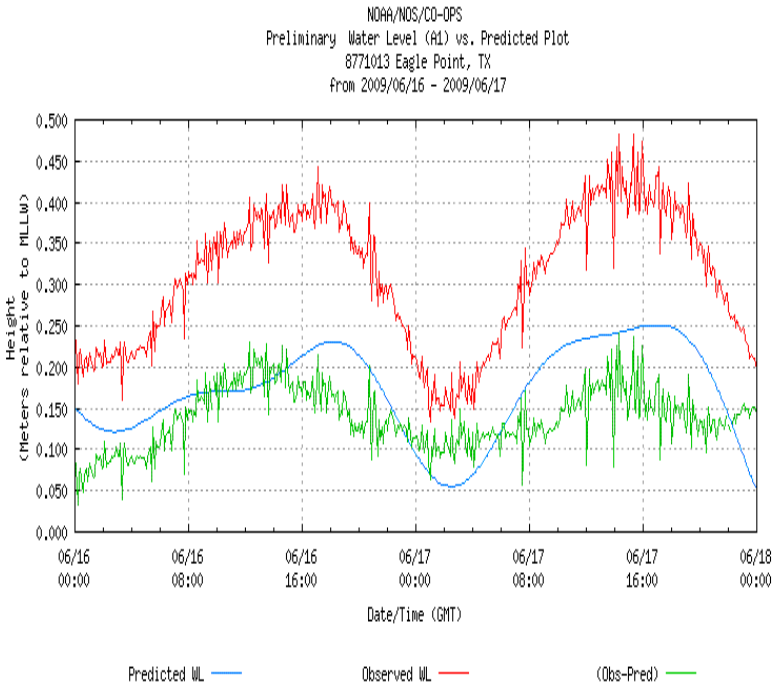
Swan Lake May 18th 2009
Data Summary



Station	Latitude (N)	Longitude (W)	Time (GMT)	Depth [m]	Salinity	Temp [C]
1	29 21.106	94 53.513	17:36	N/A	N/A	N/A
2	29 21.350	94 54.050	18:27	0.66	23.07	21.94
3	29 20.770	94 54.467	19:06	0.73	20.09	22.91
4	29 20.558	94 53.768	19:43	0.57	17.03	25.08
5	29 20.272	94 54.308	20:10	0.5	17.46	23.97
6	29 19.826	94 53.827	16:37	N/A	N/A	N/A
7	29 18.742	94 53.595	16:03	N/A	N/A	N/A
8	29 19.294	94 53.890	15:36	N/A	N/A	N/A
9	29 20.710	94 54.148	19:35	1.14	19.07	23.36
10	29 19.466	94 53.524	16:24	0.7	17.26	21.79

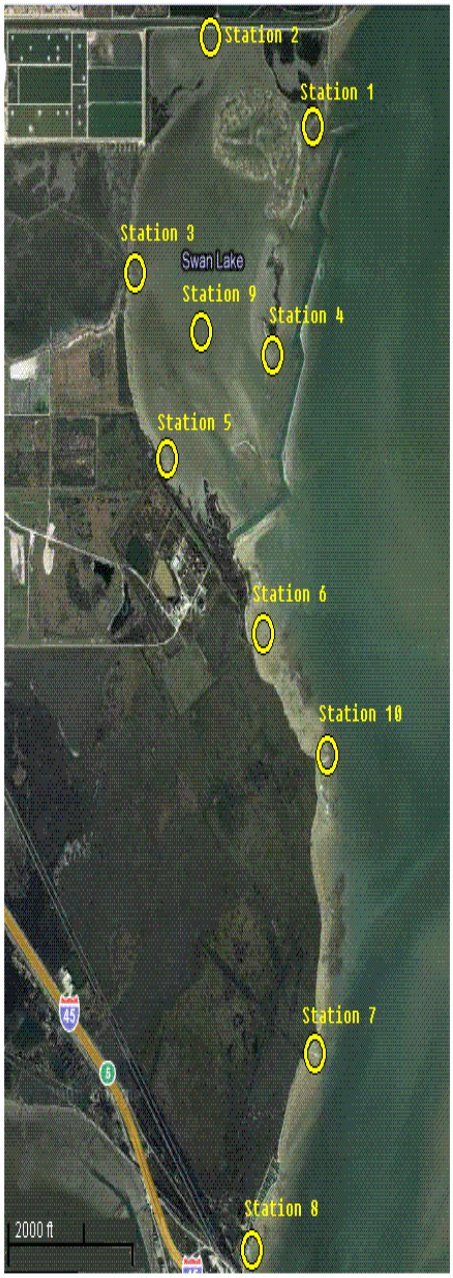
Swan Lake June 16th 2009
Data Summary

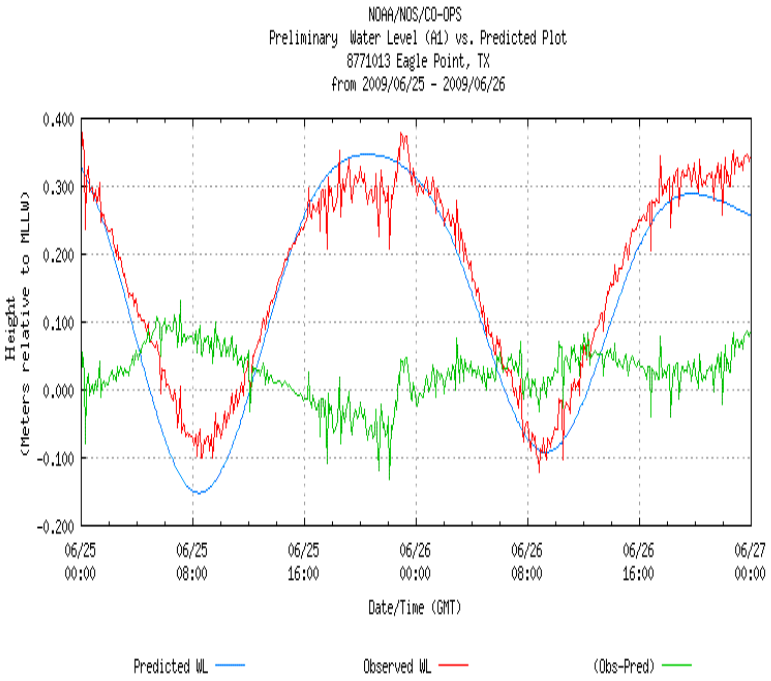




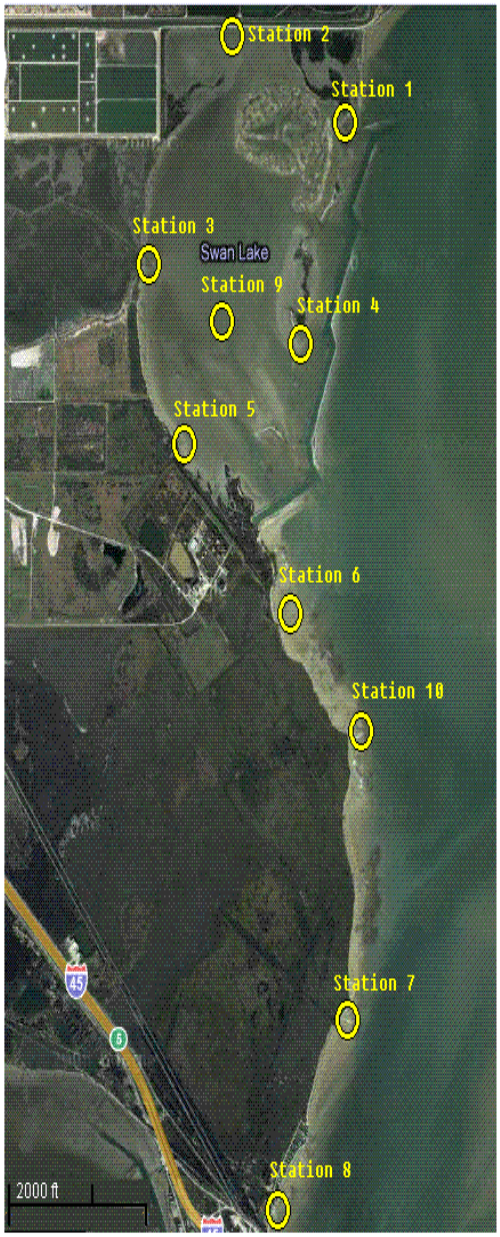
Station	Latitude	Longitude	Time In (GMT)*	Time Out (GMT)*	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.294	W 94 53.890	14:02:50	14:08:29	28.17	23.93	0.363
7	N 29 18.755	W 94 53.590	14:18:22	14:20:59	28.22	24.08	0.519
10	N 29 19.467	W 94 53.500	14:36:22	14:38:27	27.5	23.53	0.453
6	N 29 19.832	W 94 53.802	15:11:22	15:13:31	27.96	23.23	0.447
1	N 29 21.109	W 94 53.497	15:26:53	15:28:47	28.17	22.77	0.582
2	N 29 21.348	W 94 53.043	16:01:22	16:02:52	28.28	22.1	0.643
3	N 29 20.784	W 94 54.454	16:23:53	16:26:39	28.95	21.94	0.482
9	N 29 20.652	W 94 54.124	16:32:53	16:34:12	28.91	21.85	1.044
4	N 29 20.560	W 94 53.762	16:43:22	16:46:35	29.11	23.03	0.438
5	N 29 20.279	W 94 54.301	16:57:52	17:00:00	29.28	22.55	0.388

Swan Lake June 25th 2009 Data Summary

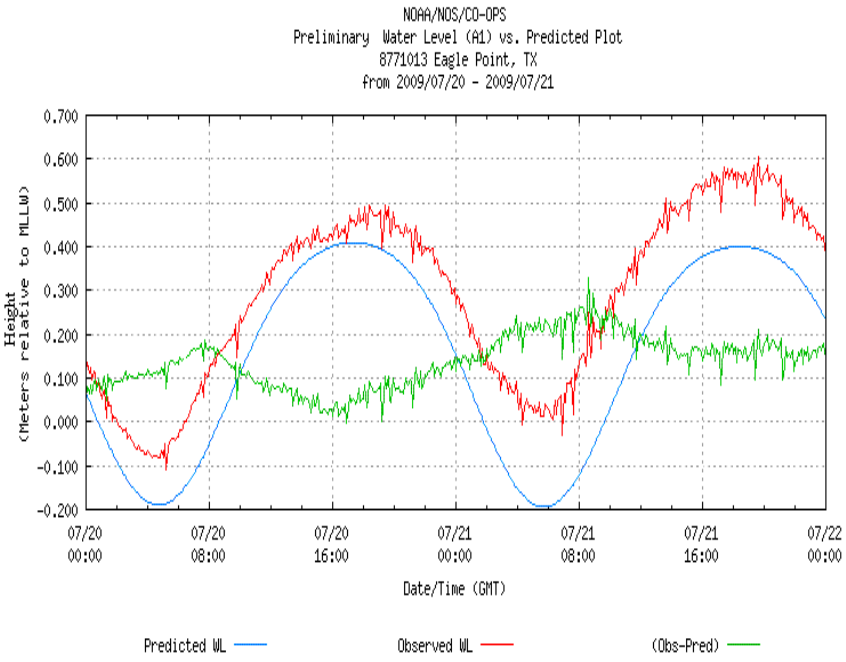




Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.285	W 94 53.866	14:33:47	14:35:45	29.71	28.18	0.61
7	N 29 18.746	W 94 53.586	14:41:43	14:43:40	28.86	28.42	0.4
10	N 29 19.463	W 94 53.509	14:51:41	14:53:14	30.29	28.22	0.35
6	N 29 19.826	W 94 53.808	15:16:03	15:18:03	30.98	28.16	0.54
1	N 29 21.103	W 94 53.503	15:25:10	15:27:10	30.25	27.29	0.71
2	N 29 21.350	W 94 53.034	15:41:40	15:43:24	30.05	26.27	0.26
3	N 29 20.775	W 94 54.454	15:56:43	15:58:59	30.27	27.99	0.46
9	N 29 20.667	W 94 54.165	16:04:12	16:06:10	30.26	27.81	0.92
4	N 29 20.558	W 94 53.770	16:10:18	16:12:30	31.3	27.72	0.44
5	N 29 20.276	W 94 54.311	16:23:30	16:25:07	30.75	28.01	0.19

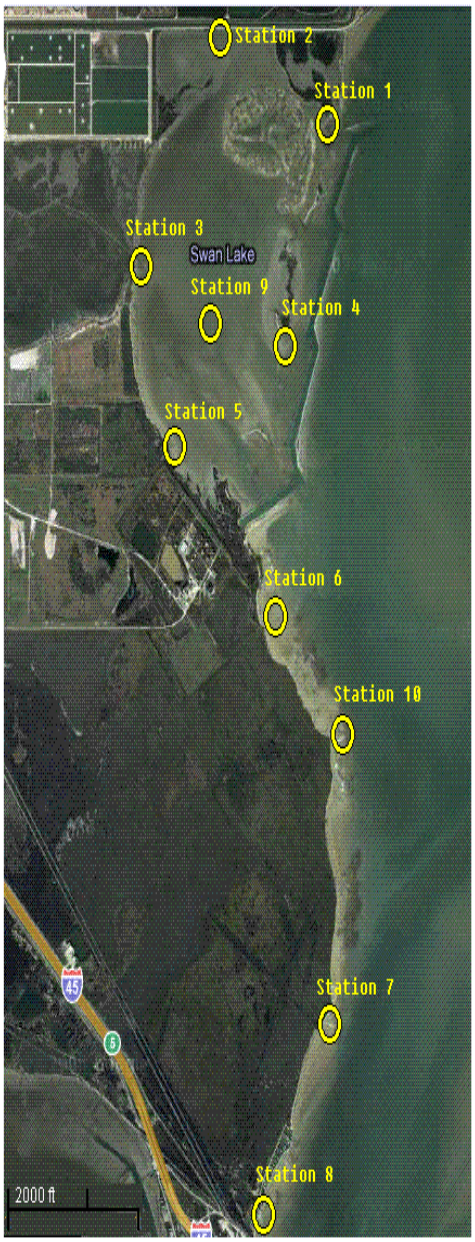


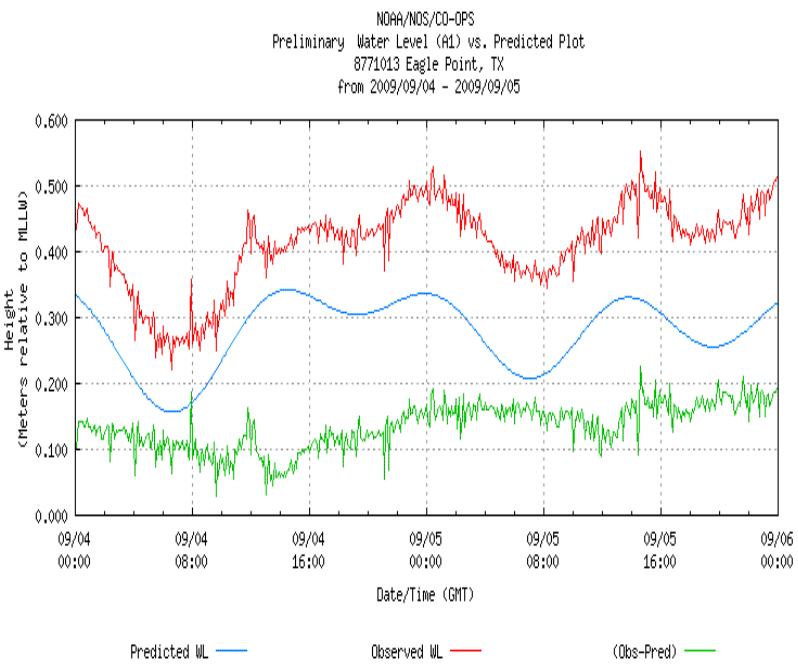
Swan Lake July 20th 2009 Data Summary



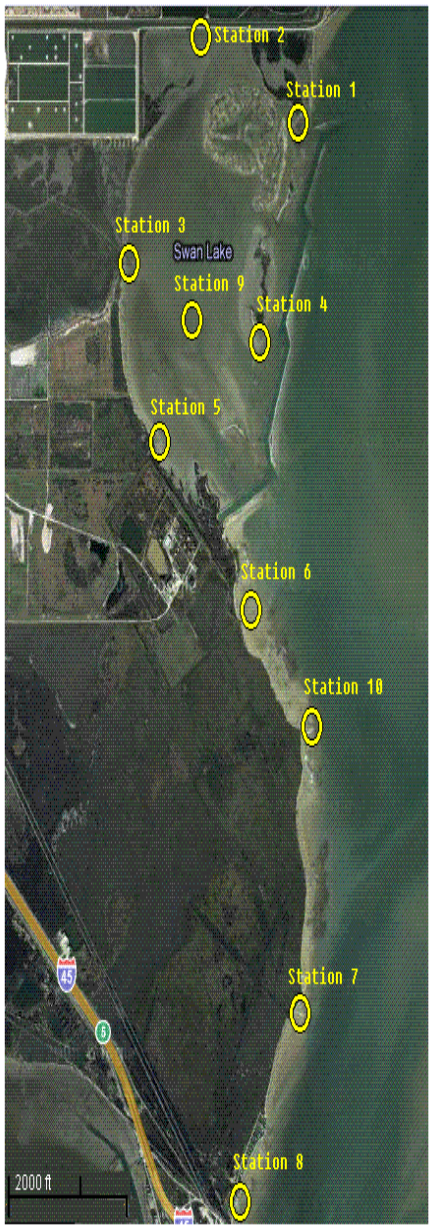
Station	Latitude	Longitude	Time In (GMT)*	Time Out (GMT)*	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.285	W 94 53.866	15:00:13	15:02:16	28.97	32.80	0.68
7	N 29 18.746	W 94 53.586	15:32:20	15:35:18	28.88	33.03	0.58
10	N 29 19.463	W 94 53.509	15:59:11	16:01:11	28.04	33.36	0.25
6	N 29 19.826	W 94 53.808	16:19:43	16:21:42	28.42	33.39	0.4
1	N 29 21.103	W 94 53.503	16:39:05	16:41:01	28.75	32.79	0.23
2	N 29 21.350	W 94 53.034	17:01:42	17:03:42	28.48	33.97	0.27
3	N 29 20.777	W 94 54.458	17:19:50	17:21:51	28.55	34.15	0.31
9	N 29 20.685	W 94 54.150	17:34:07	17:36:25	28.75	33.96	1.09
4	N 29 20.566	W 94 53.772	17:44:19	17:46:18	29.54	33.08	0.28
5	N 29 20.279	W 94 54.307	18:00:34	18:02:35	29.55	33.36	0.64

Swan Lake September 4th 2009
Data Summary

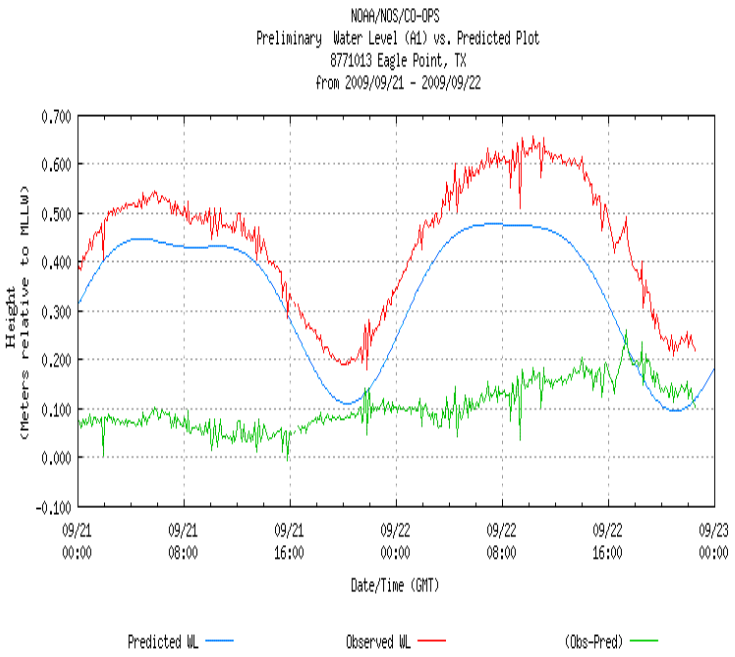




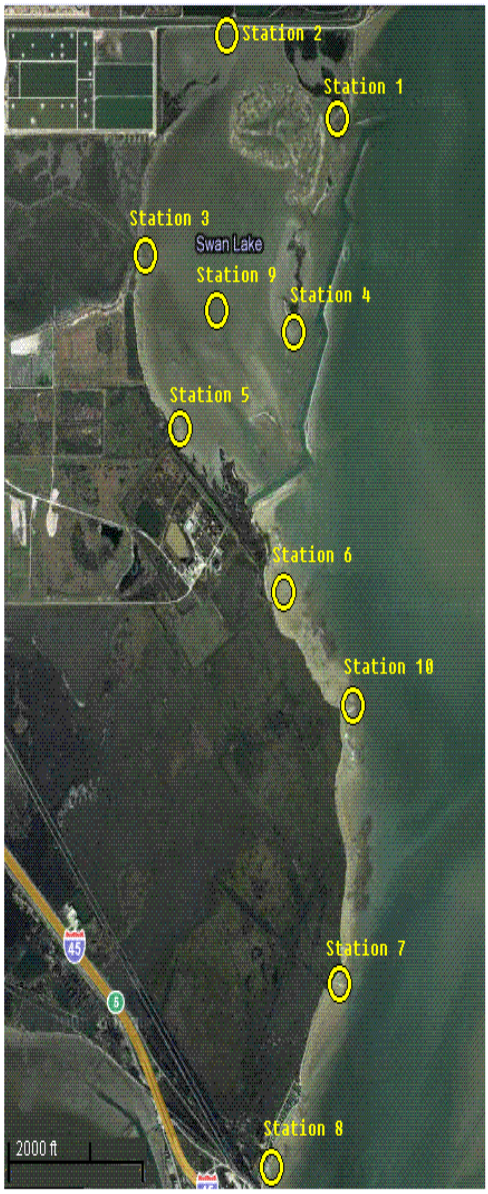
Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Temp (° C)	Salinity (PSU)	Depth (m)
8	N 29 18.290	W 94 53.871	14:14:30	14:16:30	27.044	31.79	0.294
7	N 29 18.429	W 94 53.751	14:28:00	14:30:00	27.158	31.72	0.321
10	N 29 19.464	W 94 53.508	14:45:30	14:47:30	27.94	30.735	0.338
6	N 29 19.827	W 94 53.811	15:00:00	15:02:00	27.867	30.605	0.475
1	N 29 21.108	W 94 53.503	15:19:10	15:21:10	27.766	30.539	0.45
2	N 29 21.343	W 94 54.033	15:42:50	15:44:50	27.636	34.086	0.382
3	N 29 20.776	W 94 54.466	16:11:11	16:13:11	28.185	33.264	0.421
9	N 29 20.681	W 94 54.138	16:24:45	16:26:45	28.082	32.424	1.09
4	N 29 20.614	W 94 53.851	16:34:50	16:36:50	28.009	31.601	0.465
5	N 29 20.286	W 94 54.309	16:44:15	16:46:15	28.123	31.467	0.562



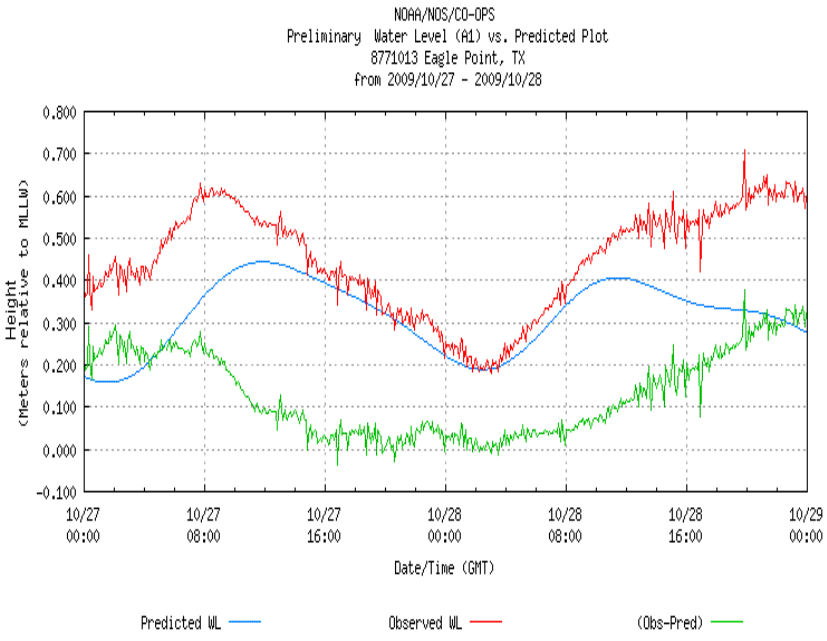
Swan Lake September 21st 2009
Data Summary



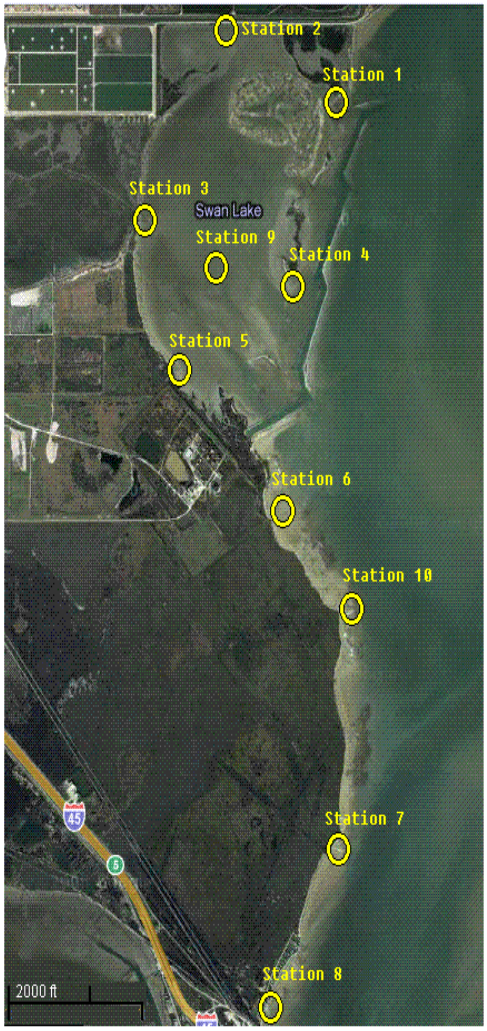
Station #	Latitude	Longitude	Time in (GMT)	Time out (GMT)	Temp(° C)	Salinity(PSU)	Depth(m)
8	N 29° 18.289	W 94° 53.869	14:51:55	14:53:55	27.426	29.851	0.315
7	N 29° 18.748	W 94° 53.590	15:10:00	15:12:00	27.667	29.566	0.325
10	N 29° 19.471	W 94° 53.511	15:31:00	15:33:00	28.057	29.143	0.419
6	N 29° 19.823	W 94° 53.814	15:49:20	15:51:20	28.075	28.69	0.304
1	N 29° 21.099	W 94° 53.503	16:25:50	16:27:50	28.448	28.21	0.451
2	N 29° 21.349	W 94° 54.034	16:56:30	16:58:30	29.066	27.307	0.324
3	N 29° 20.775	W 94° 54.461	17:20:10	17:22:10	28.811	26.643	0.291
9	N 29° 20.669	W 94° 54.152	17:29:00	17:31:00	28.805	27.953	0.326
4	N 29° 20.559	W 94° 53.765	17:43:15	17:45:15	29.726	28.111	0.251
5	N 29° 20.277	W 94° 54.307	17:58:35	18:00:35	30.818	28.279	0.245



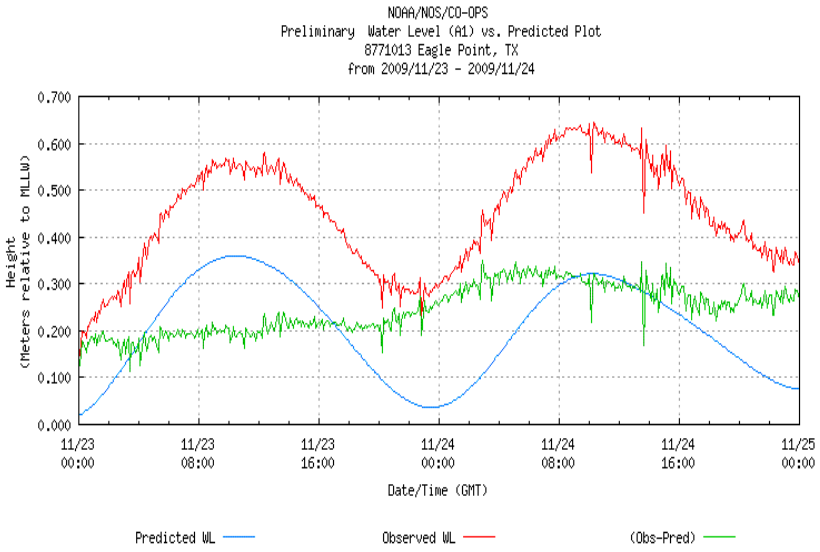
Swan Lake Oct. 27th 2009
Data Summary



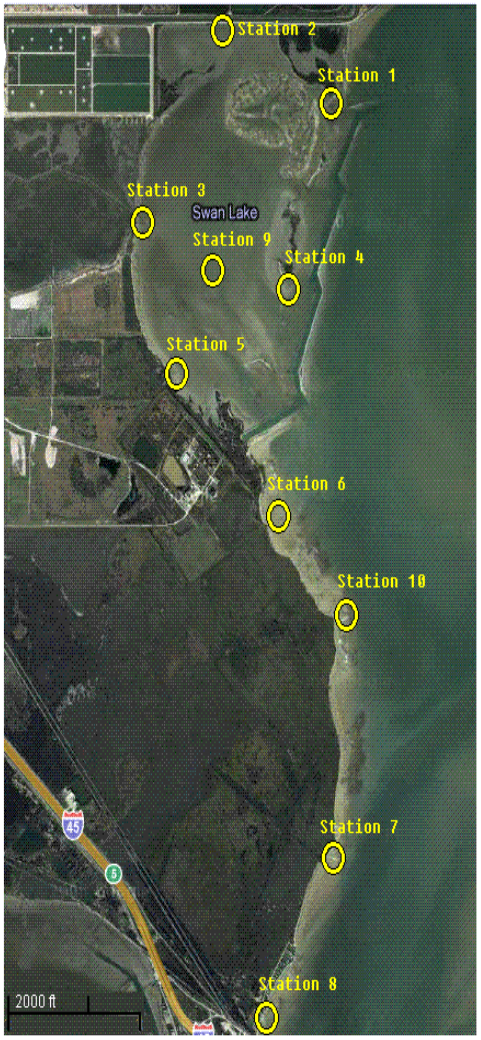
Latitude	Longitude	Time in (GMT)	Time out (GMT)	Temp(° C)	Salinity(PSU)	Depth(m)
N 29° 18.287	W 94° 53.868	14:42:00	14:44:00	19.287	24.0024	0.729
N 29° 18.748	W 94° 53.583	14:51:28	14:53:28	19.102	24.1107	0.598
N 29° 19.467	W 94° 53.503	15:03:38	15:05:38	19.023	24.1789	0.813
N 29° 19.830	W 94° 53.818	15:16:33	15:18:33	19.084	24.3748	0.546
N 29° 21.101	W 94° 53.498	15:27:28	15:29:28	18.877	23.7581	0.882
N 29° 21.349	W 94° 54.036	15:54:29	15:56:29	18.385	23.5701	0.554
N 29° 20.778	W 94° 54.463	16:05:54	16:07:54	17.979	21.0473	0.404
N 29° 20.679	W 94° 54.137	16:12:10	16:14:10	18.642	22.8554	1.098
N 29° 20.629	W 94° 53.848	16:18:22	16:20:22	18.94	24.249	0.559
N 29° 20.280	W 94° 54.313	16:29:21	16:31:21	18.927	22.974	0.509



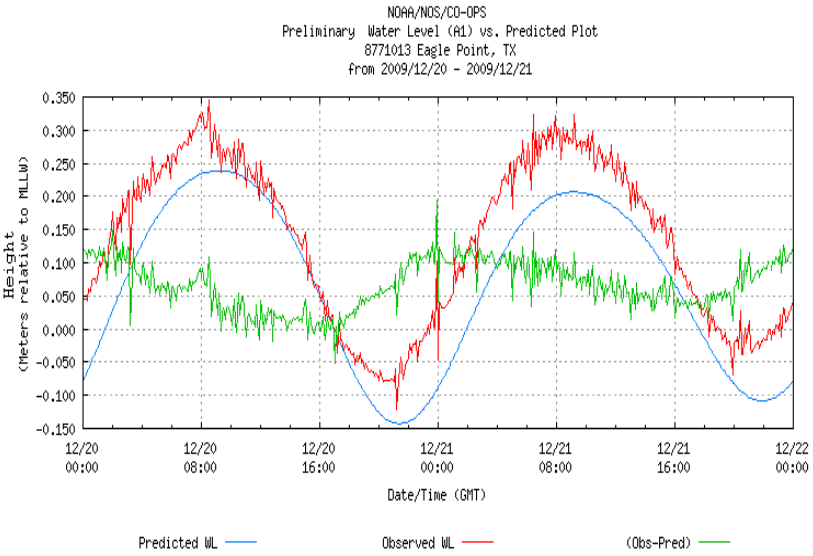
Swan Lake Nov. 23rd 2009
Data Summary



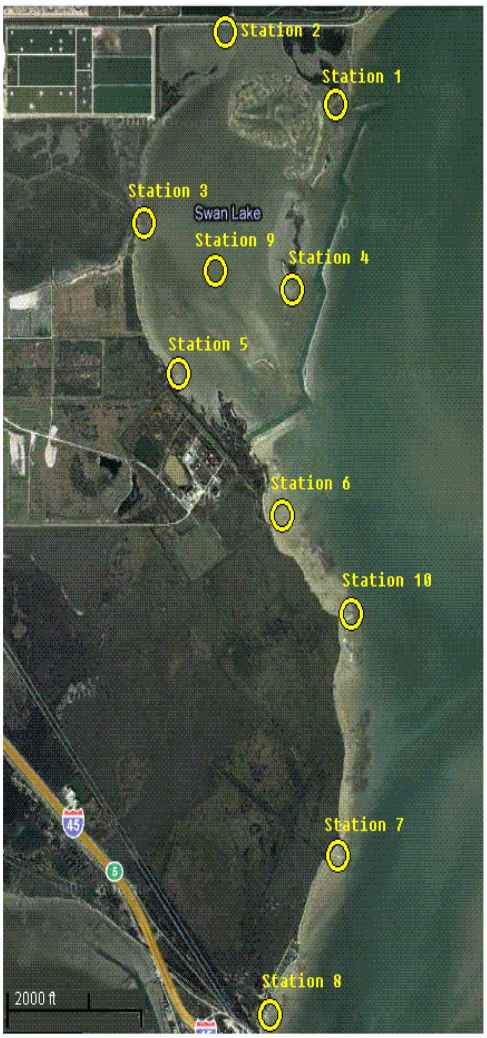
Station	Latitude	Longitude	Time In (GMT)*	Time Out (GMT)*	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29°18.291	W 94°53.864	14:47:30	14:49:30	16.08	17.48	0.45
7	N 29°18.749	W 94°53.596	15:21:00	15:23:00	16.23	17.02	0.28
10	N 29°19.472	W 94°53.518	15:58:43	16:00:43	16.95	14.65	0.49
6	N 29°19.824	W 94°53.815	16:17:48	16:19:48	17.16	14.83	0.47
1	N 29°21.102	W 94°53.513	16:36:15	16:38:15	17.42	14.47	0.46
2	N 29°21.353	W 94°54.044	17:16:00	17:18:00	19.15	16.82	0.44
3	N 29°20.778	W 94°54.457	17:44:00	17:44:00	17.54	15.66	0.46
9	N 29°20.670	W 94°54.163	18:13:33	18:15:33	17.75	16.22	0.66
4	N 29°20.558	W 94°53.766	18:21:05	18:23:05	17.99	15.99	0.47
5	N 29°20.280	W 94°54.310	18:37:19	18:39:19	18.28	15.29	0.47



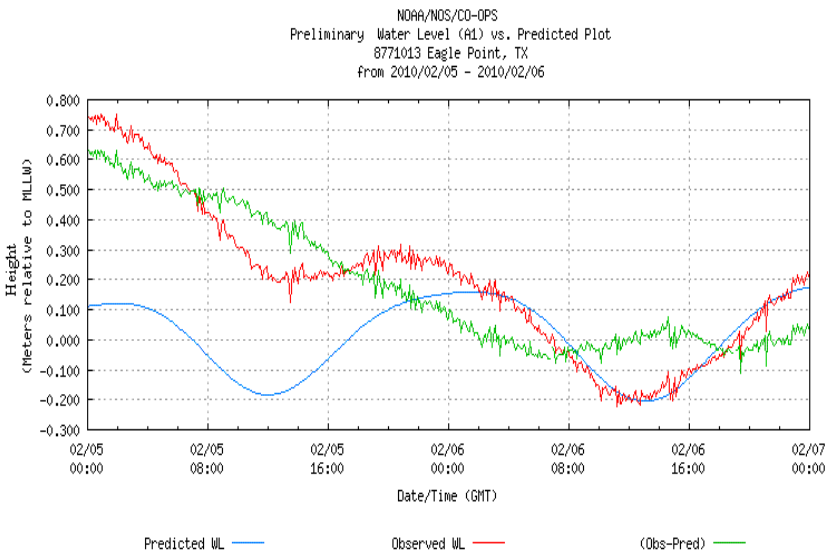
Swan Lake Dec. 20th 2009
Data Summary



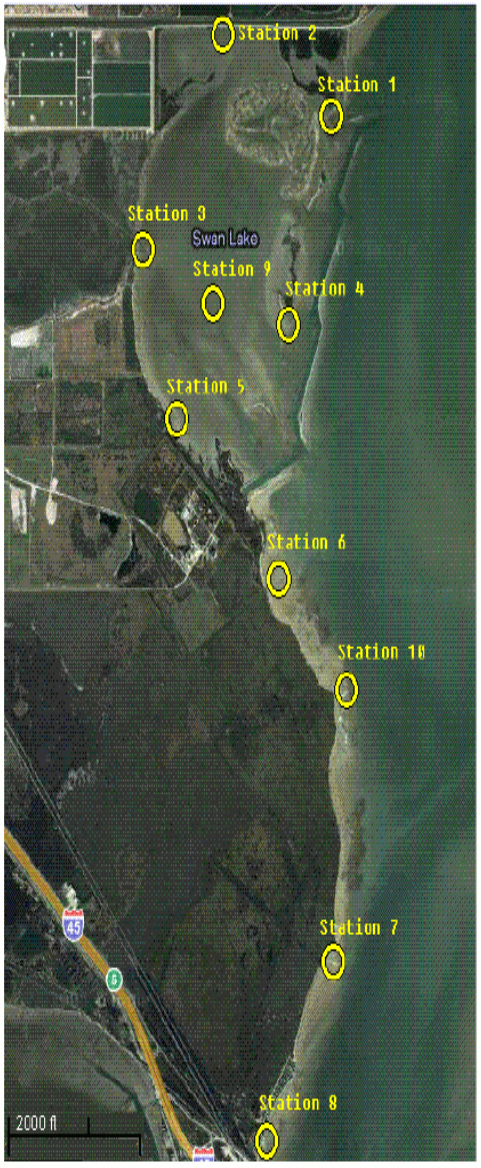
Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.281	W 94 53.844	18:09:35	18:11:35	12.47	15.86	0.524
7	N 29 18.738	W 94 53.583	18:25:40	18:27:40	13.04	16.36	0.302
10	N 29 19.455	W 94 53.507	18:41:30	18:43:30	12.76	17.03	0.445
6	N 29 19.823	W 94 53.805	19:22:55	19:24:55	13.92	17.30	0.325
1	N 29 21.102	W 94 53.501	19:43:20	19:45:20	12.63	17.17	0.501
2	N 29 21.344	W 94 53.039	21:19:25	21:21:25	14.66	17.63	0.311
3	N 29 20.755	W 94 54.433	20:57:43	20:59:43	13.82	16.95	0.385
9	N 29 20.665	W 94 54.180	20:50:15	20:52:15	13.47	17.54	0.70
4	N 29 20.551	W 94 53.763	20:02:00	20:04:00	15.04	17.71	0.372
5	N 29 20.284	W 94 54.298	20:29:45	20:31:45	13.98	16.51	0.354



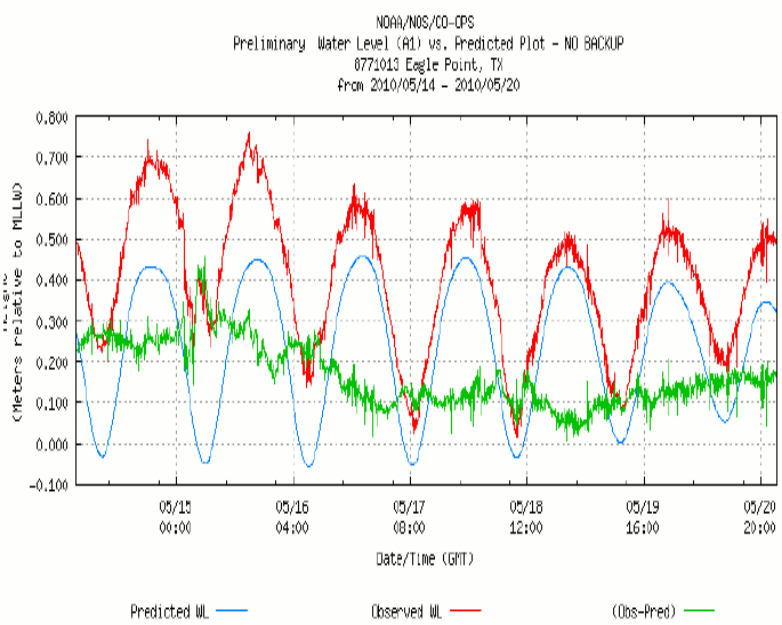
Swan Lake Feb. 5th 2010
Data Summary



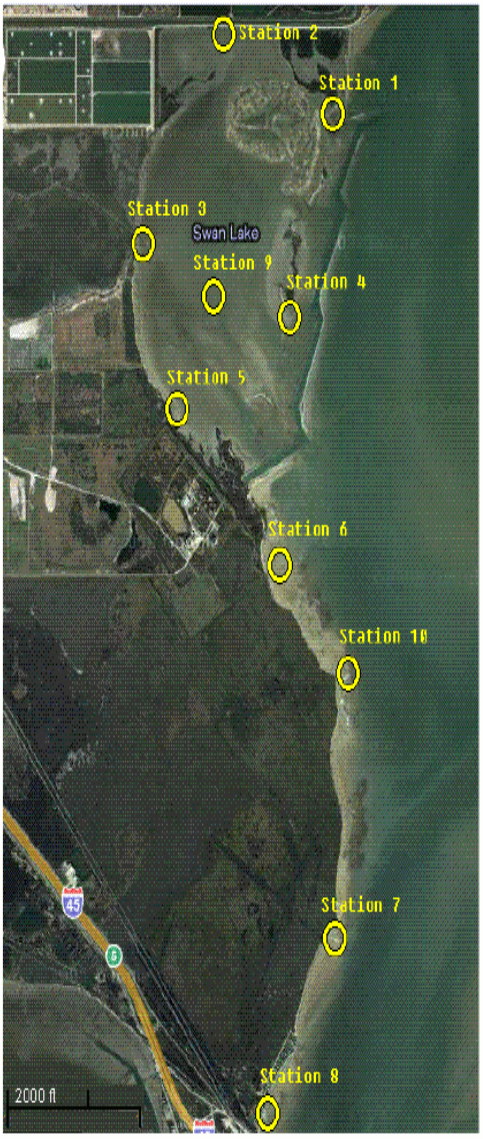
Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.290	W 94 53.867	18:46:27	18:48:27	12.23	18.60	0.49
7	N 29 18.772	W 94 53.584	19:08:11	19:10:11	13.64	20.48	0.31
10	N 29 19.465	W 94 53.508	19:19:25	19:21:25	12.26	20.65	0.36
6	N 29 19.824	W 94 53.812	19:47:53	19:49:53	12.69	20.89	0.40
1	N 29 21.096	W 94 53.509	20:11:20	20:13:20	12.56	22.42	0.34
2	N 29 21.351	W 94 54.041	20:39:09	20:41:09	13.03	19.69	0.46
3	N 29 20.775	W 94 54.463	21:03:25	21:05:25	14.05	16.03	0.23
9	N 29 20.641	W 94 54.119	21:24:35	21:26:35	12.93	18.49	0.86
4	N 29 20.555	W 94 53.760	21:32:06	21:34:06	13.83	20.63	0.35
5	N 29 20.278	W 94 54.316	21:52:15	21:54:15	15.63	18.44	0.15

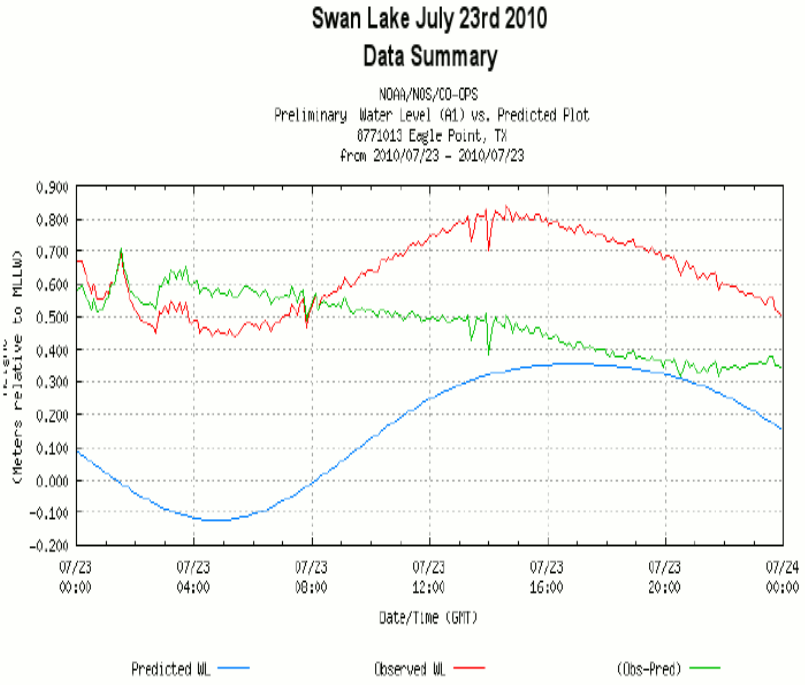


Swan Lake May 14th, 18th, 20th 2010
Data Summary

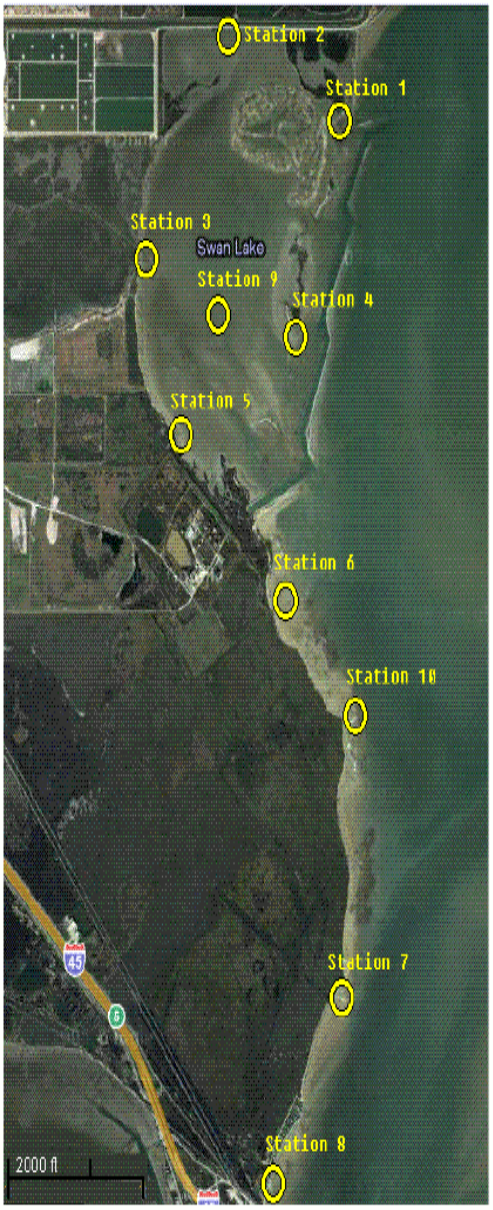


Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.288	W 94 53.867	14:35:55	14:37:55	25.71	24.60	0.44
7	N 29 18.753	W 94 53.576	17:58:30	18:00:30	27.38	24.34	0.6
10	N 29 19.469	W 94 53.515	15:55:20	15:57:20	26.16	24.59	0.66
6	N 29 19.833	W 94 53.804	16:40:45	16:42:45	26.79	24.34	0.56
1	N 29 21.119	W 94 53.498	16:01:41	16:02:01	27.14	20.78	1.2
2	N 29 21.343	W 94 54.041	15:20:25	15:21:25	26.72	18.96	0.6
3	N 29 20.789	W 94 54.456	15:12:00	15:13:00	26.81	18.94	0.8
9	N 29 20.655	W 94 54.164	18:16:55	18:18:55	28.46	19.36	0.8
4	N 29 20.555	W 94 53.764	17:07:38	17:09:40	28.99	19.91	0.4
5	N 29 20.278	W 94 54.308	15:46:10	15:48:10	27.74	19.64	0.4

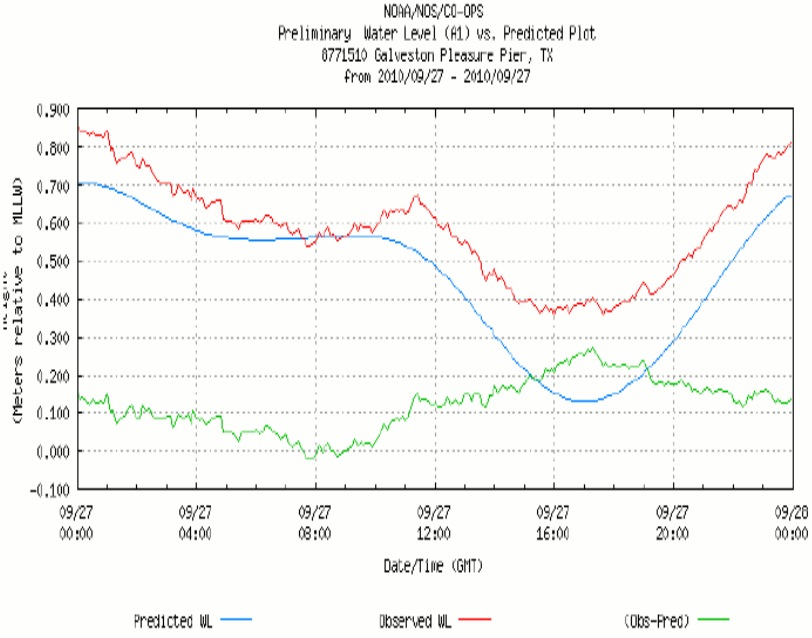




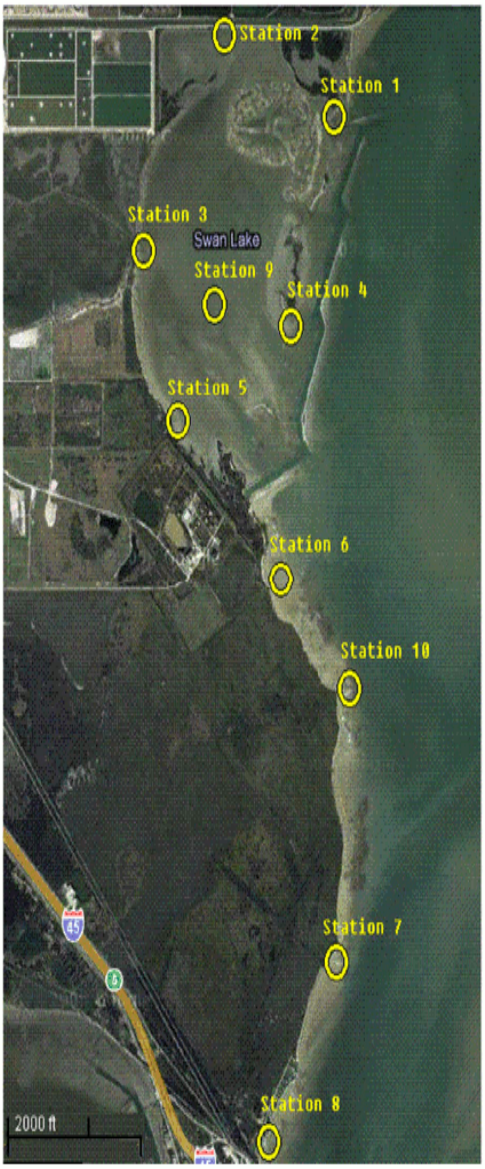
Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.289	W 94 53.863	14:11:45	14:13:45	29.20	22.22	0.51
7	N 29 18.768	W 94 53.590	14:53:25	14:55:25	28.60	22.24	0.62
10	N 29 19.467	N 94 53.531	15:16:03	15:18:03	29.45	22.20	0.59
6	N 29 19.827	W 94 53.829	15:51:26	15:53:27	29.85	22.29	0.78
5	N 29 20.276	W 94 54.310	16:36:16	16:38:16	29.66	21.18	0.63
4	N 29 20.558	W 94 53.782	16:56:00	16:58:02	30.25	21.53	0.65
3	N 29 20.783	W 94 54.469	17:23:56	17:25:56	30.88	20.97	0.8
9	N 29 20.685	W 94 54.163	17:56:38	17:58:38	30.4	21.39	0.96
2	N 29 21.343	W 94 54.043	18:04:08	18:06:08	30.59	20.25	0.64
1	N 29 21.102	W 94 53.507	18:31:50	18:33:50	30.66	20.86	1.12



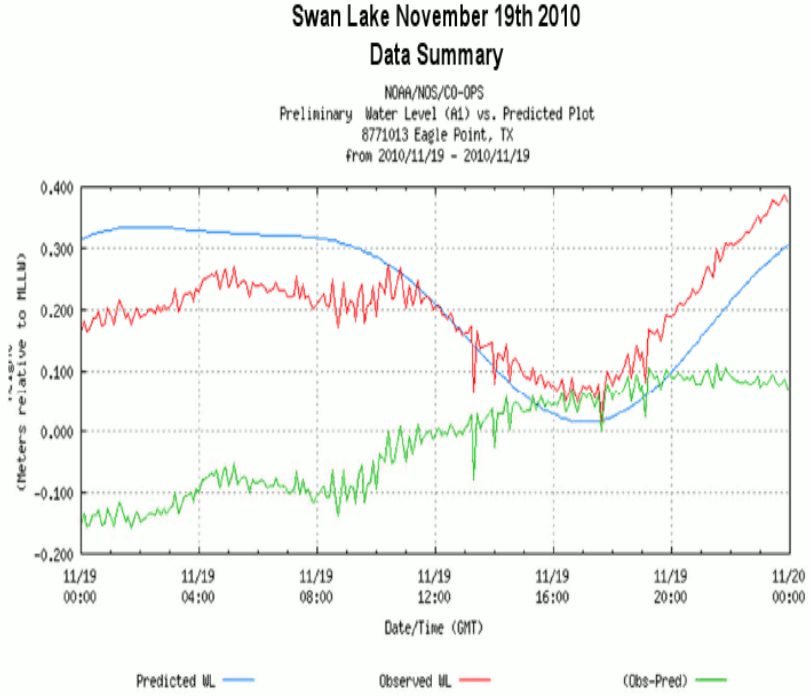
Swan Lake September 27th 2010
Data Summary



Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
8	N 29 18.284	W 94.53.853	15:21:50	15:23:53	23.78	24.58	0.79
7	N 29 18.754	W 94.53.582	16:14:41	16:16:44	24.40	14.15	0.65
10	N 29 19.461	N 94 53.505	16:47:08	16:49:08	25.14	24.48	0.79
6	N 29 19.822	W 94 53.804	17:14:41	17:16:46	25.90	24.32	0.66
5	N 29 20.276	W 94 54.301	17:40:41	17:42:42	26.33	24.44	0.67
4	N 29 20.552	W 94 53.775	18:09:03	18:11:22	26.85	24.41	0.6
3	N 29 20.658	W 94 54.158	18:38:47	18:41:56	26.46	18.96	1.07
9	N 29 20.784	W 94 54.460	18:46:12	18:48:16	26.82	24.4	0.74
2	N 29 21.345	W 94 54.040	19:07:22	19:09:26	26.83	24.8	0.64
1	N 29 21.087	W 94 53.511	19:38:23	19:40:30	27.23	23.88	1.33



Swan Lake November 19th 2010
Data Summary



Station	Latitude	Longitude	Time In (GMT)	Time Out (GMT)	Mean Temperature (°C)	Mean Salinity (PSU)	Depth (m)
1	N 29 21.087	W 94 53.507	15:18:43	15:20:45	15.04	25.91	0.92
2	N 29 21.347	W 94 54.042	15:51:14	15:53:26	14.78	25.11	0.51
3	N 29 20.778	W 94 54.457	16:18:02	16:20:04	15.09	24.65	0.51
9	N 29 20.666	W 94 54.165	16:36:04	16:38:38	15.61	25.7	0.85
4	N 29 20.553	W 94 53.768	16:43:03	16:45:05	16.05	24.78	0.56
5	N 29 20.274	W 94 54.306	17:07:22	17:09:24	15.82	24.59	0.56
6	N 29 19.826	W 94 53.806	17:24:24	17:26:28	15.74	25.44	0.65
10	N 29 19.467	N 94 53.515	17:41:42	17:43:47	16.61	25.47	0.65
7	N 29 18.761	W 94.53.584	18:03:01	18:05:08	17.33	25.47	0.54
8	N 29 18.284	W 94.53.870	18:23:16	18:25:18	17.16	25.27	0.62

Appendix C:

The following appendix summarizes the biological data collected for the research trips conducted during this project when both oysters and phytoplankton were collected at the same time.

Date	No. of stations visited	Oyster Data	Phytoplankton Data	Comments
2008				
May	10	Y	Y	
September	10	Y	Y	Hurricane Ike devastated Galveston shortly after this sampling event; All Oysters were lost and we had to start again in 2009
2009				
March	10	Y	Y	
May	10	Y	Y	
June - 16	10		Y	No oyster measurements
June - 25	10		Y	No oyster measurements
July	10	Y	Y	
September – 4	10		Y	No oyster measurements
September - 21	10		Y	No oyster measurements
October	10		Y	No oyster measurements
November	10	Y	Y	
December	10		Y	No oyster measurements
2010				
February	10	Y	Y	
May 14, 18 & 20	10	Y	Y	
July	10	Y	Y	
September	10	Y	Y	Not available at time of writing report – 11/1/2010
November	10	Y	Y	Not available at time of writing report – 11/1/2010

In the following tables: specific data has been highlighted:
Weighted prevalence of dermo disease in oysters: 0-1 = green; > 1 and < 2 = yellow; > 2 = red.
Dominate phytoplankton group = blue.
No data is indicated by ND
The high salinity control station in West Galveston Bay, referred to as Sportsmans Road (SPR) in Figure 1.

Swan Lake (5/21/08): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	23.1	23	22.2	21.1	19.2	20.7	20.9	22.1	21.8	ND	21.4
		Temperature (°C)	26.7	26.9	27.3	28.1	28.8	28	27.9	30.2	28.8	ND	26.8
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	100	100	100	100	100	90	100	66.67	no live oysters at site; sub-tidal	ND	90
		Weighted Prevalence	2.43	1.83	1.88	2.43	2.03	2.1	2.2	1.06		ND	1.44
		Oyster Meat Index (Average 10 Market Oysters)	14.62	11.49	11.3	11.69	13.44	11.74	--	--		ND	11.08
	Spat	No. Spat/Shell	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Prevalence (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Weighted Prevalence	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	0.76	2.11	2.66	1.84	2.66	2.77	1.36	2.28	3.32	3.14	4.53
		Cyanobacteria	0.16	0.44	0.56	0.94	0.60	0.47	0.24	0.43	0.69	0.73	0.73
		Green Algae	0.04	0.12	0.20	0.13	0.18	0.24	0.09	0.15	0.19	0.22	0.28
		Euglenoids	0.18	0.38	0.35	0.38	0.64	0.36	0.26	0.40	0.63	0.59	1.28
		Cryptophytes	0.05	0.09	0.16	0.10	0.22	0.21	0.08	0.07	0.12	0.14	0.07
		Red Algae	0.07	0.16	0.18	0.00	0.10	0.28	0.09	0.05	0.08	0.09	0.13

Swan Lake (9/5/08): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	100.00	100.00	93.75	100.00	100.00	90.00	100.00	100.00	ND	100.00	90.00
		Weighted Prevalence	2.53	2.63	2.67	3.03	3.11	3.00	2.77	2.80	ND	2.94	2.60
		Oyster Meat Index (Average 10 Market Oysters)	ND	15.61	ND	15.79	16.53	15.24	11.93	10.88	ND	ND	13.20
	Spat	No. Spat/Shell	0.00	0.56	0.47	1.47	1.00	2.18	0.76	1.41	ND	ND	3.14
		Prevalence (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	15.00
		Weighted Prevalence	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.13
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	2.26	2.57	3.03	4.30	4.07	2.98	2.90	3.78	2.17	4.12	ND
		Cyanobacteria	0.75	4.78	1.73	1.55	2.15	2.97	2.62	2.01	3.10	1.41	ND
		Green Algae	0.28	1.75	0.42	0.36	0.63	0.64	0.39	0.74	1.04	0.46	ND
		Euglenoids	0.55	2.66	0.98	0.82	2.24	1.43	1.15	2.94	1.61	0.65	ND
		Cryptophytes	0.27	0.27	0.39	0.33	0.64	0.28	0.31	0.70	0.22	0.32	ND
		Red Algae	0.15	0.56	0.11	0.13	0.16	0.15	0.17	0.11	0.22	0.20	ND

Swan Lake (3/16/09): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	24.94	23.10	20.10	17.00	17.50	24.70	24.79	24.87	ND	17.30	27
		Temperature (°C)	15.68	21.90	22.90	25.10	24.00	14.50	13.84	13.95	ND	21.80	23
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	75.00	90.00	81.81	100.00	85.71	90.00	90.00	80.00	ND	90.00	
		Weighted Prevalence	1.39	1.43	1.36	1.34	1.57	1.70	1.24	2.07	ND	1.70	
		Oyster Meat Index (Average 10 Market Oysters)	12.32	10.82	10.62	12.59	13.11	13.44	11.35	12.45	ND	9.63	12.15
	Spat	No. Spat/Shell	ND	1.62	0.50	1.96	1.18	2.80	ND	1.17	ND	ND	
		Prevalence (%)	ND	80.00	27.30	58.82	40.00	31.60	ND	25.00	ND	ND	
		Weighted Prevalence	ND	1.60	0.48	1.32	0.43	0.35	ND	0.13	ND	ND	
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	4.07	1.47	0.65	2.42	1.19	1.86	3.05	1.43	0.83	0.65	2.41
		Cyanobacteria	0.20	0.00	0.02	0.03	0.00	0.07	0.00	0.00	0.03	0.00	0.00
		Green Algae	0.60	0.20	0.03	0.33	0.20	0.17	0.39	0.18	0.05	0.04	0.62
		Euglenoids	0.69	0.74	0.24	0.84	0.24	0.45	0.48	0.37	0.15	0.15	1.06
		Cryptophytes	0.58	0.49	0.12	0.49	0.18	0.53	0.36	0.29	0.19	0.13	0.20
		Red Alae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Swan Lake (5/18/09): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6a	6b	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	ND	23.1	20.1	17.0	17.5	ND	Same	ND	ND	19.1	17.3	ND
		Temperature (°C)	ND	21.9	22.9	25.1	23.9	ND	Same	ND	ND	23.4	21.8	ND
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	80.00	100.00	80.00	80.00	80.00	90.00	N/A	100.00	90.00	ND	90.00	ND
		Weighted Prevalence	1.70	2.57	1.50	1.76	1.57	1.60	N/A	2.07	2.46	ND	1.54	ND
		Oyster Meat Index (Average 10 Market Oysters)	13.98	11.92	11.43	15.22	14.01	13.59	N/A	13.35	12.45	ND	12.90	11.84
	Spat	No. Spat/Shell	ND	1.20	0.64	0.86	1.56	2.35	1.33	ND	1.47	ND	ND	0.07
		Prevalence (%)	ND	77.77	30.00	30.00	40.00	90.00	0.00	ND	20.00	ND	ND	ND
		Weighted Prevalence	ND	1.78	0.47	0.53	0.73	2.27	0.00	ND	0.01	ND	ND	ND
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	17.62	7.36	11.01	10.28	11.73	22.01	ND	5.12	6.28	16.45	4.97	6.49
		Cyanobacteria	1.65	1.33	1.26	1.09	1.87	2.70	ND	0.45	0.62	1.26	0.58	0.56
		Green Algae	0.62	0.37	0.37	0.39	1.12	1.54	ND	1.01	0.73	1.28	0.72	0.40
		Euglenoids	1.84	1.57	1.64	1.62	1.69	2.99	ND	0.84	0.87	1.85	0.60	0.73
		Cryptophytes	0.92	0.92	0.75	0.79	0.83	1.59	ND	0.59	0.57	1.29	0.46	0.46
		Red Alae	0.00	0.08	0.00	0.00	0.00	0.00	ND	0.00	0.00	0.00	0.00	0.00

Swan Lake (7/20/09): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	32.8	34.0	34.2	29.5	33.4	33.4	33.0	32.8	ND	33.4	39.0
		Temperature (°C)	28.8	28.5	28.6	33.1	29.6	28.4	28.9	29.0	ND	28.0	33.0
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	90.00	90.00	90.00	90.00	90.00	70.00	100.00	10.00	ND	90.00	80.00
		Weighted Prevalence	2.83	2.57	1.87	2.07	1.97	1.37	3.23	2.43	ND	2.20	1.80
		Oyster Meat Index (Average 10 Market Oysters)	12.28	11.70	10.73	12.76	11.97	9.43	10.85	11.57	ND	10.71	10.27
	Spat	No. Spat/Shell	5.73	0.33	1.60	7.47	1.23	3.00	3.29	4.17	ND	1.37	0.10
		Prevalence (%)	5.55	ND	0.00	11.11	ND	0.00	0.00	5.00	ND	0.00	ND
		Weighted Prevalence	0.04	ND	0.00	0.13	ND	0.00	0.00	0.02	ND	0.00	ND
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	3.29	4.50	3.01	4.33	4.69	4.45	4.61	2.77	6.03	2.82	4.40
		Cyanobacteria	0.81	1.18	0.55	1.13	0.76	0.67	0.83	0.67	0.89	0.58	4.17
		Green Algae	0.35	0.82	0.53	0.50	0.47	0.45	0.32	0.23	0.64	0.22	1.42
		Euglenoids	0.83	2.09	1.54	1.58	1.13	0.90	1.32	0.71	2.10	0.35	2.37
		Cryptophytes	0.32	0.40	0.65	0.59	0.37	0.34	0.43	0.24	0.65	0.30	0.56
		Red Algae	0.14	0.33	0.13	0.18	0.09	0.00	0.23	0.13	0.30	0.00	0.09

Swan Lake (11/23/09): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	14.5	16.8	15.7	16.0	15.3	14.8	17.0	17.5	ND	14.7	11.0
		Temperature (°C)	17.4	19.2	17.5	18.0	18.3	17.2	16.2	16.1	ND	17.0	21.0
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	100.00	80.00	100.00	100.00	100.00	100.00	100.00	100.00	ND	100.00	100.00
		Weighted Prevalence	1.97	1.44	1.90	2.07	1.84	1.90	2.13	1.80	ND	1.96	1.37
		Oyster Meat Index (Average 10 Market Oysters)	15.79	17.11	13.72	13.20	14.32	26.10	10.12	10.90	ND	12.38	13.20
	Spat	No. Spat/Shell	6.8	0.5	1.5	4.4	2.7	4.5	2.8	4.9	ND	3.1	1.7
		Prevalence (%)	30.00	30.77	25.00	35.00	30.00	10.00	13.33	23.30	ND	40.72	5.00
		Weighted Prevalence	0.60	0.67	0.63	0.33	0.42	0.22	0.02	0.23	ND	0.41	0.02
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	2.85	3.87	1.44	2.24	1.36	2.71	2.05	1.02	3.93	2.25	4.94
		Cyanobacteria	0.39	0.21	0.05	0.17	0.12	0.38	0.32	0.11	0.16	0.26	0.26
		Green Algae	0.26	0.46	0.18	0.20	0.18	0.23	0.18	0.12	0.30	0.24	0.39
		Euglenoids	0.48	0.33	0.32	0.40	0.39	0.39	0.46	0.28	0.40	0.43	0.63
		Cryptophytes	0.55	1.67	0.60	0.68	0.61	0.39	0.32	0.25	0.83	0.44	0.69
		Red Algae	0.08	0.08	0.00	0.05	0.02	0.05	0.04	0.01	0.06	0.07	0.11

Swan Lake (2/15/10): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	22.4	19.7	16	20.6	18.4	20.9	20.5	18.6	18.5	20.7	12.0
		Temperature (°C)	12.7	13	14.1	13.8	15.6	12.7	13.6	12.2	12.9	12.3	18.0
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	ND	60.00	50.00	70.00	90.00	ND	50.00	ND	ND	90.00	60.00
		Weighted Prevalence	ND	0.90	0.40	0.47	0.73	ND	0.60	ND	ND	0.67	0.40
		Oyster Meat Index (Average 10 Market Oysters)	ND	11.73	13.48	15.91	13.84	ND	11.41	ND	ND	12.18	13.03
	Spat	No. Spat/Shell	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Prevalence (%)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Weighted Prevalence	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	3.80	0.83	0.73	0.91	0.86	1.22	1.20	0.53	1.14	0.50	3.41
		Cyanobacteria	0.05	0.03	0.08	0.03	0.00	0.04	0.04	0.10	0.04	0.00	0.05
		Green Algae	0.32	0.16	0.16	0.09	0.18	0.11	0.10	0.05	0.13	0.07	0.23
		Euglenoids	0.30	0.36	0.31	0.28	0.20	0.27	0.28	0.19	0.54	0.11	0.31
		Cryptophytes	1.02	0.37	0.41	0.14	0.09	0.16	0.19	0.10	0.34	0.07	0.27
		Red Algae	0.11	0.05	0.06	0.03	0.07	0.02	0.05	0.00	0.07	0.05	0.14

Swan Lake (5/14/10): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4	5	6	7	8	9	10	SPR
	Physical Conditions	Salinity (%)	20.8	18.9	18.9	19.9	19.4	24.3	24.3	24.6	ND	24.6	25.0
		Temperature (°C)	27.1	26.7	26.8	29.0	27.7	26.8	27.4	25.7	ND	26.2	26.0
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	70.00	90.00	70.00	80.00	90.00	90.00	90.00	60.00	ND	80.00	90.00
		Weighted Prevalence	1.23	1.67	1.13	1.43	1.44	2.04	1.63	0.93	ND	1.20	1.27
		Oyster Meat Index (Average 10 Market Oysters)	13.49	13.12	10.32	13.94	13.65	13.32	11.94	13.47	ND	11.92	12.92
	Spat	No. Spat/Shell	ND	0.4	ND	2.4	3.3	3.1	ND	2.9	ND	1.4	0.2
		Prevalence (%)	ND	25.00	ND	30.00	50.00	5.00	ND	20.00	ND	9.09	40.00
		Weighted Prevalence	ND	0.50	ND	0.38	0.68	0.12	ND	0.08	ND	0.03	0.40
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	3.68	7.72	7.25	6.02	3.33	11.47	6.87	6.29	6.16	7.75	7.44
		Cyanobacteria	0.86	1.55	1.35	2.05	1.50	0.55	0.59	0.41	2.10	0.61	0.74
		Green Algae	0.38	0.56	0.81	0.52	0.43	0.78	0.60	0.74	0.41	0.84	0.78
		Euglenoids	0.40	1.60	1.55	0.97	1.15	0.42	1.05	0.77	1.01	0.92	1.21
		Cryptophytes	0.24	1.18	0.91	0.48	0.58	0.31	0.27	0.24	0.42	0.35	0.27
		Red Algae	0.34	0.16	0.25	0.21	0.16	0.59	0.42	0.60	0.09	0.64	0.35

Swan Lake (7/23/10): "Dermo" (*Perkinsus marinus*) Infections, Meat Index of Oysters and Phytoplankton Data

		Station Number	1	2	3	4a	4b	5a	5b	6	7	8	9	10	SPR
	Physical Conditions	Salinity (‰)	20.9	20.3	21.0	21.5	21.5	21.2	21.2	22.3	22.2	22.2	ND	22.2	21.0
		Temperature (°C)	30.7	30.6	30.9	30.3	30.3	30.0	30.0	30.0	28.6	29.2	ND	29.5	33.0
Dermo/ Oyster Data	Market Sized Oysters	Prevalence (%)	80.00	55.55	90.00	70.00	70.00	100.00	100.00	60.00	90.00	50.00	ND	80.00	80.00
		Weighted Prevalence	1.40	0.70	1.33	1.17	1.17	1.47	1.47	1.10	1.74	1.30	ND	1.47	1.27
		Oyster Meat Index (Average 10 Market Oysters)	11.89	12.01	9.45	12.73	12.73	11.17	11.17	9.92	9.82	11.52	ND	10.60	10.74
	Spat	No. Spat/Shell	2.8	0.8	0.9	5.0	4.6	2.4	1.8	ND	ND	ND	ND	4.2	ND
		Prevalence (%)	0.00	20.00	0.00	95.00	0	60.00	5.00	ND	ND	ND	ND	45.00	ND
		Weighted Prevalence	0.00	0.01	0.00	2.35	0.00	1.18	0.02	ND	ND	ND	ND	0.50	ND
Phyto-plankton Data	Algal Group Abundance (µg Chl a per liter)	Brown Algae	3.80	5.27	8.68	2.95	ND	4.98	ND	1.92	4.58	2.27	6.23	1.72	5.32
		Cyano-bacteria	2.90	8.57	4.47	2.39	ND	3.67	ND	2.14	1.97	1.86	4.31	1.73	2.68
		Green Algae	0.54	1.32	0.99	0.16	ND	0.26	ND	0.18	0.22	0.24	0.51	0.14	0.54
		Euglenoids	1.33	2.57	2.48	1.30	ND	1.62	ND	0.97	1.16	0.94	2.08	0.82	1.71
		Crypto-phytes	0.16	0.44	0.52	0.28	ND	0.28	ND	0.13	0.20	0.13	0.37	0.11	0.38
		Red Algae	0.35	0.59	0.60	0.13	ND	0.21	ND	0.11	0.29	0.30	0.31	0.20	0.28