Oyster monitoring in the northern estuaries on the Southeast coast of Florida

2009 Annual Report

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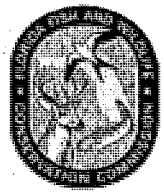

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Executive Summary

In this report we present the 2009 observations by the Molluscan Fisheries research group at the Florida Fish and Wildlife Research Institute (FWRI) on oysters in southeast Florida. The main objective of this project is to continue a long-term monitoring program intended to document the response of oysters, *Crassostrea virginica*, in south Florida to CERP activities. FWRI monitored changes in oyster ecology at six sites in three estuaries in southeast Florida: the St. Lucie estuary (3 sites), the Loxahatchee River (2 sites) and Lake Worth Lagoon (1 site). Four aspects of oyster ecology were monitored: spatial and size distribution patterns of adult oysters, distribution and frequency patterns of the oyster diseases *Perkinsus marinus* (dermo) and *Haplosporidium nelsoni* (MSX), reproduction and recruitment, and juvenile oyster growth. Water quality parameters including salinity, temperature and turbidity were also monitored at each study site.

At most study sites, salinities were consistently high throughout the first four or five months of the year, but decreased rapidly in either May or June. In St. Lucie estuary (SLE), salinities were variable throughout the summer reaching lowest levels (<5 ppt) in August after which they began steadily increasing reaching the optimal range (15-20 ppt) for oyster survival and recruitment success at most stations by October. At the Loxahatchee-North site, salinities also reached lows in August but remained closer to optimal levels throughout the rest of the year. Salinities in Loxahatchee-South were higher and less variable, rarely falling below 20 ppt, with values at most stations near 30 ppt for most of the year. In Lake Worth Lagoon (LWL), salinities were greater than 30 ppt from January through April then decreased rapidly in May where they remained near the optimal range through September before increasing to more 30 ppt by the end of the year.

Oysters were recovering from a fall 2008 die-off at most SLE stations during 2009, but the increase in densities was more pronounced in the central estuary site. Oyster densities at the Loxahatchee-North site were high and increased from spring to fall 2008 while densities in the Loxahatchee-South and LWL sites were moderate and consistent between seasons. Presence of the dermo (*Perkinsus marinus*) parasite was sporadic and rare in SLE but more consistent in LOX and LWL sites. However, infection levels were low throughout the year in oysters sampled from all sites. Reproductive development and physiological condition was highest during the spring and summer months in oysters collected from the

SLE and LWL while oysters from LOX had greatest condition values in early winter months of the year. Both LOX and LWL had bimodal recruitment peaks in spring and fall with continuous recruitment occurring throughout months in between. In contrast, SLE oysters only had a fall recruitment peak. Juvenile growth rates were high in all three SLE sites but only moderate in the LOX and LWL sites which may have been biased by continual recruitment of small oysters to those populations.

Introduction

The Comprehensive Everglades Restoration Program (CERP) has been implemented as a means of reinitiating, to the greatest degree possible, natural freshwater flow to coastal waters on both coasts of south Florida. The Monitoring and Assessment Program (MAP) component of CERP is designed to provide a diverse approach to documenting and describing the impacts of changed freshwater flow to the flora and fauna inhabiting inland landscapes and coastal waters. Because of their wide distribution, historical context, and essential habitat value, the eastern oyster (*Crassostrea virginica*) is included as a target species for monitoring. Oyster beds provide important habitat for numerous organisms and are indicators of a healthy estuary. Changes in the spatial extent and health of oyster beds in southeast Florida estuaries are key performance measures that will help assess the success of CERP.

The eastern oyster occupies estuarine and nearshore habitats throughout the eastern and Gulf of Mexico coasts of the United States. This animal supported a subsistence fishery even before European colonization of the United States (MacKenzie et al., 1997), and throughout recent history has provided an important economic and cultural resource to coastal inhabitants. In addition to its direct economic benefits, the oyster also provides essential habitat for many other estuarine inhabitants (Bahr and Lanier, 1981). The eastern oyster is one of the most culturally, economically, and ecologically important residents of U.S. coastal waters.

In Florida, oysters occur along both the Atlantic and Gulf of Mexico coasts in almost all estuarine and nearshore waters. Along the Atlantic coast, oysters are generally confined within bays and lagoons such as Lake Worth Lagoon or the Indian River. Those areas are expected to experience changes in water quality, quantities and timing due to the implementation of the C-44 and Indian River Lagoon – South CERP components. Those waters, and other coastal waters on the southeast coast of the state, have experienced altered patterns of water delivery and quality as a result of water management practices related to the St. John's River and Kissimmee River basins, Lake Okeechobee, and the Everglades. In particular, the redirection of freshwater out of those inland basins and into the coastal waters mentioned above has altered both the timing and the range of salinity variation in those coastal waters. Alterations in freshwater flow have reduced or eliminated many oyster reef areas and have impacted both the timing and extent of oyster reproduction (Berrigan et al., 1991). The diverse community associated with the oyster reefs has

been impacted to an equivalent or greater degree. Monitoring in the St. Lucie estuary, the Loxahatchee River, and Lake Worth Lagoon began in 2005and was intended to establish pre-restoration conditions and to assess and evaluate any changes related to the implementation of the previously mentioned restoration components.

The main objective of this project is to continue a long-term monitoring program intended to document the response of oysters, *Crassostrea virginica*, in south Florida to CERP activities. The Molluscan Fisheries research group at the Florida Fish and Wildlife Research Institute (FWRI) in conjunction with Dr. Aswani Volety at Florida Gulf Coast University (FGCU) monitored changes in oyster distribution and abundance at a variety of sites on the Atlantic and Gulf of Mexico coasts of south Florida. Six sites in three estuaries in southeast Florida were monitored by FWRI (Figure 1): the St. Lucie estuary (3 sites), the Loxahatchee River (2 sites) and Lake Worth Lagoon (1 site). The data collected by FWRI and FGCU use methods that, to the greatest degree possible, ensure the resultant data from these contemporaneous projects are statistically and conceptually comparable. Four aspects of oyster ecology are monitored: spatial and size distribution patterns of adult oysters, distribution and frequency patterns of the oyster diseases *Perkinsus marinus* (dermo) and *Haplosporidium nelsoni* (MSX), reproduction and recruitment, and juvenile oyster growth. In this report we present the 2009 observations by FWRI on oysters in southeast Florida.

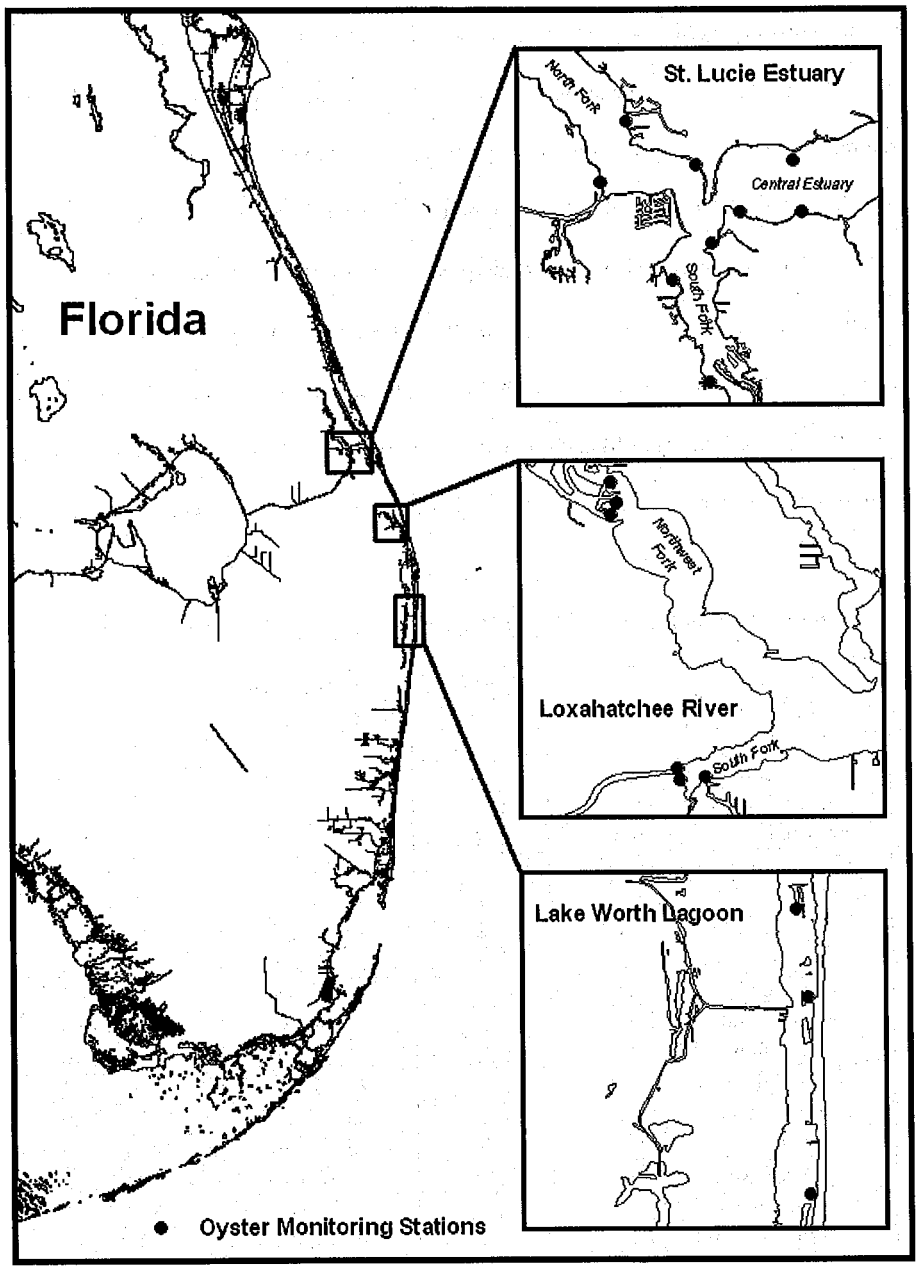

Figure 1. CERP oyster monitoring study sites and stations on the east coast of Florida.

Methods

Study Sites

Oyster sampling occurred on oyster reefs within three estuarine ecosystems on the southeast coast of Florida that included the St. Lucie estuary, the Loxahatchee River, and Lake Worth Lagoon. Within the St. Lucie estuary, we considered the north fork, the south fork, and the central estuary to be separate sites and we sampled three oyster reefs (= stations), or three potential oyster reef locations if no oysters were present, within each of those sites. Similarly, in the Loxahatchee River, we considered the south fork and the northwest fork to be separate sites and we sampled three oyster reefs within each of those sites. Three oyster reefs were also selected as study stations within Lake Worth Lagoon. This strategy resulted in a total of six separate study sites (St. Lucie-North, St. Lucie-Central, St. Lucie-South, Loxahatchee-North, Loxahatchee-South, and Lake Worth) each with three stations (i.e., oyster reefs) that were monitored. Station locations can be seen in Figure 1, and coordinates for each sampling reef are provided in Table 1.

Table 1. Station locations for CERP oyster monitoring sites in southeast Florida.

Site	Station	Latitude °N	Longitude °W
St. Lucie North Fork	1	27 13.232	80 16.737
St. Lucie North Fork	2	27 12.686	80 15.846
St. Lucie North Fork	3	27 12.459	80 17.072
St. Lucie Central Estuary	1	27 12.743	80 14.599
St. Lucie Central Estuary	2	27 12.087	80 14.493
St. Lucie Central Estuary	3	27 12.096	80 15.282
St. Lucie South Fork	1	27 11.691	80 15.636
St. Lucie South Fork	2	27 11.228	80 16.149
St. Lucie South Fork	3	27 09.949	80 15.671
Loxahatchee NW Fork	1	26 58.164	80 07.688
Loxahatchee NW Fork	2	26 58.237	80 07.649
Loxahatchee NW Fork	3	26 58.370	80 07.686
Loxahatchee SW Fork	1	26 56.574	80 07.112
Loxahatchee SW Fork	2	26 56.630	80 07.280
Loxahatchee SW Fork	3	26 56.560	80 07.257
Lake Worth Lagoon	1	26 40.181	80 02.618
Lake Worth Lagoon	2	26 38.848	80 02.436
Lake Worth Lagoon	3	26 35.851	80 02.417

Adult Sampling

Adult sampling was conducted in the late spring and fall of 2009. On each sampled reef, we haphazardly deployed fifteen replicate 1/4-m^2 quadrats and harvested all oysters within each quadrat for

determination of the number of live and dead oysters with articulated shells. A maximum of 10 live oyster shell heights (SH = maximum linear distance from the umbo to the ventral shell margin) were also measured from each quadrat.

Mean densities of live and dead oysters, as well as mean live oyster SHs, were calculated for each station within each site. Statistical comparisons between surveys and among stations were performed using the GLIMMIX procedure for mixed models in the SAS 9.2 software package (Littell et al., 2006). In order to find the most appropriate model, several different distributions were applied, including the normal, negative binomial, Poisson, and gamma distributions, and the model with the best fit was chosen for each individual site. In all cases, either the negative binomial or the gamma distributions comprised the best fit models.

Reproductive and Disease Monitoring

Oysters were collected for analysis of physiological condition, gonadal development state, and for the prevalence and intensity of the oyster diseases *Perkinsus marinus* (dermo) and *Haplosporidium nelsoni* (MSX) on a monthly basis whenever present. A sample of ten oysters from each of the three reefs within a study site (total N = ten oysters * three reefs * six sites = 180 per month if live oysters were available at all stations) were transported, live and chilled, to the FWRI laboratory for processing. Each individual oyster was measured (SH mm), shucked, and the tissues processed for reproductive stage, disease status and physiological condition according to the methods described below.

For condition analysis, five of the oysters collected from each station within a site were processed by thoroughly cleaning each individual, measuring the shell height, weighing the whole animal, and then shucking each oyster to obtain the tissue wet weight. The shells and tissues were dried for 48 hours and then the shell and tissue dry weights were recorded. Oyster condition index was calculated as the ratio of tissue dry weight to shell dry weight. Mean condition index and SH were calculated for each station within each site. The remaining five animals collected from each station were processed for reproductive and disease analysis.

For *Perkinsus marinus* (dermo) disease analysis, prevalence and intensity were diagnosed with Ray's fluid thioglycollate method (RFTM) as described by Bushek et al. (1994). Small (1 cm^2) pieces of

gill and mantle tissue were incubated in RFTM media with antibiotics for seven days in the dark at 25°C. Tissue pieces were then placed onto glass microscope slides, macerated with razor blades, stained with Lugol's, and examined at 400x for the presence of hypnospores. Parasite density (infection intensity) was ranked using the Mackin scale, which ranges from 0 to 5 (Table 2). Average parasite densities were calculated for each individual sample and from those values mean dermo infection intensity and prevalence were calculated for each station within each site.

Table 2. Mackin scale showing different stages of *Perkinsus marinus* (dermo) infection intensity.

Stage	Category	Cell Number	Notes
0	Uninfected	No cells detected	
0.5	Very light	<10 cells in entire preparation	
1	Light	11-100 cells in entire preparation	Cells scattered or in localized clusters of 10-15 cells
2	Light-moderate		Cells distributed in local concentrations of 24-50 cells; or uniformly distributed so that 2-3 cells occur in each field at 100X
3	Moderate	3 cells in all fields at 100X	Masses of 50 cells may occur
4	Moderate heavy	Cells present in high numbers in all tissues	Less than half of tissue appears blue-black macroscopically
5	Heavy	Cells in enormous numbers	Most tissue appears blue-black macroscopically

For reproductive and MSX disease analyses, the remaining oyster tissue was preserved in Dietrich's fixative solution (Barber, 1996). Following 20 hours of fixation, the oyster tissues were thoroughly rinsed in tap water and preserved in 70% ethanol for subsequent histological preparation. Histological preparation consisted of dehydrating each oyster in 95% ethanol for a minimum of three hours, then embedding the tissue in paraffin. Depending upon the size of the individual oyster, a minimum of one to a maximum of six 3.5-µm sections were cut from each embedded sample using a microtome mounted with a glass knife, maintaining a minimum separation of 60 µm (the approximate maximum diameter of an oocyte) between sections. The sections were stained with hematoxylin and eosin, and then mounted onto pre-labeled glass slides for analysis. Resultant slides were examined at 200-400x on a compound microscope and each sample was assigned to a reproductive stage following the classification scheme (Table 3) modified from the work of Fisher et al. (1996). Finished slides were also examined at 100x for the presence of MSX parasites.

Table 3. Qualitative reproductive staging criteria for oysters collected from Florida waters.

Value	Observations
0	Neuter or resting stage with no visible signs of gametes
1	Gametogenesis has begun with no mature gametes
2	First appearance of mature gametes to approximately one-third mature gametes in follicles
3	Follicles have approximately equal proportions of mature and developing gametes
4	Gametogenesis progressing, but follicles dominated by mature gametes
5	Follicles distended and filled with ripe gametes, limited gametogenesis, ova compacted into polygonal configurations, and sperm have visible tails
6	Active emission (spawning) occurring; general reduction in sperm density or morphological rounding of ova
7	Follicles one-half depleted of mature gametes
8	Gonadal area is reduced, follicles two-thirds depleted of mature gametes
9	Only residual gametes remain, some cytolysis evident
10	Gonads completely devoid of gametes, and cytolysis is ongoing

For graphical presentation, the 11 reproductive stages were simplified by combining them into 4 different categories. The indifferent category includes those oysters that have no visible gametes and are in the neuter or resting stage (stages 0 and 10). The developing category includes those oysters that are undergoing gametogenesis but show no evidence of recent spawning (stages 1-4). The ripe category includes those oysters that have follicles filled with ripe gametes and have either begun to or are nearly ready to spawn (stages 5 and 6). Finally, the spent/recycling category includes those oysters that have follicles containing both mature and immature gametes, and an apparent reduction in gonadal area (stages 7-9).

Spat Recruitment

Juvenile oyster recruitment was monitored at each of the reefs within each study site. Three replicate spat monitoring arrays were deployed and retrieved at each station on a monthly schedule. Each array consisted of 12 axenic adult oyster shells (5 -10 cm SH) strung onto two separate lengths of galvanized wire. The shells were oriented with their inner surface facing downward when suspended off the bottom, and spat recruitment was estimated by counting the number of settled spat on the underside of the strung shells.

Mean numbers of spat per shell per month were calculated for each station within each site. Statistical comparisons among stations were performed using the GLIMMIX procedure for mixed models in the SAS 9.2 software package (Littell et al., 2006). In order to find the most appropriate model, several different distributions were applied, including the normal, negative binomial, Poisson, and gamma distributions, and the model with the best fit was chosen for each individual site. In all cases, either the gamma or the poisson distributions comprised the best fit models.

Juvenile Growth Monitoring

Juvenile growth monitoring was initiated at each study site in March 2009. Growth arrays were constructed of 12.7-mm-mesh plastic-coated wire mesh with dimensions of approximately 0.6-m L x 0.6-m W. On each of these growth arrays, 25 adult, axenic oyster shells were attached by fishing line to serve as settlement substrate for wild oyster spat. Sampling involved measuring the shell heights of 30 haphazardly selected live oyster juveniles (or all live oysters if <30). This monitoring was conducted in concurrence with the monthly recruitment sampling at all sites. Monitoring of juvenile oyster growth continued until March 2010 at all sites. Mean SHs of juvenile oysters were calculated for each station within each site.

Water Quality Monitoring

Monthly water quality sampling was conducted in conjunction with field sampling at all stations within each study site. Recorded parameters included water depth, temperature, salinity, turbidity, pH, and dissolved oxygen concentration. Chlorophyll *a* concentrations were measured from January through May 2009, after which it was determined that the cost of maintaining the chlorophyll probe exceeded the value of the data. Water depth was determined with a sounding line and turbidity was obtained using a standard Secchi disk. All other parameters were measured with a YSI instrument. Graphical presentations show the values measured at each station within each site.

Results

St. Lucie Estuary

Adult Sampling

Results from the spring and fall 2009 oyster surveys in the St. Lucie estuary (SLE) indicate a slow but steady population recovery following the low salinity event in fall 2008. Mean live oyster densities increased at all sites between fall 2008 and spring 2009, with the greatest increase occurring in St. Lucie-Central where mean densities increased from less than $10m^{-2}$ to over 300 m^{-2}. Live densities were fairly consistent between spring and fall 2009 surveys, with the only exception being a small, but significant increase in the fall at the St. Lucie-North study site (P=0.0255; Figure 2). Mean shell heights of oysters also increased during each subsequent survey. In fall 2008, those oysters that survived the low salinity event had mean shell heights ranging from 5 to 15 mm (these oysters were only present in the central estuary site). In spring 2009, mean shell heights had increased to the 30 mm range at most sites, followed by a significant increase to the 50 mm range in fall 2009 (P<0.0001 in all 3 sites; Figure 3). This suggests that juvenile oysters that recruited to SLE oyster reefs after the 2008 mortality survived and grew throughout 2009. Numbers of dead oysters also significantly decreased from spring to fall 2009 (P<0.002 in all 3 sites), further indicating that oysters were recovering (Figure 2).

Statistical comparisons among stations revealed that there were significant differences in numbers of live and dead oysters, as well as in live oyster shell heights among stations. In St. Lucie-North, significantly higher live densities were found at station 2 (P=0.0361) while the highest dead oyster densities were found at station 1 (P<0.0001). No significant differences in oyster sizes were found among stations in the north fork site. Station 1 in both the south fork and central estuary sites had significantly higher numbers of live and dead oysters (P<0.0009). In St. Lucie-Central, station 1 also boasted the largest oyster sizes followed by station 2 which was intermediate, and station 3, which was smallest (P<0.0001). In the south fork, station 2 oysters were larger than those at station 1 (P<0.0001). No live oysters were present at station 3 in the south fork.

Disease Monitoring

As a result of the oyster die-off in 2008, live oysters were not available for collection from any station in each of the three SLE sites in January 2009, and from both the north fork and south fork sites through March 2009. In April, oysters were again present in large enough quantities in the north and south fork sites for collection however, they were not available at all stations within each of those sites. In fact, while oysters recovered at all stations in the north fork by May 2009, both stations 2 and 3 in the south fork exhibited much slower recovery, i.e., live oysters were not found at station 2 again until October 2009 and to date we have been unable to find any live oysters at station 3.

Dermo infection was almost absent from oysters collected from all three study sites in 2009 (Figures 4 and 5). Presence of the dermo parasite was intermittent and only occurred during the wet season months at station 3 in the north fork and stations 1 in both the north fork and the central estuary study sites. Even those infection levels were relatively low with mean intensities remaining near or below 1, indicating that sampled oysters were only lightly infected with the parasite. Dermo prevalence in those oysters was also low, with most collections containing 20% or less infected oysters. At this time we have found no evidence of *Haplosporidium nelsoni* (MSX) infection in any of the oysters collected from the SLE.

Physiological Condition and Reproductive Development

Oyster collections did not occur at all sites or stations in SLE during each month of 2009. Analysis of gonadal tissues indicated that most oysters are in various stages of reproductive development including gametogenesis, active spawning and gonadal recycling throughout most of the year (Figure 6). However, oysters classified as developing or ripe/spawning were more prevalent through August. In the fall months, reproductive development began decreasing as more oysters entered the winter resting stage. Changes in physiological condition reflected these reproductive patterns in that peak condition index values occurred in June and July when reproductive development was also highest (Figure 7). This was followed by a substantial decrease in physiological condition which corresponds to the end of spawning season in the fall.

Spat Recruitment

Peak larval oyster recruitment rates occurred in October and/or November at most of the stations (Figure 8). In previous years, recruitment had a bimodal pattern in the SLE sites with peaks in the summer and in the fall. However, because SLE oysters were recovering from a die-off, the 2009 spawning population was most likely comprised of young, newly developing oysters that did not reach reproductive maturity until mid-summer. As a result, there was no summer recruitment peak in 2009. While recruitment rates in the St. Lucie-North and Central sites were higher than those recorded in 2008, rates in the south fork were lower than in 2008 with peaks of <1 spat/shell/month which reflects the slower recovery rate at this study site. Statistical analysis revealed no significant differences in spatfall among the stations in any of the study sites.

Juvenile Growth Monitoring

Juvenile oysters first appeared in all three sites in June, but were not present all stations within the sites until July (Figure 9). Mean shell heights of those oysters increased steadily over the next few months, but decreased substantially at most stations in October. That decrease corresponds with the fall recruitment peak which is reflected in the shell height measurements, i.e., the new recruits were smaller, thus the mean shell height of the oysters on the growth array decreased. However, those newly settled juveniles exhibited a rapid growth rate adding an average of over 5 mm shell height per month at some stations. When the study was completed in March 2010, the juvenile oysters had reached a mean size of approximately 30 mm shell height.

Water Quality Monitoring

Salinity was highly variable in the estuary, ranging from a low of nearly 0 ppt to almost 30 ppt over the year. In the early months of the year, salinities were fairly consistent but slightly higher than the optimal range (15-20 ppt) for oyster survival and recruitment (Figure 10). In June, salinities began decreasing and reached a low point in August after which salinities began increasing. By November, when oyster recruitment was peaking, salinities had reached the optimal range at most stations.

Other water quality parameters exhibited patterns and ranges that were similar to those recorded in 2008. Temperatures at each station in the estuary exhibited a typical seasonal pattern with values ranging from approximately 16°C to 33°C over the year (Figure 11). Dissolved oxygen concentrations and pH measurements in the estuary were as expected ranging from approximately 3mg/L to 12 mg/L and 7.2 to 8.1 respectively (Figures 12 and 13). Chlorophyll *a* concentrations ranged from a minimum of 3 ug/L to a maximum of 16 ug/L (Figure 14). Turbidity in the water column is presented as a Secchi penetration value which is calculated as the percentage of the water column through which the Secchi disk could be seen. Water clarity was high in St. Lucie-Central where Secchi penetration was 100% throughout the year (Figure 15). In St. Lucie-North, turbidity was higher during the summer and fall months. In St. Lucie-South, turbidity was intermittently high at various stations throughout the year, but highest in August. This corresponds with the lowest salinity values of the season, suggesting large freshwater inputs into the estuary at that time.

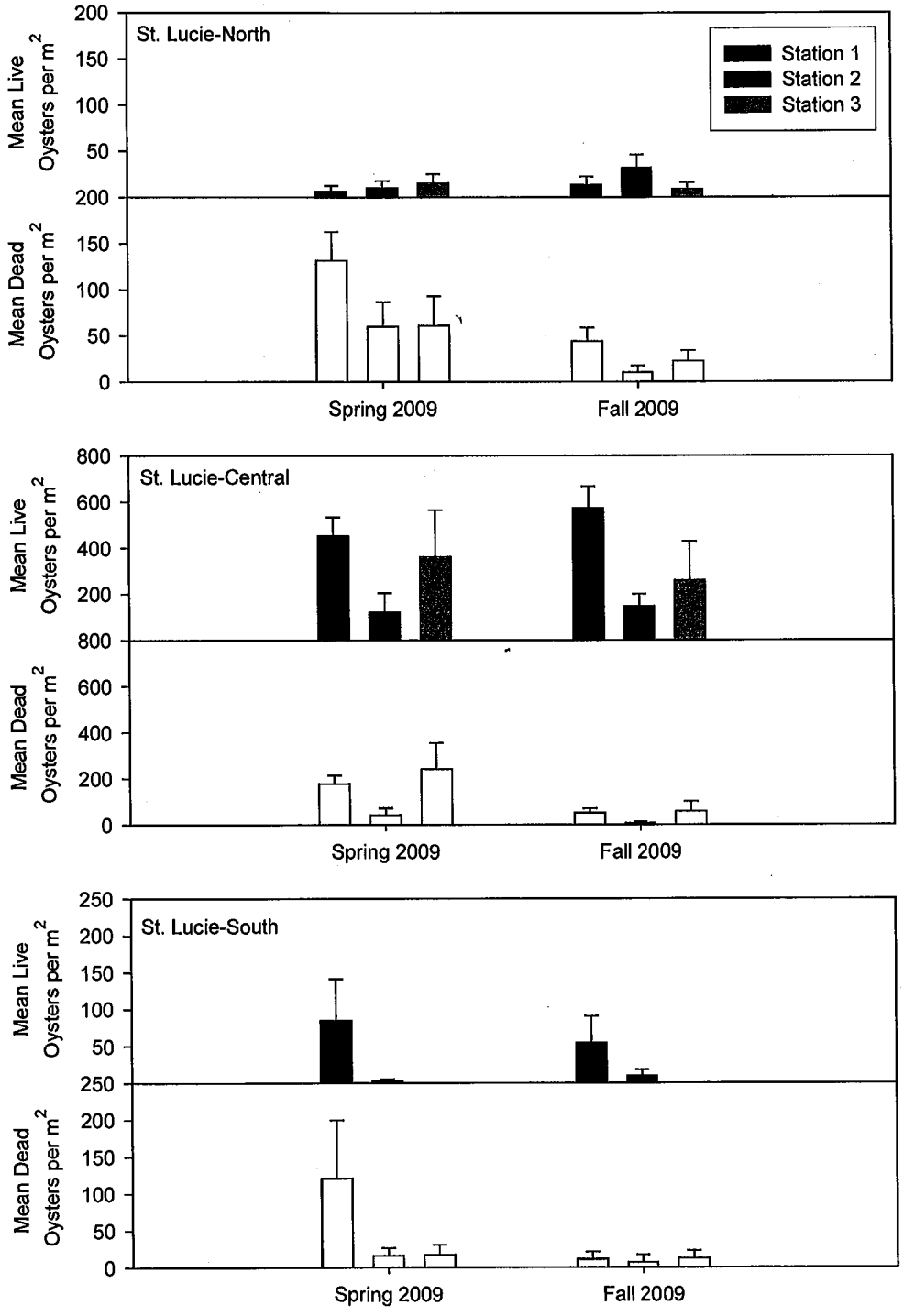

Figure 2. Mean number (± S.D.) of live and dead oysters present at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during the spring and fall 2009 surveys. Filled bars represent the number of live oysters and the hollow bars represent the number of dead oysters with articulated shells. Please note the differences in the y-axis range among the different study sites.

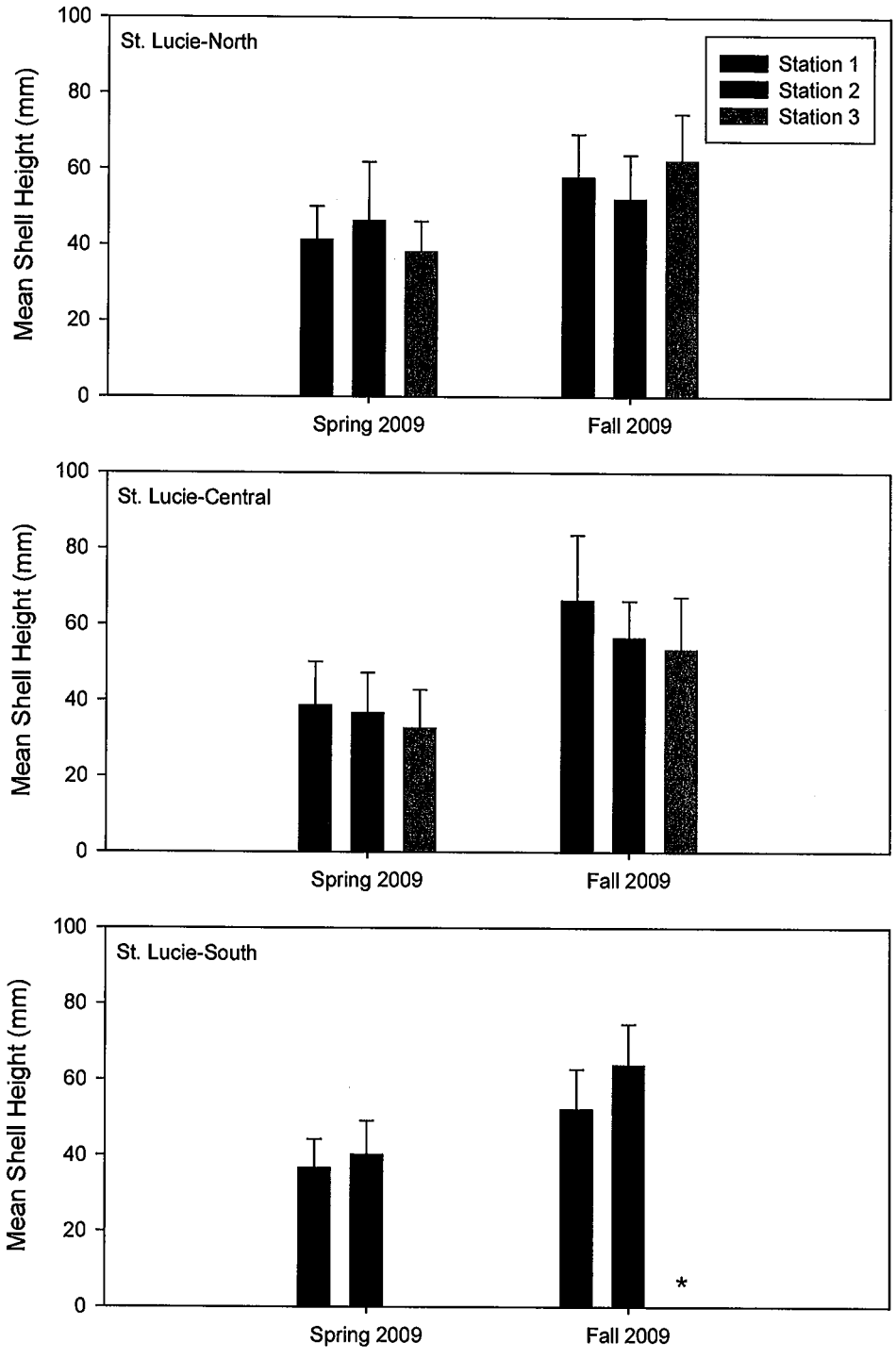

Figure 3. Mean shell height (± S.D.) of live oysters present at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during the spring and fall 2009 surveys. Asterisks denote stations where no live oysters were present for measurement.

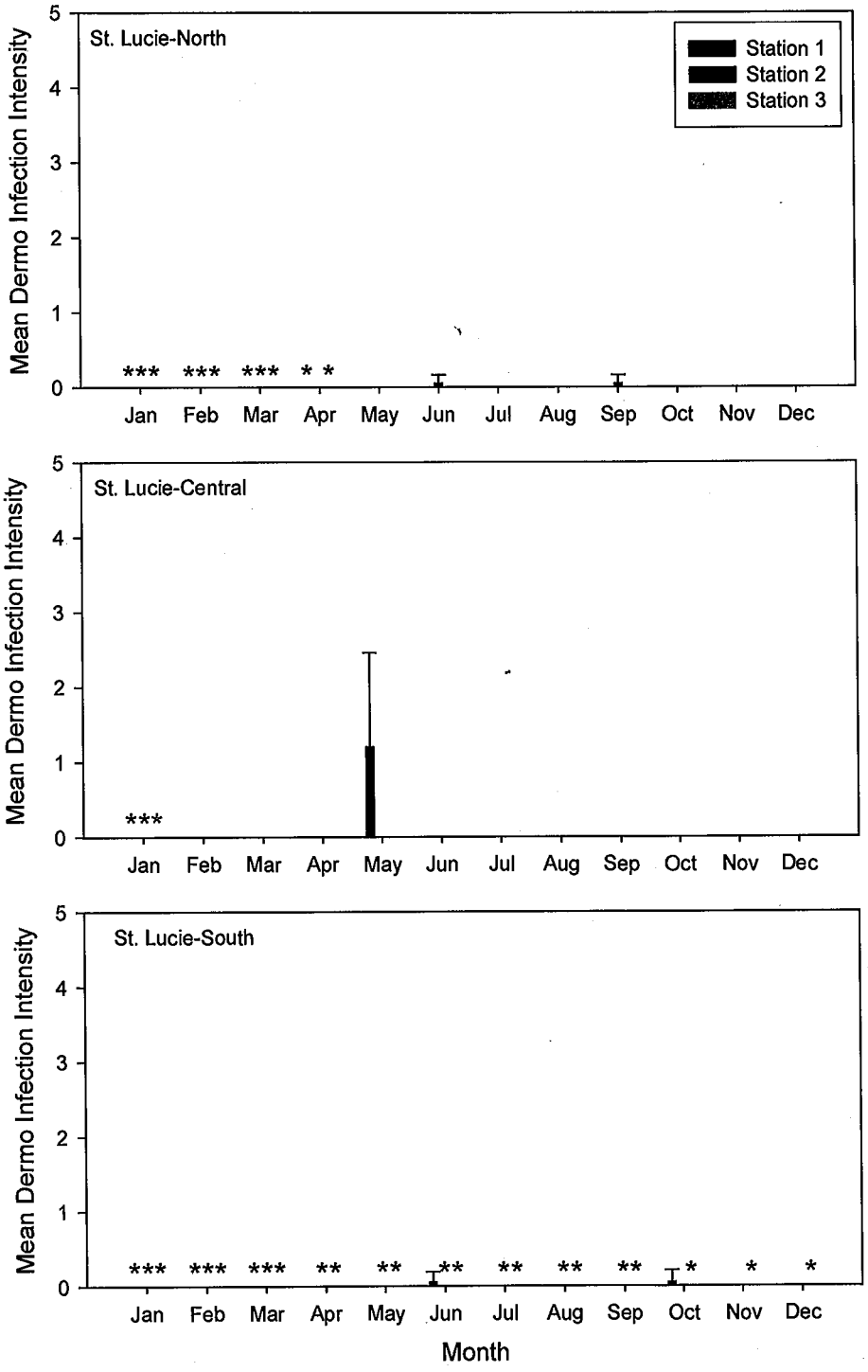

Figure 4. Monthly mean infection intensity (± S.D.) of oysters infected with *Perkinsus marinus* at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009. Asterisks denote stations where no live oysters were present for collection and disease analyses.

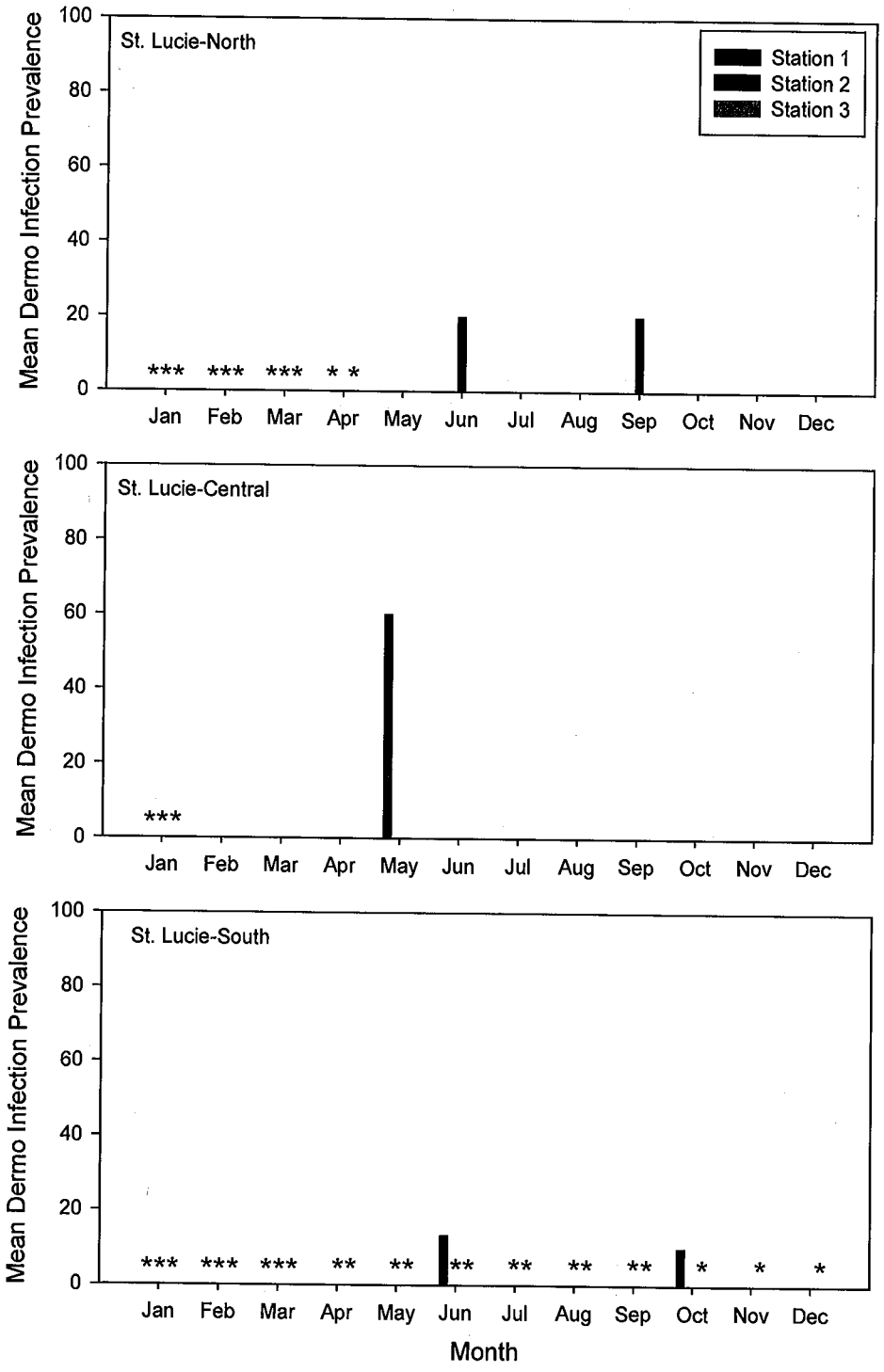

Figure 5. Monthly mean prevalence (%) of oysters infected with *Perkinsus marinus* at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009. Asterisks denote stations where no live oysters were present for collection and disease analyses.

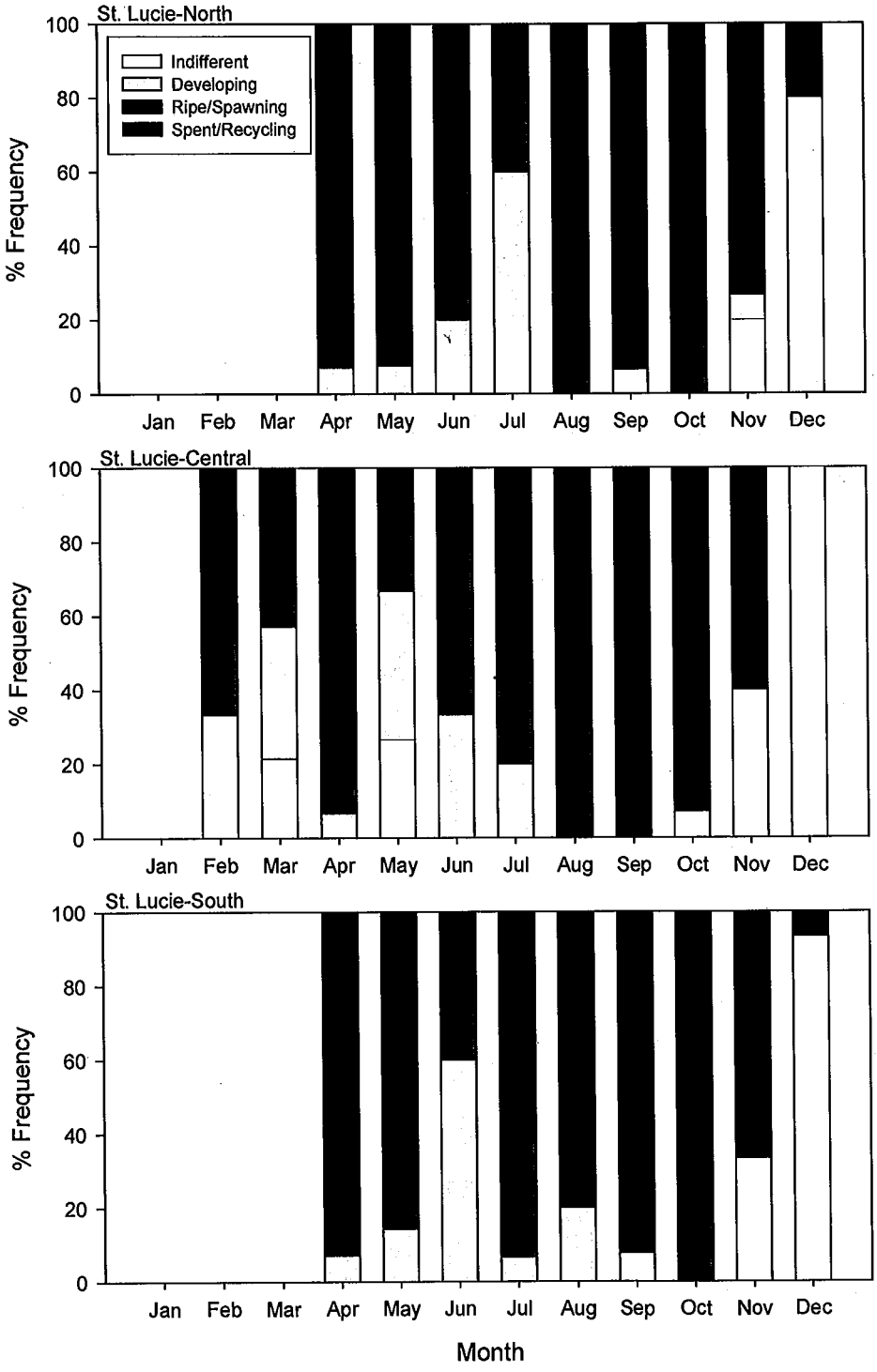

Figure 6. Reproductive development of oysters collected from the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009. Months with no data represent time periods when live oysters were not available for collection from any of the three stations within a site.

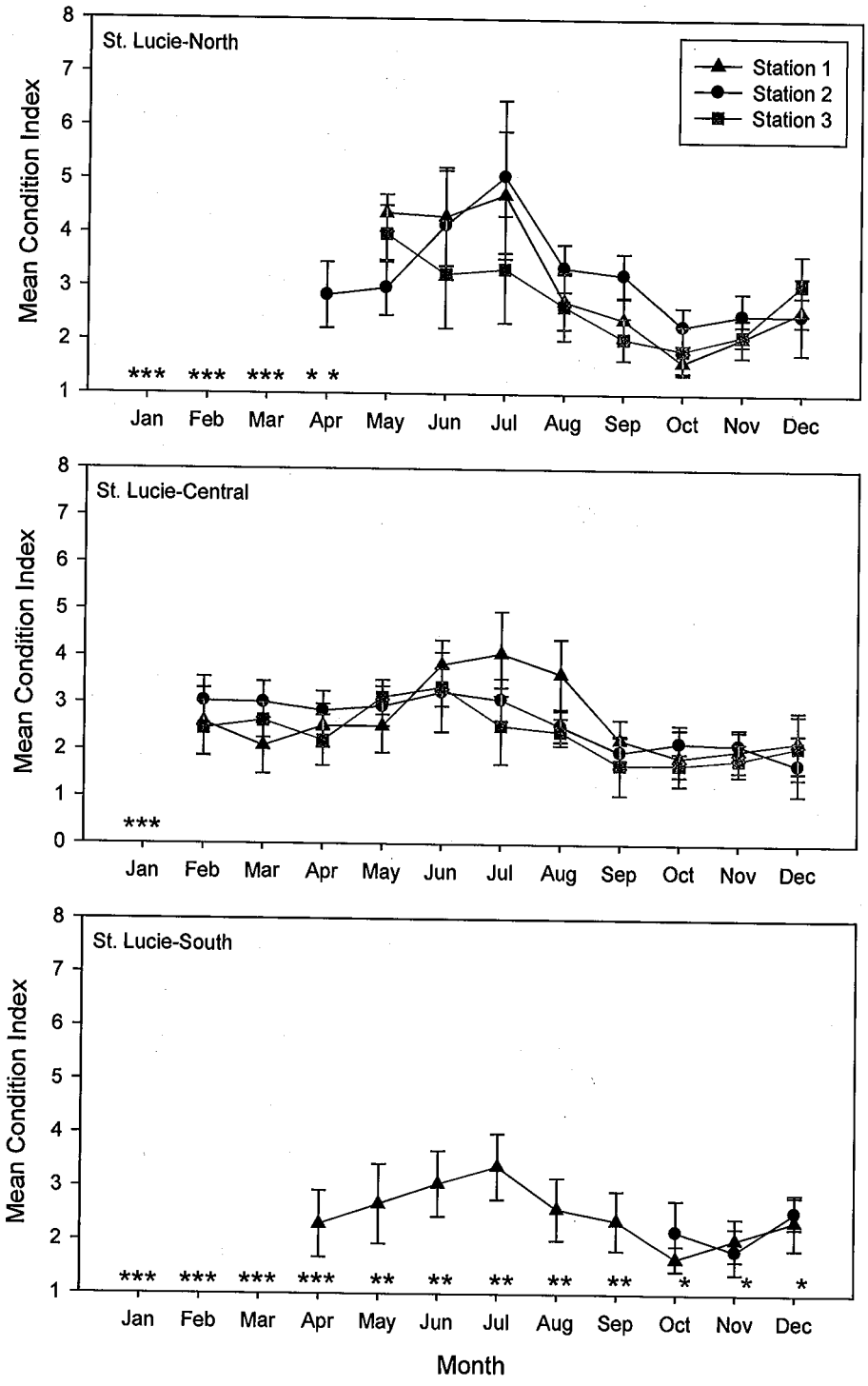

Figure 7. Monthly mean condition index (± S.D.) of oysters collected from stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009. Asterisks denote stations where no live oysters were present for collection and physiological condition analysis.

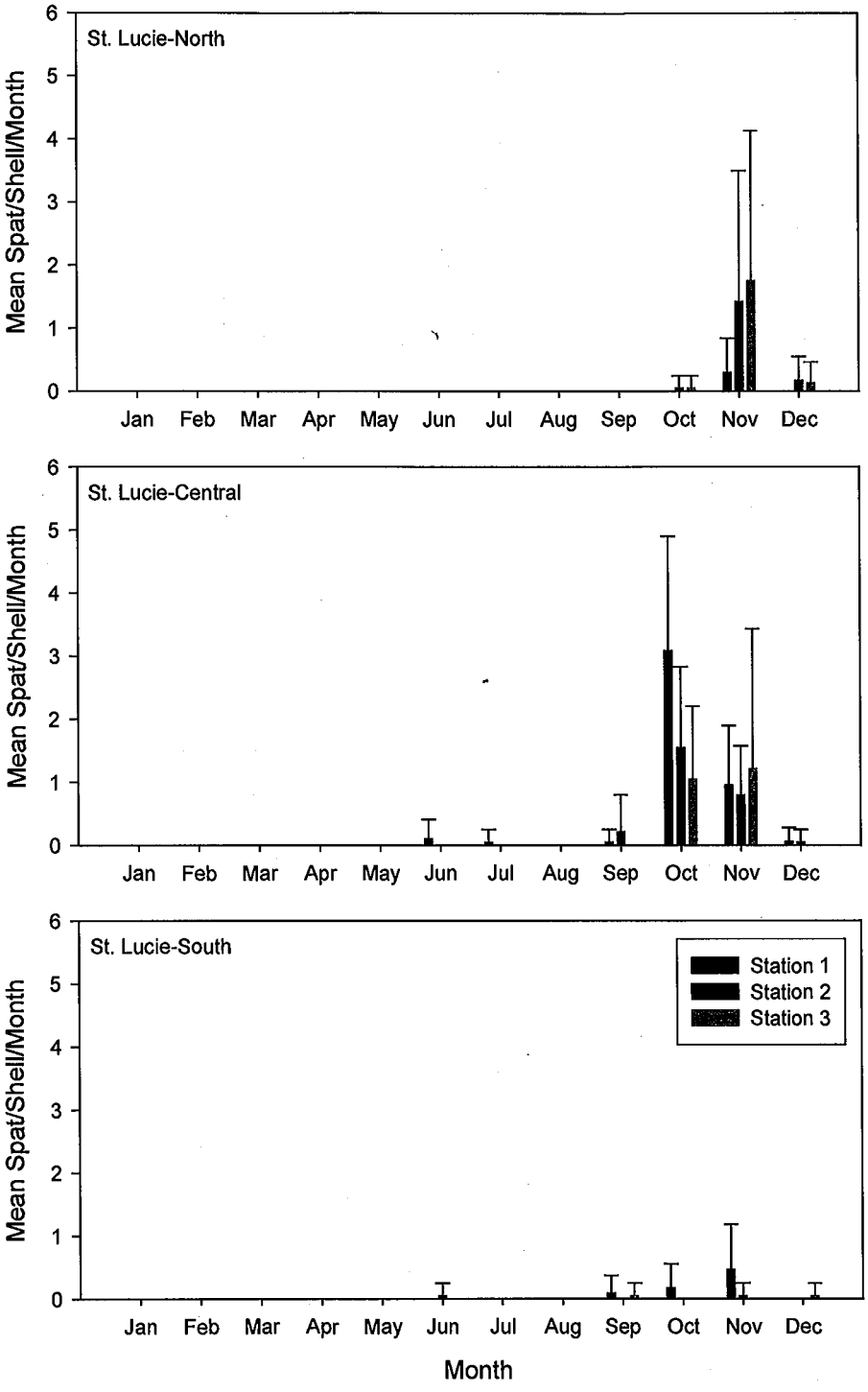

Figure 8. Mean number (± S.D.) of oyster recruits collected per shell each month from stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009.

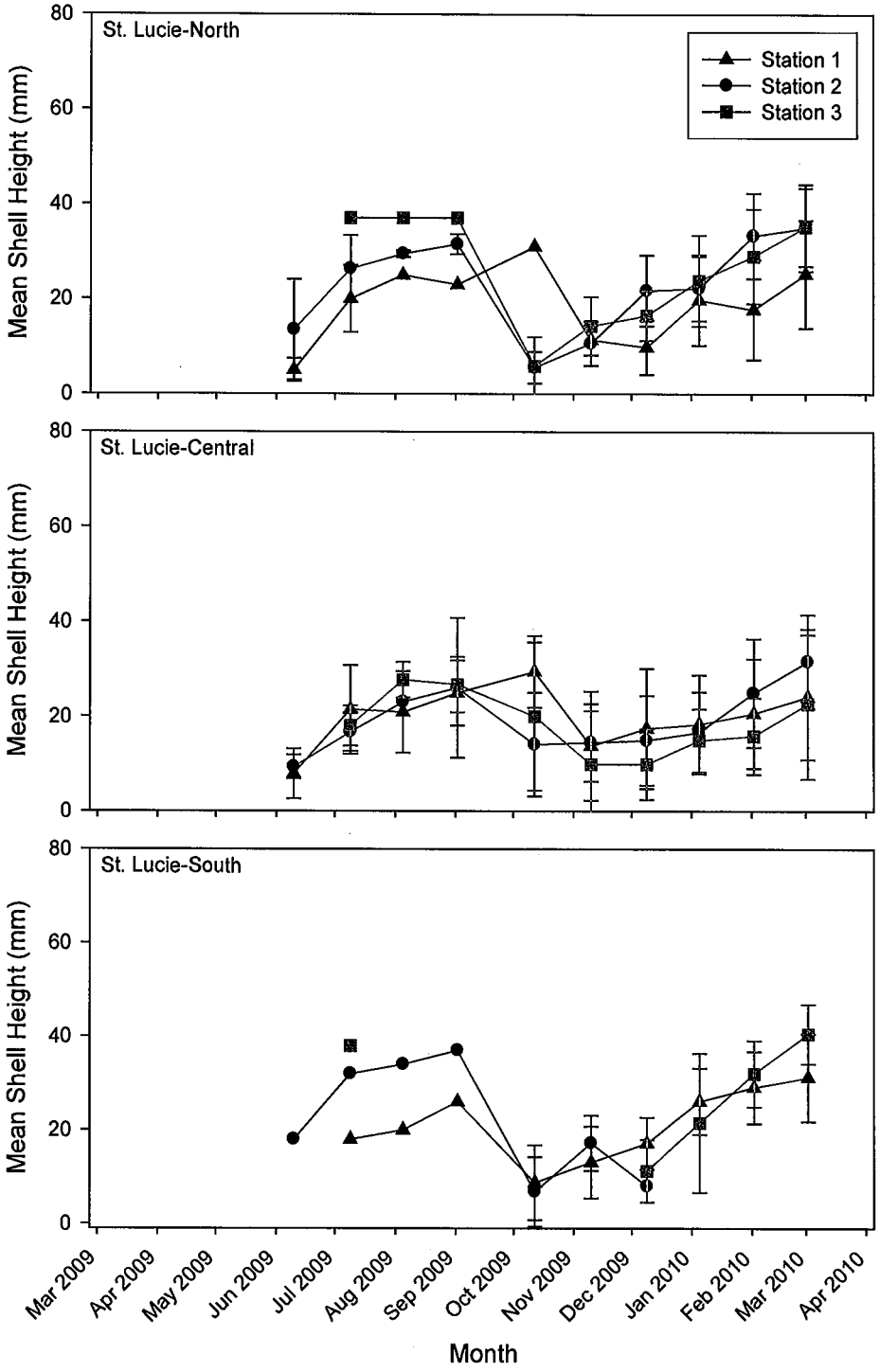

Figure 9. Monthly mean shell height (± S.D.) of wild juvenile oysters settled onto growth arrays at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites. Growth arrays were planted in March 2009. Months with no data indicate months when no juvenile oysters were present on the growth arrays.

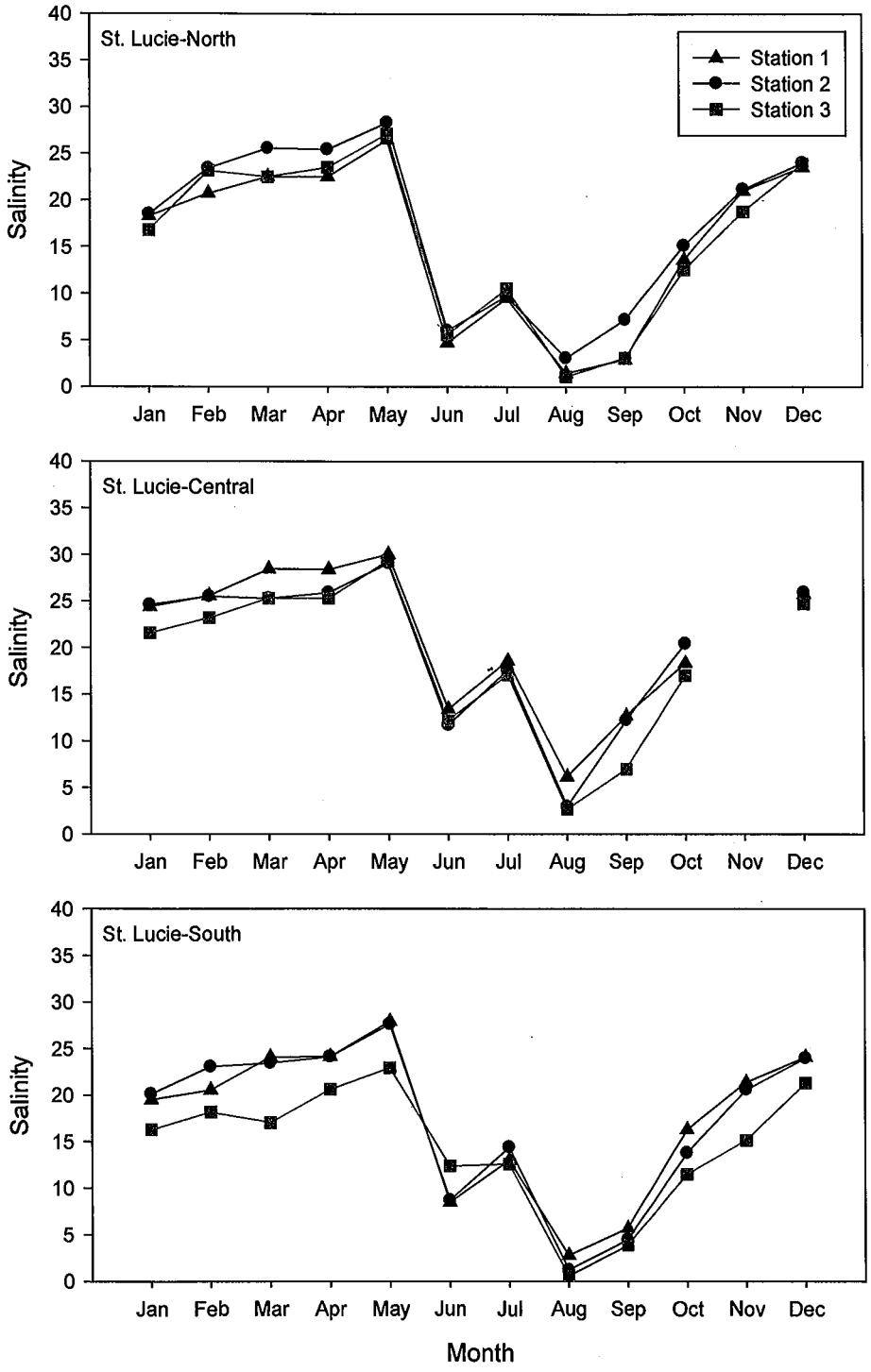

Figure 10. Monthly salinity recorded at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009. Missing data for November in St. Lucie-Central was due to a malfunctioning YSI unit.

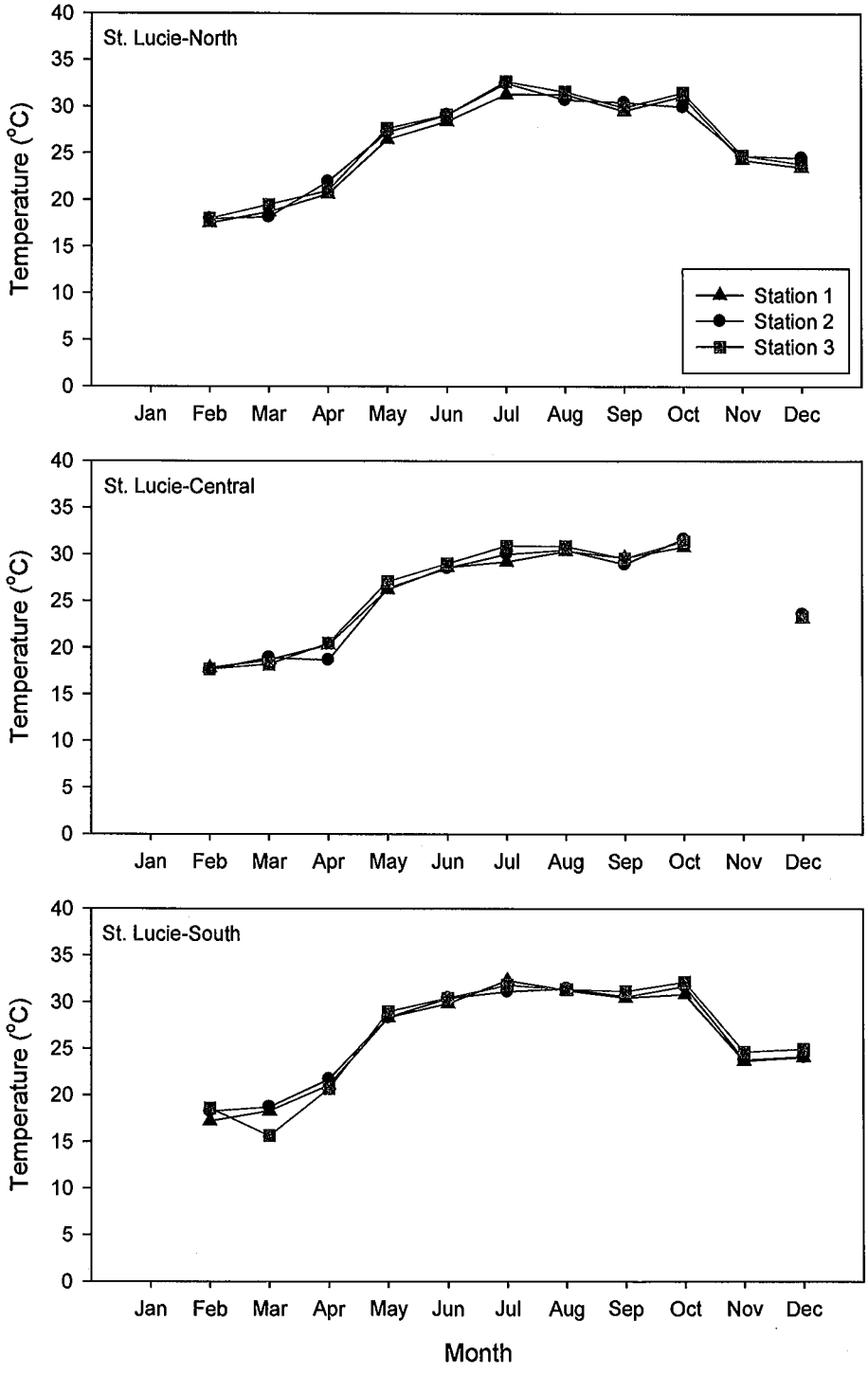

Figure 11. Monthly temperature recorded at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites during 2009. Missing data for January in all sites and for November in St. Lucie-Central was due to a malfunctioning YSI unit.

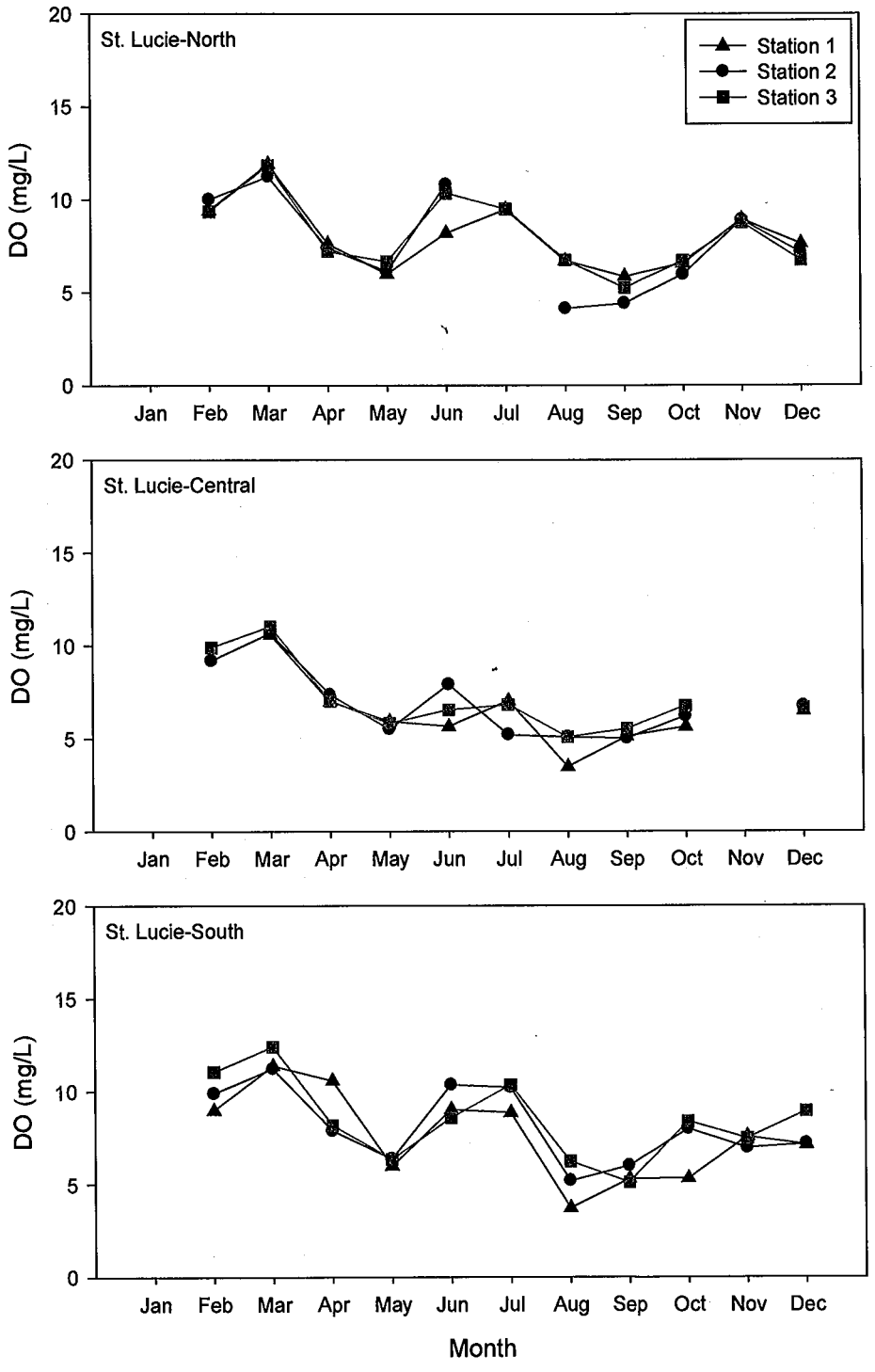

Figure 12. Monthly dissolved oxygen concentration recorded at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites in 2009. Missing data for January in all sites, July in St. Lucie-North and November in St. Lucie-Central was due to a malfunctioning YSI unit.

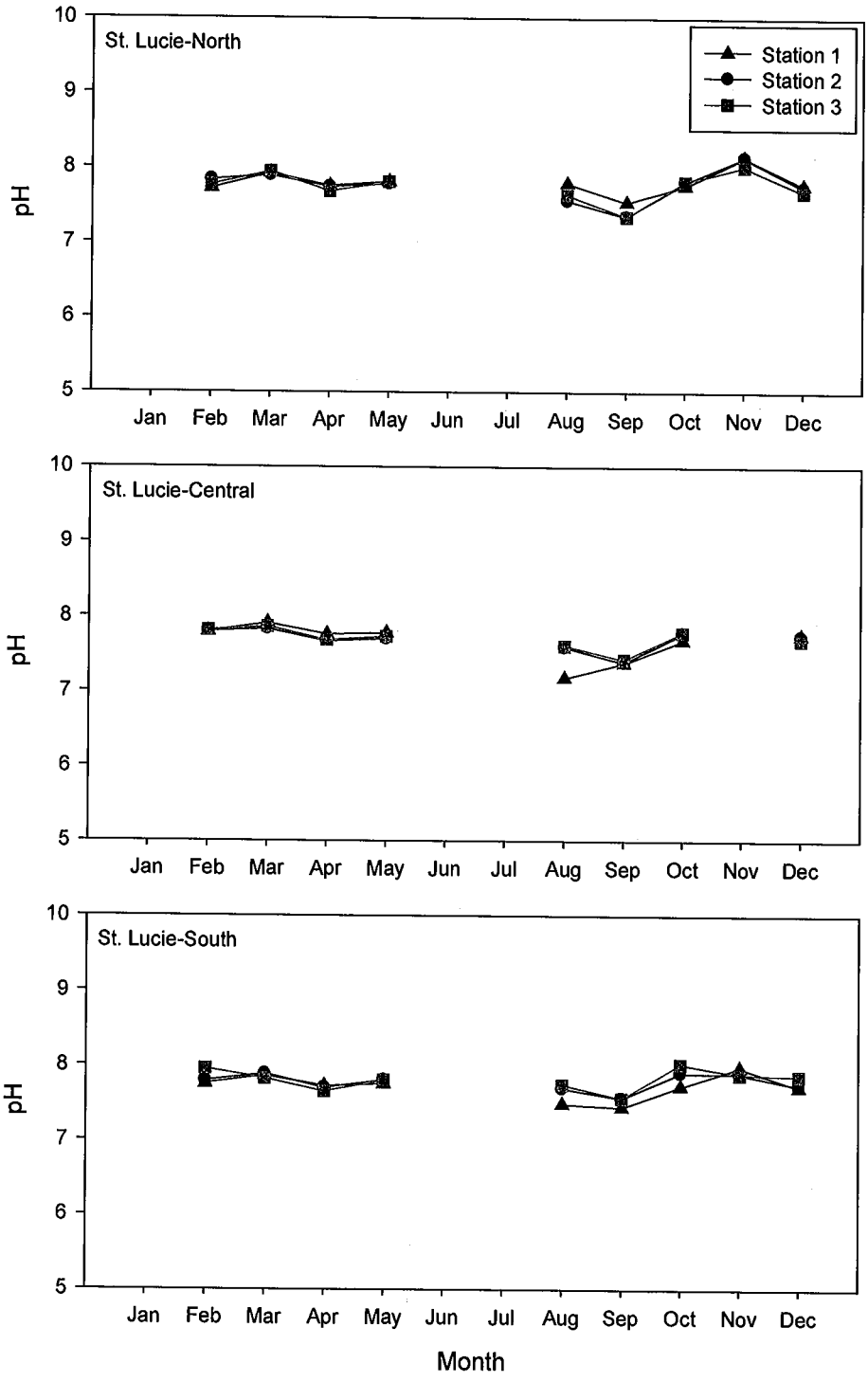

Figure 13. Monthly pH recorded at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites in 2009. Missing data for January, June and July in all sites and for November in St. Lucie-Central was due to a malfunctioning YSI unit.

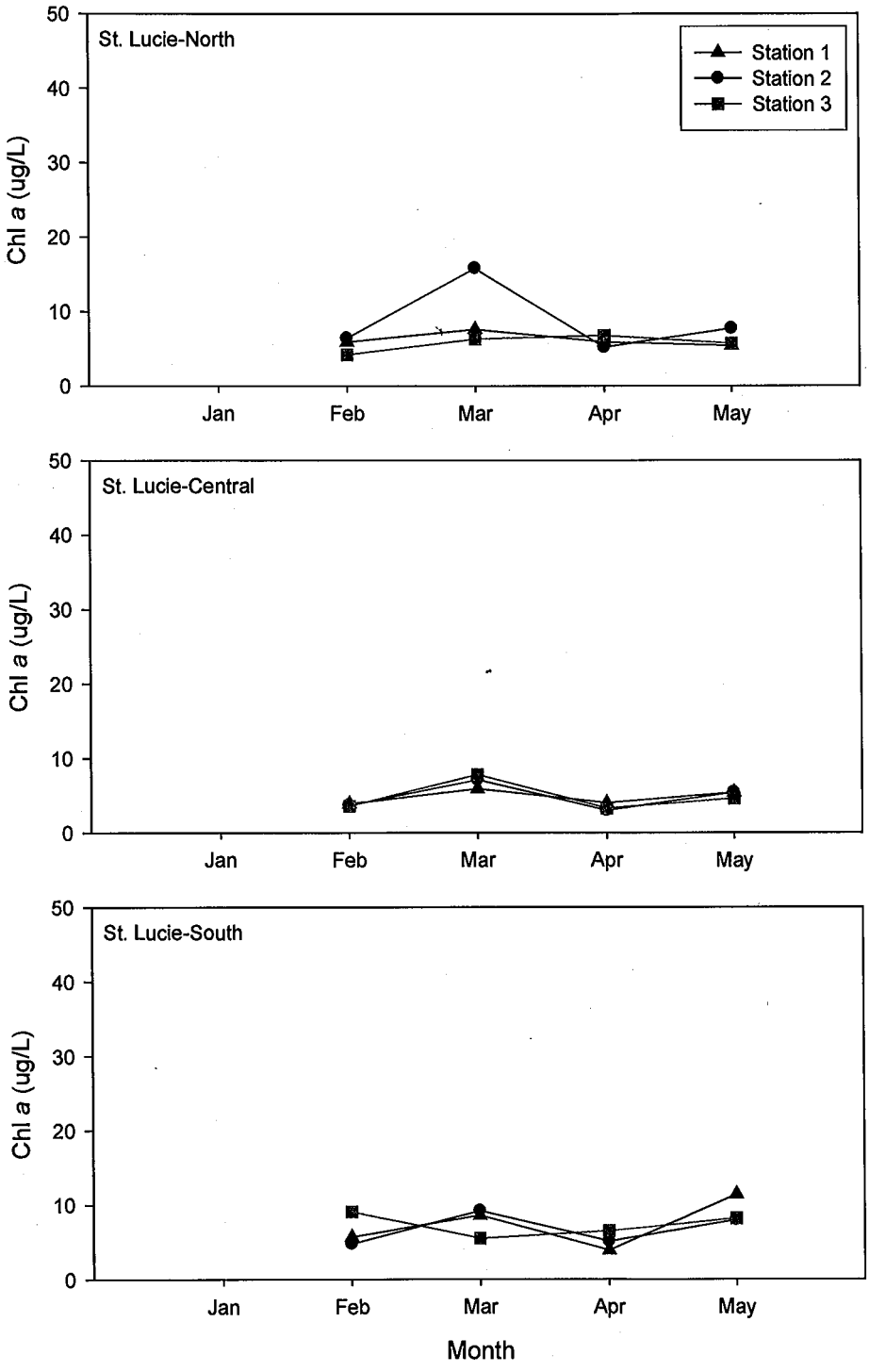

Figure 14. Monthly chlorophyll *a* concentration recorded at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites in 2009. Missing data for January in all sites was due to a malfunctioning YSI unit. Chlorophyll *a* concentration was no longer measured after May 2009.

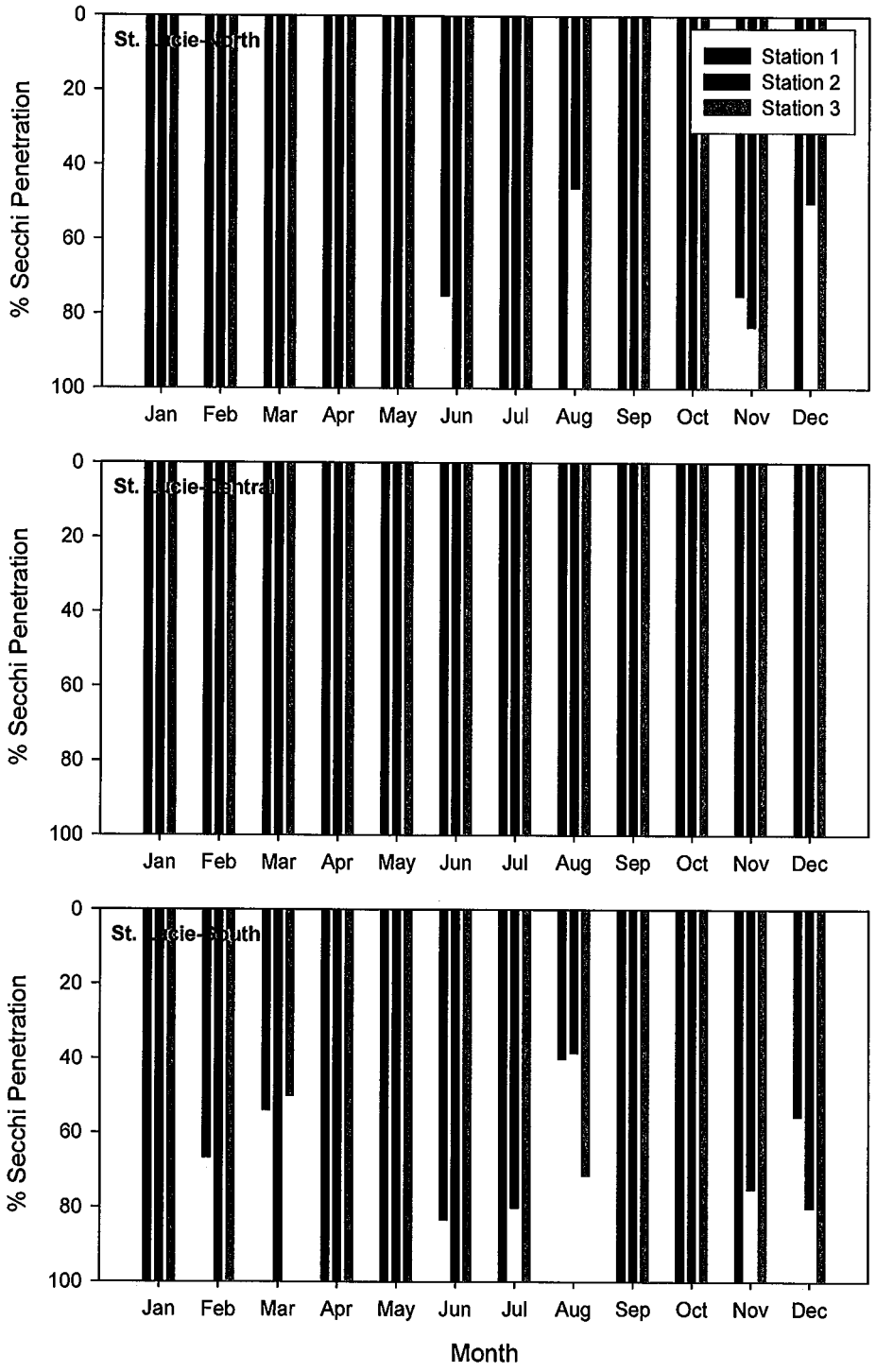

Figure 15. Monthly percent Secchi penetration recorded at stations in the St. Lucie-North (top), St. Lucie-Central (middle) and St. Lucie-South (bottom) study sites in 2009.

Loxahatchee River

Adult Sampling

Oyster densities in the Loxahatchee River exhibited similar patterns to those seen in 2008. At the Loxahatchee-North site, mean live-oyster densities exceeded 400 m^{-2} in the spring and increased significantly to over 700 m^{-2} in the fall (P=0.0264; Figure 16). This near doubling in oyster density was also seen in the Loxhatchee-North site in 2008, albeit at slightly lower densities (250 m^{-2} in the spring vs. 500 m^{-2} in the fall). In contrast, at the south fork study site, live-oyster densities were similar between spring and fall at stations 1 and 2 with a non-significant decrease in station 3 counts only. Mean shell heights at both study sites decreased significantly from spring to fall (P<0.003); the smallest sizes recorded in the spring were the same as the largest sizes recorded in the fall. In the Loxahatchee, fall mean shell heights are typically lower than those from the spring surveys due to the presence of recently settled larval oysters. Fall 2009 was no exception with mean shell heights in the northwest fork ranging from 35 mm to 37 mm and in the south fork from 29 mm to 41 mm (Figure 17). Dead oyster density patterns were similar between seasons and reflected those seen in previous years (Figure 16).

Statistical comparisons among stations revealed that there were no significant differences in live and dead densities, but there were differences in live oyster shell heights. In Loxahatchee-North, station 2 exhibited the largest oysters (P=0.0034) while in the south fork site, station 2 oysters were the smallest (P<0.001).

Disease Monitoring

Dermo infection was present throughout the year in oysters collected from both the northwest and south fork study sites but was low with levels rarely exceeding a score of 1 (light infection) on the Mackin scale (Figure 18). However, prevalence of the disease was moderate to high with anywhere from 20% to 80% of oysters from the northwest fork and 33% to 80% from the south fork infected each month (Figure 19). At this time we have found no evidence of *Haplosporidium nelsoni* (MSX) infection in any of the oysters collected from the Loxahatchee River.

Physiological Condition and Reproductive Development

Analysis of gonadal tissues indicated that most oysters are in various stages of reproductive development including gametogenesis, active spawning and gonadal recycling throughout most of the year (Figure 20). However, oysters classified as either developing or ripe/spawning were more prevalent during the summer months in Loxahatchee-North and during the first few months of the year in Loxahatchee-South. In the fall, reproductive development began decreasing as more oysters entered the winter resting stage. Changes in physiological condition reflected these reproductive patterns in that peak condition index values in the northwest fork occurred between April and July, coinciding with the greatest percentage of reproductively developing oysters (Figure 21). Similarly, south fork condition index values were maximal from January through March, also coinciding with the time period of greatest reproductive development.

Spat Recruitment

Recruitment rates peaked twice in both study sites the Loxahatchee River. In the northwest fork, there was a recruitment peak in May and October while in the south fork the peaks occurred in May and September (Figure 22). In both study sites, recruitment occurred continuously from April through December. Overall, the peaks and duration of the recruitment season are comparable to rates seen in previous years at the Loxahatchee River study sites. Statistical comparisons of spatfall among stations revealed no significant differences in the northwest site, but showed that station 1 in the south fork site had significantly fewer recruits than the other two stations (P=0.0311).

Juvenile Growth Monitoring

Juvenile oysters first appeared in Loxahatchee-South in April and in Loxahatchee-North in May (Figure 23). This corresponds to the spat recruitment results in that the first recruits recorded in each study site were found in April. Juvenile oysters in both sites exhibited moderate growth rates, adding an average of approximately 2 mm shell height per month. When the study was completed in March 2010, the juvenile oysters had reached a mean size of approximately 28 mm shell height in the northwest fork and 33 mm shell height in the south fork.

Water Quality Monitoring

Salinity was highly variable in both Loxahatchee study sites ranging from a low of 2 ppt to 28 ppt over the year. From January through May, salinities were fairly consistent but slightly higher than the optimal range (15-20 ppt) for oyster survival and recruitment (Figure 24). Salinities that exceed the optimal range can increase predation and disease incidence in oysters, as is evidenced in the dermo disease analyses.

Other water quality parameters exhibited patterns and ranges that were similar to those recorded in 2008. Temperatures at each station in the river exhibited a typical seasonal pattern with values ranging from approximately 19°C to 35°C over the year (Figure 25). Dissolved oxygen concentrations and pH measurements in the estuary were as expected ranging from approximately 5 mg/L to 11 mg/L and 7.3 to 7.9 respectively (Figures 26 and 27). Chlorophyll *a* concentrations ranged from a minimum of 3ug/L to a maximum of 9 ug/L (Figure 28). Turbidity in the water column is presented as a Secchi penetration value which is calculated as the percentage of the water column through which the Secchi disk could be seen. Secchi penetration was 100% at all six stations in the Loxahatchee River for almost the entire year (Figure 29). The only exceptions were at station 1 in both Loxahatchee-North and South in December. Even so, Secchi penetration was still greater than 85% of the water column at both stations.

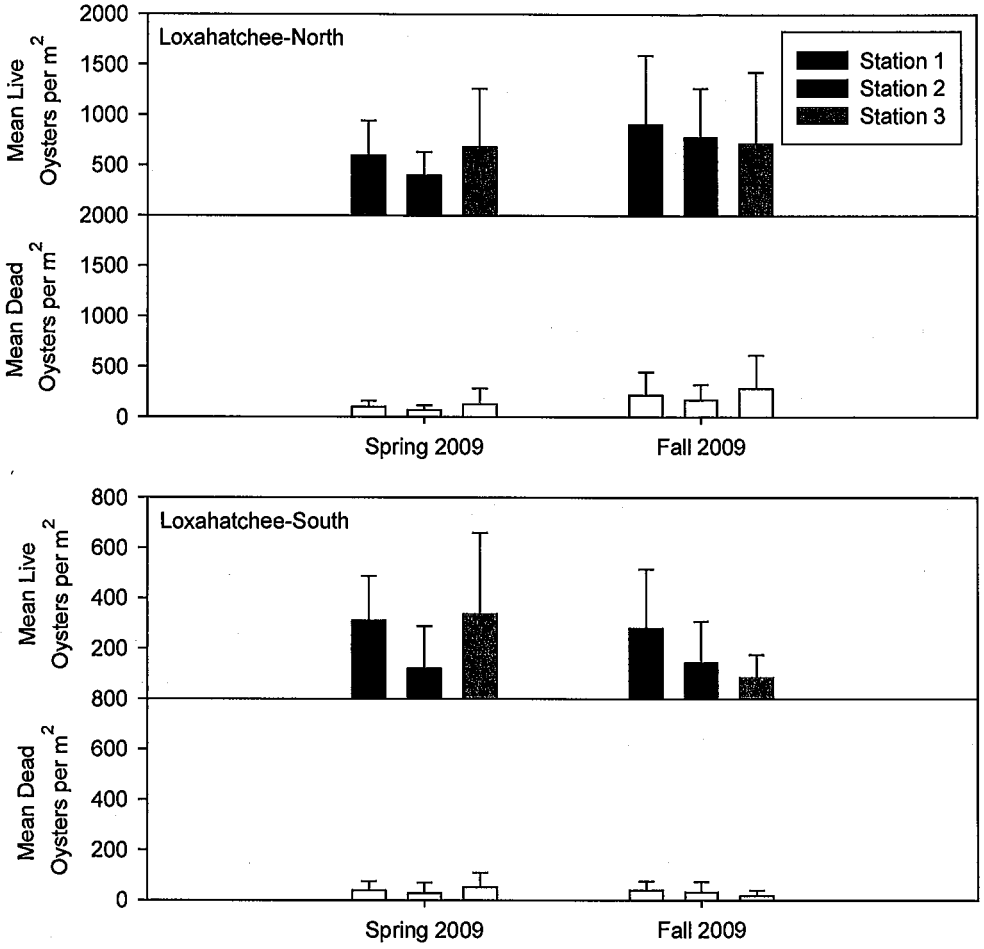

Figure 16. Mean number (± S.D.) of live and dead oysters present at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during the spring and fall 2009 surveys. Filled bars represent the number of live oysters and the hollow bars represent the number of dead oysters with articulated shells. Please note the differences in the y-axis range between the two study sites.

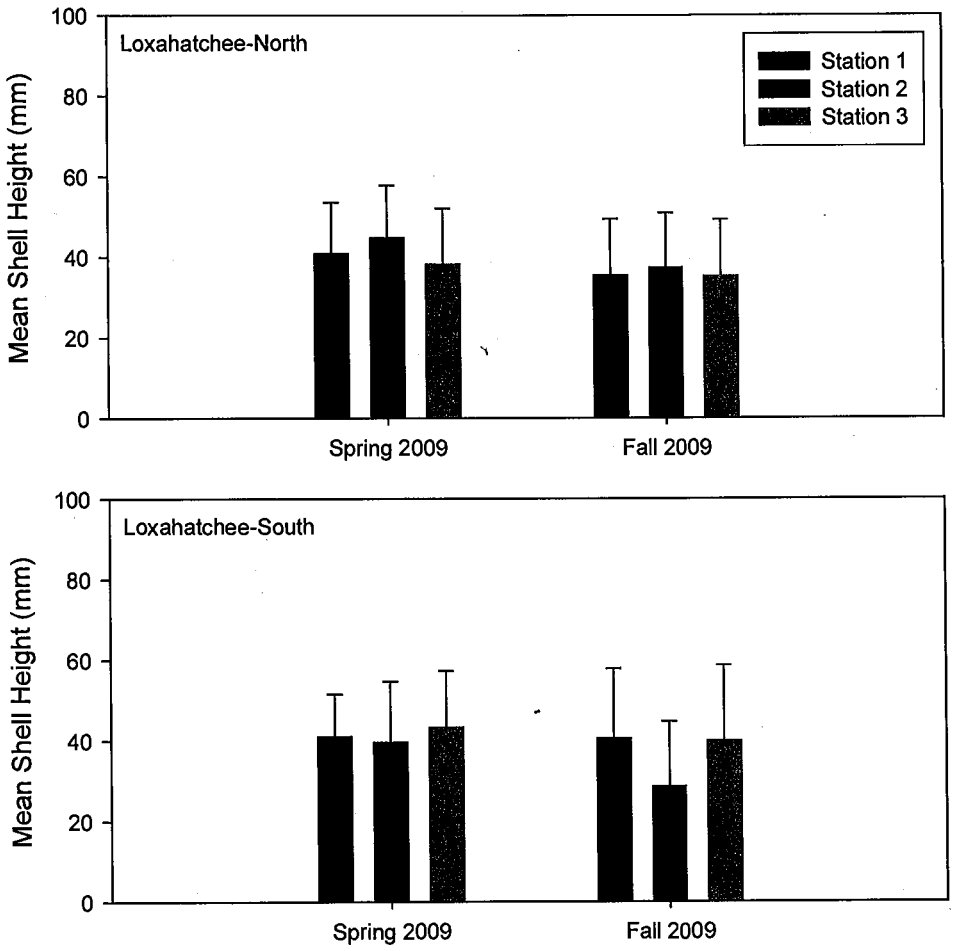

Figure 17. Mean shell height (± S.D.) of live oysters present at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during the spring and fall 2009 surveys.

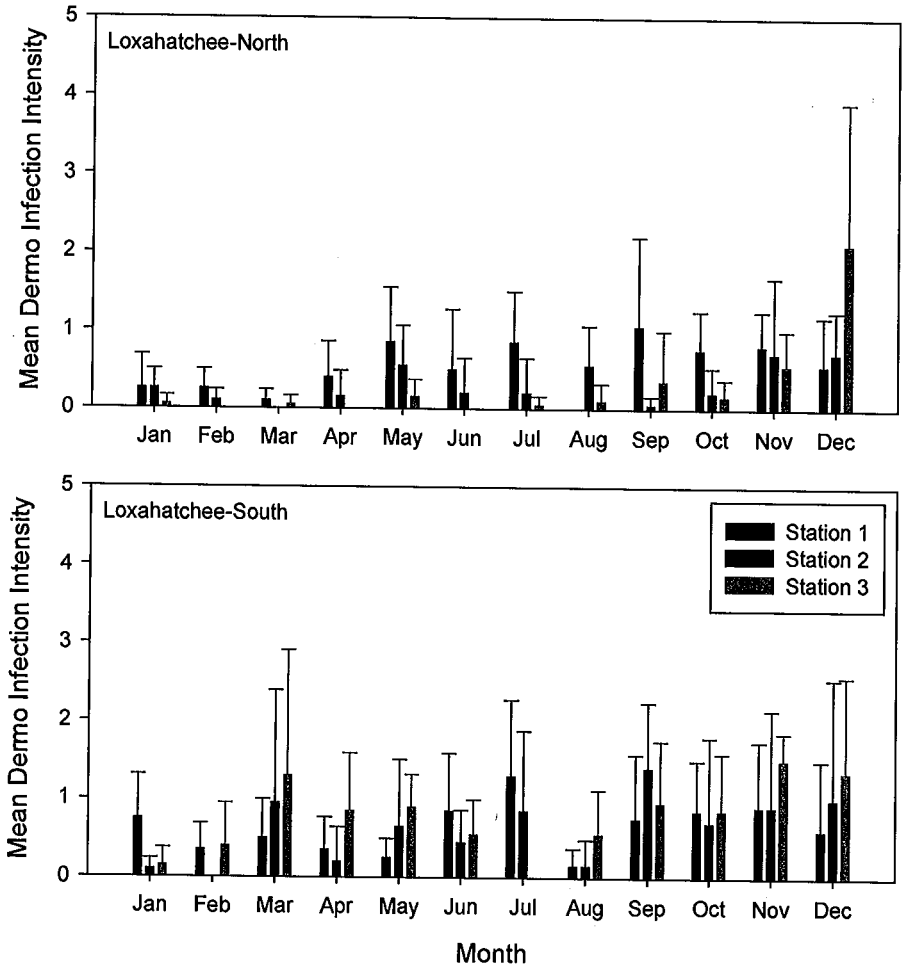

Figure 18. Monthly mean infection intensity (± S.D.) of oysters infected with *Perkinsus marinus* at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009.

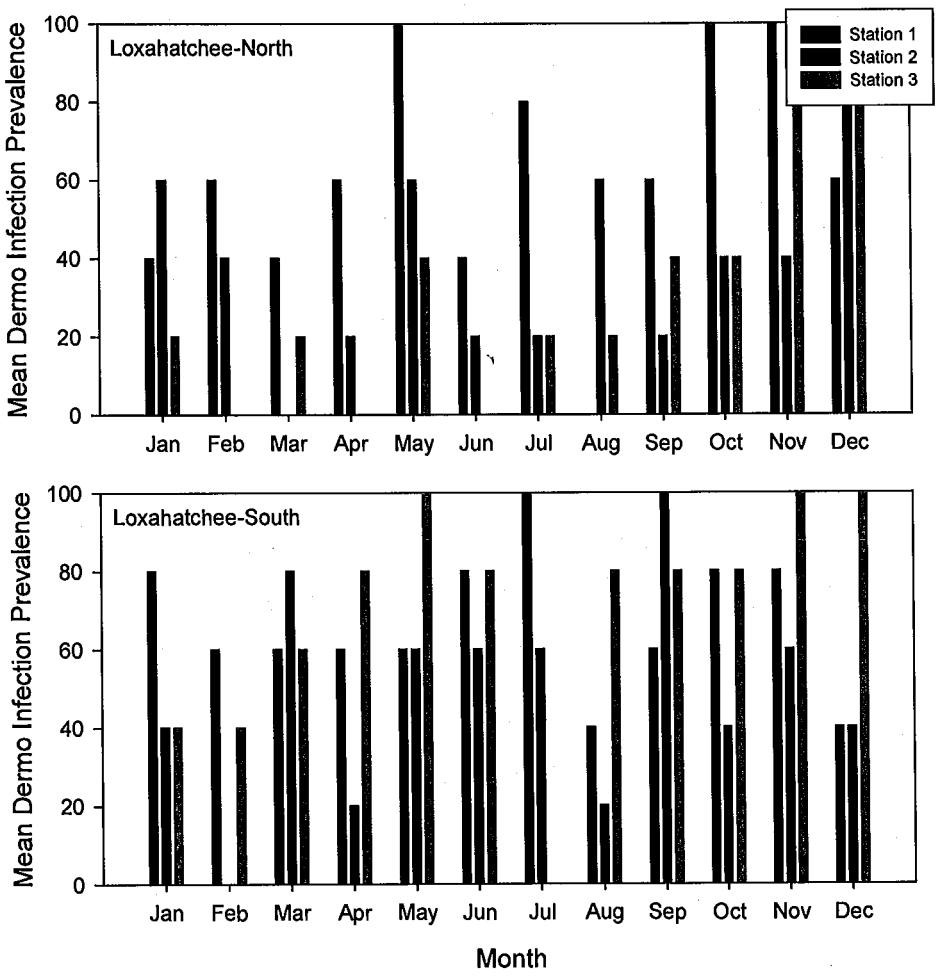

Figure 19. Monthly mean prevalence (%) of oysters infected with *Perkinsus marinus* at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009.

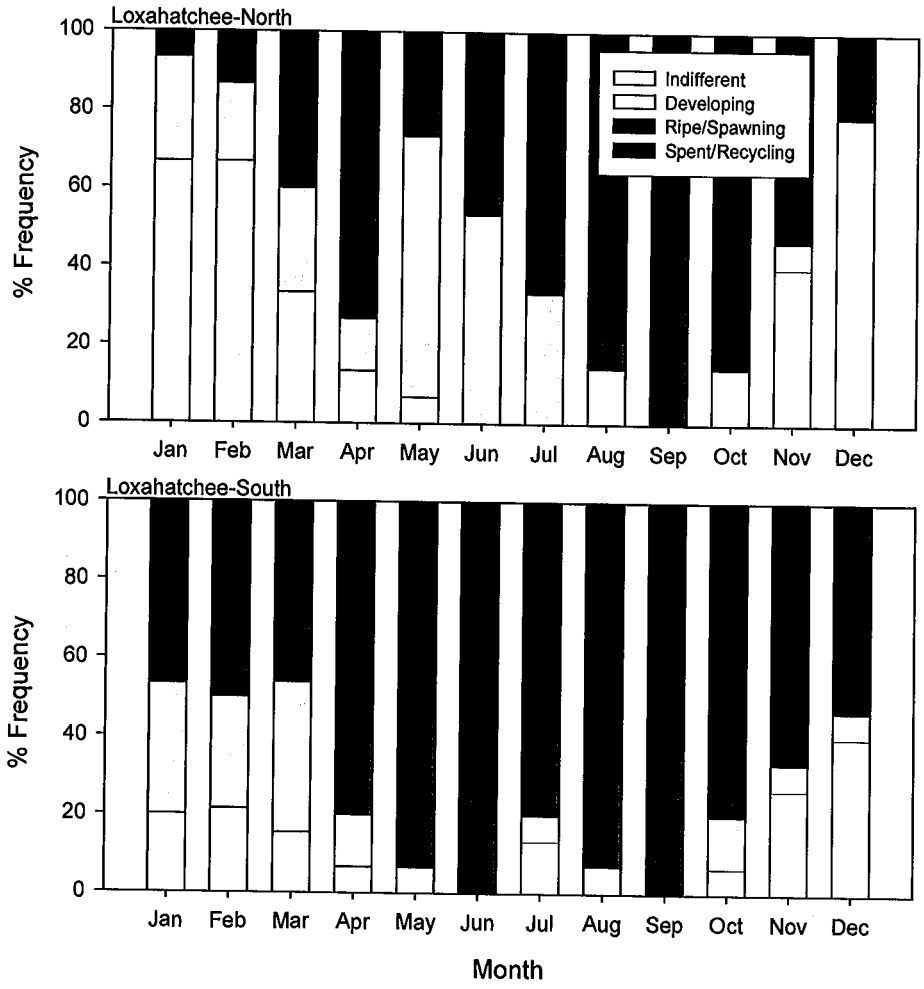

Figure 20. Reproductive development of oysters collected from the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009.

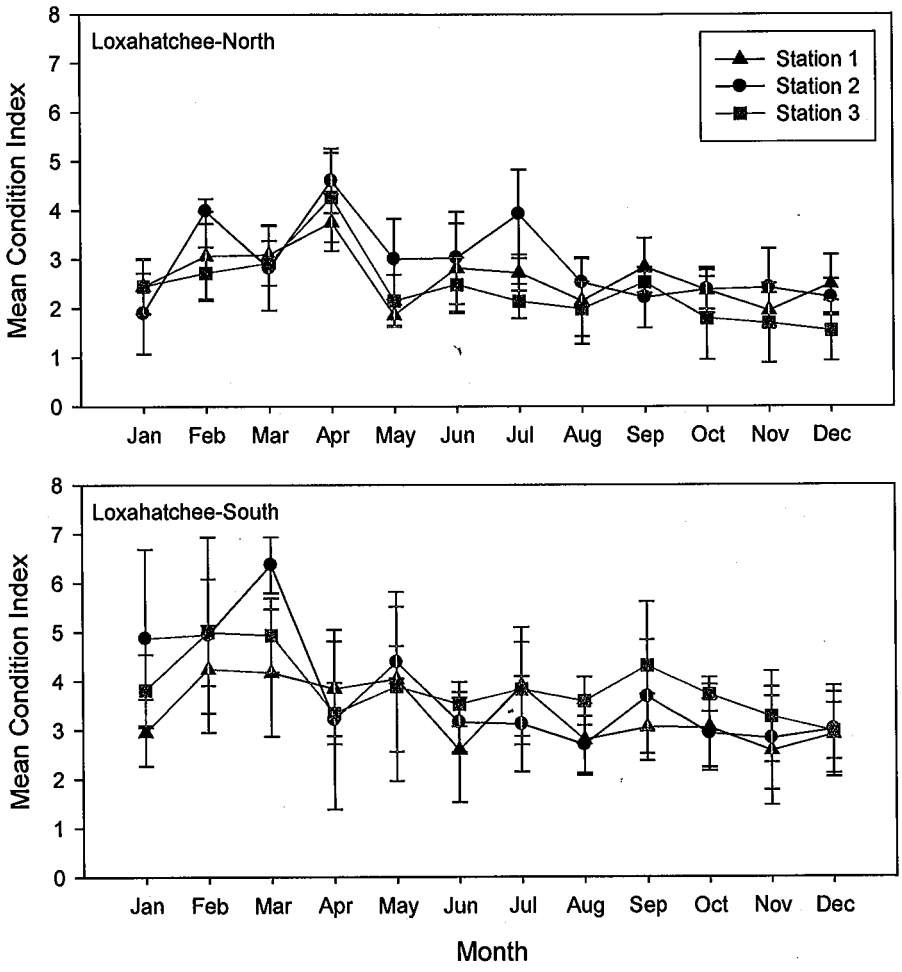

Figure 21. Monthly mean condition index (± S.D.) of oysters collected from stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009.

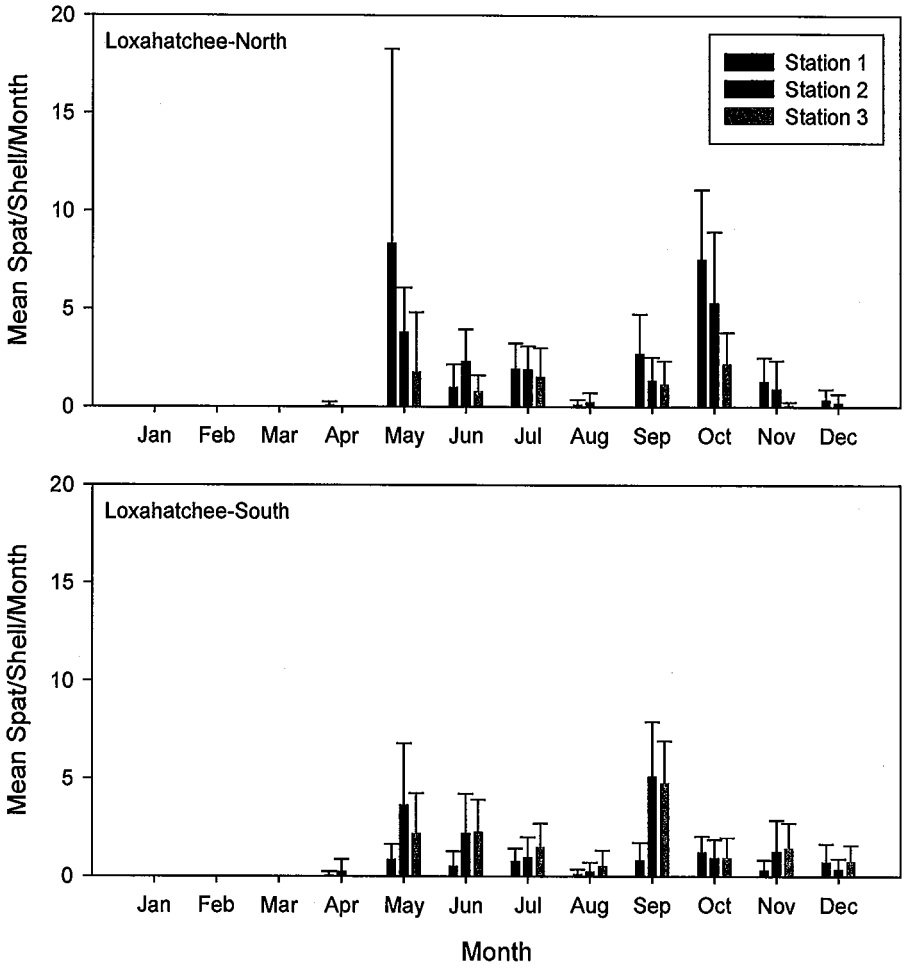

Figure 22. Mean number (± S.D.) of oyster recruits collected per shell each month from stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009.

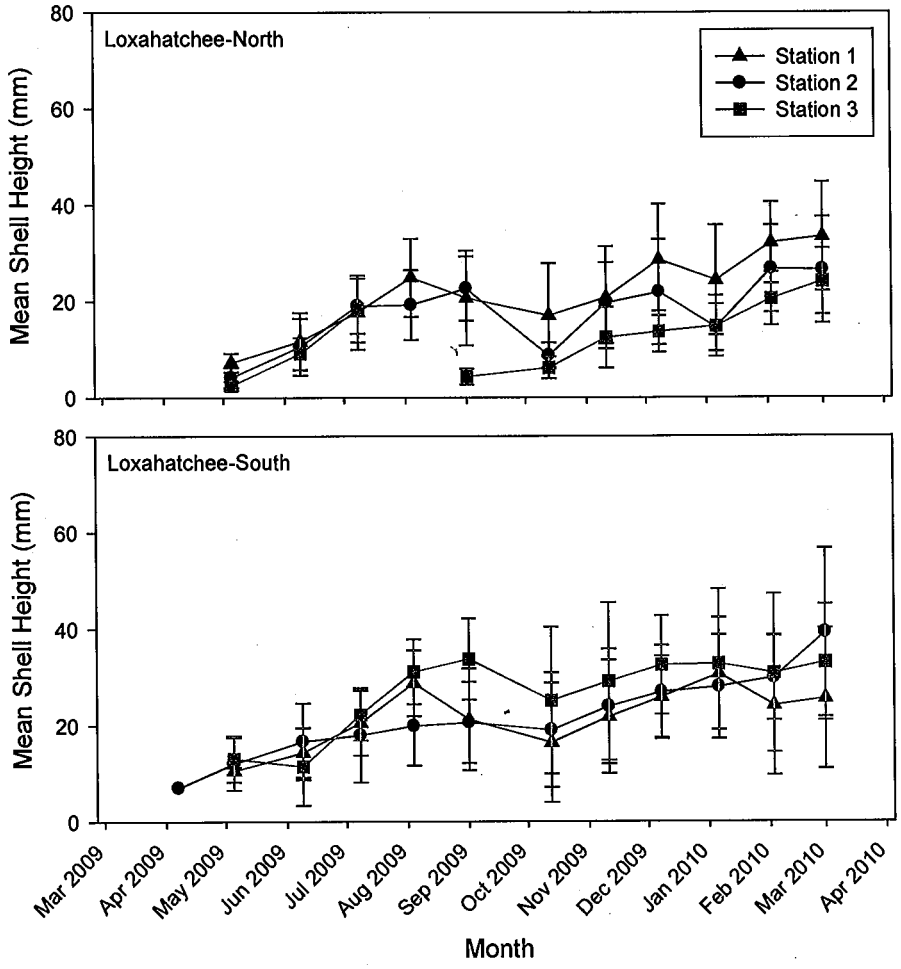

Figure 23. Monthly mean shell height (± S.D.) of wild juvenile oysters settled onto growth arrays at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites. Growth arrays were planted in March 2009. Months with no data indicate months when no juvenile oysters were present on the growth arrays.

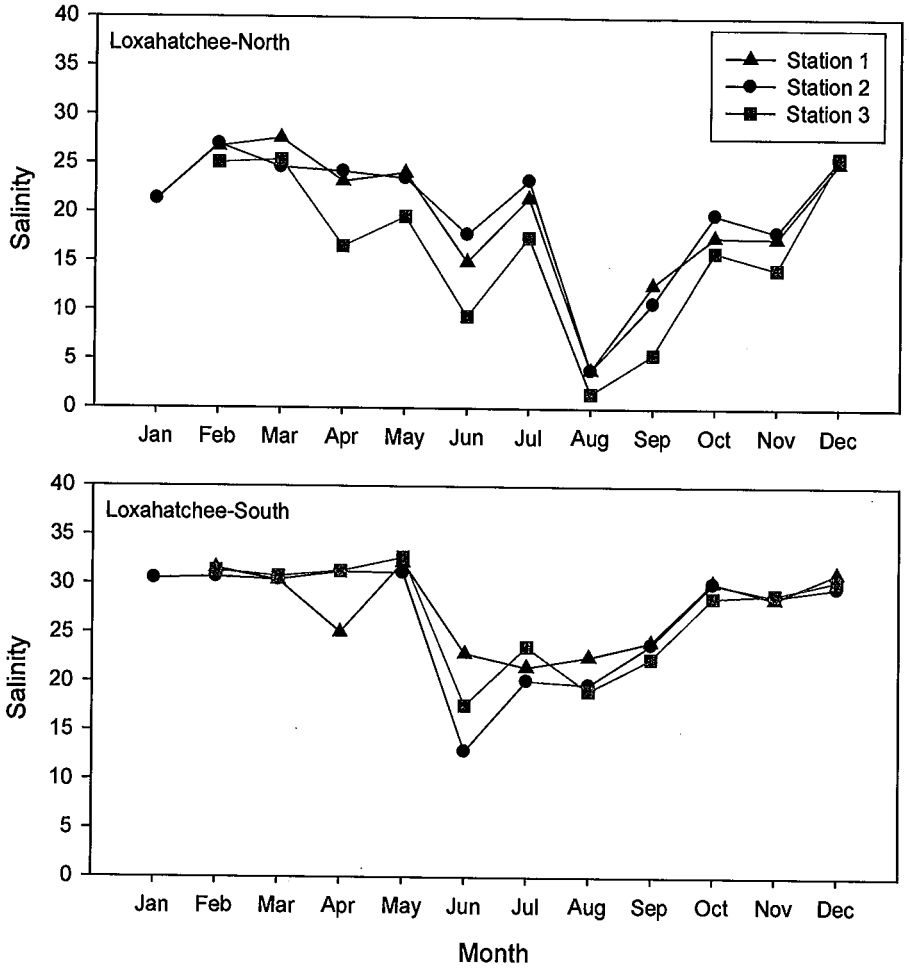

Figure 24. Monthly salinity recorded at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009. Missing data in January for stations 1 and 3 in both sites was due to a malfunctioning YSI unit.

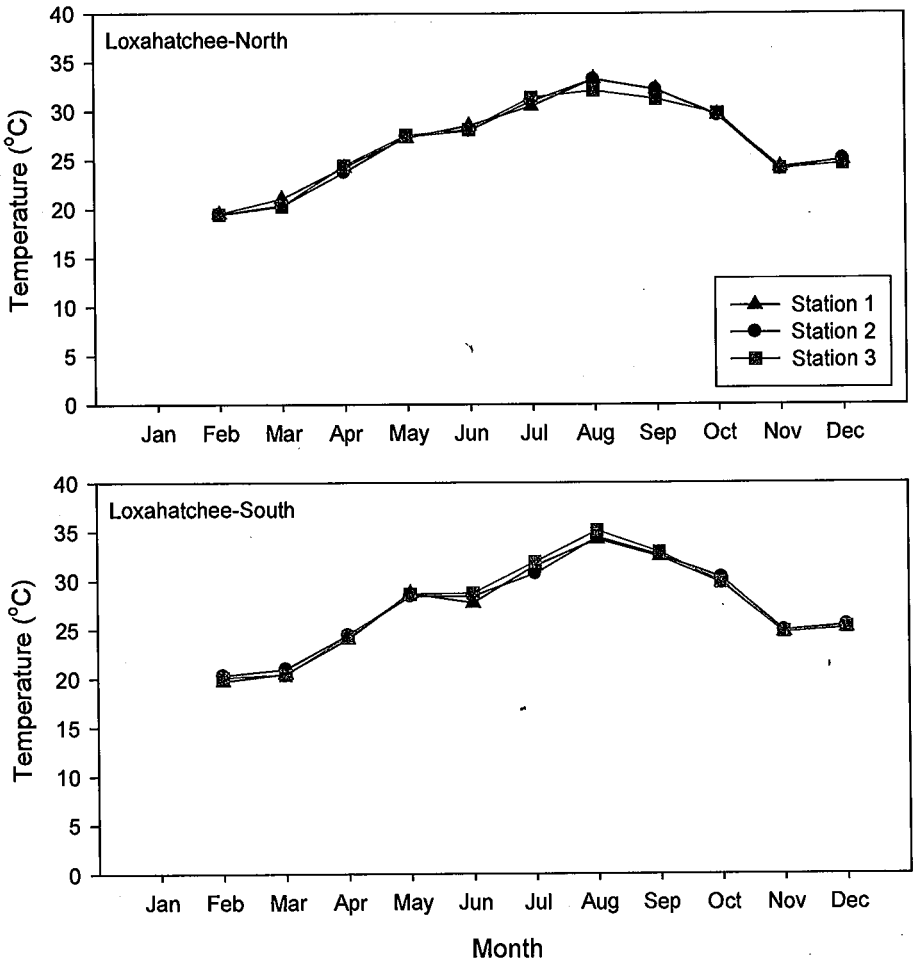

Figure 25. Monthly temperature recorded at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009. Missing data in January for both sites was due to a malfunctioning YSI unit.

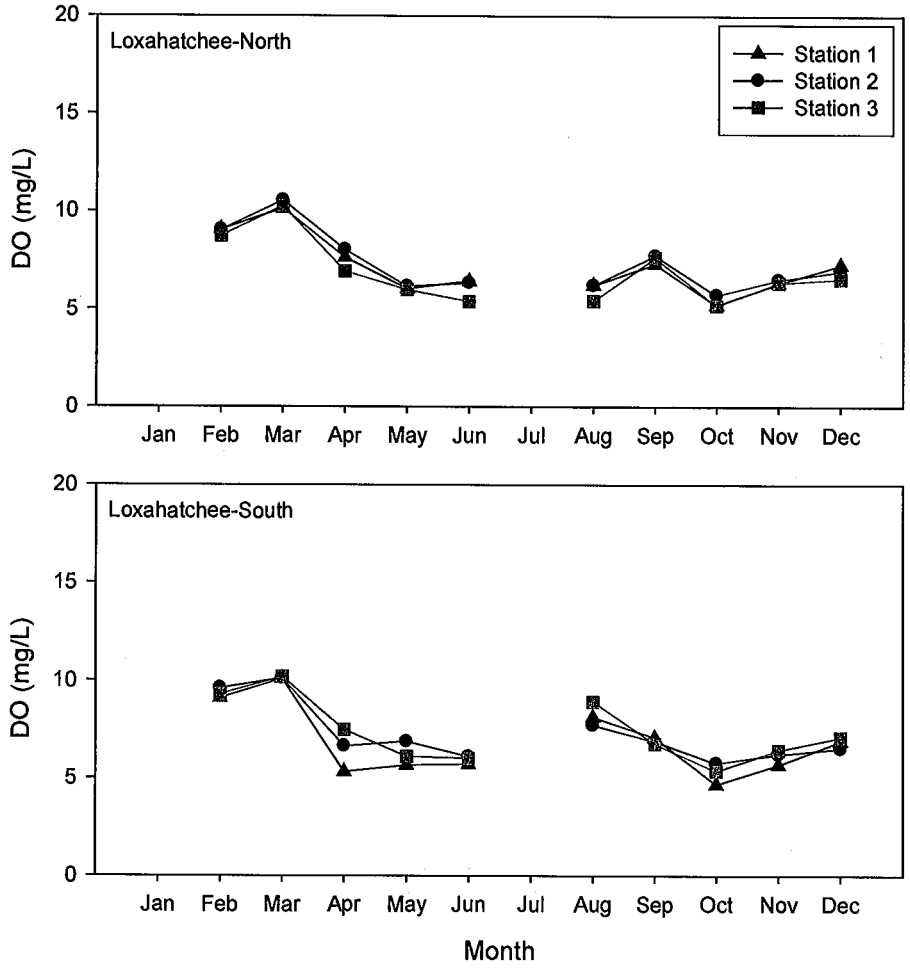

Figure 26. Monthly dissolved oxygen concentration recorded at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009. Missing data in January and July for both sites was due to a malfunctioning YSI unit.

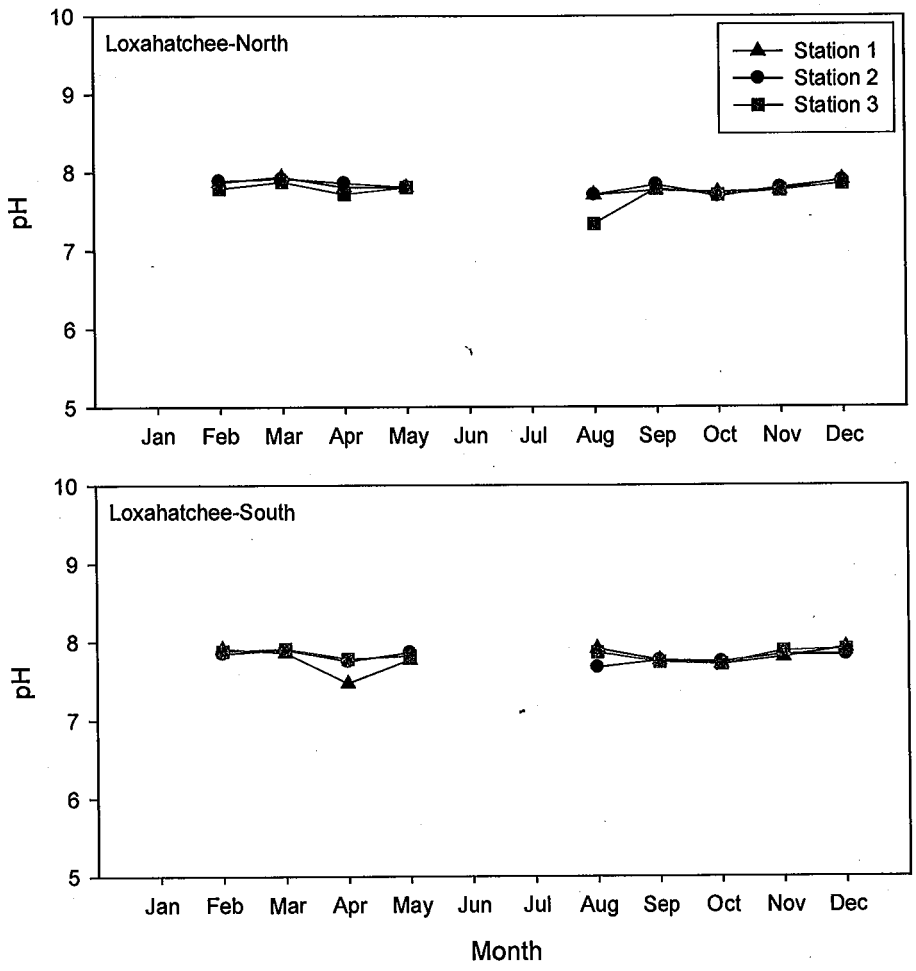

Figure 27. Monthly pH recorded at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009. Missing data in January, June and July for both sites was due to a malfunctioning YSI unit.

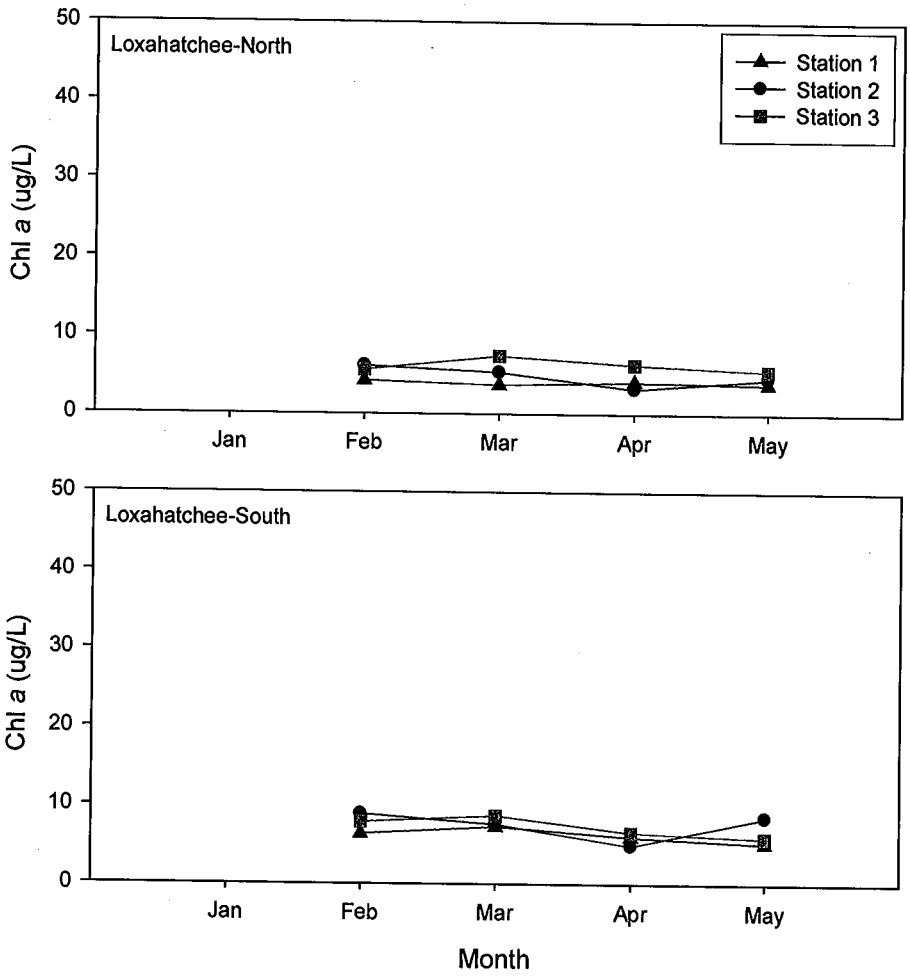

Figure 28. Monthly chlorophyll *a* concentration recorded at stations in Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009. Missing data in January for both sites was due to a malfunctioning YSI unit. Chlorophyll *a* concentration was no longer measured after May 2009.

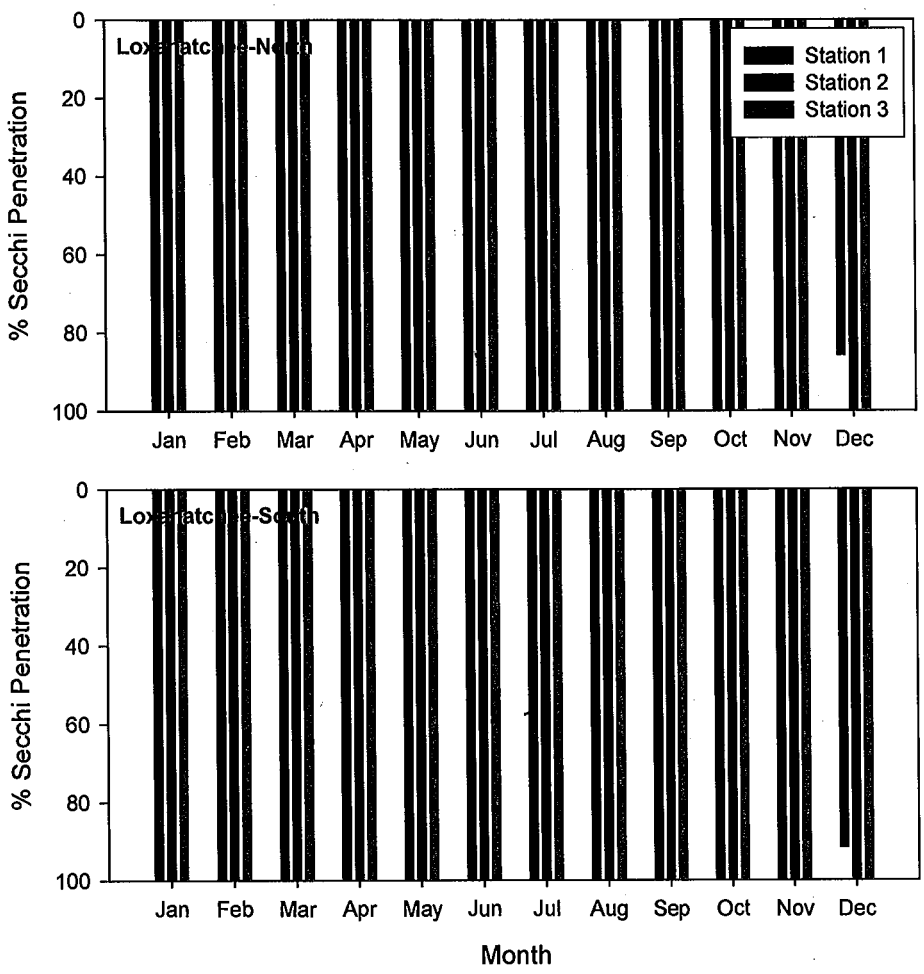

Figure 29. Monthly percent Secchi penetration recorded at stations in the Loxahatchee-North (top) and Loxahatchee-South (bottom) study sites during 2009.

Lake Worth Lagoon

Adult Sampling

Oyster densities and shell heights at each station in Lake Worth Lagoon were similar between the spring and fall surveys (Figure 30). This is in contrast to 2008 results, when there was a substantial increase in live densities and SHs from spring to fall. Although there were no differences between 2009 seasons, there were significant differences in densities among stations. Station 2 had significantly higher densities of live (>700 m^{-2}) and dead oysters (>100 m^{-2}) than those recorded at the other two stations (P<0.0001). Mean shell heights were also significantly higher at stations 2 and 3 than at station 1 (P<0.001; Figure 31). Although there is usually a decrease in oyster shell heights from spring to fall as result of juvenile recruitment, there was no decrease in 2009 with mean SH at each station ranging from 24-33 in the spring and from 24-36 in the fall.

Disease Monitoring

Dermo infection was consistently present in oysters collected from the Lake Worth study site but was low with infection levels rarely exceeding a score of 1 (light infection) on the Mackin scale (Figure 32). However, prevalence of the disease was sporadic and moderate with anywhere from 0 to 100% of the oysters collected from each station infected each month (Figure 33). At this time we have found no evidence of *Haplosporidium nelsoni* (MSX) infection in any of the oysters collected from the Lake Worth Lagoon.

Physiological Condition and Reproductive Development

Analysis of gonadal tissues indicated that oysters in various stages of reproductive development including gametogenesis, active spawning and gonadal recycling throughout most of the year (Figure 34). However, oysters classified as either developing or ripe/spawning were more prevalent during the spring and summer months, while the majority of oysters in winter and fall had decreased reproductive development and were in the resting stage. As in previous years, it is noted that this is a more protracted period of time for oysters remain in the resting stage than seen in SLE or Loxahatchee oysters. Changes in physiological condition reflect these reproductive patterns in that peak condition index values were

measured in the summer months, coinciding with the period of greatest reproductive development (Figure 35).

Spat Recruitment

At most stations, recruitment was observed continuously from May through December with peaks occurring in June and October (Figure 36). Overall, the peaks and duration of the recruitment season are comparable to those seen in previous years with exception of 2008. In that anomalous year, the duration of the season was similar but recruitment values peaked in August rather than in the spring and fall. Statistical comparisons of spatfall among stations revealed no significant differences.

Juvenile Growth Monitoring

Juvenile oysters first appeared at station 1 in May and at stations 2 and 3 in June (Figure 37). This corresponds to the spat recruitment results in that the first recruits recorded were found in May. Juvenile oysters at the Lake Worth stations exhibited moderate growth rates, adding an average of 2 mm shell height per month. When the study was completed in March 2010, the juvenile oysters had reached a mean size of approximately 25 mm shell height in the Lake Worth study site.

Water Quality Monitoring

Salinity was highly variable in the Lake Worth study site ranging from a low of 7 ppt to 35 ppt over the year (Figure 38). From January through April, salinities were consistent but exceeded the optimal range (15-20 ppt) which likely impacted Lake Worth oysters by increasing the incidence of predation and disease infection (dermo). However, there was a substanstial drop in salinities at all three stations in May and as a result, there was no dermo infection detected in oysters collected that month.

Other water quality parameters exhibited patterns and ranges that were similar to those recorded in 2008. Temperatures at each station exhibited a typical seasonal pattern with values ranging from approximately 17°C to 34°C over the year (Figure 39). Dissolved oxygen concentrations and pH measurements in the estuary were as expected ranging from approximately 5 mg/L to 11 mg/L and 7.5 to 8.0 respectively (Figures 40 and 41). Chlorophyll *a* concentrations ranged from a minimum of 1ug/L to a

maximum of 5 ug/L (Figure 42). Turbidity in the water column is presented as a Secchi penetration value which is calculated as the percentage of the water column through which the Secchi disk could be seen. Secchi penetration was 100% at all three stations in Lake Worth for the entire year with the only exceptions at station 3 in April and October (Figure 43).

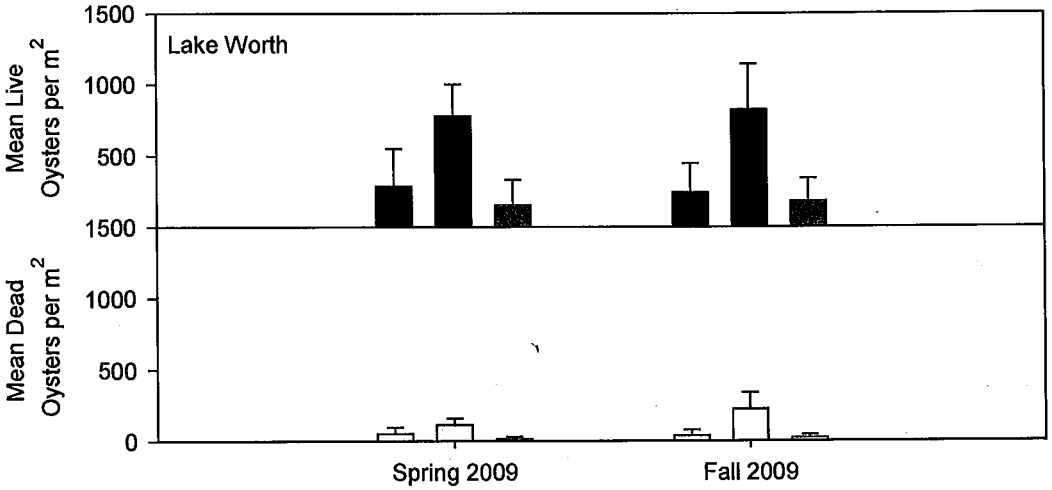

Figure 30. Mean number (± S.D.) of live and dead oysters present at stations in the Lake Worth study site during the spring and fall 2009 surveys. Filled bars represent the number of live oysters and the hollow bars represent the number of dead oysters with articulated shells.

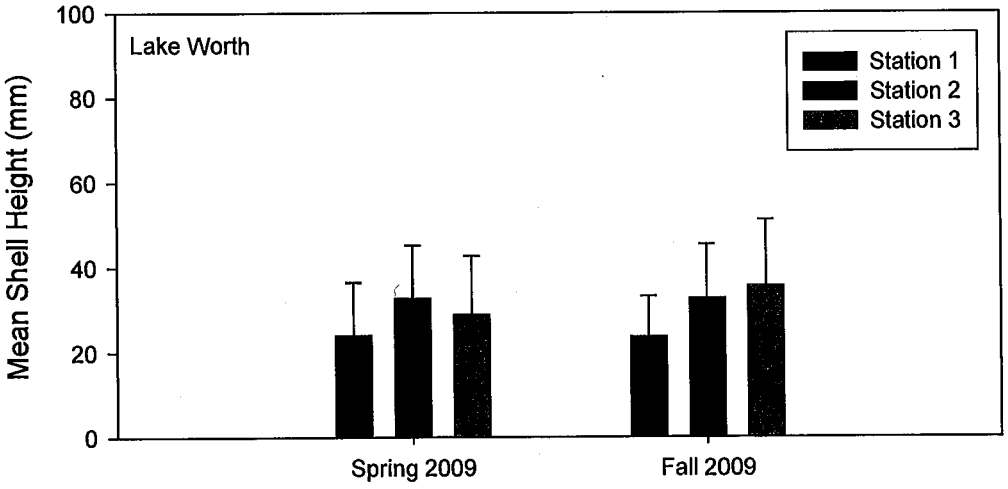

Figure 31. Mean shell height (± S.D.) of live oysters present at stations in the Lake Worth study site during the spring and fall 2009 surveys.

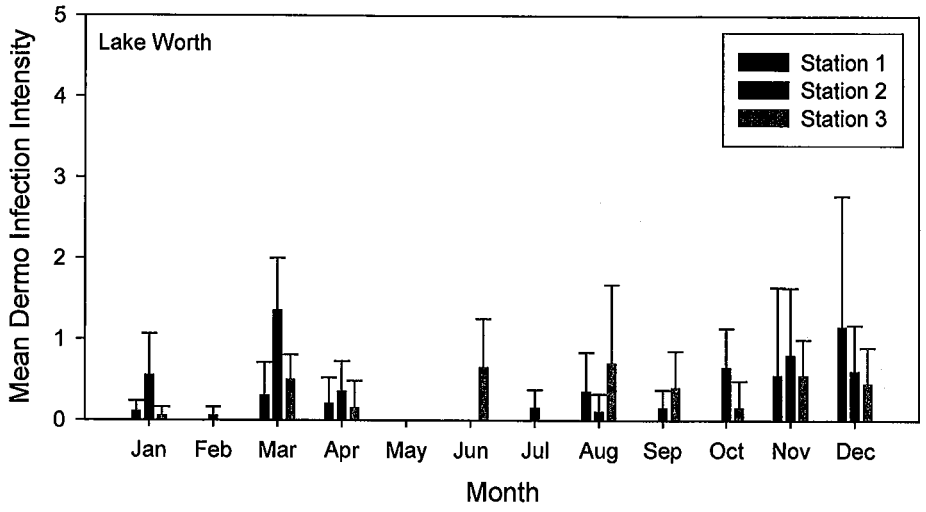

Figure 32. Monthly mean infection intensity (± S.D.) of oysters infected with *Perkinsus marinus* at stations in the Lake Worth study site during 2009.

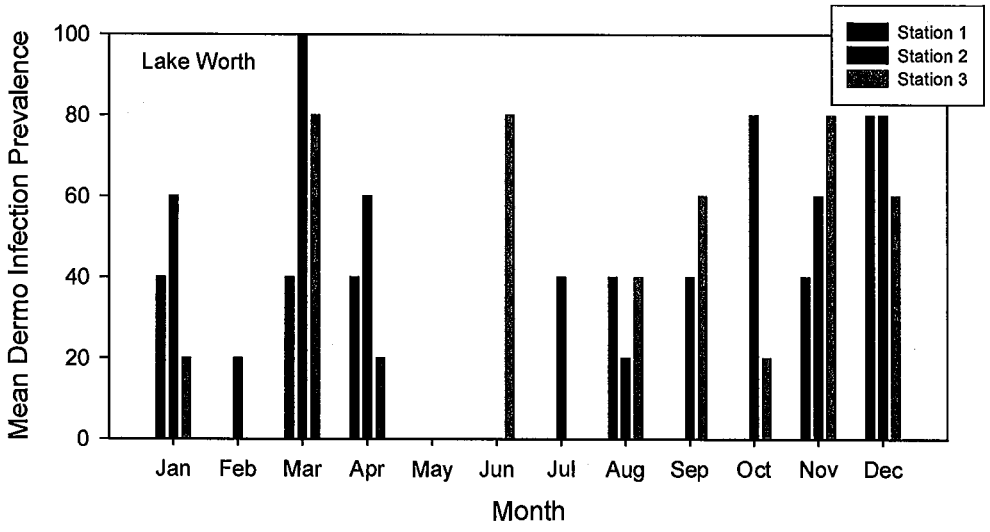

Figure 33. Monthly mean prevalence (%) of oysters infected with *Perkinsus marinus* at stations in the Lake Worth study site during 2009.

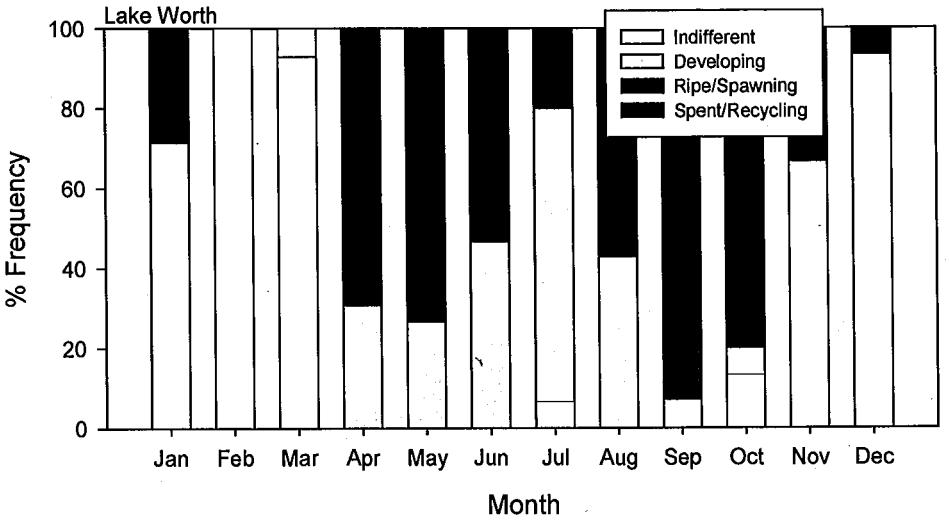

Figure 34. Reproductive development of oysters collected from the Lake Worth study site in 2009.

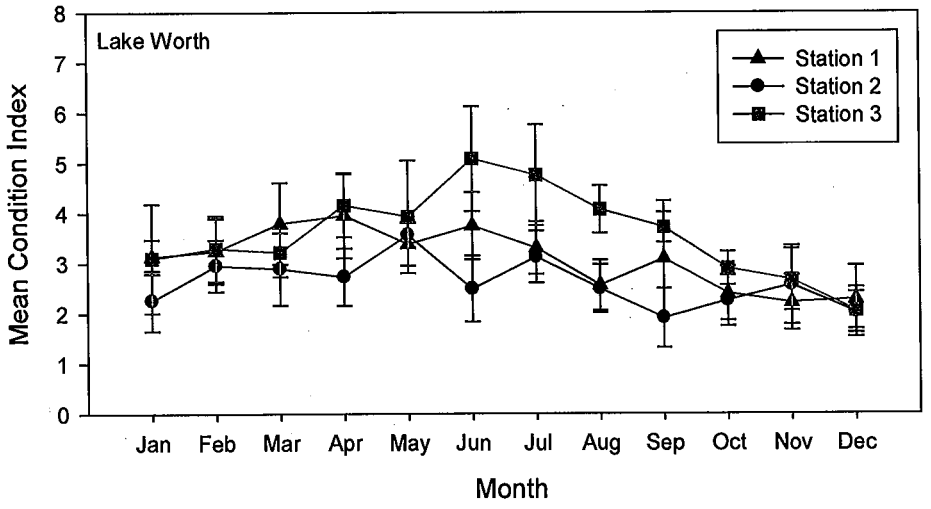

Figure 35. Monthly mean condition index (± S.D.) of oysters collected from stations in the Lake Worth study site during 2009.

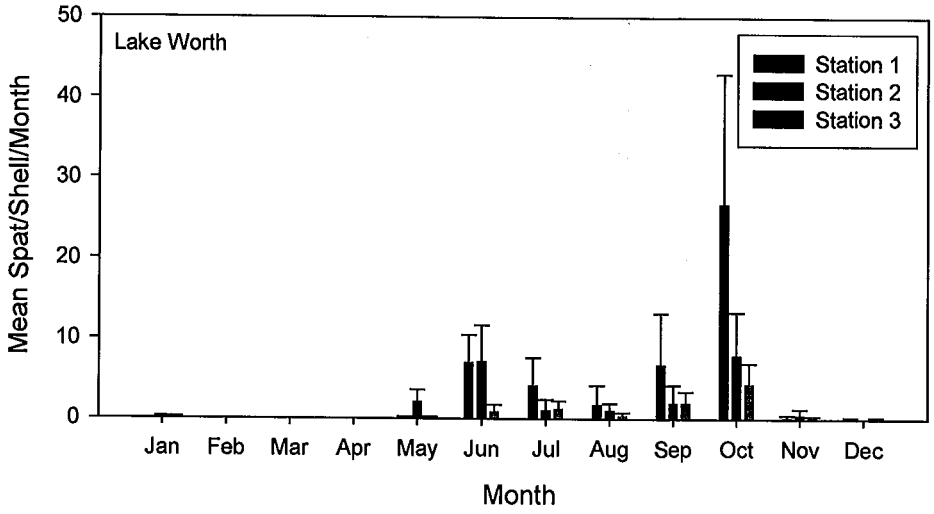

Figure 36. Mean number (± S.D.) of oyster recruits collected per shell each month from stations in the Lake Worth study site during 2009.

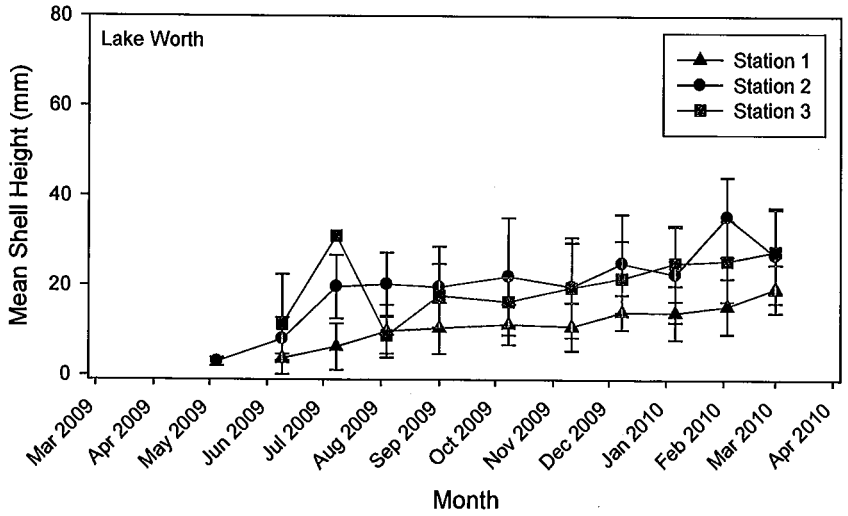

Figure 37. Monthly mean shell height (± S.D.) of wild juvenile oysters settled onto growth arrays at stations in the Lake Worth study site. Growth arrays were planted in March 2009. Months with no data indicate months when no juvenile oysters were present on the growth arrays.

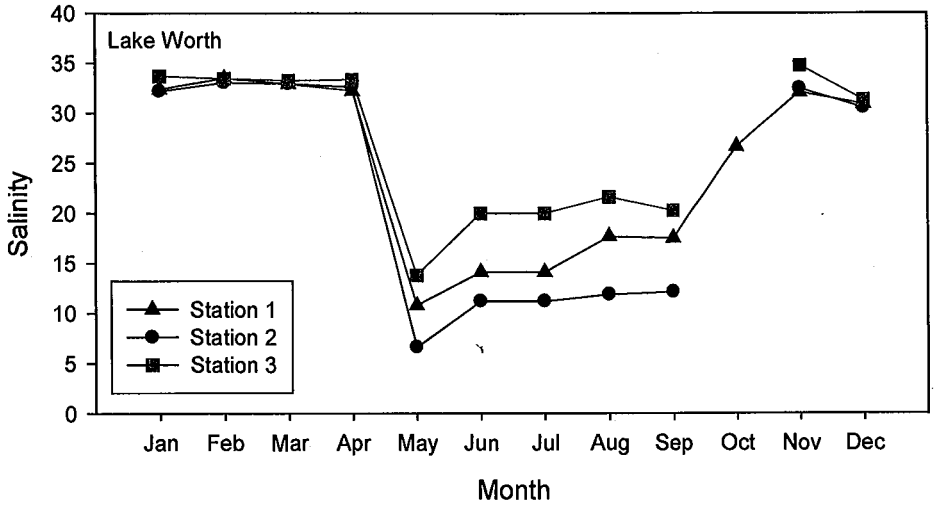

Figure 38. Monthly salinity recorded at stations in the Lake Worth study site during 2009. Missing data in October for stations 2 and 3 was due to a malfunctioning YSI unit.

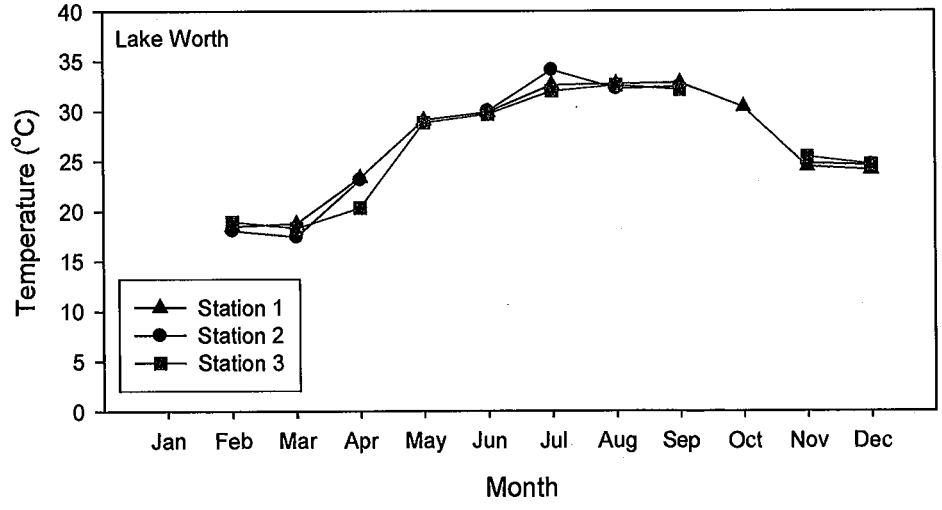

Figure 39. Monthly temperature recorded at stations in the Lake Worth study site during 2009. Missing data in January was due to a malfunctioning YSI unit.

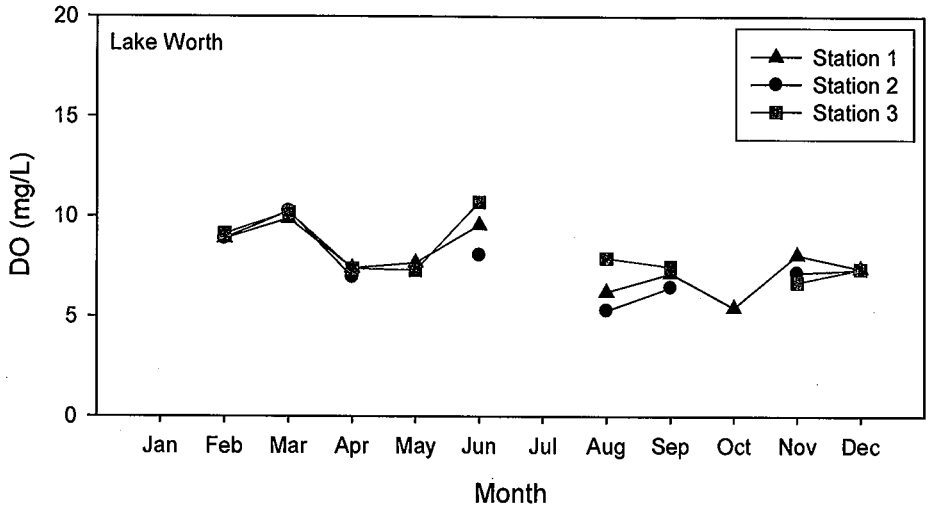

Figure 40. Monthly dissolved oxygen concentration recorded at stations in the Lake Worth study site during 2009. Missing data was due to a malfunctioning YSI unit.

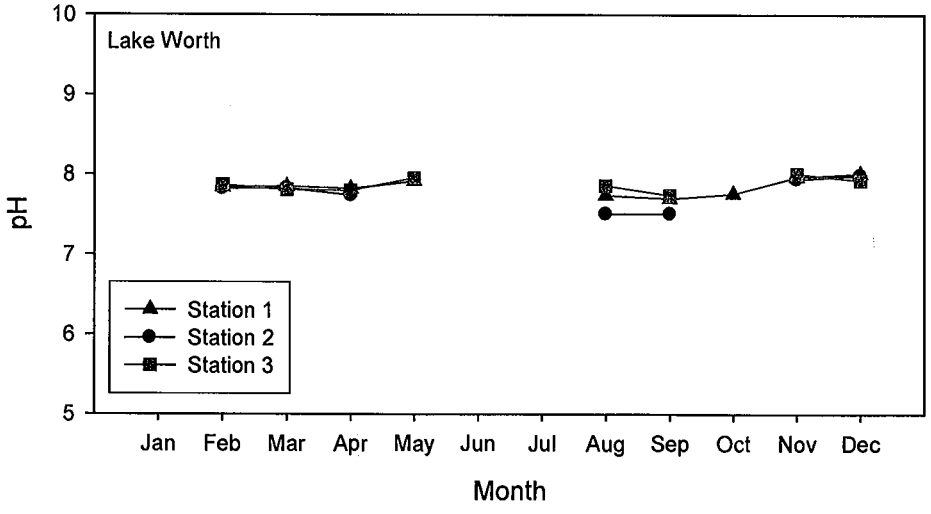

Figure 41. Monthly pH recorded at stations in the Lake Worth study site during 2009. Missing data was due to a malfunctioning YSI unit.

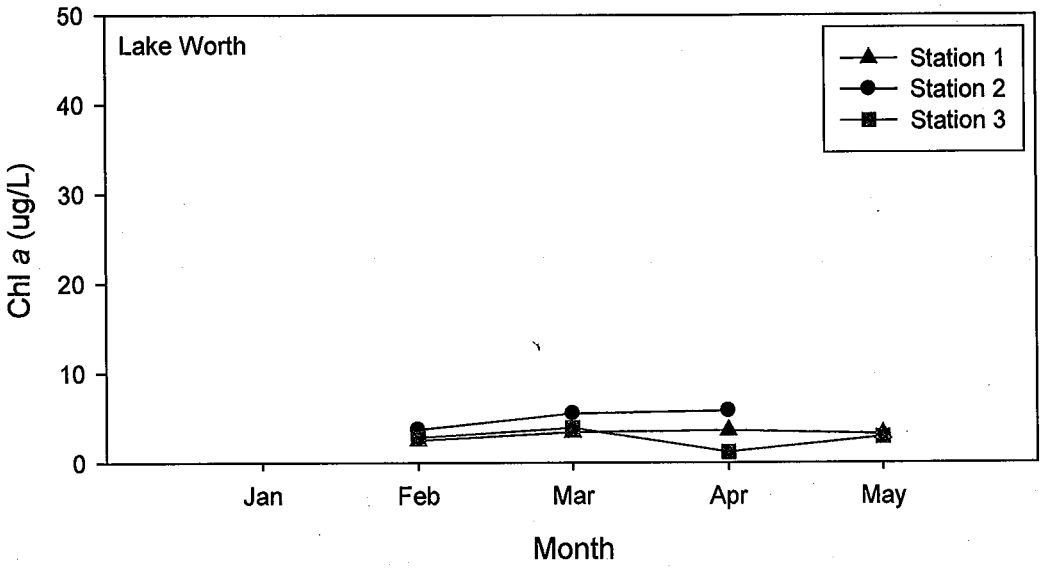

Figure 42. Monthly chlorophyll *a* concentration recorded at stations in Lake Worth study site during 2009. Missing data in January and May was due to a malfunctioning YSI unit. Chlorophyll *a* concentration was no longer measured after May 2009.

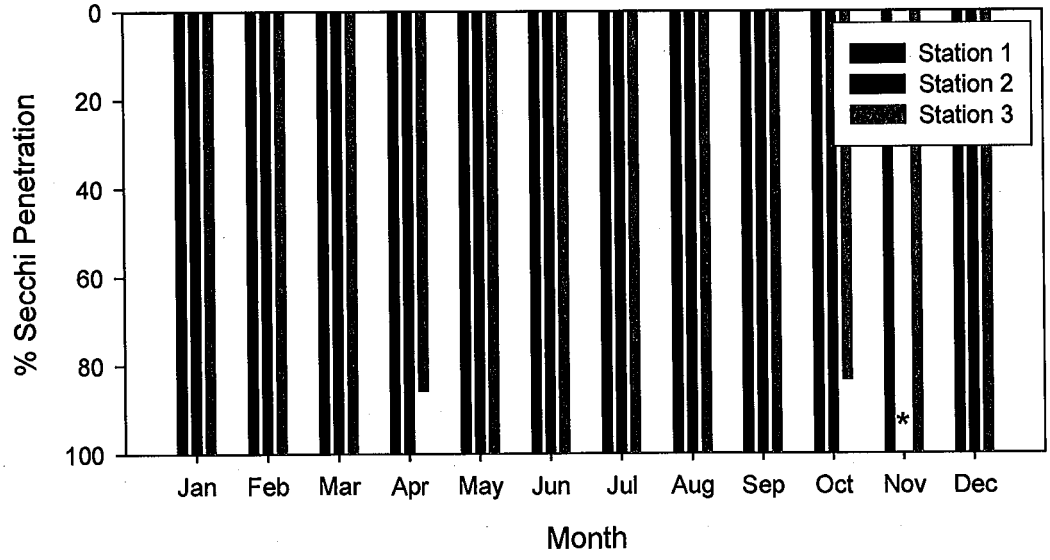

Figure 43. Monthly percent Secchi penetration recorded at stations in the Lake Worth study site during 2009. The asterisk indicates a month when the station was exposed during low tide.

Discussion

In January 2005, a long term monitoring program intended to document the response of oysters, *Crassostrea virginica*, to CERP activities was initiated in six Florida estuaries. The current study began in early 2008 and continued the previous monitoring effort in three of those six estuaries: St. Lucie estuary (SLE), Loxahatchee River (LOX), and Lake Worth Lagoon (LWL). Four aspects of oyster ecology were monitored: spatial and size distribution patterns of adult oysters, distribution and frequency patterns of the oyster diseases *Perkinsus marinus* (dermo) and *Haplosporidium nelsoni* (MSX), reproduction and recruitment, and juvenile oyster growth.

Salinity continues to be the driving force behind changes in oyster survival, abundance and health in our study sites. Although oysters in each estuary were subjected to large variations in salinity, 2009 was a relatively innocuous; there were no extreme rainfall events or prolonged freshwater releases. At most study sites, salinities were consistently high throughout the first four or five months of the year, but decreased rapidly in either May or June. In SLE, salinities were variable throughout the summer with minima (<5 ppt) occurring in August after which they began steadily increasing, reaching the optimal range (15-20 ppt) for oyster survival and recruitment success at most stations by October. At the Loxahatchee-North site, lowest salinities occurred in August but remained close to optimal levels throughout the rest of the year. Salinities in Loxahatchee-South were higher and less variable, rarely falling below 20 ppt, with values at most stations near 30 ppt for most of the year. In LWL, salinities were greater than 30 ppt from January through April then decreased rapidly in May where they remained near the optimal range through September before increasing to more 30 ppt by the end of the year.

The eastern oyster thrives in salinities from 10-30 ppt but does poorly when salinity falls below 5 ppt for a period of from one to five months (Shumway, 1996). Although there were no significant storm and/or water release events in 2009, it is important to mention that during this time period SLE oysters were recovering from a near complete die-off related to Tropical Storm Fay in fall 2008. Fortunately, salinities increased rapidly after the low salinity event, allowing for some settlement of new recruits in the central estuary site near the end of 2008. Those recruits successfully overwintered, allowing for a more rapid recovery of oysters at this site in 2009. This is reflected in our 2009 survey results, where mean oyster densities in the central estuary increased from less than 10 m^{-2} in fall 2008 to over 300 m^{-2} in 2009 and mean sizes of oysters increased from <15 mm SH to over 50 mm SH by fall 2009. Although live

oysters were again present in both the north and south fork sites during 2009, recovery at those sites has been slower with densities of less than 50 m^{-2} in the fall. In fact, by the end of 2009 there were still no live oysters at one of the three reefs in the south fork site. The slow recovery in the forks is most likely due to a combination of low availability of settlement substrate and limited oyster recruits.

Differences in oyster densities among stations in the SLE sites can also be attributed to local salinity conditions. In the both the north and south forks, oyster densities were significantly higher at stations that were closer to the main estuary rather than farther upstream. In 2009, average annual salinities at those stations in the north and south fork were oyster densities was higher were near 17 ppt (within the optimal range) which is approximately 1.5 ppt higher than the other stations in the north fork and 3 ppt higher than the most upstream station in the south fork, which is the reef with no live oysters. While the central estuary site is further downstream and more buffered from low salinity events, there are still differences in salinity regimes. At the more abundant oyster reef on the north side of the central estuary, the minimum summer salinity only decreased to 6 ppt but at the two reefs on the south side of the central estuary salinities fell to 3ppt which is below the critical 5 ppt threshold. These rather small differences in mean salinity highlight the importance of even subtle shifts in salinity near the critical tolerance limits.

Despite the fact that the LOX and LWL sites are rarely impacted by low salinity events, local salinity regimes do influence density patterns both directly and indirectly. In 2009, oyster densities in the Loxahatchee-North site increased from spring to fall while densities in the Loxahatchee-South and LWL sites were similar between seasons. What may have allowed the LOX northwest fork site densities to increase between seasons is that salinities at this site were relatively lower and closer to the optimal range for maximal oyster survival and recruitment success throughout the year (annual average of 18.5 ppt). In contrast, salinities in both the LOX south fork site and LWL site were much higher, reaching annual averages of 25 ppt or greater. While those average salinities are within the tolerance range for oysters (10-30 ppt), it important to note that salinities in both sites were at or exceeded 30 ppt for six months of the year. As a consequence, oyster densities in those two sites were likely kept in check by a resultant increase in predation and/or disease incidence related to the high salinities.

The patterns of disease intensity and prevalence are markedly different between the three estuaries studied. Both intensity and prevalence were much higher in LOX and LWL, where salinities were both

higher and more stable, than in SLE, where salinities were relatively lower and more variable. Those patterns are typical of what has been seen in previous years in each estuary. The most straightforward explanation for the differences in parasite incidence is that the salinities experienced in much of the SLE are too low for completion of the life history of the *Perkinsus marinus* (dermo) parasite. It is well established that low temperature and low salinity are correlated with reduced levels of infection (Craig et al., 1989), thus oysters in SLE suffered reduced prevalence and intensity of the disease relative to the oysters in the LOX or LWL sites. Only when salinities exceeded 25 ppt in May and during the warmer summer months, was dermo detected in any of the SLE oysters. It appears that, because salinity fluctuates so consistently at the SLE study sites, that dermo never gains a foothold and although the parasite may be present the intensity of the infection remains low. The frequent low salinity events that SLE experiences may further reduce the success of the parasite by killing off its host organism. Infection intensity levels in LOX and LWL are similar, but because those estuaries experience longer periods of high salinity the oysters that occupy those estuaries experience relatively elevated prevalence of dermo. Nonetheless, intensity remained low at all sites in 2009 with levels rarely exceeding 1 on the Mackin scale and the severity of dermo in southeast Florida estuaries remains considerably less than it is in most Gulf of Mexico populations (Craig et al., 1989). To date, we have not detected the MSX parasite (*Haplosporidium nelsoni*) in any samples collected from the three estuaries.

Reproductive development showed similarities among our study sites and some notable differences. In general, those oysters in what is considered developmental or fully ripe stages were most prevalent during the spring and summer months while most oysters collected in January, February, and December were classified as indifferent, completely devoid of gametes, or resting. In some sites, there were substantial numbers of oysters in the resting period as late as March, or as early as November. Both the Loxahatchee-South and LWL sites also had some indifferent stage oysters present in mid-summer. Those may represent young-of-the-year oysters which have not matured, or could represent early spawning oysters which were completely spent by the end of the spring. The greatest difference observed among estuaries was related to the nearly complete mortality of oysters throughout the SLE in fall 2008, making collection of samples for assessment of reproductive development impossible in January for the central estuary site and from January through March for the north and south fork sites.

Physiological condition in the LOX sites began the year high and gradually declined, representative of the transfer of energetic reserves into gamete production. In contrast, at all SLE sites and in LWL, physiological condition peaked during the summer months of June or July when the majority of oysters were in developmental or ripe reproductive stages and gradually declined throughout late summer and fall. This pattern is suggestive of one where metabolic demands are low enough and food supply high enough that acquired food is sufficient for both growth and reproduction. This result corresponds well with the observation that recruitment peaks were either non-existent in the spring (SLE sites) or lower in magnitude than the fall peak (LWL site). In previous years, most sites, when oysters were present, exhibited the pattern of high condition early in the year, with a gradual rate of decline as the reproductive season progressed. This reversal in 2009 condition index patterns was also noted in higher salinity outlier populations, Tampa Bay and Mosquito Lagoon, during our 2005-2007 study and may be indicative of populations in either higher salinity habitats or more stable salinity habitats.

Not surprisingly, recruitment patterns differed among the estuaries. In SLE, recruitment began in June at two of three sites, but was sporadic and low until the fall when the largest peaks occurred at all three sites. Although fall recruits were observed in the south fork, even at the peak in November the numbers were minimal. In the LOX and LWL sites, recruitment commenced as early as April and continued for the remainder of the year. However, each site had two strong recruitment peaks. Both LOX sites had strong spring peaks in May but in the fall peaks occurred in September in the south fork and October in the northwest fork. Similarly, LWL peaked in June and October. This bimodal pattern of recruitment is typical of oysters in other Florida waters such as Apalachicola Bay (Ingle, 1951) and has been observed in most of our study sites in past years (Arnold et al., 2008). The missing peak in the SLE sites is most likely due to the fact that those populations were composed of a new year-class of oysters resulting from the fall 2008 recruits, who settled after the summer die-off, but did not reach reproductive maturity until mid-summer.

As in previous years when oyster populations were decimated in SLE due to a low salinity event, the source of recruits that reestablishes the SLE oyster populations remains a mystery. Although we could find almost no live oysters in SLE during the fall 2008 survey, it is probable that a small relict population remained in the estuary. This population may have contributed the recruits that were detected in November

2008 in the central portion of SLE. It is also possible that those recruits were contributed by oysters living outside of the SLE, but there is no direct evidence to support either alternative. The source of these recruits is of more than academic interest. Whether the larval source was autochthonous or allochthonous, it is possible that continued coastal development will degrade the oyster population of southeast Florida to the point that recruits are no longer available at some sites. This condition does not have to remain for long, as evidence from consecutive oyster reef mapping efforts in the SLE suggest that at least the smaller reefs can subside in only a few years. This subsidence will eliminate the essential larval settlement substrate provided by an exposed reef, and once removed from the system it may require decades to rebuild (Mann and Powell, 2007) without intervention.

Juvenile growth rate was high in all three SLE sites and moderate in the LOX and LWL sites. This may be explained by each estuaries recruitment patterns. In LOX and LWL, if new recruits were consistently settling to the growth arrays from April through December, their smaller sizes would decrease the mean shell height recorded during those months. This is one drawback to setting up a growth study in this manner in that there is no efficient way to mark and follow the same cohort of oysters throughout the experiment. Growth rates in the SLE were high until October when mean oyster size plummeted. This again can be attributed to recruitment patterns since recruitment in those sites peaked in October and November. Following recruitment, the juvenile SLE oysters grew rapidly reaching a mean SH of 30 mm in just 5 months. These growth rates are typical of oysters in the southeastern United States and particularly in the Gulf of Mexico, but are more rapid than those typically reported for more northern populations (Shumway, 1996). Consistent with other bivalves, the more rapid growth of oysters in southern latitudes may be attributed to the longer growing season rather than to an inherently more rapid growth rate (Jones et al., 1990). This distinction is important, because factors other than temperature also influence growth rate. In particular, oysters do not grow well at salinities less than 10 ppt (Loosanoff, 1953). Ramifications of growth variation can be significant, as faster growing oysters will more quickly escape the ravages of size-limited predators and also would be expected to reallocate energy from growth to reproduction at an earlier age.

Water quality parameters generally fell within expected ranges within each site. Although overall annual salinities were highly variable in each estuary, they were generally higher and relatively stable over

the months than recorded in previous years, especially in SLE. Temperatures rose and fell almost as expected. The water column at each study site remained well oxygenated and pH was near or slightly below 8. Water clarity was generally good, with Secchi depth penetrating to the bottom at most sites throughout the year. The notable exceptions were at the SLE fork sites, which were more impacted by low salinity and freshwater releases.

This report summarizes oyster population monitoring at six sites within three estuaries in southeast Florida within the South Florida Water Management District's domain during 2009. Results indicate that the patterns of oyster abundance, health, and population ecology within two (LOX and LWL) of the study estuaries generally fell within the bounds expected for central and south Florida oyster populations. The impact of anthropogenic events, particularly introductions of freshwater into the estuaries to manage inland water levels, forced salinity values outside of expected and suitable ranges in the SLE in late 2008 and as result those oyster populations were again decimated. The impacts of the 2008 conditions continued to be observed in the 2009 oyster population. Detailed examination of each die-off event and their consequences continues as we correlate actual control structure flow rates with the biological and ecological responses of the oysters. In the meantime, it is apparent that such freshwater releases must be carefully considered with respect to their impact on a host of downstream organisms but particularly oysters. Because the oyster repertoire includes habitat engineering, impacts to oyster populations will have uniquely broad-ranging consequences for a host of ancillary organisms and for the oysters themselves, whose recovery from such events may be serially degraded to the point of no return.

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