SARASOTA BAY
Numeric Nutrient Criteria:
Task 3 – Dissolved Oxygen

Letter Memorandum

Prepared for:

Sarasota Bay Estuary Program

Prepared by:

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FOREWORD

This letter memo was produced in partial fulfillment of SBEP Contract 2011SBEP04 - Development of Numeric Nutrient Criteria for Sarasota Bay, Task 3.

ACKNOWLEDGEMENTS

We wish to thank the partners of the Sarasota Bay Estuary Program (SBEP) for the numerous conversations providing direction and insight into concerns regarding numeric nutrient criteria establishment and appropriate methodology for developing the proposed criteria. We would particularly like to thank the following individuals who serve on the water quality subcommittee of the Technical Advisory Committee: Mark Alderson, Dr. Jay Leverone, Jack Merriam, Rob Brown, Lizanne Garcia, Kris Kaufmann, Veronica Craw, John Ryan, Gary Serviss, Amber Whittle, Pete Wenner, Charles Kovach, and Jon Perry.

EXECUTIVE SUMMARY

The Sarasota Bay Estuary Program (SBEP) has recommended numeric nutrient criteria to U.S. Environmental Protection Agency (EPA) for the segments of the SBEP area. The criteria, as proposed to EPA, are segment-specific and are expressed as annual total nitrogen (TN) and total phosphorus (TP) concentrations and loadings. An integral component of the establishment of numeric nutrient criteria involves the assessment of protecting full aquatic life support within the estuary.

This investigation examines the characteristics of dissolved oxygen (DO) concentrations in Sarasota Bay segments with respect to the Florida Department of Environmental Protection's (FDEP) dissolved oxygen standard of 4 mg/L. Dissolved oxygen is also used as an additional indicator of eutrophic conditions and can serve as an indicator of habitat suitability for a wide range of aquatic fauna (e.g., fishes and benthic invertebrates). The conceptual model applied by FDEP in establishing the DO standard is that excess nutrients from anthropogenic assaults result in algal blooms which in turn result in increased organic deposition and decomposition which in turn lead to reduced DO concentrations.

The objective of this study was to assess the percentage of state standard exceedances in DO and assess drivers of DO exceedances with respect to the proposed numeric nutrient criteria for the SBEP area. This study also explored evidence that the FDEP conceptual model described above is currently relevant in the SBEP area. In particular, this assessment investigated the relationship between the percentage of DO exceedances in each of Sarasota Bay's five bay segments and the threshold values for chlorophyll *a* established. Descriptive and quantitative analyses were used to evaluate the effects of known drivers of DO including temperature, depth, bottom type, stratification, and chlorophyll *a* concentrations

The following conclusions can be drawn from the analyses presented in this report:

- Based on an assessment similar to FDEP's Impaired Waters Rule, the empirical evidence presented here suggests that all major segments of Sarasota Bay are meeting full aquatic life uses with respect to DO.

- The most obvious principal factor affecting DO in Sarasota Bay is temperature. That is evident in both the descriptive temporal plots and in the generalized linear model assessed in the quantitative assessment of those factors affecting the probability of DO being less than 4 mg/L. The model results indicate that stratification, bottom type, and sample depth were other factors that contributed to the probability of low DO conditions (i.e., < 4 mg/L). Furthermore, it was determined that chlorophyll *a* concentrations were not a significant factor contributing to probability of low DO conditions in Sarasota Bay. In other words, the occurrence of DO values below 4 mg/L were not significantly related to observed chlorophyll *a* concentrations at the time of sampling.

- Based on the weight-of-evidence presented here, it is reasonable to conclude that the numeric nutrient criteria proposed by the Sarasota Bay Estuary Program are protective of full aquatic life uses with respect to DO.

1.0 Introduction and Objective

The Sarasota Bay Estuary Program (SBEP) has recommended numeric nutrient criteria to U.S. Environmental Protection Agency (EPA) for the following bay segments: Sarasota Bay, Palma Sola Bay, Roberts Bay North, Little Sarasota Bay and Blackburn Bay (Figure 1) (Janicki Environmental, 2010a). The criteria, as proposed to EPA, are segment-specific and are expressed as annual total nitrogen (TN) concentrations using chlorophyll *a* concentrations as a primary response variable. An integral component of the establishment of numeric nutrient criteria involves the assessment of protecting full aquatic life support within the estuary. Total phosphorus (TP) concentration criteria were developed using a reference period approach (Janicki Environmental, 2010b).

This investigation examines the characteristics of dissolved oxygen (DO) concentrations in Sarasota Bay segments with respect to the Florida Department of Environmental Protection's (FDEP) dissolved oxygen standard of 4 mg/L as part of that process. The FDEP has established the state water quality standards (FAC 62.302) to protect the designated uses of Florida waterbodies. The standard established for DO in predominantly marine waters requires meeting the 4 mg/L standard no less than 90% of the time (i.e., a 10% exceedance). Dissolved oxygen is also used as an additional indicator of eutrophic conditions and can serve as an indicator of habitat suitability for a wide range of aquatic fauna (e.g., fishes and benthic invertebrates).

The conceptual model applied by FDEP in establishing the DO standard is that excess nutrients from anthropogenic assaults result in algal blooms which in turn result in increased organic deposition and decomposition which in turn lead to reduced DO concentrations. There are several case studies that demonstrate that excess nutrients from poorly treated municipal wastewater as well as non-point source runoff have contributed to eutrophic estuarine conditions. Symptoms of eutrophication include excess primary production, deposition and decomposition of phytodetritus and consequently increased biological oxygen demand which reduces the DO content of estuarine waters (Nixon, 1995).

The objective of this effort was to assess the percentage of state standard exceedances in DO and assess drivers of DO exceedances with respect to the proposed numeric nutrient criteria for the Sarasota Bay estuary (Janicki Environmental, 2010a). This study also explored evidence that the FDEP conceptual model described above is currently relevant in the Sarasota Bay estuary. In particular, this assessment investigated the relationship between the percentage of DO exceedances in each of Sarasota Bay's five bay segments and the threshold values for chlorophyll *a* established. Descriptive and quantitative analyses were used to evaluate the effects of known drivers of DO including temperature, depth, bottom type, stratification, and chlorophyll *a* concentrations

Figure 1. Sarasota Bay Estuary Program bay segments.

2.0 Data Sources

The data sources for this assessment include:

- Routine water quality monitoring data collected by Mote Marine Laboratory for Sarasota County (SC),
- Routine water quality monitoring data collected by Manatee County Department of Environmental Management (MCDEM), and
- Physical chemistry data collected by the Florida Fish and Wildlife Conservation Commission's Fisheries Independent Monitoring Program (FIM) program.

Monthly fixed station water quality data have been collected within Sarasota County bay waters by the Sarasota County from 1998-2009 using a monthly-specific, fixed station hierarchical design. The sampling locations for the Sarasota County sampling program are provided in Figures 2-5. Manatee County water quality data were obtained from Florida IWR run 40 and include quarterly sampling at fixed stations located in upper Sarasota Bay and Palma Sola Bay between1998-2009 (Figure 6). Physical chemistry profile data including temperature, salinity, conductivity and DO from the Florida Fish and Wildlife Conservation Commission's Fisheries Independent Monitoring Program (FIM) program were also obtained and analyzed. These data were collected concurrent with fisheries samples throughout the Sarasota Bay Estuary Program study area. The FIM program sampling in Sarasota County began in 2009 using a probabilistic design and a bi-monthly sampling frequency. The FIM sampling locations for data used in this analysis is provided in Figures 7-11. The total number of DO observations in each year from 1998 through 2009 is provided for each segment in Figure 12.

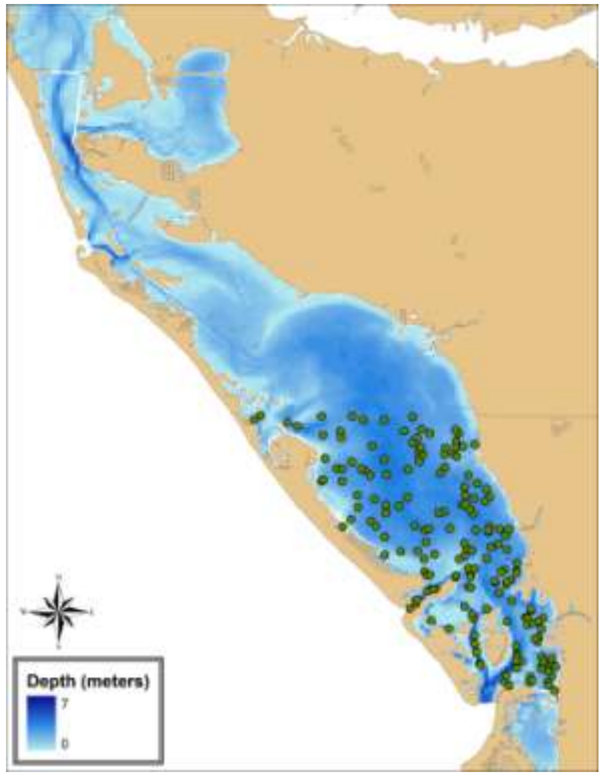

Figure 2. Sarasota County - Sarasota Bay water quality sampling locations.

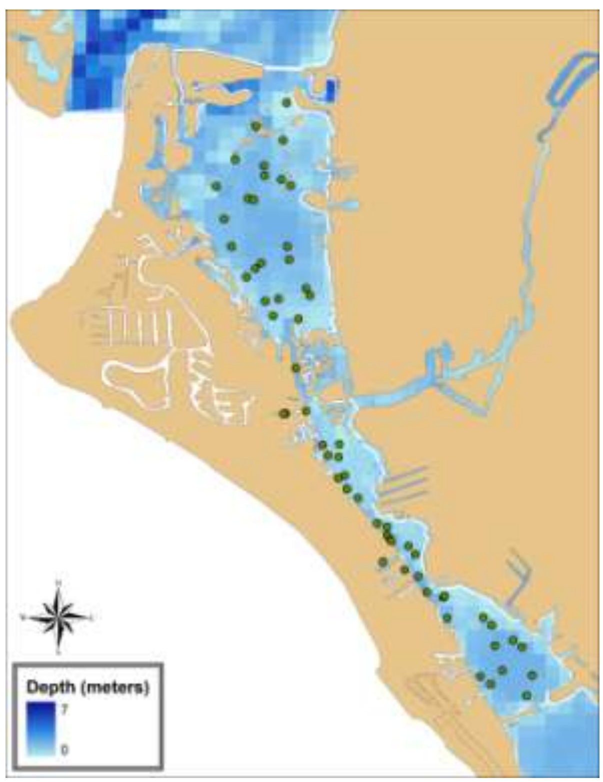

Figure 3. Sarasota County - Roberts Bay water quality sampling locations.

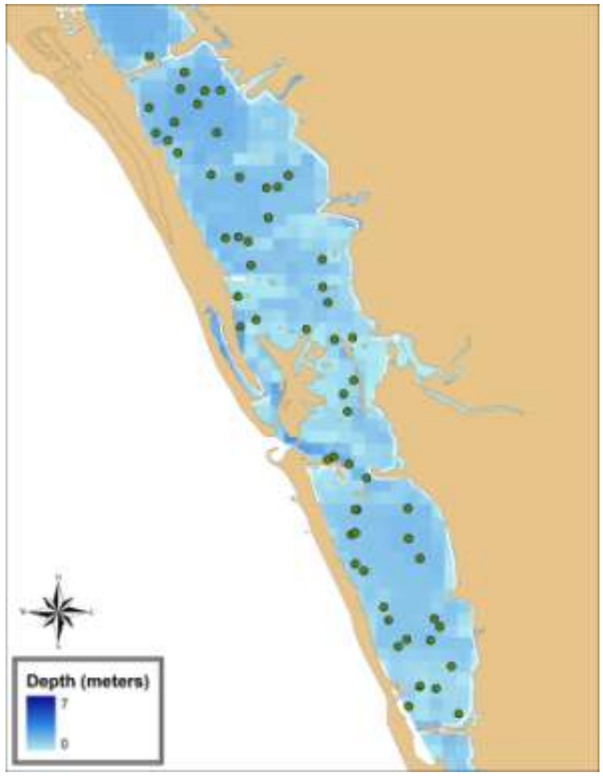

Figure 4. Sarasota County – Little Sarasota Bay water quality sampling locations.

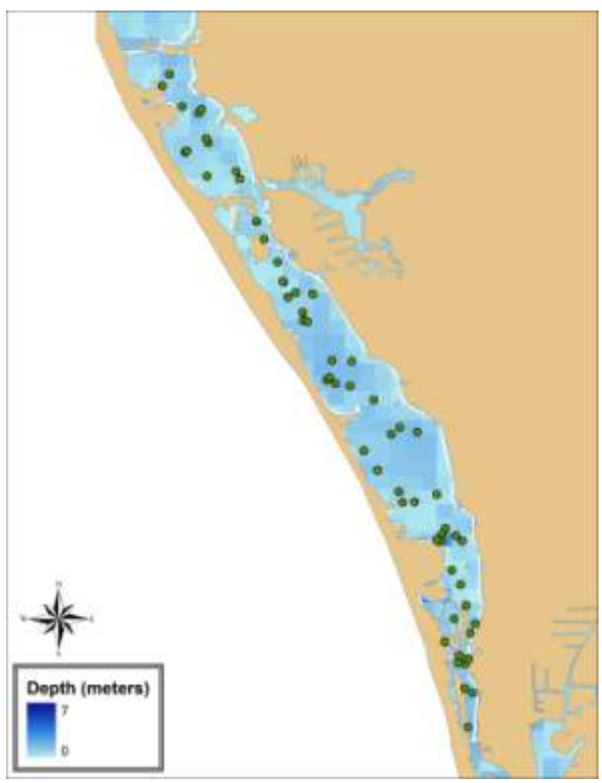

Figure 5. Sarasota County – Blackburn Bay water quality sampling locations.

Figure 6. Manatee County bay water quality sampling locations.

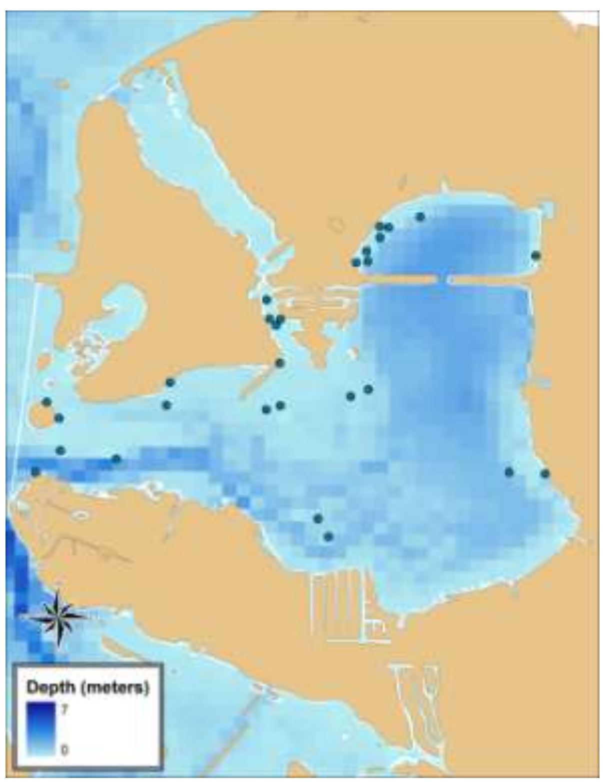

Figure 7. Fisheries Independent Monitoring – Palma Sola Bay sampling locations.

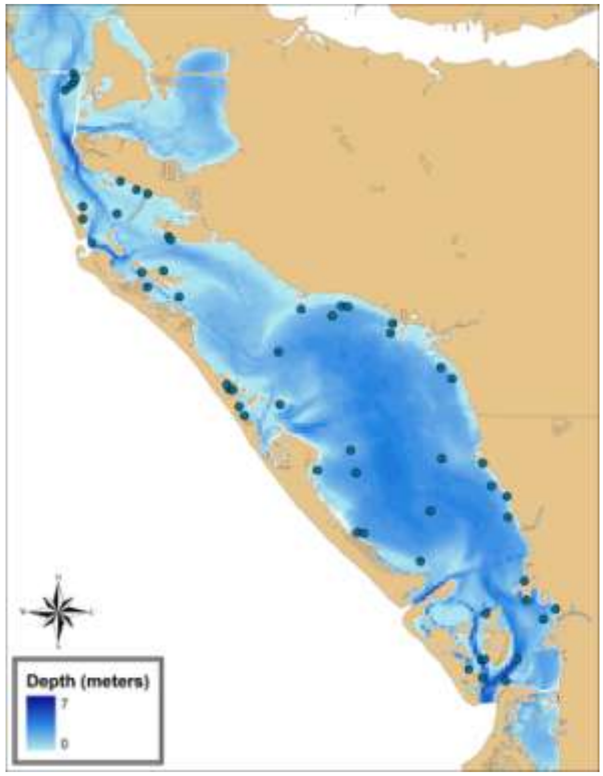

Figure 8. Fisheries Independent Monitoring – Sarasota Bay sampling locations.

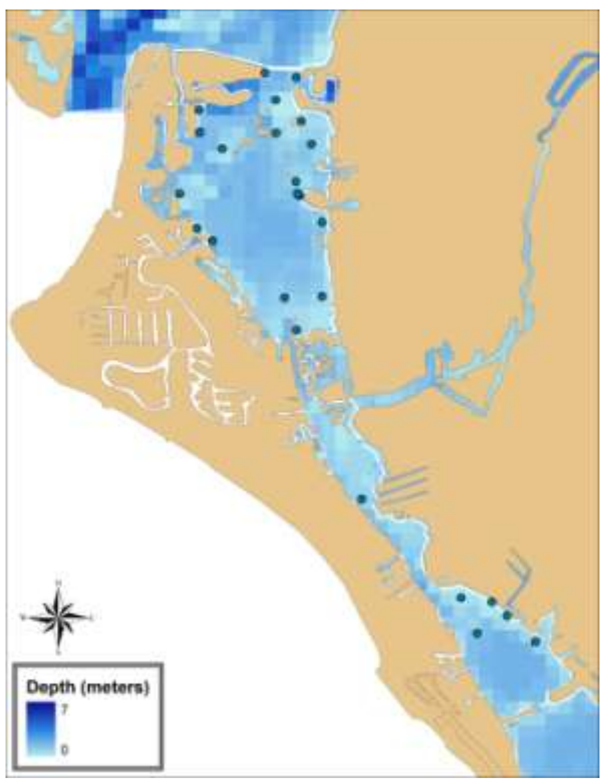

Figure 9. Fisheries Independent Monitoring – Roberts Bay sampling locations.

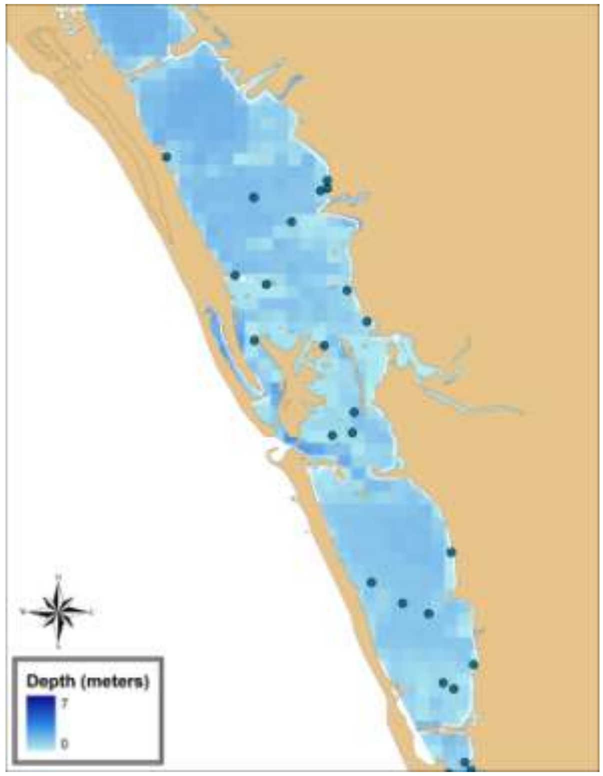

Figure 10. Fisheries Independent Monitoring – Little Sarasota Bay sampling locations.

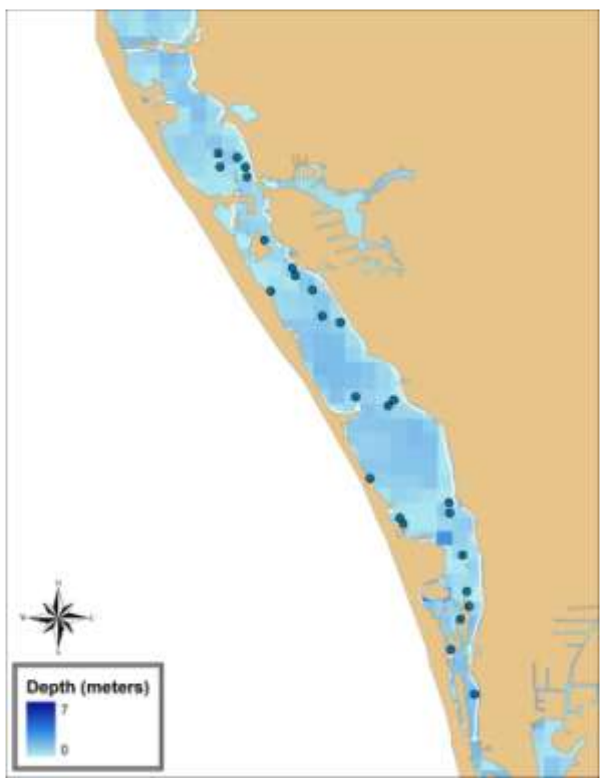

Figure 11. Fisheries Independent Monitoring – Blackburn Bay sampling locations.

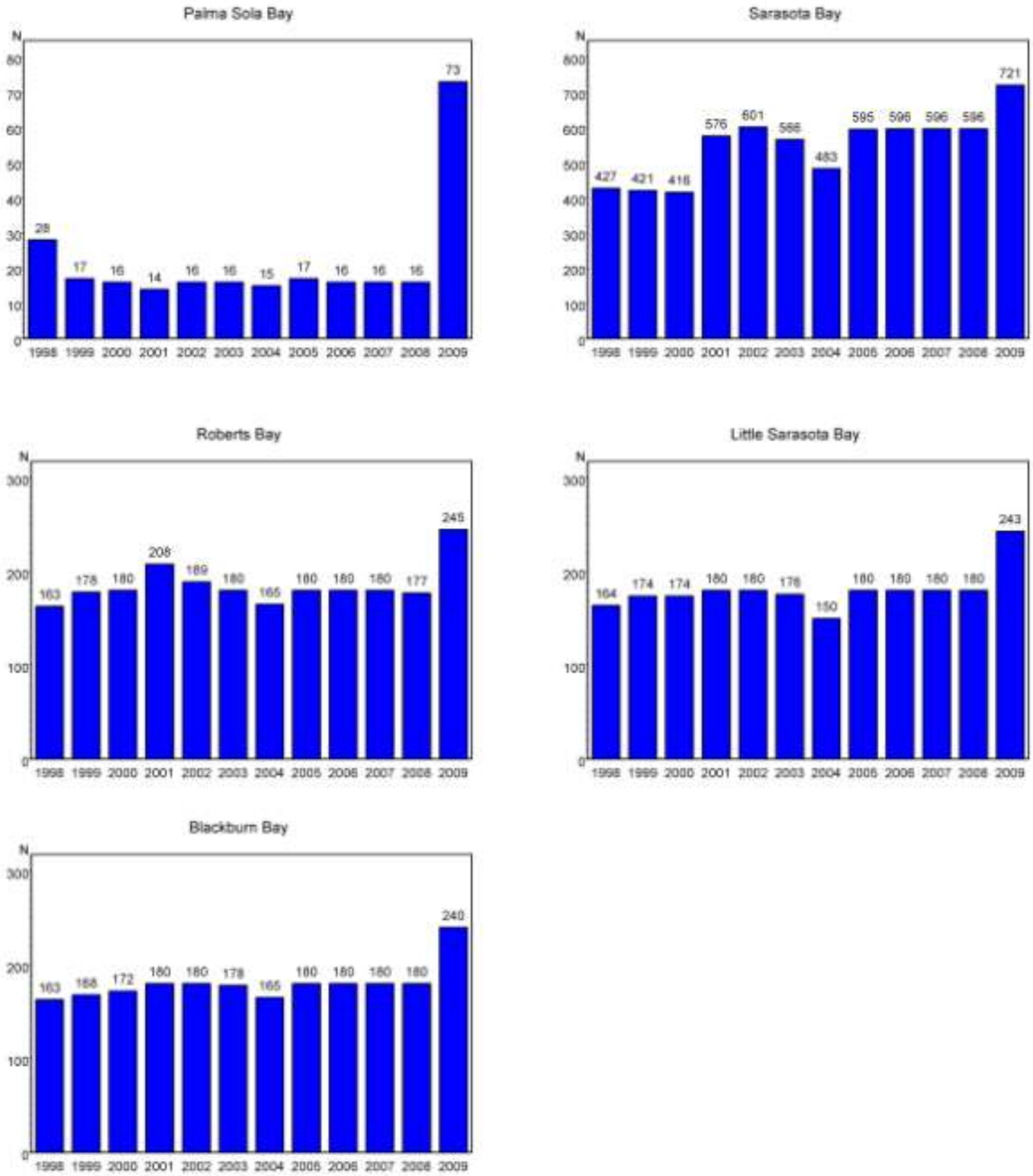

Figure 12. Number of DO observations by year in each bay segment.

3.0 Approach

Descriptive and exploratory data analyses were conducted to characterize DO in the bay segments of SBEP study area. The DO data were mapped using ArcGIS (ESRI, 2009) to allow examination of the spatial representation of the sampling within Sarasota Bay. Spatial and temporal variation in DO was represented using descriptive plots and a series of ArcGIS maps. An exploratory data analysis was conducted to investigate the factors affecting dissolved oxygen concentrations in the bay segments which included examining the effects of seasonality, location and physical factors such as salinity stratification that are known to affect DO concentrations.

4.0 Results

This section presents the following results:

- examination of the temporal patterns in DO exceedances in each segment,
- examination of the spatial patterns in DO in each segment, and
- analysis of the factors affecting DO in Sarasota Bay segments.

4.1 DO exceedances – temporal patterns

The first step in the analysis was to examine the temporal patterns in DO in each bay segment. A time series plot of all DO observations (surface, middle, bottom) with each agency denoted using a different symbol is presented in Figures 13-17 (reference line at 4 mg/l state standard).

The average of all DO observations (i.e., all depths) in all segments was around 6.5 mg/L with very few observations below the FDEP state standard of 4 mg/L. The few observations below 4 mg/L tended to occur during summer when temperatures were at their highest as expected. The annual exceedance percentage (i.e., the percentage of the total number of DO samples [surface, middle, bottom] collected within a year that are less than 4 mg/L) for each segment is plotted in Figures 18-22. A reference line at the 10 % state standard has been included in these plots for ease of comparison. Only in Palma Sola Bay in 2009 were greater than 10% of the observations below 4 mg/L. This was the only year for which data were available from the FIM sampling effort and may incorporate either a spatial or temporal bias in the data This indicates that all segments in nearly all years are meeting their full aquatic life uses with respect to dissolved oxygen.

The within-year variation in the percentage of all samples less than 4 mg/L for each bay segment is shown in Figures 23-27. The influence of temperature and salinity on the capacity of estuarine water to hold oxygen is evident. There are very few values below 4 mg/L in winter months, while in summer months a higher preponderance of observations with a DO value below 4 mg/L in all segments. The proportion of DO values less 4 mg/L only exceeded 10% in August and September.

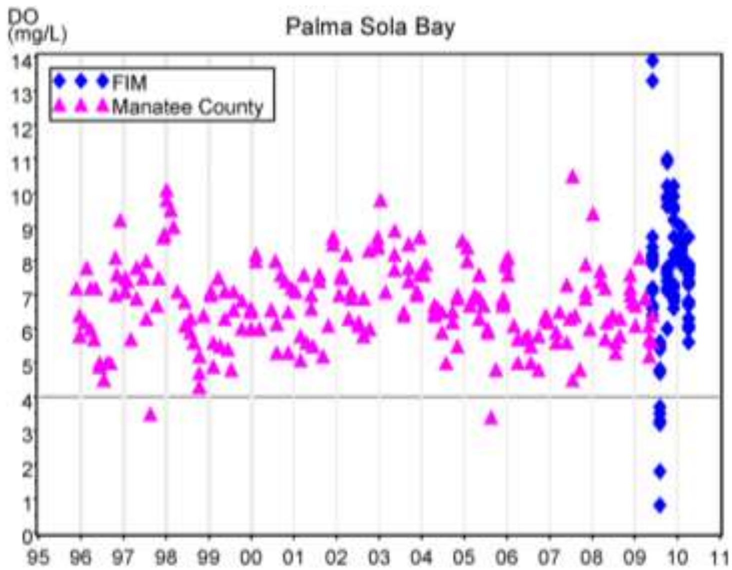

Figure 13. Time series plot of dissolved oxygen values in Palma Sola Bay between 1998 and 2009.

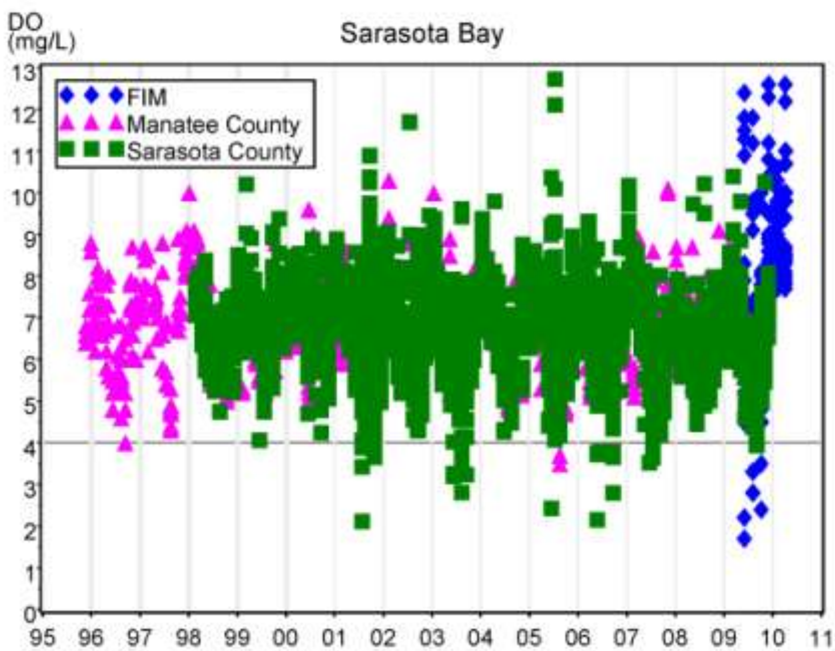

Figure 14. Time series plot of dissolved oxygen values in Sarasota Bay between 1998 and 2009.

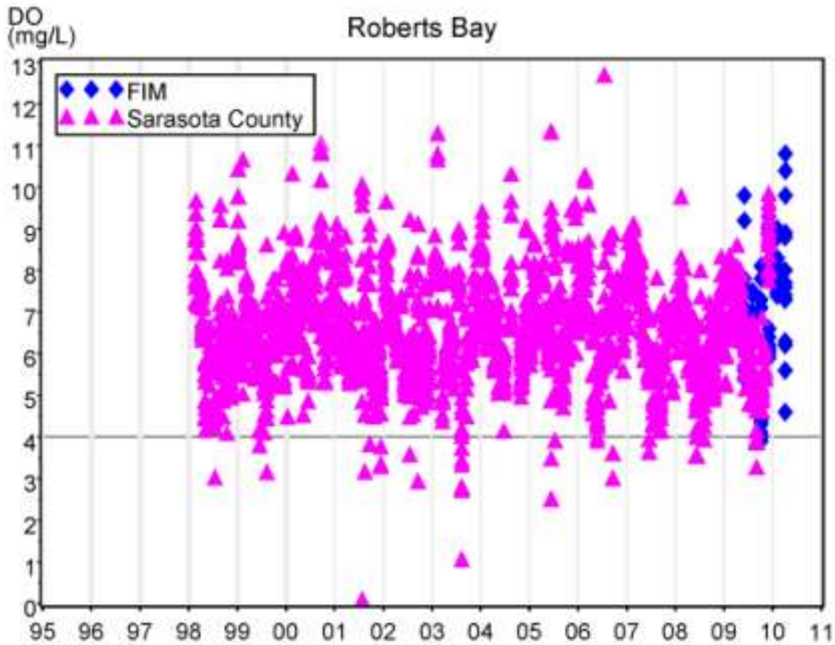

Figure 15. Time series plot of dissolved oxygen values in Roberts Bay North between 1998 and 2009.

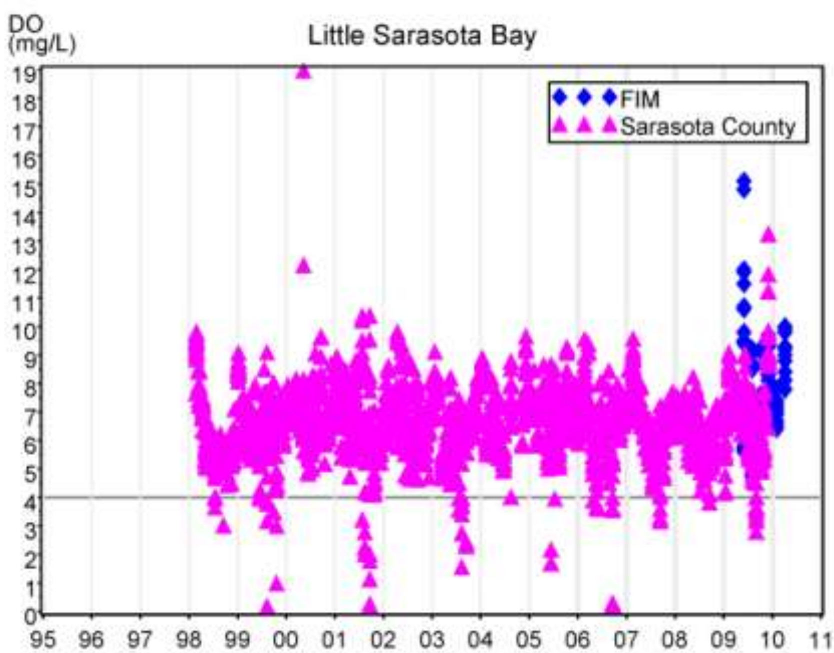

Figure 16. Time series plot of dissolved oxygen values in Little Sarasota Bay between 1998 and 2009.

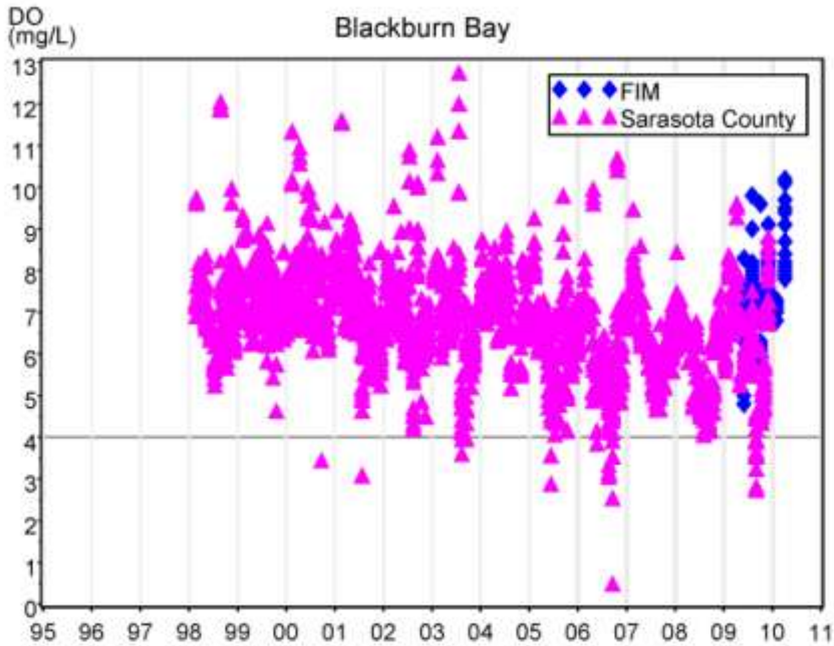

Figure 17. Time series plot of dissolved oxygen values in Blackburn Bay between 1998 and 2009.

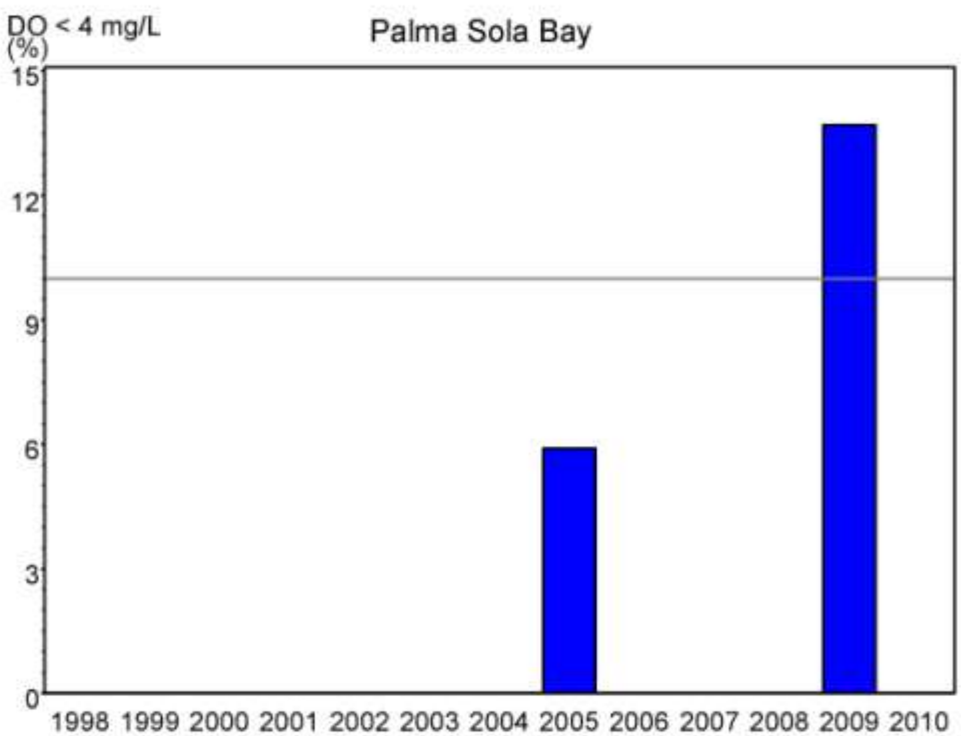

Figure 18. Annual frequency of DO exceedances in Palma Sola Bay.

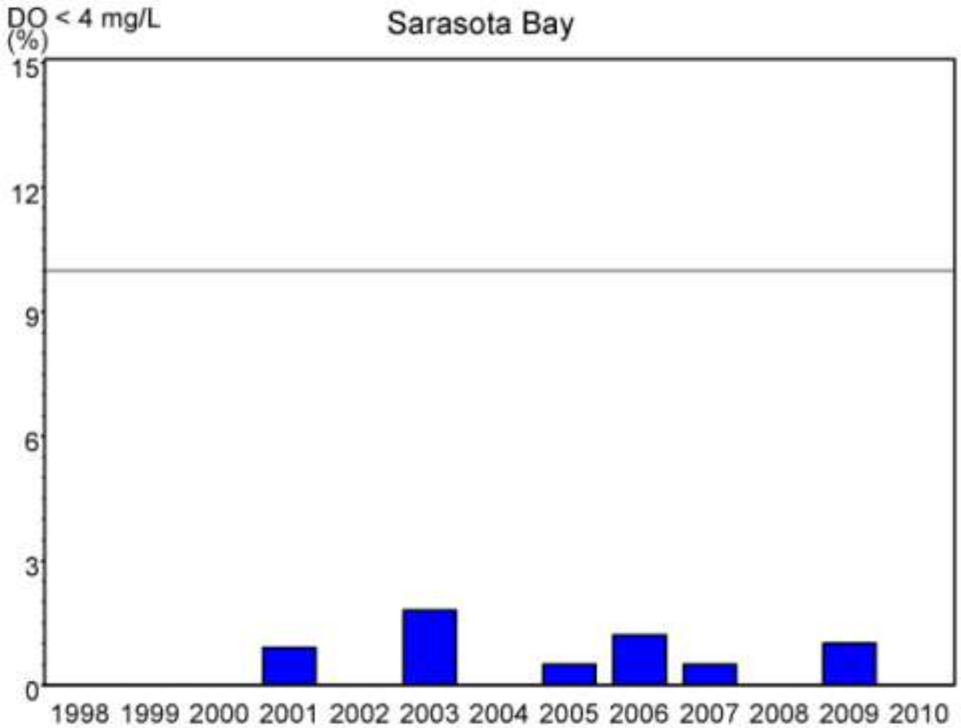

Figure 19. Annual frequency of DO exceedances in Sarasota Bay.

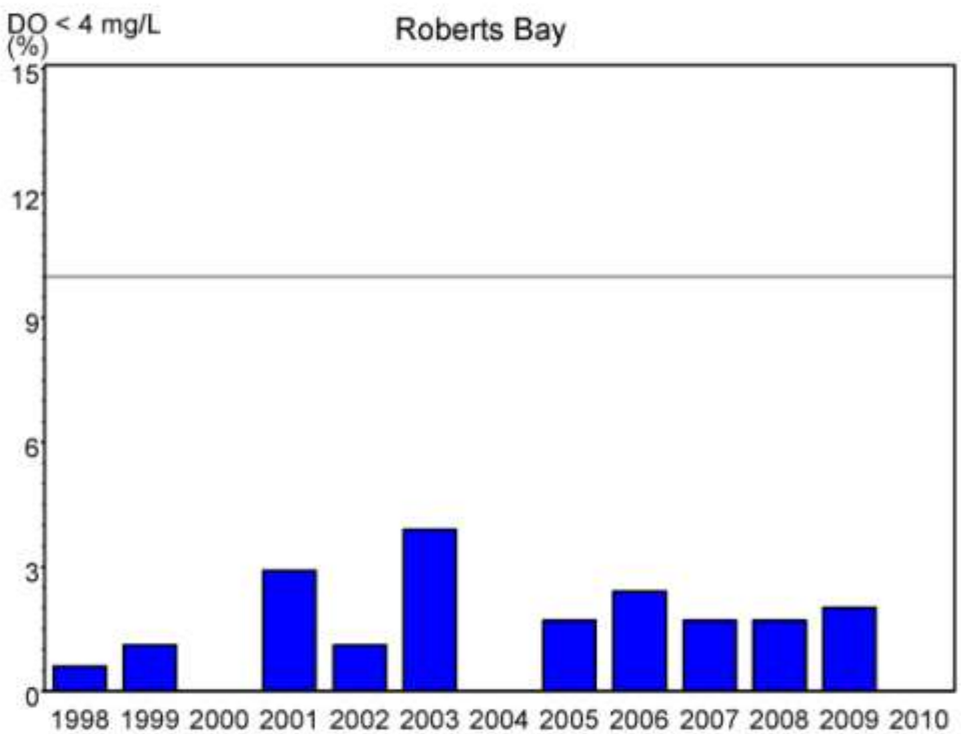

Figure 20. Annual frequency of DO exceedances in Roberts Bay.

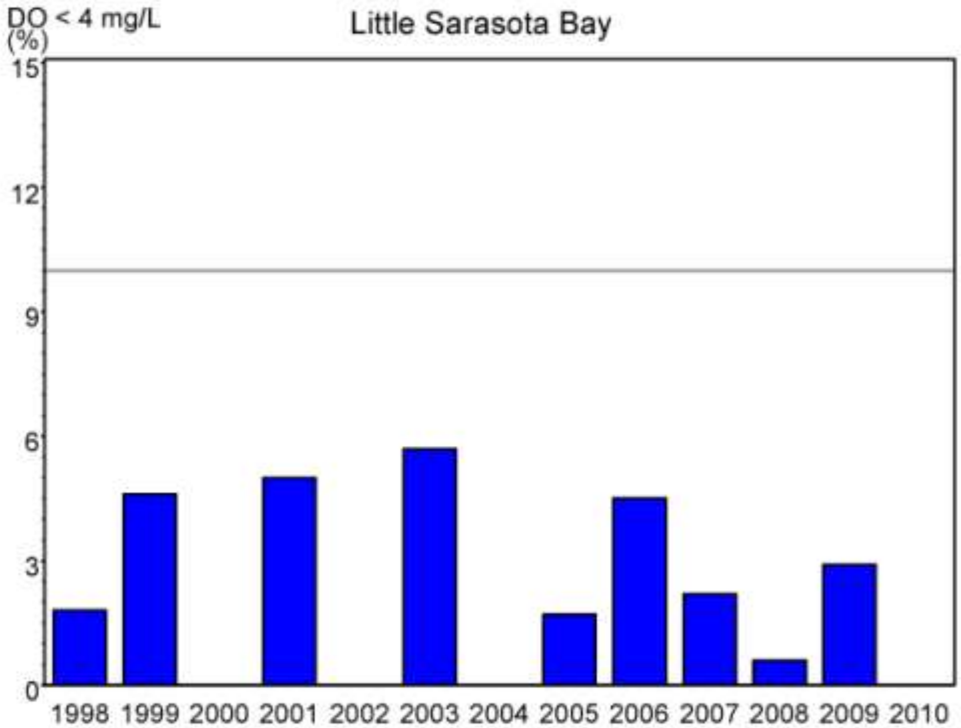

Figure 21. Annual frequency of DO exceedances in Little Sarasota Bay.

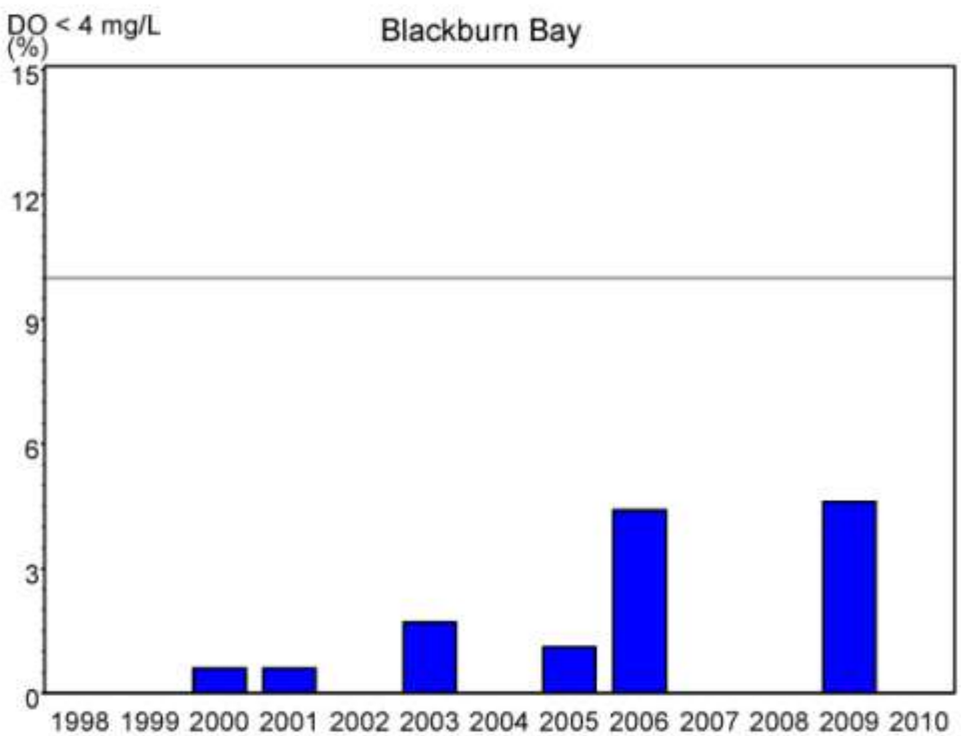

Figure 22. Annual frequency of DO exceedances in Blackburn Bay.

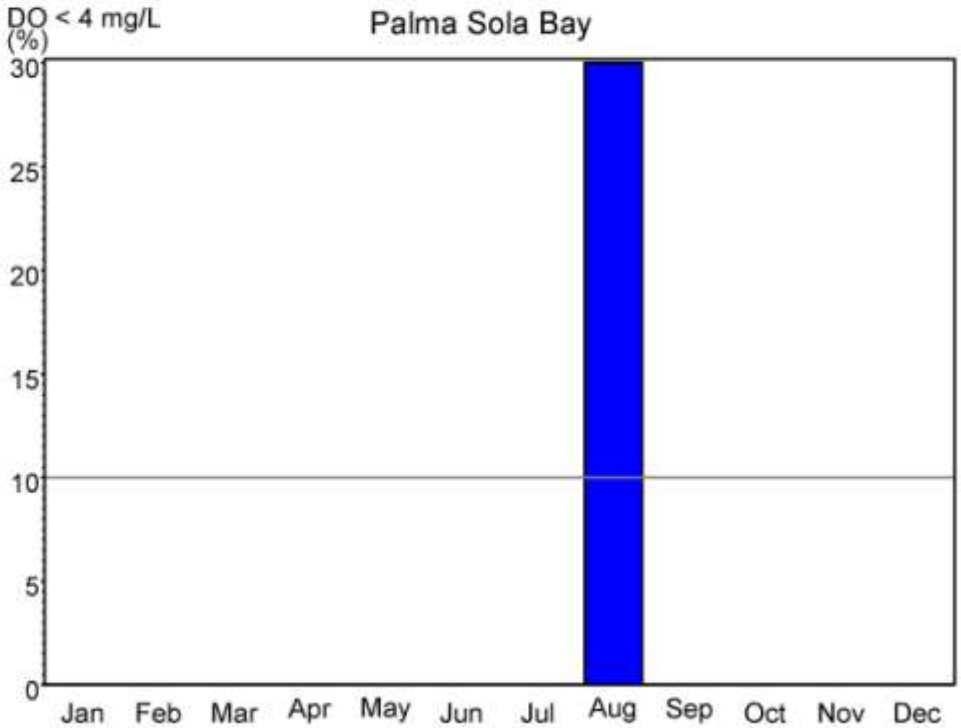

Figure 23. Frequency of DO exceedances in Palma Sola Bay by calendar month.

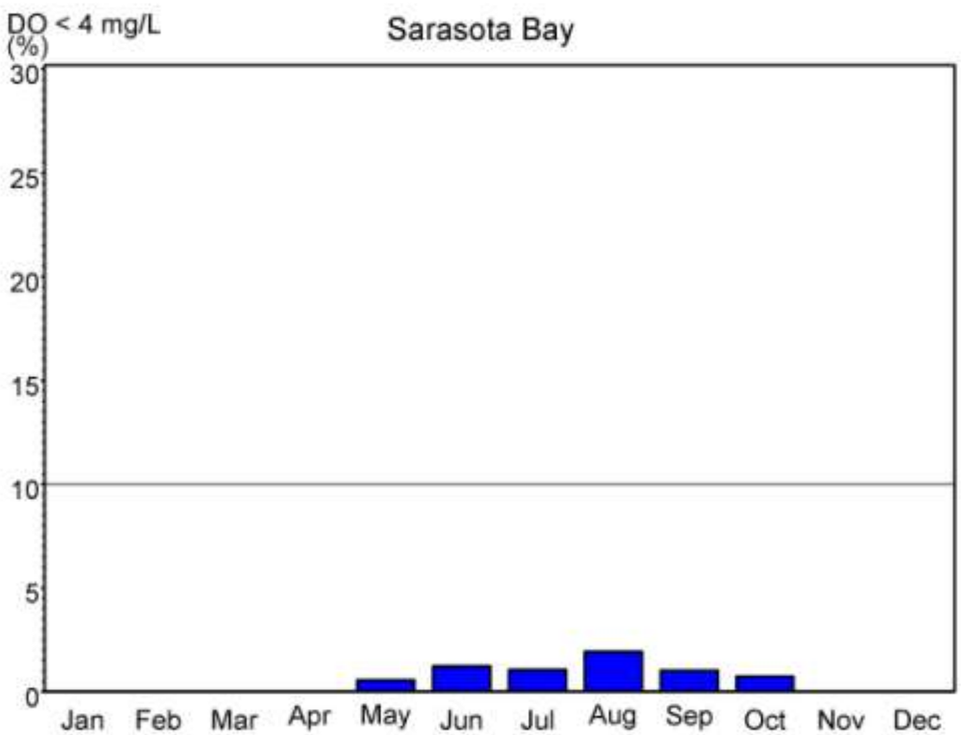

Figure 24. Frequency of DO exceedances in Sarasota Bay by calendar month.

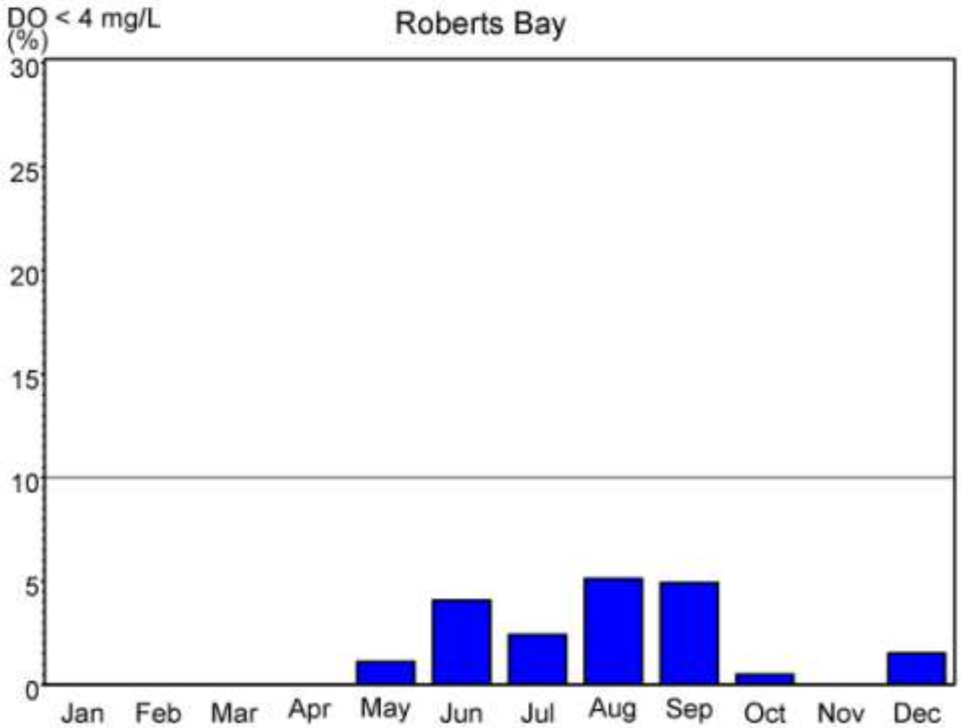

Figure 25. Frequency of DO exceedances in Roberts Bay by calendar month.

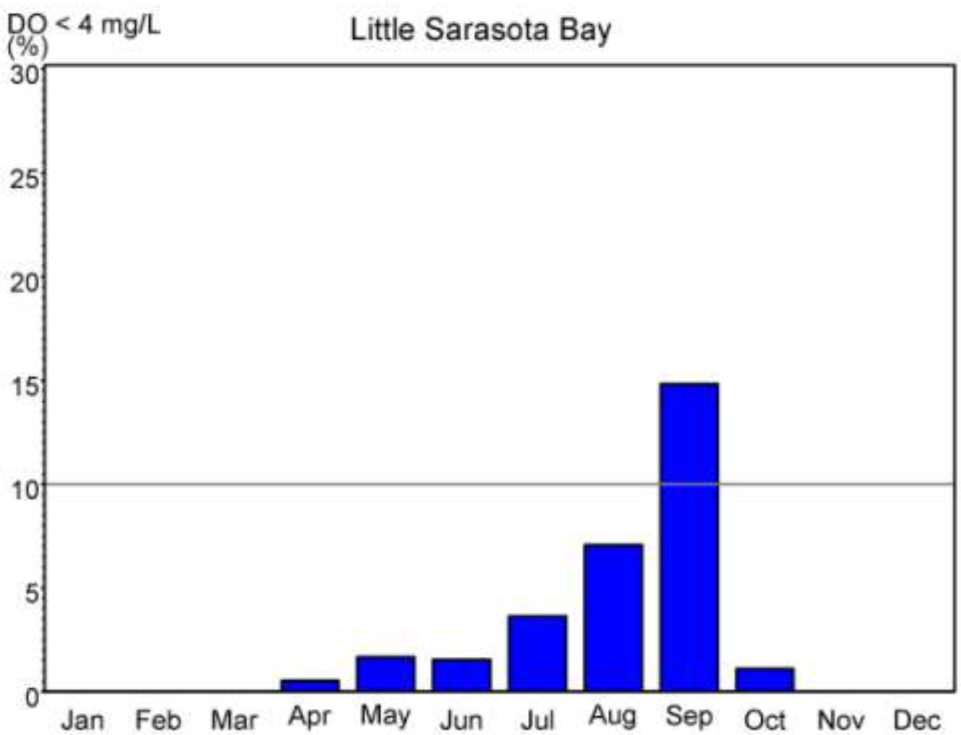

Figure 26. Frequency of DO exceedances in Little Sarasota Bay by calendar month.

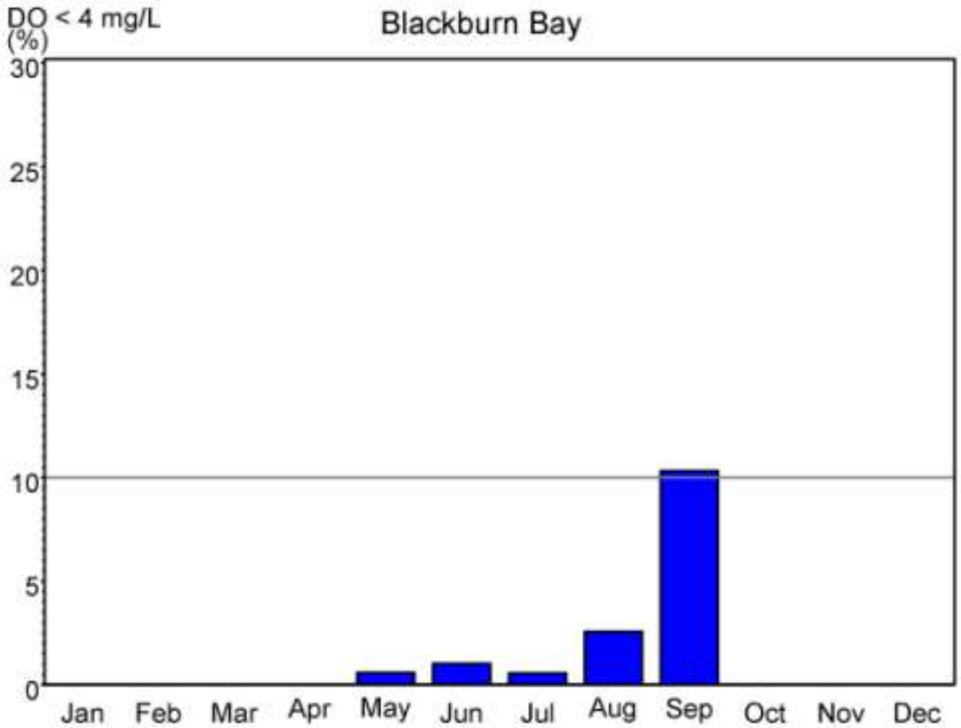

Figure 27. Frequency of DO exceedances in Blackburn Bay by calendar month.

4.2 DO exceedances – spatial patterns

While on a bay segment scale there were few instances when the percentage of DO values less than 4 mg/L exceeded 10% in a given year, there may be smaller scale areas where the probability of low DO conditions might be higher. In these smaller areas, confounding factors (e.g., circulation, water quality, depth, salinity, etc.) can result in localized conditions that affect the probability of observing a low DO condition.

To identify areas with a higher potential for DO exceedances, the spatial distribution of DO values throughout each bay segment was investigated during the warmest months of the year when low DO values are most likely to occur. All data collected during July, August, and September (Summer) were mapped in ArcGIS. The sampling points were labeled using a graduated scale from 0 to 4 by 1.0 mg/L increments and those over 4 mg/L were labeled as a single color (grey). When sample points fell on top of one another the lowest value was displayed to denote the lowest value recorded in that area. Therefore, it is important to note that this map does not represent typical conditions but rather is meant to highlight areas that may be susceptible to a low DO occurrence under certain circumstances. These circumstances are further investigated later in this document. For comparison, an additional map is provided using samples taken between November and March to represent Winter conditions. These maps are provided in Figures 28-32.

Examination of these maps indicates the following:

- DO values below 4 mg/L are rare and restricted to summer months.
- DO values below 4 mg/L tended to be above 3 mg/L.
- There appeared to be no observable spatial patterns (e.g., deeper depths, near creek mouths, etc.) in DO exceedances when they occurred
- The lowest DO values occurred without a discernable cause

Attachment 1 presents a series of maps depicting the spatial DO distributions within each year for each bay segment.

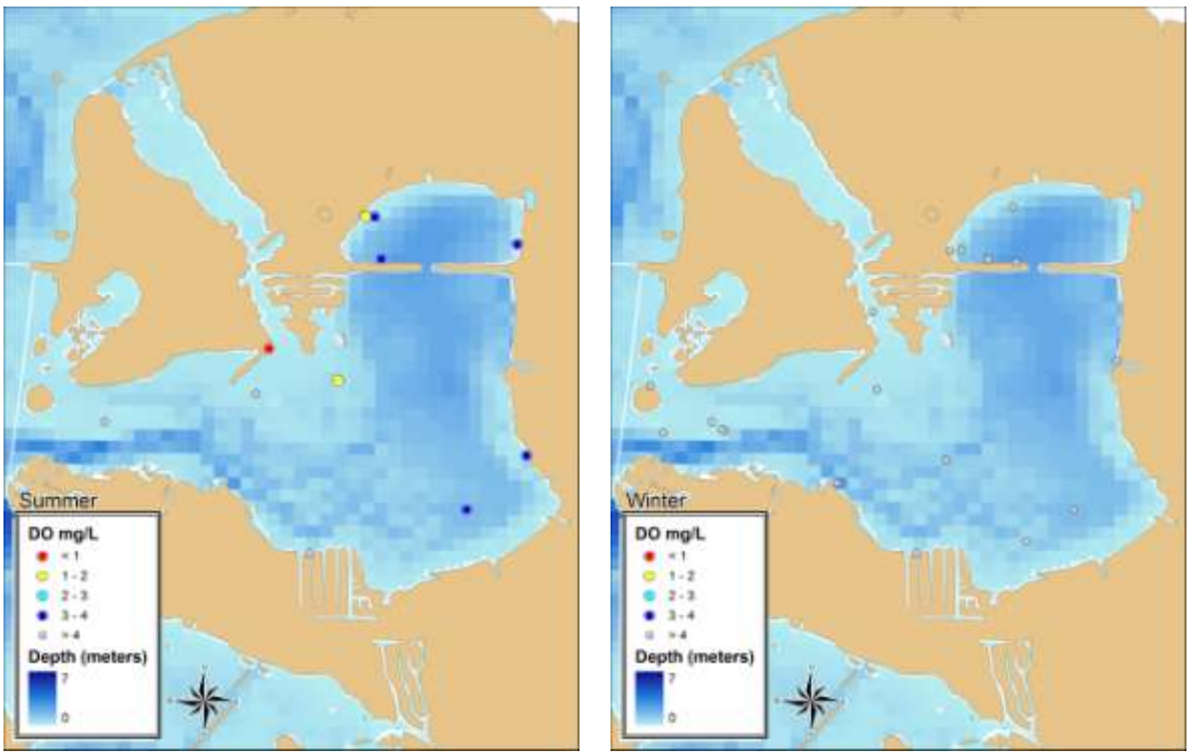

Figure 28. Comparison map of Summer and Winter DO samples from Palma Sola Bay.

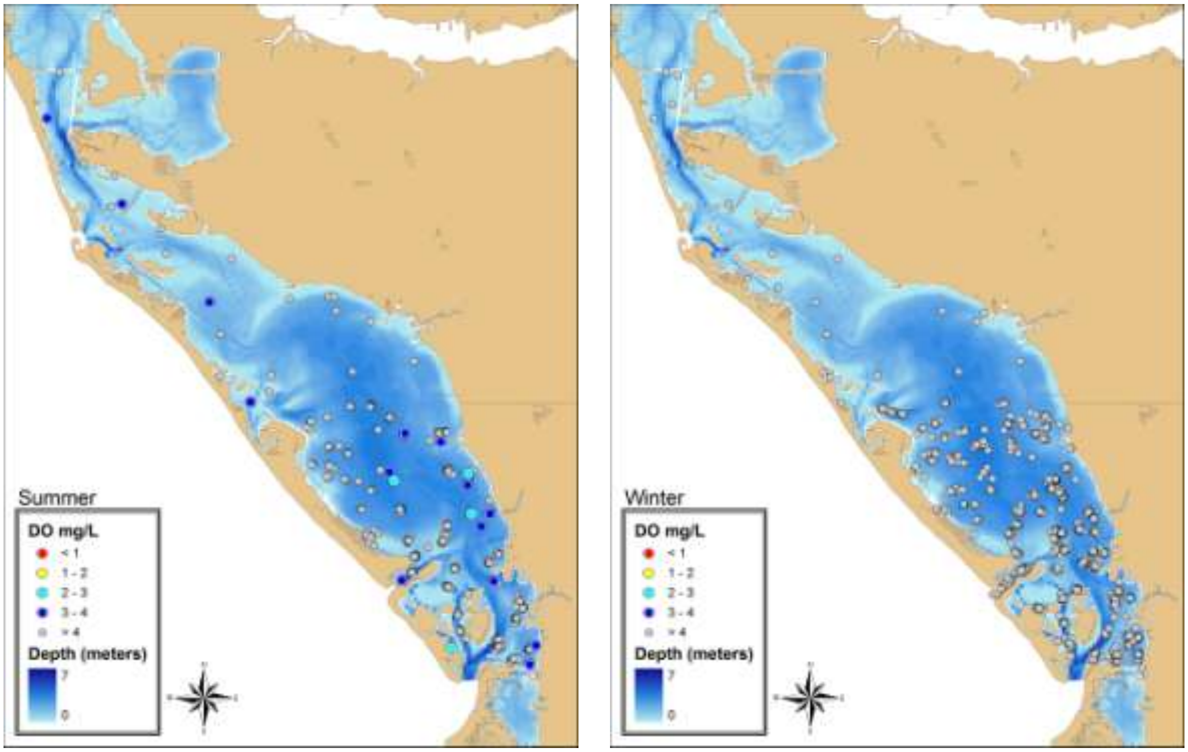

Figure 29. Comparison map of Summer and Winter DO samples from Sarasota Bay.

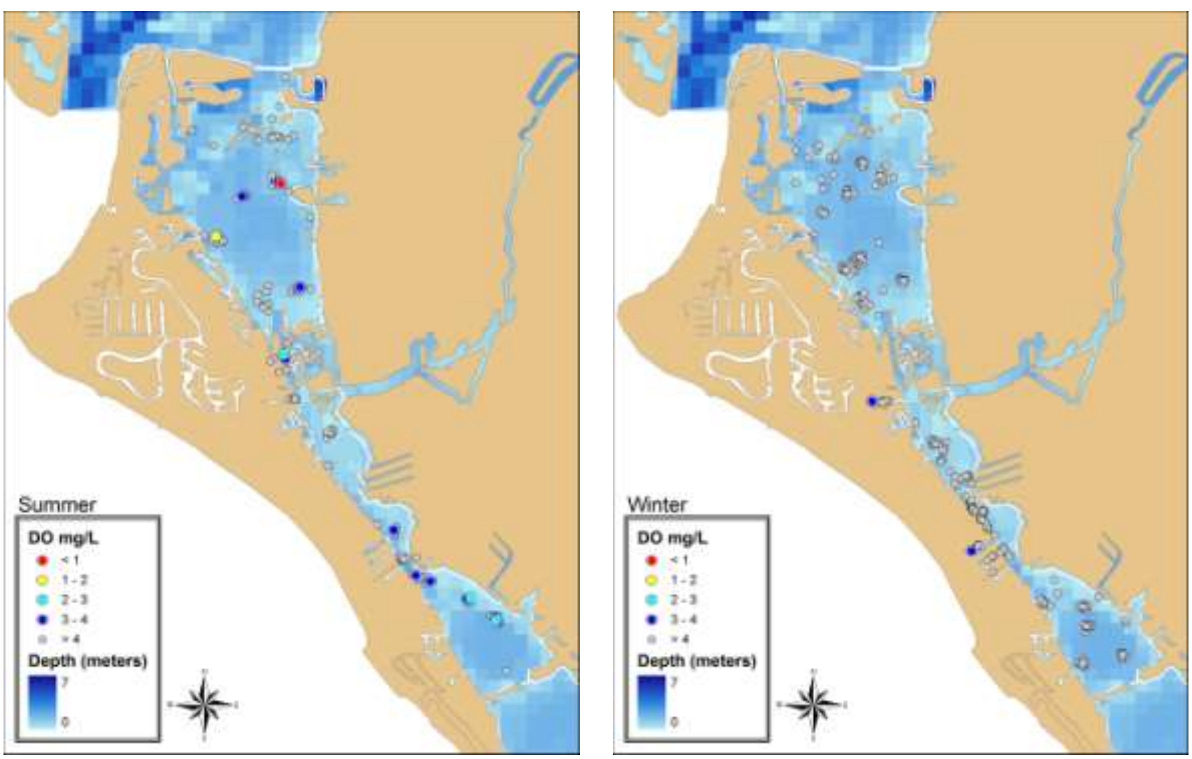

Figure 30. Comparison map of Summer and Winter DO samples from Roberts Bay North.

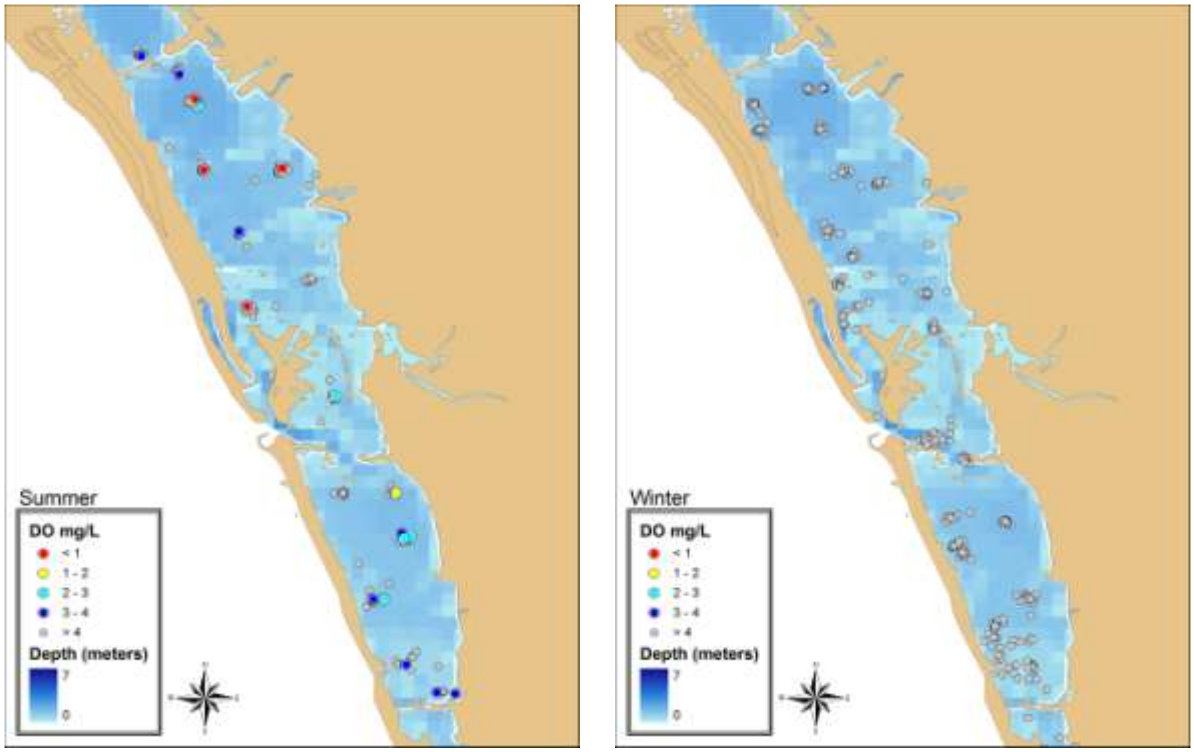

Figure 31. Comparison map of Summer and Winter DO samples from Little Sarasota Bay.

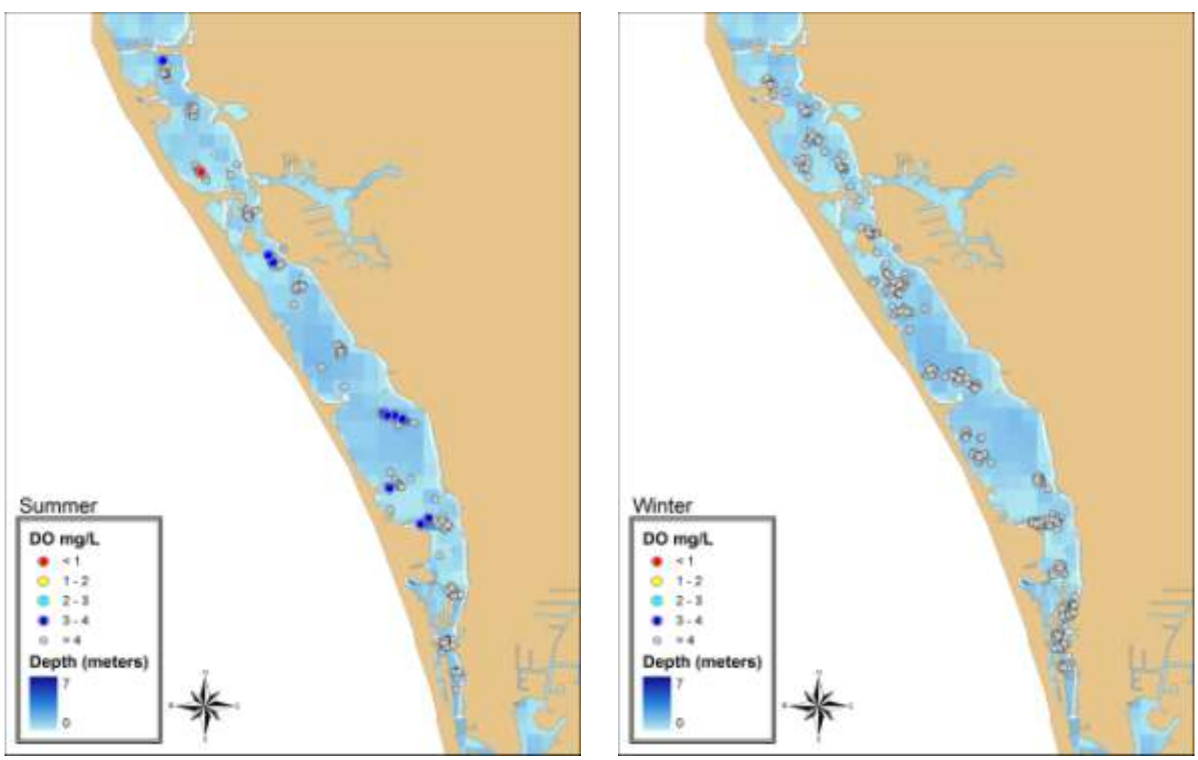

Figure 32. Comparison map of Summer and Winter DO samples from Blackburn Bay.

4.3 Investigation of Factors Affecting Dissolved Oxygen in SBEP Estuarine Waters

Salinity stratification is known to result in depressed dissolved oxygen concentrations when a freshwater lens builds on surface waters, restricting the exchange of bottom water with the atmosphere. To investigate the degree to which salinity stratification occurs in the SBEP study area, the difference between bottom and surface salinity was calculated from every observation where both surface and bottom values were recorded (generally where depths were greater than 1 meter) and the difference ("delta salinity") was plotted as a cumulative distribution function (CDF) (Figure 33). The results suggest that little stratification is evident throughout the study area with over 90% of the differences less than 5 ppt. Fifty percent of the time the difference between surface and bottom salinity was near zero in all segments. Of the SBEP segments, Roberts Bay North had the highest proportion of observations with some stratification which was expected given the influence of Phillippi Creek on a relatively small receiving waterbody. Little Sarasota Bay and Blackburn Bay also exhibited some stratification while Sarasota Bay exhibited very little stratification. There were few observations in Palma Sola Bay from which to calculate stratification due to its shallow nature and limited number of samples.

In general, stratification due to freshwater influence in the study area occurred infrequently over the time period. A scatterplot of bottom DO and delta salinity is provided in Figure 34. There are several noteworthy observations regarding this plot.

- First, the overwhelming majority of DO values were observed when there was less than 1 ppt of difference between surface and bottom salinity.
- Second, bottom DO values below 2 mg/L occurred infrequently throughout the range of stratification.
- Finally, seasonality affects both DO concentrations because of temperature effects and stratification because of season rainfall variation. Warmer months is when the physical properties of water result in lower DO concentrations and this corresponds to a period of time when the system receives the overwhelming majority of its rainfall.

The relationship between DO and temperature is also well understood and the expected decrease in DO is apparent in the scatterplot of Figure 35. A univariate linear regression suggests that the expected average decrease in DO for every degree increase in temperature is 0.16 mg/L. Variability around this expected decrease is worthy of further investigation. A scatterplot of bottom depth and bottom DO concentrations (Figure 36) suggest that shallower depths had higher variability in DO concentrations and that many of the bottom DO concentrations below 4 mg/L occurred in depths shallower than 2 meters.

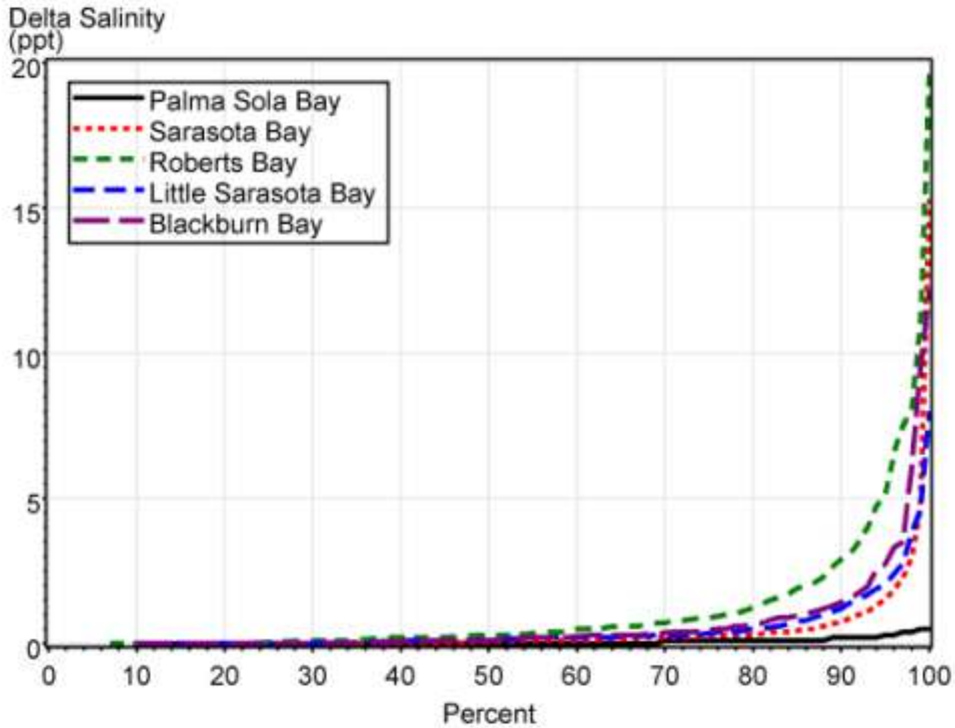

Figure 33. Cumulative frequency diagram of the difference between bottom and surface salinity in each of the SBEP bay segments.

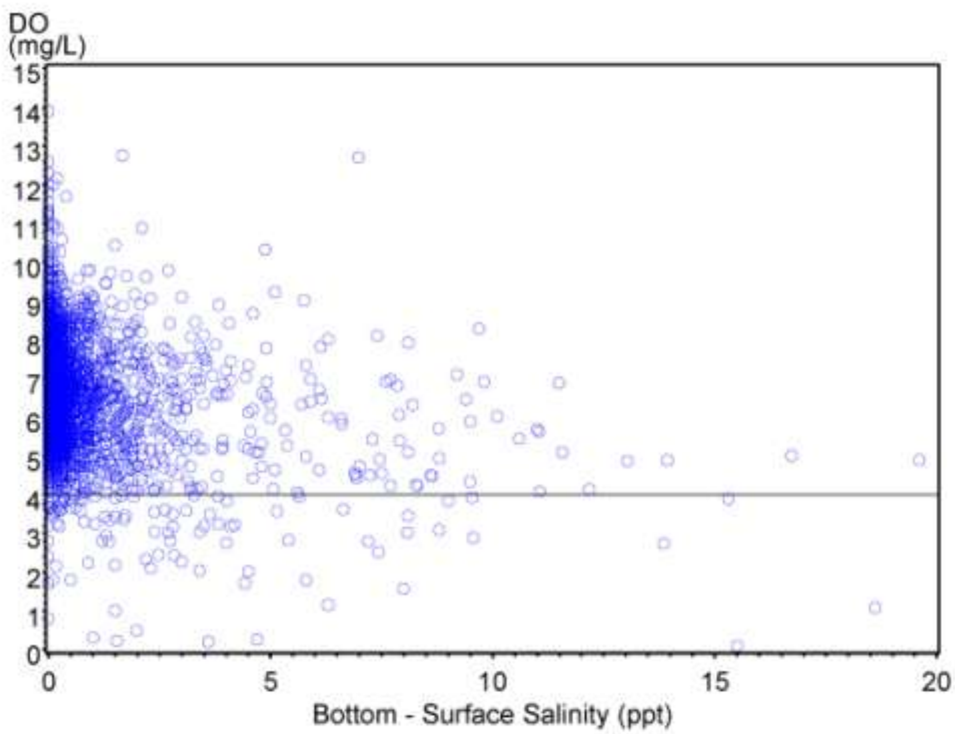

Figure 34. Scatterplot of bottom DO and the degree of salinity stratification across bay segments.

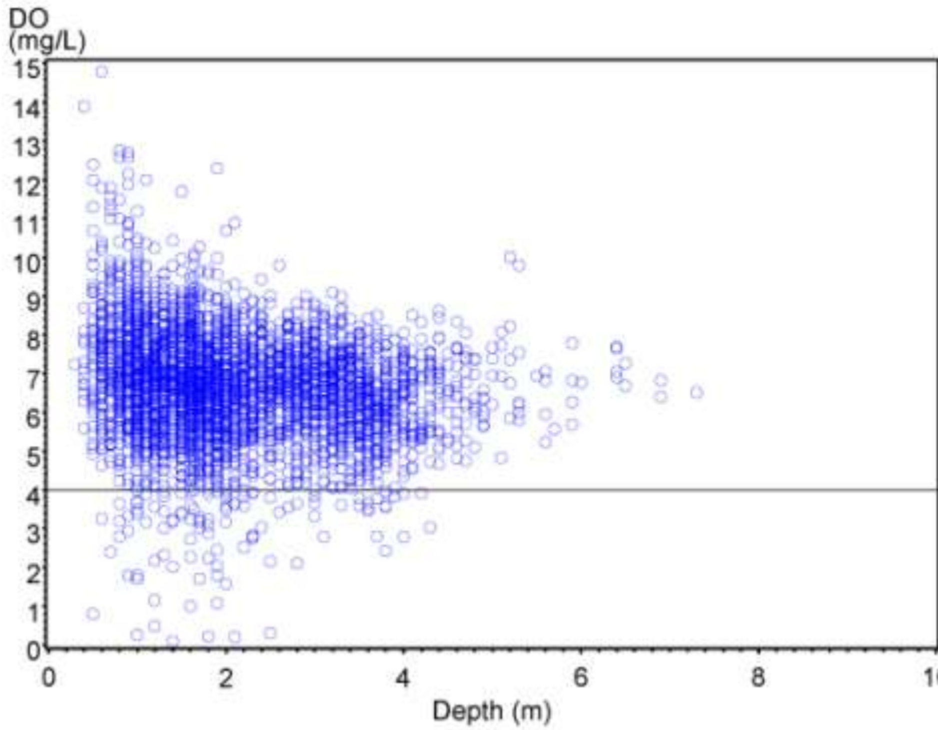

Figure 35. Scatterplot of bottom DO and the sample depth across bay segments.

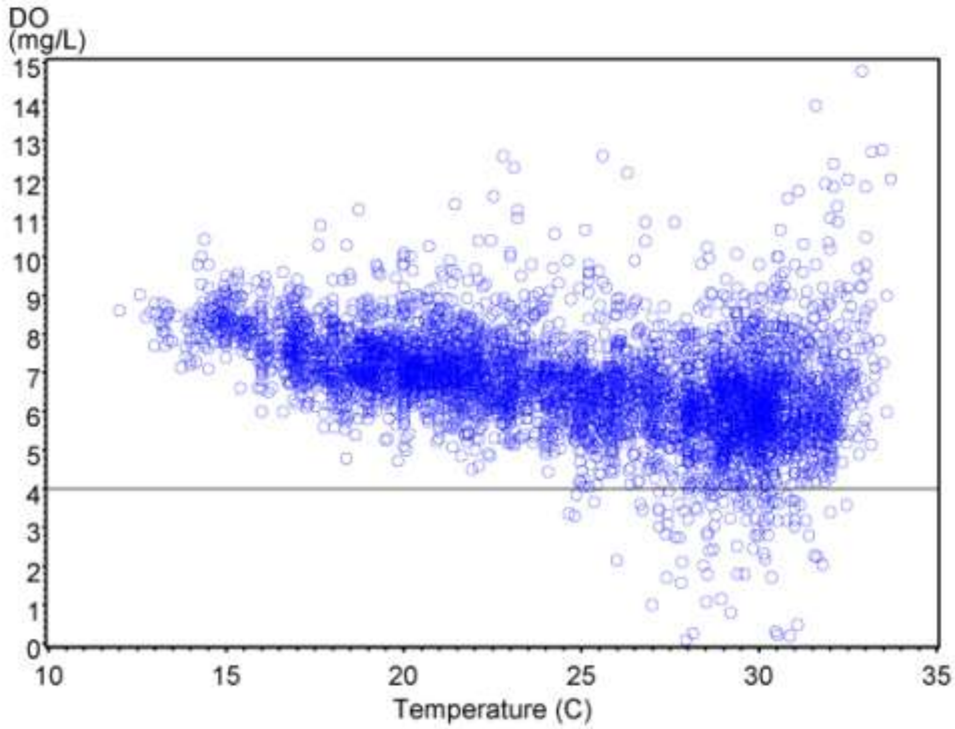

Figure 36. Scatterplot of bottom DO and bottom temperature across bay segments.

Percent saturation is a measure of the oxygen content in water that accounts for temperature and salinity according principals of physics. A plot of DO percent saturation against temperature (Figure 37) suggest that much of the time Sarasota Bay estuarine waters are near their theoretical maximum or 100 percent saturated. While the theoretical maximum is 100 percent, there were clearly times when values were above the theoretical maximum. This is known to occur when primary productivity is generating oxygen within the water column. Primary productivity in the water column may lead to two consequences with respect to percent saturation; either super-saturation as evidenced by percent saturation values greater than 140%, or depressed percent saturation values below 60% when phytoplankton blooms respire, result in phytodetritus and subsequently microbial decomposition consumes oxygen. There was no evidence that phytoplankton blooms (as measured by chlorophyll *a*) was leading to either super-saturation or depletion (Figure 38).

Quantitative analysis was conducted with the primary objective of assessing the relative influence of temperature, delta salinity, bottom depth and chlorophyll *a* levels on bottom DO concentrations. Linear regression provided confirmatory evidence that:

- Temperature is the major driver of bottom DO concentrations.
- Bottom depth and stratification (as defined by delta salinity) was also significant drivers of dissolved oxygen concentrations.
- Chlorophyll *a* concentrations were not significant in the linear regression model (Table 1).

Differences in bottom DO among segments were accounted for by including a segment term in the model. The largest average difference in bottom DO among segments was between Blackburn Bay (6.71 mg/L) and Palma Sola Bay (6.30 mg/L); less than 0.5 mg/L. The coefficient of determination was low in this model (R^2=0.29) indicating that despite accounting for temperature, stratification and bottom depth, there was a substantial degree of unexplained variation in bottom DO concentrations. However, it is important to remember that this variation is around an overall average concentration of 6.6 mg/L; indicating a healthy well-aerated water column. Much of the bay segment area is dominated by submerged aquatic vegetation which may be contributing to the unexplained variation in bottom DO concentrations at local scales resulting in model uncertainty in predicting exact concentrations.

A generalized linear model predicting the probability of a bottom DO less than 4 mg/L suggested that chlorophyll *a* had a significant but very small positive influence on the probability of a bottom DO concentration less than 4 mg/L but again that the primary determinants were temperature and stratification (Table 2). Tests for residual correlation suggested that samples were independent likely due again to the local scale effects of submerged aquatic vegetation on DO concentrations.

A simple linear regression model developed to assess the influence of water column average chlorophyll *a* concentrations on water column average DO percent saturation values also provided confirmatory evidence that suggested chlorophyll *a* was not a significant factor in predicting the saturation levels ($P>0.60$).

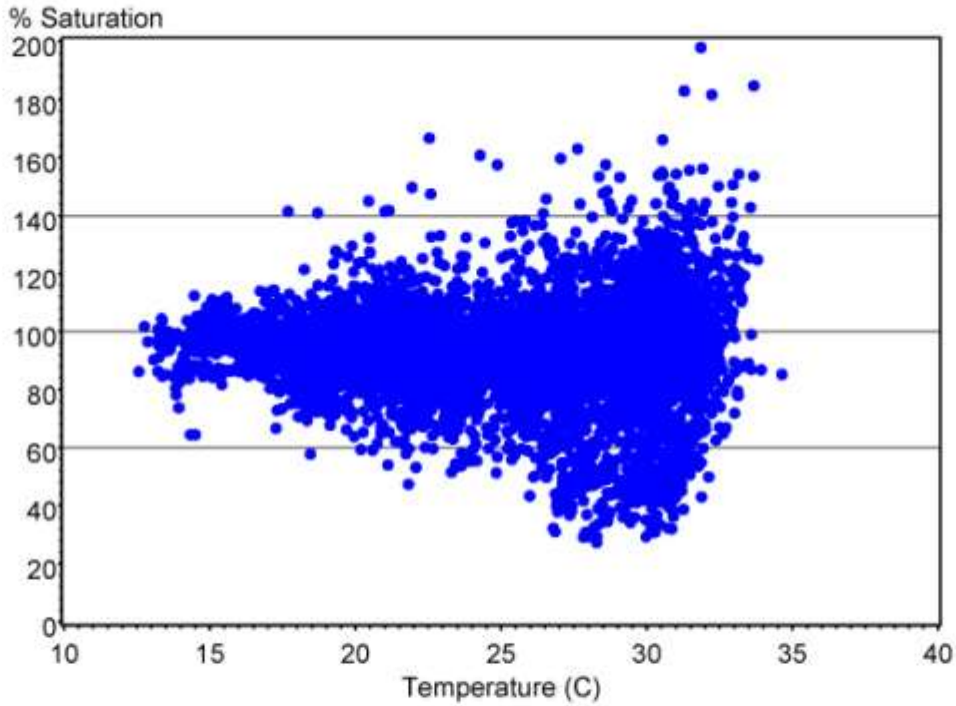

Figure 37. Scatterplot of water column average percent saturation and water column average temperature across bay segments.

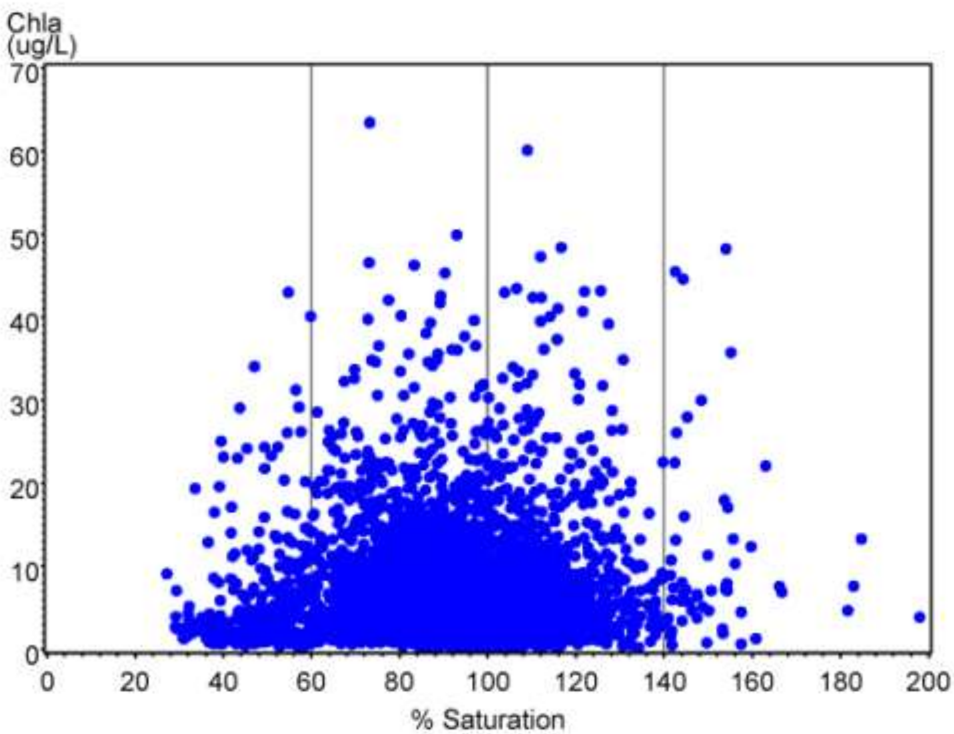

Figure 38. Scatterplot of chlorophyll *a* and water column average percent saturation across bay segments.

Table 1. Results of linear regression model on bottom DO concentrations in SBEP bay segments. Parameter estimates are estimated after accounting for differences among segments.			
Parameter	**Coefficient**	**T value**	**Prob > T**
Bottom Temperature (ºC)	-0.113	-32.56	<0.001
Stratification (delta salinity - ppt)	-0.157	-12.38	<0.001
Bottom Depth (m)	-0.179	-10.39	<0.001
Chlorophyll *a* (µg/L)	-0.001	-0.32	0.745

Table 2. Results of generalized linear model predicting the probability of a bottom DO below 4 mg/L. Parameter estimates are estimated after accounting for differences among segments.			
Parameter	**Coefficient**	**T value**	**Prob > T**
Bottom Temperature (ºC)	0.272	7.62	<0.001
Stratification (delta salinity - ppt)	0.255	7.07	<0.001
Bottom Depth (m)	0.274	3.18	0.002
Chlorophyll *a* (µg/L)	0.043	3.88	0.001

5.0 Conclusions

The following conclusions can be drawn from the analyses presented above:

- Based on an assessment similar to FDEP's Impaired Waters Rule, the empirical evidence presented here suggests that all major segments of Sarasota Bay are meeting full aquatic life uses with respect to DO.

- The most obvious principal factor affecting DO in Sarasota Bay is temperature. That is evident in both the descriptive temporal plots and in the generalized linear model assessed in the quantitative assessment of those factors affecting the probability of DO being less than 4 mg/L. The model results indicate that stratification, bottom type, and sample depth were other factors that contributed to the probability of low DO conditions (i.e., < 4 mg/L). Furthermore, it was determined that chlorophyll *a* concentrations were not a significant factor contributing to probability of low DO conditions in Sarasota Bay.. In other words, the occurrence of DO values below 4 mg/L were not significantly related to observed chlorophyll *a* concentrations at the time of sampling.

- Based on the weight-of-evidence presented here, it is reasonable to conclude that the numeric nutrient criteria proposed by the Sarasota Bay Estuary Program are protective of full aquatic life uses with respect to DO.

6.0 References

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