# *Final Report to the Bayous Preservation Association (BPA)*

*Water quality results and analysis from four stations near Blind Pass, Sanibel-Captiva Islands, Florida 2006-2012; significant changes after the dredging (re-opening) of Blind Pass in August 2009.*

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## Summary

Water quality samples before and after the opening of Blind Pass were collected and analyzed by the SCCF Marine Laboratory. There were several significant changes that occurred in water quality after the opening of Blind Pass, many indicate improvements around Blind Pass. There was lower salinity variation, increased dissolved oxygen, lower CDOM concentrations (Milbrandt el al. 2011), lower TN with less variability, and lower TP after the opening of the Pass. These changes are mostly attributed to the increased influence (dilution effects) of Gulf of Mexico waters which now circulate to the back bayous. As a consequence of increased tidal exchange, there were increased flow velocities resulting in re-suspension of sediments and higher turbidity and chlorophyll *a* (benthic algae). The increased turbidity may also be a reflection of increased habitat usage by higher abundances of benthic foragers (fish and invertebrates). Overall, the opening of the Pass seems to have improved water quality conditions and the improvements in water quality shown here will translate to healthier seagrass and oyster reef communities as well as more resilient invertebrate and fish populations.

The team at the SCCF Marine Laboratory dedicates this report to the memory of Tim Gardner, a BPA founding member and friend.

## Introduction

This report presents water quality results obtained from the analysis of samples collected from four locations within the Blind Pass Ecozone (Wilson 2008). Samples were collected from July 2006 until September 2008, by the Bayous Preservation Association (BPA) and from April 2009 to December 2012 by the Sanibel-Captiva Conservation Foundation (SCCF) Marine Lab. The original intent of the BPA volunteer monitoring program was to detect changes in water quality resulting from the opening of Blind Pass which occurred August 1, 2009. The Blind Pass dredging project was undertaken by Lee County with strong community encouragement and support. It was anticipated that improvements to water quality and associated habitats would be realized when Blind Pass was re-opened connecting the Gulf of Mexico with Pine Island Sound and providing enhanced tidal exchange and flushing to nearby water bodies (e.g. Wulfert Cut, Roosevelt Channel, Dinkins Bayou and Clam Bayou).

This study contains 30 months of pre-opening sample collection followed by 33 months of post-opening sample collection. This report also contains water quality data from SCCF Marine Lab's RECON fixed water quality monitoring stations located in the Caloosahatchee estuary, Gulf of Mexico and Pine Island Sound. Additional data from continuously recording water quality and level data sondes within Clam Bayou was collected and reported here. In this report we deliberate water quality changes associated with opening Blind Pass. However, we emphasize many factors influence changes in water quality data annually and daily.

Additional background information about water quality and its relationship to barrier islands can be found in Thompson et al. 2012, Milbrandt et al. 2012, or is available upon request from the SCCF Marine Laboratory. The SCCF Marine Lab provided monthly reports to the BPA from April 2009 to June 2012 and are also available upon request.

## Approach and Methods

Four water quality monitoring sites were established by BPA in 2006 in the Blind Pass Ecozone where the Bayous Preservation Association (BPA) anticipated water quality improvements related to the restoration of Clam Bayou and the re-opening of Blind Pass. The study area is the west end of Sanibel and the south end of Captiva Island, two barrier islands in Southwest Florida. The first site was located near Blind Pass in Roosevelt Channel between Captiva Island and Buck Key. A second site was located in Sunset Bay south of Blind Pass. Two other sites were located southeast of Blind Pass in Dinkins Bayou and Clam Bayou where tidal flushing is more limited (Figure 1).

Water sampling was often conducted during the last week of each month. The first samples were collected by BPA volunteers in July 2006 and they continued sampling until October 2008. With support from BPA, SCCF Marine Lab staff collected samples from June 2011 and continued through December 2012. This monitoring schedule resulted in 30 monthly samples before the opening of the pass on August 1, 2009 and 32 months of sampling after the opening.

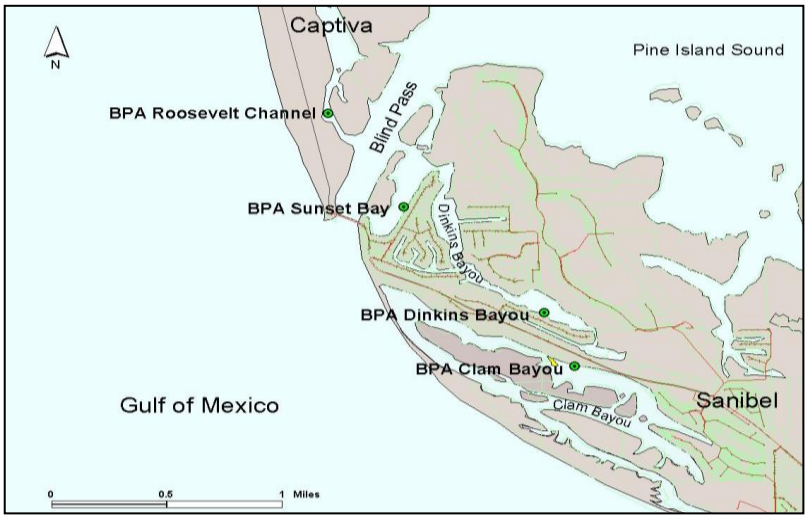


Figure 1. Locations of the four water quality monitoring sites established by Bayous Preservation Association in 2006.

Water samples were conducted in the early morning, just after sunrise. A handheld sonde (YSI Instruments) was used to collect some of the parameters including dissolved oxygen (DO), turbidity, pH, salinity and water temperature. Secchi depth and total depth were determined following established protocols. Samples were stored on ice and were returned to the SCCF Marine Laboratory for subsequent analysis. Chlorophyll a, pheophytin, enterococci, and CDOM were analyzed at the SCCF Marine Lab. A subsample was transported to Lee County's Environmental Lab (LCEC) in Fort Myers for wet chemistry analysis of total (TKN Kjeldahl) nitrogen, nitrate plus nitrite nitrogen, ammonia ($NH_3$), total nitrogen (TN), total phosphorus (TP), and orthophosphate (OP). All measurements and analyses followed Environmental Protection Agency (EPA) approved methodologies.

Data were entered into the dedicated Microsoft Access SCCF water quality database system housed and maintained at the SCCF Marine Lab. Descriptive statistics including mean, median, min, max, standard deviation, and sample number were calculated and reported by parameter for the study area. For all parameters, a general linear model (GLM) ANOVA was used on log transformed data to evaluate differences before and after the opening of Blind Pass, and between wet and dry seasons. Log transformation was necessary to meet the assumptions of

the GLM. Whisker plots by water quality parameter help to visualize the trends for each site. A GLM ANOVA was also used to evaluate rainfall and S-79 flow data before and after the opening of Blind Pass. To evaluate trends in parameter values during the monitoring period, seasonal Kendall tests were performed on data before the opening and then again on data collected after the opening. Using this approach, an evaluation of whether there were significant trends were interrupted or altered by the dredging and whether new trends may have been initiated. The calendar year is divided into wet season months (June 1 to October 31) and dry season months (November to May 31). All analyses were conducted using Minitab® (Version 13.1) and WQ Stats® statistical software with an alpha (significance) level of $p \leq 0.05$ unless otherwise noted.

In order to bring a more regional overview to the information presented for this report, we evaluated data from four RECON stations near the study area: The Marine Laboratory operates seven real-time water quality monitoring stations as part of the River, Estuary, and Coastal Observing Network (RECON). The sensors are located within the Caloosahatchee Estuary and Pine Island Sound between Beautiful Island and Redfish Pass (map, Figure 2). These stations continuously record temperature, salinity, dissolved oxygen, chlorophyll *a*, CDOM, nitrates, and depth. The data are transmitted via cellular phone to a remote computer which stores the data and makes it available for visualization in *real* time on the internet http://recon.sccf.org/. Shell Point RECON, Gulf of Mexico RECON, Blind Pass RECON and Redfish Pass RECON. Results from the Shell Point RECON, Gulf of Mexico RECON, Blind Pass RECON and Redfish Pass RECON were plotted for a two year period.

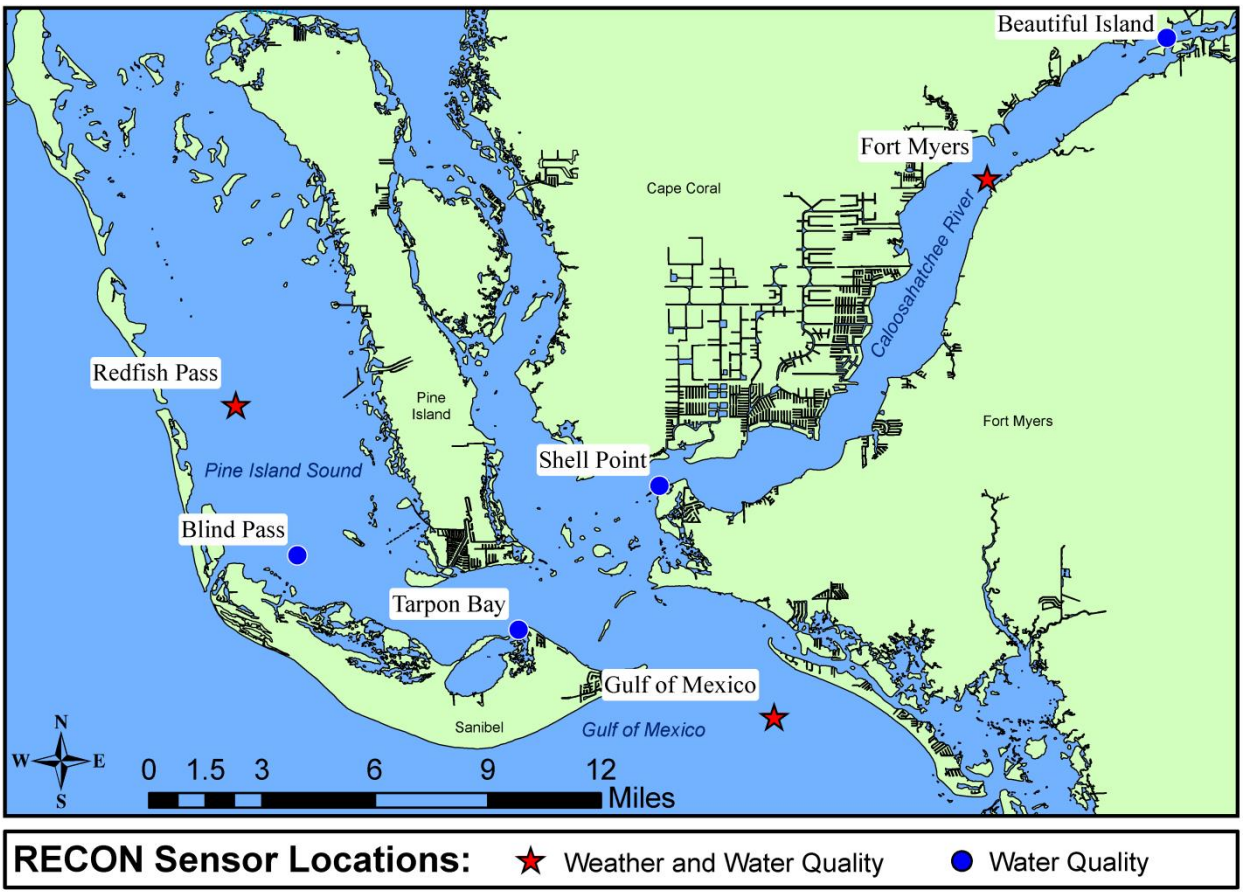


Figure 2. SCCF Marine Lab RECON water quality monitoring stations are shown with red stars. Data from the Shell Point, Gulf of Mexico, Blind Pass, and Redfish Pass stations were evaluated for this report.

## Results

The results are organized by water quality parameter. For each parameter there is a table which summarizes the most important findings. In the table there is an indication whether there was a trend before and after the opening of Blind Pass. The table also shows the mean (average) value for each parameter before and after the opening and a statistical comparison of before and after values. For example, is salinity significantly higher or lower after the opening of the pass? Also of importance in each table is the variance value before and after the opening. Variance indicates the minimum and maximum tendency of values. The calculated mean may not be statistically different after the opening, the variance often is different. In general, a more stable environment (lower variation) favors a healthy ecosystem. The results of the monitoring are presented in this section; a more detailed description of the results and their meaning is provided in the Discussion section.

### *Precipitation and S-79 Discharge*

Precipitation was measured at the Lee County rain gauge located at the corner of Summerland and San Carlos Avenue for 30 months prior to the opening of Blind Pass and 32 months after the opening of the pass (Figure 3). The mean monthly value before the opening was 2.5 inches/month compared to 4.3 inches/month after the opening of the pass. There were no differences between in monthly precipitation values (Figure 4; GLM ANOVA $p = 0.38$, $f = 1.1$). Similarly, no significant differences could be found for the mean river discharge from the S-79 structure (W.P. Franklin Locks at Alva) for the monitoring period before and after the opening of Blind Pass even though the mean flow after the opening was slightly higher (mean = 804 cubic feet per sec (CFS) before and 1308 CFS after) (Figure 5 and 6; GLM ANOVA $p = 0.982$, $f = 0.3$).

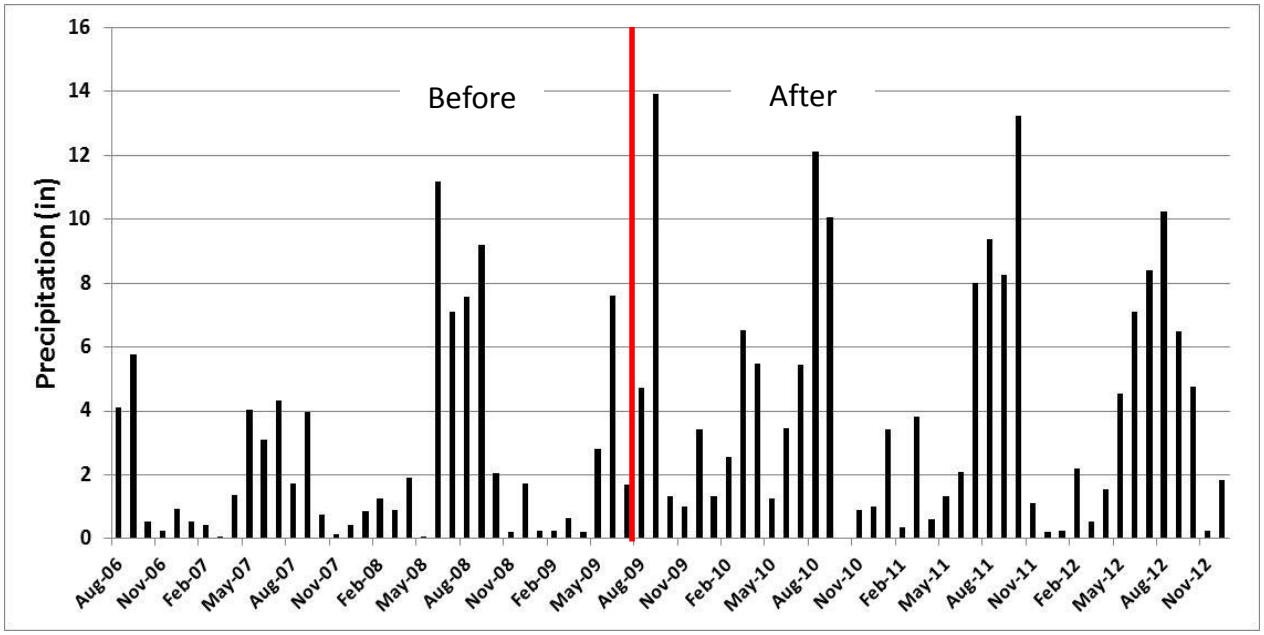


Figure 3: Daily precipitation measured at the Lee County rain gauge at Summerlin and San Carlos Avenues in Ft. Myers for the study period.

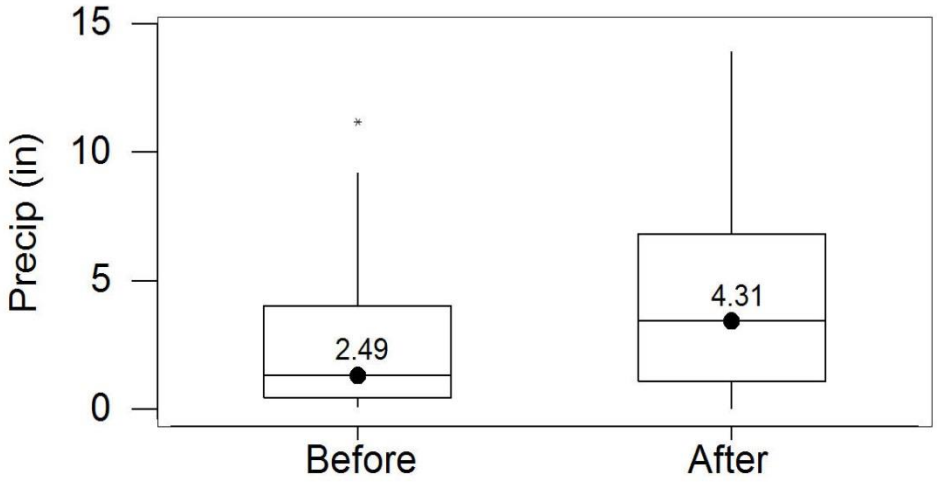


Figure 4: Whisker plot showing mean monthly precipitation for the monitoring period before and after the opening of Blind Pass. Statistically, there were no differences between mean monthly precipitation.

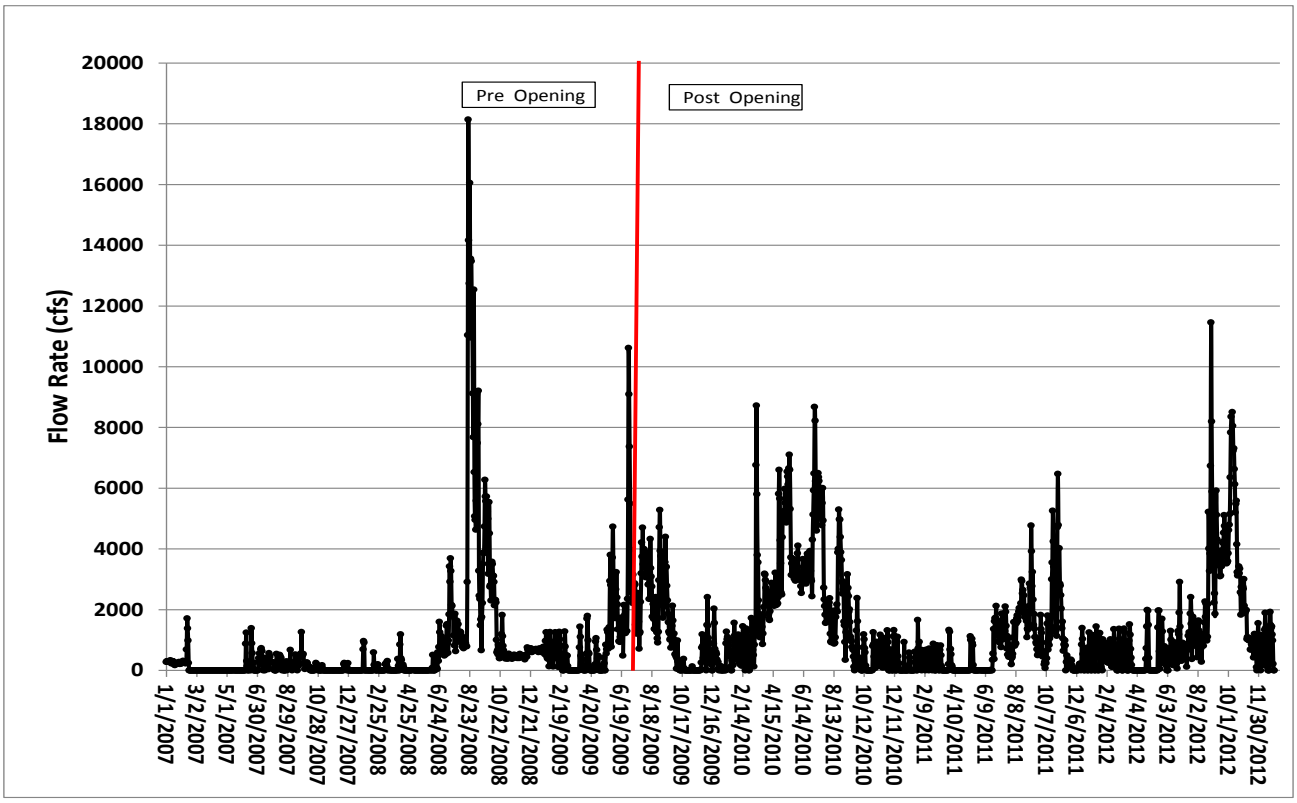


Figure 5: Daily river discharge rate from S-79 (Franklin Locks) during the study period. This structure discharges freshwater from the Lake Okeechobee watershed into the Caloosahatchee Estuary.

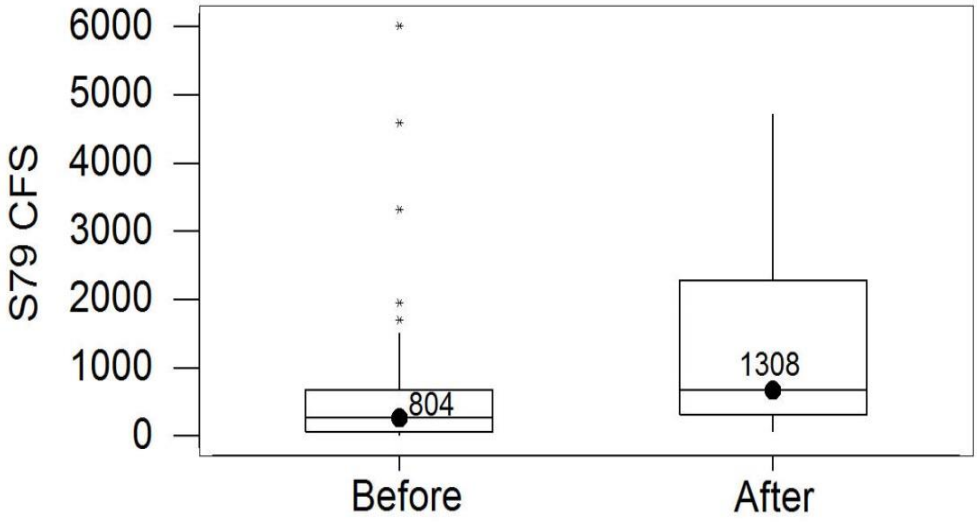


Figure 6: Whisker plot showing flow from S-79 (Franklin Locks) before and after the opening of Blind Pass. Even though the mean discharge rate from S79 was greater after Blind Pass was re-opened, there was not a statistically significant difference found.

***Salinity***

Salinity values for the four study sites are plotted in Figure 7. Overall, the mean salinity of 34.6 for the study period was significantly lower than before the opening (36.1) (Table 1, GLM ANOVA, F= 23.6, $p < 0.001$; n = 63). The differences in salinity occurred during the dry season months with significantly lower salinity after the opening (T = 6.14, $p < 0.05$). There were not significant differences in salinity when only the wet season months were analyzed. When compared by station, Clam Bayou (Kruskal-Wallis, $z = -2.24$, $p < 0.05$; n = 63), Sunset Bay (Kruskal-Wallis, $z = -2.41$, $p < 0.001$; n = 175) and Roosevelt Channel (Kruskal-Wallis, $z = -2.91$, $p < 0.001$; n = 175) all had significantly reduced salinity after the opening (Figure 8, Table 1). When wet and dry seasons were compared among all stations, the wet season salinity (34.2 PSU) was significantly lower than dry season salinity (36.5 PSU) (GLM ANOVA, F= 28.9, $p < 0.001$; n = 63). No significant differences could be seen for salinity compared between sites.

Overall, variability in salinity was significantly reduced after the dredging Blind Pass compared to before (Levene's test, F = 16.1, p < 0.001) (Table 1). When analyzed by station, every station showed reduced salinity variability after the opening of Blind Pass (Levene's test, p < 0.05) (Table 1).

We found a significant increasing trend in salinity at the Clam Bayou (Seasonal Kendall, z = 2, p < 0.05, n = 30), Dinkins Bayou (Seasonal Kendall, z = 2.3, p < 0.05, n = 30) and Sunset Bay (Seasonal Kendall, z = 2.5, p < 0.05, n = 30) stations before the opening of Blind Pass (Table 1). After the opening of Blind Pass significant trends were not found at any of the stations (Seasonal Kendall, p > 0.05, n = 33).

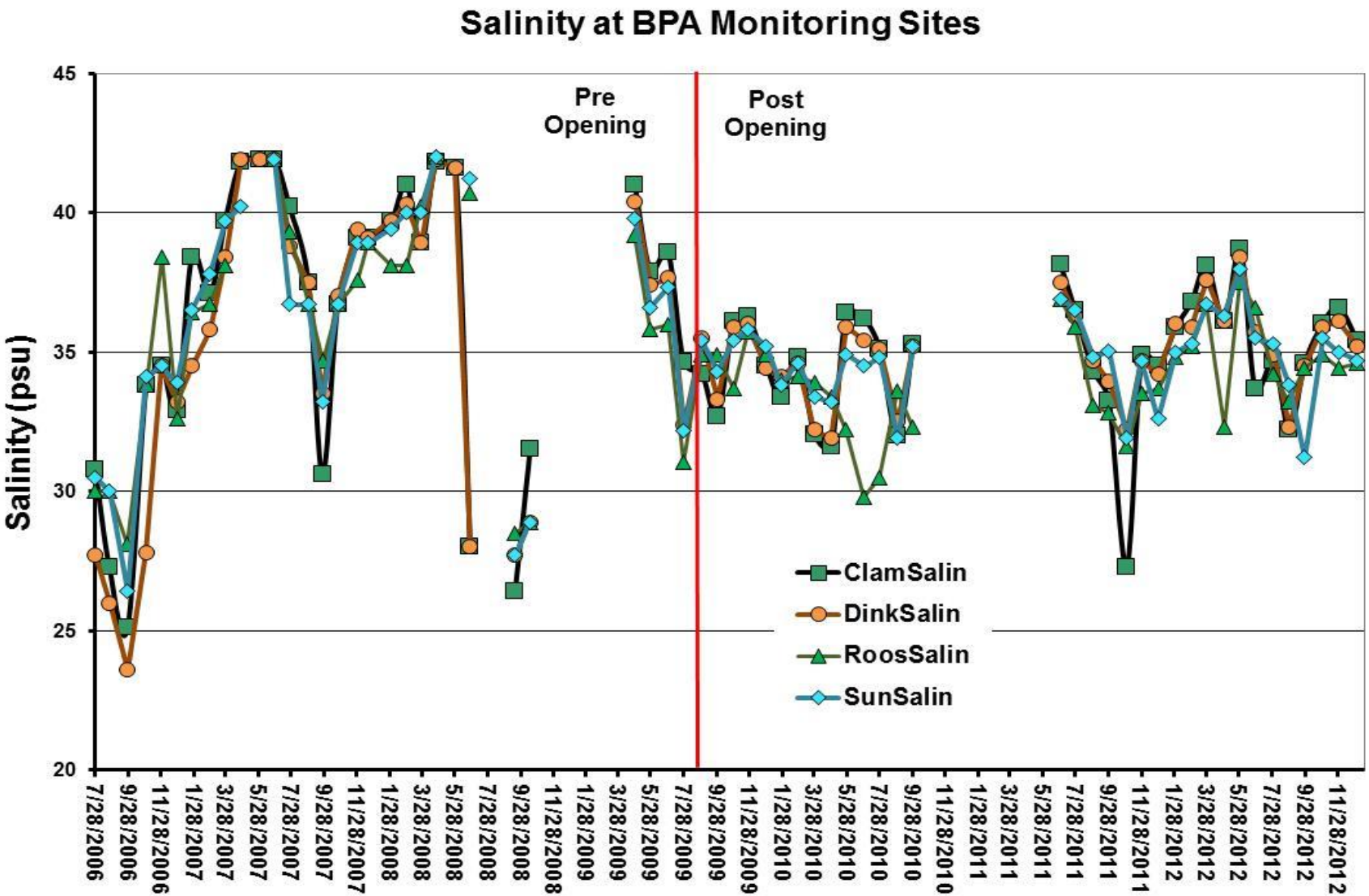


Figure 7. Monthly salinity values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 1. Summary of monthly salinity monitoring results analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall mean salinity was found to be significantly less after the opening and the variation in salinity values also decreased. NST = No significant Trend.

| Salinity | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | 36.2 | 17.9 | NST | 34.1 | 3 | NST | Significantly less after. | Significantly reduced after. | No Change. |
| Sunset Bay | 36.3 | 19.4 | Increasing | 34.7 | 2 | NST | Significantly less after. | Significantly reduced after. | Increasing trend interrupted. |
| Dinkens Bayou | 35.6 | 30.1 | Increasing | 34.9 | 2.5 | NST | Not significantly different. | Significantly reduced after. | Increasing trend interrupted. |
| Clam Bayou | 36.3 | 25 | Increasing | 34.8 | 5 | NST | Significantly less after. | Significantly reduced after. | Increasing trend interrupted. |
| Overall | 36.1 | 22.9 | Increasing | 34.6 | 3.2 | NST | Significantly less after. | Significantly reduced after. | Increasing trend interrupted. |

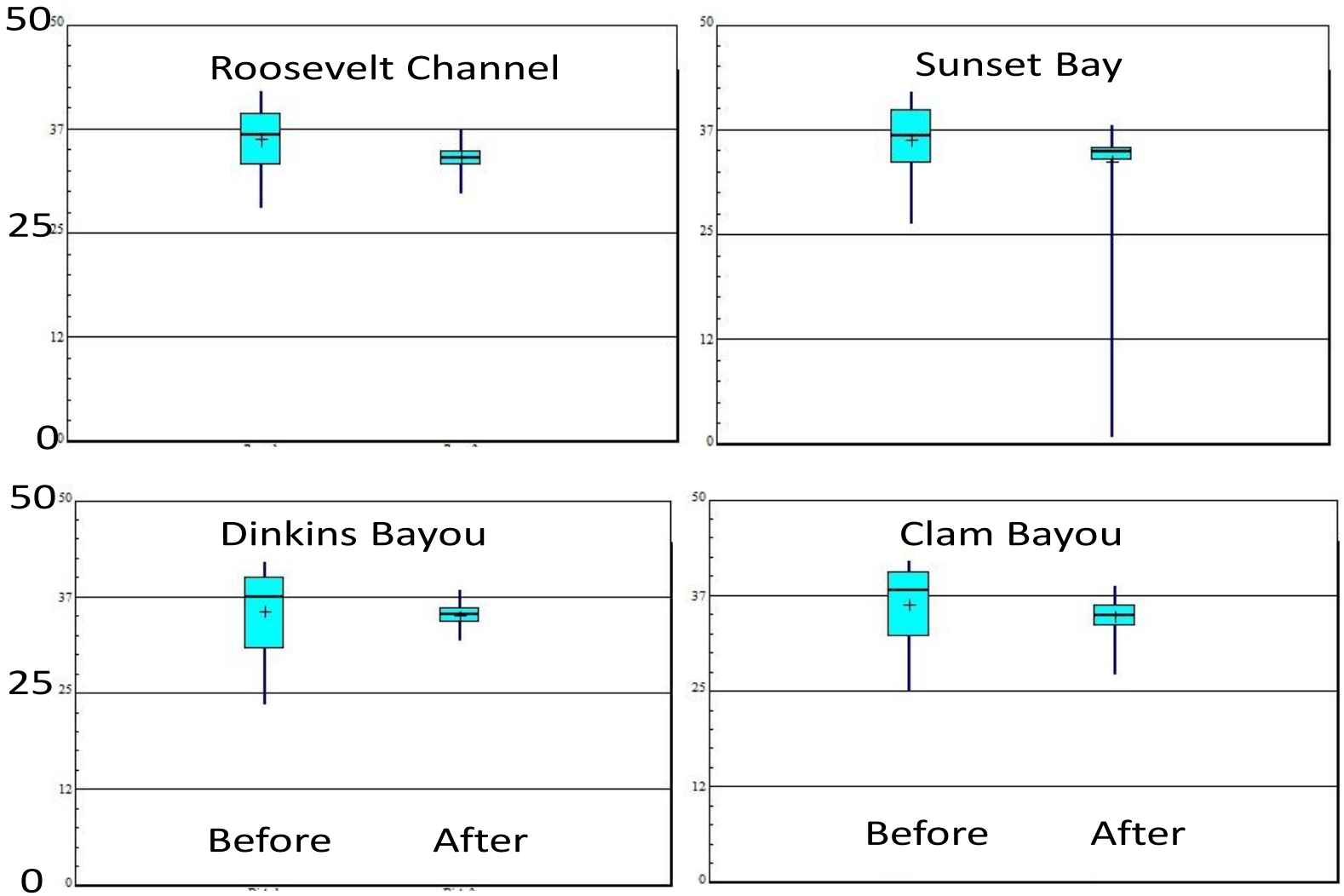


Figure 8. Monthly salinity values (PSU) at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass. Salinity was found to be significantly reduced at each station except Dinkins Bayou in the 33 months after the dredging compared to the 30 months prior to the pass opening. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

***Turbidity***

Monthly turbidity values for the four study sites are plotted in Figure 9. Overall, the mean turbidity of 14.9 NTUs for the study period after the opening was significantly greater than before the opening (6.2 NTUs) (Table 2, GLM ANOVA, F= 147.2, $p < 0.001$; n = 63). The difference in turbidity before and after the opening was significant in both the dry season (T = 9.8, $p < 0.05$) and wet season (T = 7.2, $p < 0.05$). When compared by station, all stations had significantly higher turbidity in the 33 months after the dredging than the 30 months before (Kruskal-Wallis, $p < 0.05$; n = 63) (Figure 10, Table 2). Dry season mean turbidity (11.9 PSU) was found to be significantly greater than wet season turbidity (9.7 PSU) (GLM ANOVA, F= 5.5, $p = 0.001$; n = 63). No significant differences could be seen for turbidity compared between sites.

Overall, variability in turbidity was significantly greater after the dredging Blind Pass compared to before (Levene's test, F = 7.4, p = 0.007) (Table 2). When analyzed by station, every station showed increased turbidity variability after the opening of Blind Pass (Levene's test, $p < 0.05$) (Table 2).

Overall, no trends were found in turbidity before or after the opening of Blind Pass (Table 2). However, even though mean turbidity values were greater after the dredging, significant decreasing trends may be occurring at Clam Bayou (Seasonal Kendall, z = 1.9, $p < 0.05$, n = 33) and Dinkins Bayou (Seasonal Kendall, z = 1.8, $p < 0.05$, n = 33) in the 33 months after the dredging (Table 2).

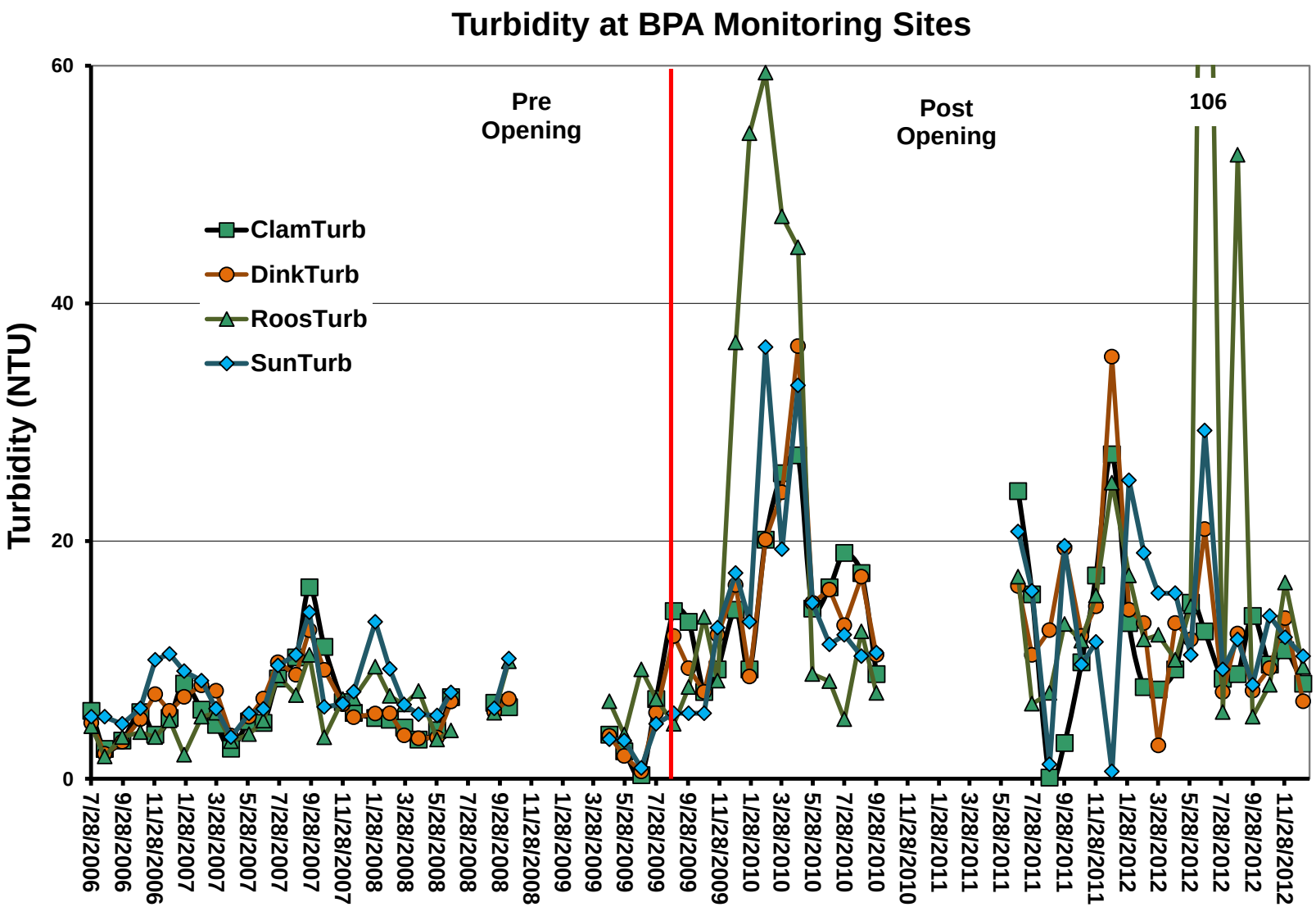


Figure 9: Monthly turbidity values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 2. Summary of monthly turbidity monitoring results analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall mean turbidity was found to be significantly greater after the opening and the variation in turbidity values also increased. NST = No significant Trend.

| Turbidity | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| **Roosevelt Channel** | 5.8 | 19.3 | Increasing | 19.3 | 451.9 | NST | Significantly greater after. | Significantly greater after. | Increasing trend interrupted |
| **Sunset Bay** | 7.3 | 6.8 | NST | 14.4 | 62.6 | NST | Significantly greater after. | Significantly greater after. | No Change. |
| **Dinkens Bayou** | 5.8 | 5.2 | Decreasing | 13.4 | 34.4 | Decreasing | Significantly greater after. | Significantly greater after. | Decreasing trend continues |
| **Clam Bayou** | 5.8 | 7.8 | NST | 12.8 | 33.2 | Decreasing | Significantly greater after. | Significantly greater after. | Decreasing trend begins after. |
| **Overall** | 6.2 | 6.5 | Mixed results. | 14.9 | 145 | Mixed results. | Significantly greater after. | Significantly greater after. | Mixed results. |

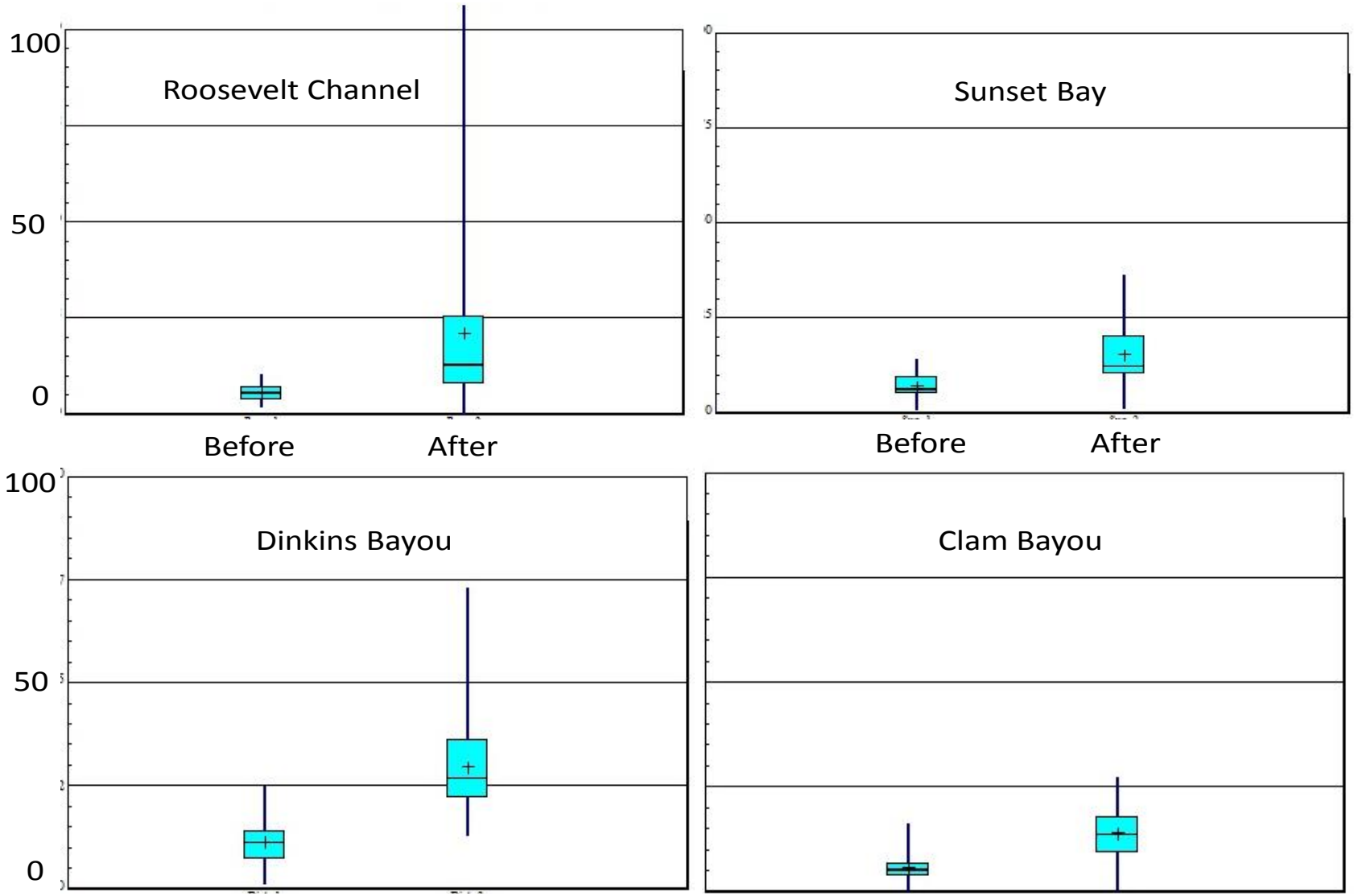


Figure 10. Monthly turbidity values (NTU) at BPA monitoring sites over the duration of the study period showing increases before and after opening of Blind Pass. Each station was found to have significantly greater mean turbidity in the 33 months after the dredging compared to the 30 months prior to the pass opening. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

### *Chlorophyll a*

Data for chlorophyll *a* are plotted in Figure 11. Overall, the mean chlorophyll *a* of 8.5 µg/l for the 33 months after the opening was significantly greater than the 30 months prior to the dredging (6.7 µg/l) (Table 3, GLM ANOVA, F= 30.5, $p < 0.001$; n = 63). The increase in chlorophyll *a* after the opening was significant when the dry season months were analyzed separately (T = 5.4, $p < 0.001$). Chlorophyll *a* was not significantly different before and after the re-opening when only the wet season months were analyzed (T = 2.2, $p < 0.12$). When compared by station, only Clam Bayou had significantly greater chlorophyll *a* after the dredging than before (Kruskal-Wallis, $p < 0.05$; n = 63) (Figure 12, Table 3). Wet season mean chlorophyll *a* (9.4 µg/l) was found to be significantly greater than dry season chlorophyll *a* (5.5 µg/l) (GLM ANOVA, F= 5.5, $p = 0.001$; n = 63). There were no significant differences in chlorophyll *a* between sites (GLM ANOVA, F= 1.75, $p = 0.06$; n = 63).

Overall, variability in chlorophyll *a* was significantly lower following the dredging Blind Pass compared to before (Levene's test, F = 27.5, $p < 0.001$) (Table 3). When analyzed by station, Sunset Bay and Dinkins Bayou showed decreased chlorophyll *a* variability after the opening of Blind Pass (Levene's test, $p < 0.05$) (Table 3).

Overall, no clear trends were found in chlorophyll *a* before or after the opening of Blind Pass (Table). However, significant decreasing trends were found at Clam Bayou (Seasonal Kendall, z = 1.9, $p < 0.05$, n = 33) and Dinkins Bayou (Seasonal Kendall, z = 1.8, $p < 0.05$, n = 33) in the 33 months after the dredging (Table 3).

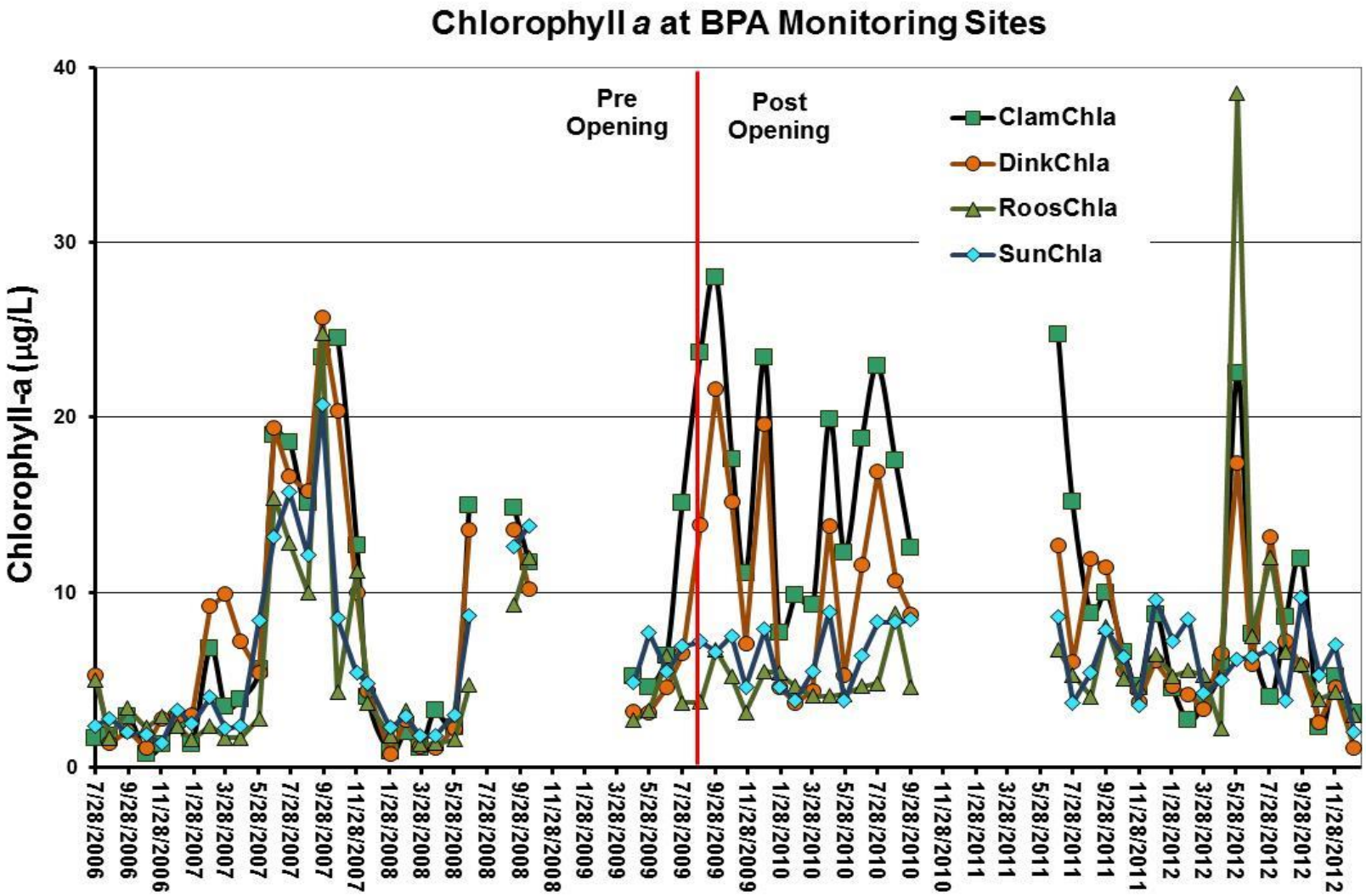


Figure 11: Monthly chlorophyll *a* values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 3. Summary of monthly chlorophyll *a* monitoring results analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall mean chlorophyll *a* was found to be significantly greater after the opening but the variation in chlorophyll *a* values decreased. NST = No significant Trend.

| Chlorophyll *a* | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | 5.3 | 28.6 | NST | 6.4 | 37.8 | NST | Not significantly different. | Not significantly different. | No Change. |
| Sunset Bay | 6.2 | 24.9 | NST | 6.4 | 3.9 | NST | Not significantly different. | Significantly reduced after. | No Change. |
| Dinkens Bayou | 7.5 | 44.8 | NST | 9 | 28.4 | Decreasing | Not significantly different. | Significantly reduced after. | Decreasing trend begins after. |
| Clam Bayou | 7.7 | 52.3 | NST | 12.2 | 55.7 | Decreasing | Significantly greater after. | Not significantly different. | Decreasing trend begins after. |
| Overall | 6.7 | 37.7 | NST | 8.5 | 33.5 | Mixed results | Significantly greater after. | Significantly reduced after. | Mixed results |

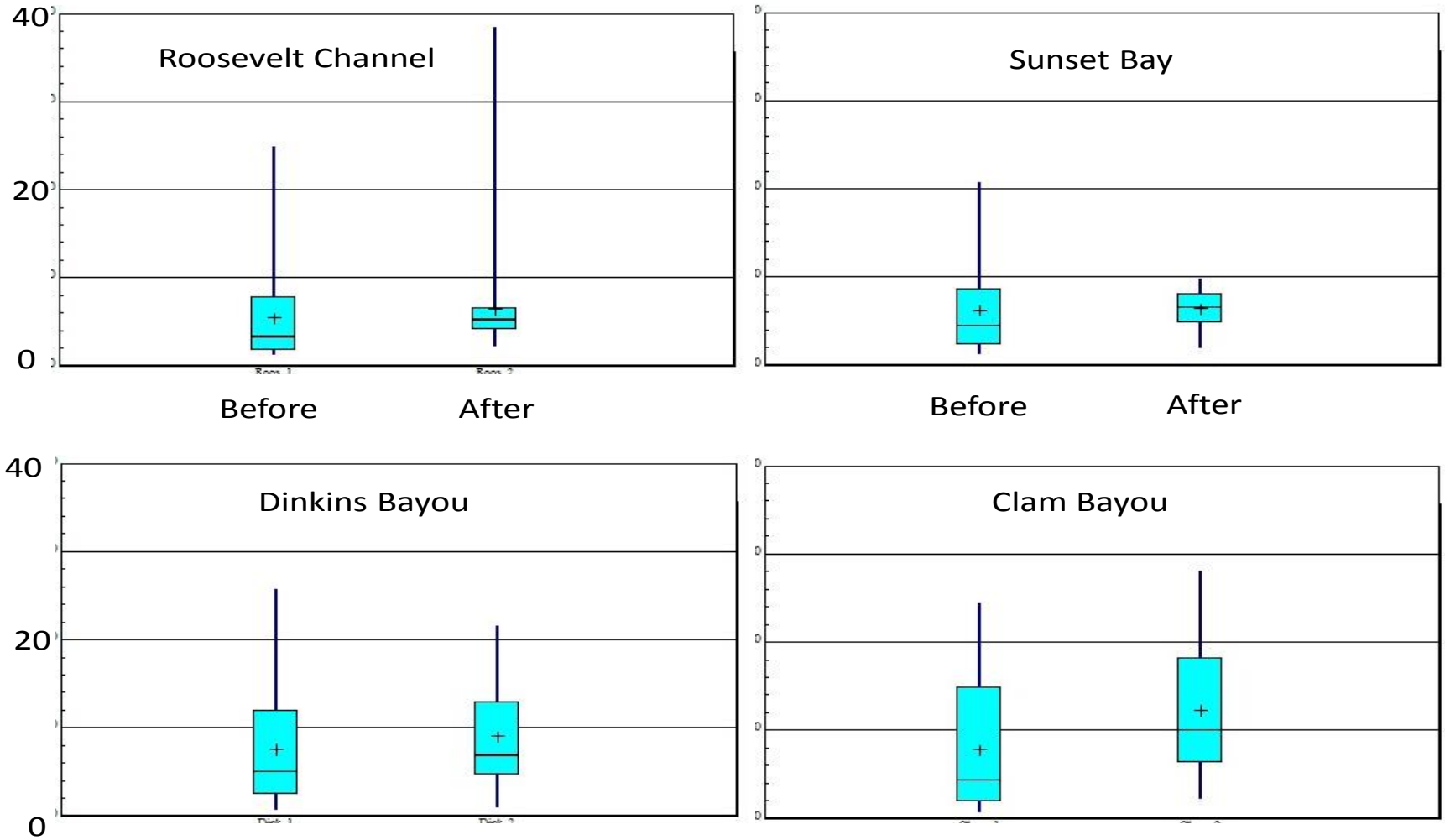


Figure 12: Whisker plot showing mean chlorophyll *a* values (ug/l) for the study period before and after the opening of Blind Pass. Overall, the GLM ANOVA test found significantly higher chlorophyll *a* after the opening, however, only Clam Bayou was shown to be greater on a station by station basis. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

***Total Nitrogen (TN)***

Monthly TN values for the four study sites are plotted in Figure 13. Overall, the mean TN of 0.7 mg/l for the study period after the opening was significantly lower than before the opening (0.82 mg/l) (Table 4, GLM ANOVA, F= 5.1, $p < 0.02$; n = 63). The reduction in TN after the opening of Blind Pass was found to be significant for both wet season (T = 6.7, $p < 0.001$) and dry season (T = 3.1 $p = 0.01$). When compared by station, Clam Bayou (Kruskal-Wallis, z = -1.9, $p < 0.05$; n = 63), and Dinkins Bayou (Kruskal-Wallis, z = -2.0, $p < 0.001$; n = 63) had significantly reduced TN after the opening (Figure 14, Table 4). Wet season mean TN (0.81 mg/l) was significantly greater than dry season TN (0.71 mg/l) (GLM ANOVA, F= 7.1, $p = 0.001$; n = 63). Clam Bayou mean TN was found to be significantly greater than Roosevelt Channel TN (T = 3.5 $p = 0.05$). No other significant differences could be seen between sites for TN.

Overall, variability in TN was significantly reduced after the dredging Blind Pass compared to before (Levene's test, F = 7.3, p < 0.01) (Table 4). When analyzed by station, Clam and Dinkins Bayou stations showed reduced TN variability after the opening of Blind Pass (Levene's test, p < 0.05) (Table 4).

We found a significant decreasing trend in TN was occurring at all stations before the opening of Blind Pass (Seasonal Kendall, p < 0.05) (Table 4). After the opening of Blind Pass significant trends were not found at any stations (Seasonal Kendall, p > 0.05, n = 33).

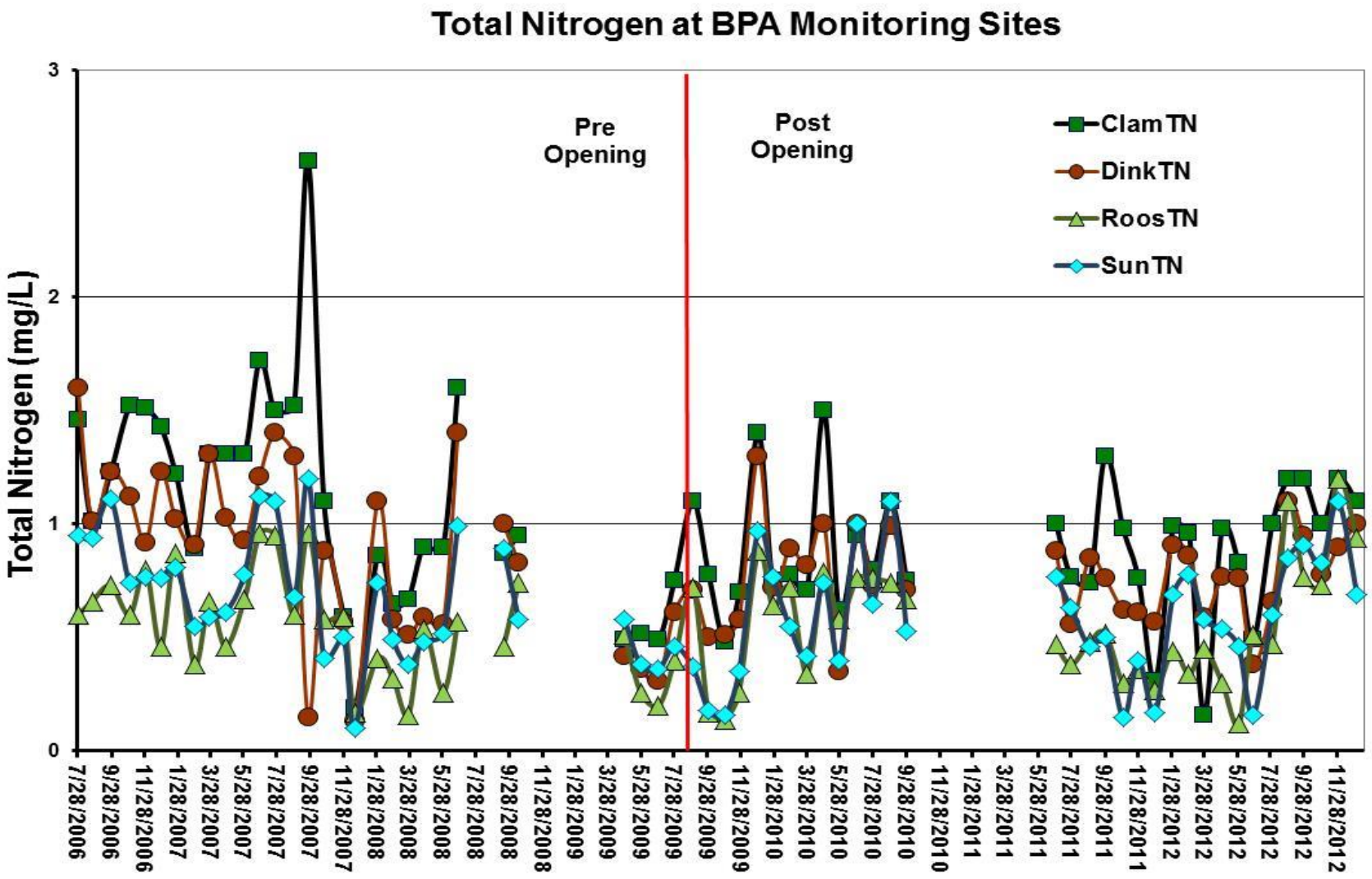


Figure 13: Monthly total nitrogen values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 4. Summary of monthly TN monitoring result analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall mean TN was found to be significantly reduced after the opening and the variation in TN values also decreased. NST = No significant Trend.

| Total Nitrogen | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| **Roosevelt Channel** | 0.55 | 0.05 | Decreasing | 0.55 | 0.07 | NST | Not significantly different. | Not significantly different. | Decreasing trend interrupted. |
| **Sunset Bay** | 0.69 | 0.07 | Decreasing | 0.59 | 0.07 | NST | Not significantly different. | Not significantly different. | Decreasing trend interrupted. |
| **Dinkens Bayou** | 0.95 | 0.21 | Decreasing | 0.77 | 0.04 | NST | Significantly less after. | Significantly reduced after. | Decreasing trend interrupted. |
| **Clam Bayou** | 1.1 | 0.23 | Decreasing | 0.89 | 0.09 | NST | Significantly less after. | Significantly reduced after. | Decreasing trend interrupted. |
| **Overall** | 0.82 | 0.189 | Decreasing | 0.7 | 0.09 | NST | Significantly less after. | Significantly reduced after. | Decreasing trend interrupted. |

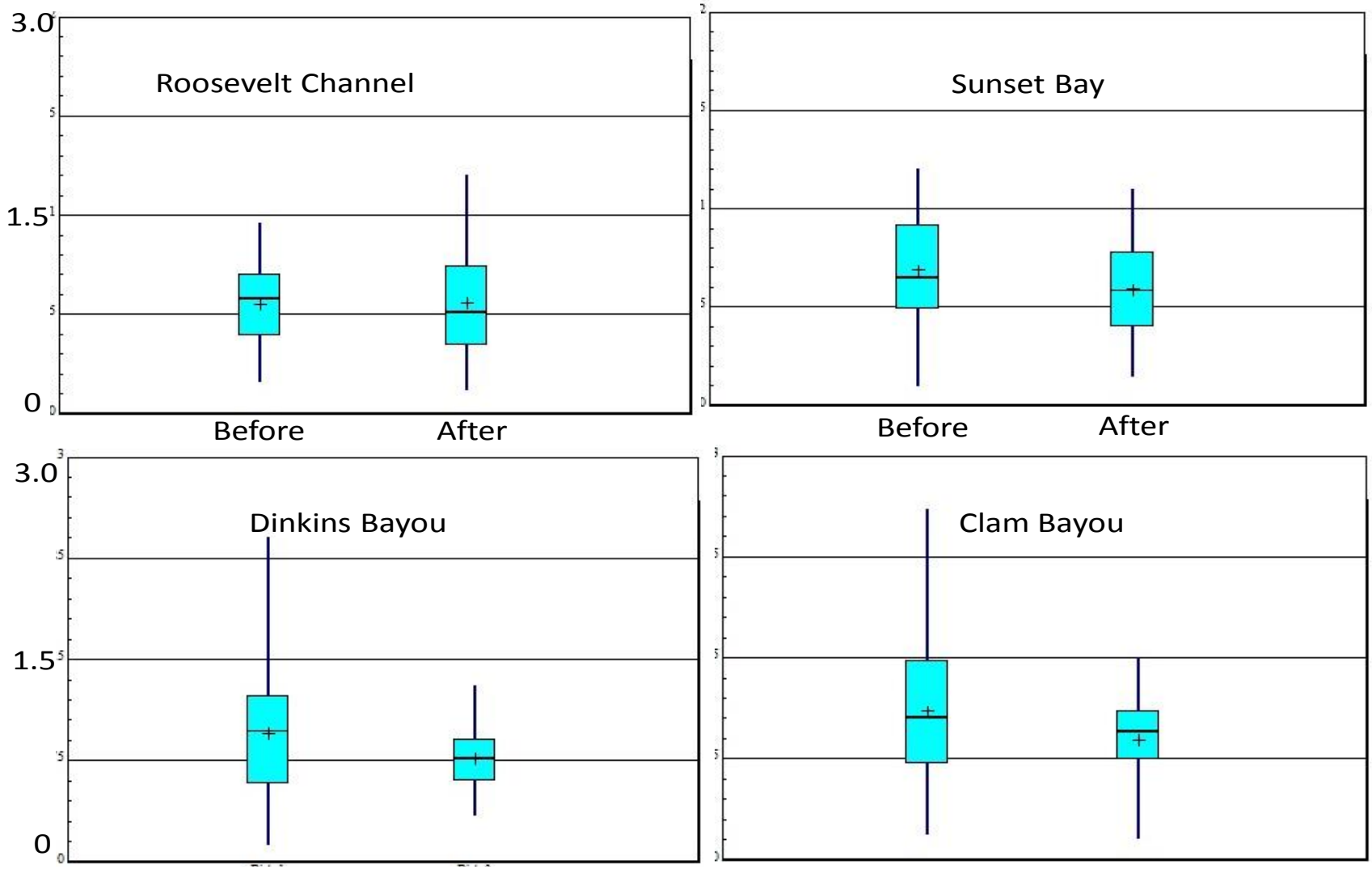


Figure 14: Whisker plot showing mean total nitrogen values (mg/l) for the monitoring period before and after the opening of Blind Pass. ANOVA was unable to find a significant difference in mean TN after the opening of Blind Pass. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile

***Nitrate-Nitrite Nitrogen (NOx)***

No statistically significant differences could be found in the mean NOx value after the opening of Blind Pass (0.011 mg/l) compared to before (0.013 mg/l). No differences were seen between wet and dry season or between sites (Table 5, Figure 15).

Similarly, variability in NOx was also not significantly different after the dredging project was completed compared to before (Table 5).

No significant trends were found in NOx before or after the opening of Blind Pass (Table).

Table 5. Summary of monthly nitrate-nitrite (NOx) monitoring results analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall no significant difference could be found in mean NOx or variation in NOx after the opening. NST = No significant Trend.

| Nitrate/Nitrite | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| **Roosevelt Channel** | 0.012 | 0 | NST | 0.01 | 0 | NST | Not significantly different. | Not significantly different. | No change. |
| **Sunset Bay** | 0.013 | 0 | NST | 0.012 | 0 | NST | Not significantly different. | Not significantly different. | No change. |
| **Dinkens Bayou** | 0.015 | 0 | NST | 0.011 | 0 | NST | Not significantly different. | Not significantly different. | No change. |
| **Clam Bayou** | 0.015 | 0.00004 | NST | 0.011 | 0.00002 | NST | Not significantly different. | Not significantly different. | No change. |
| **Overall** | 0.013 | 0.00006 | NST | 0.011 | 0.00002 | NST | Not significantly different. | Not significantly different. | No change. |

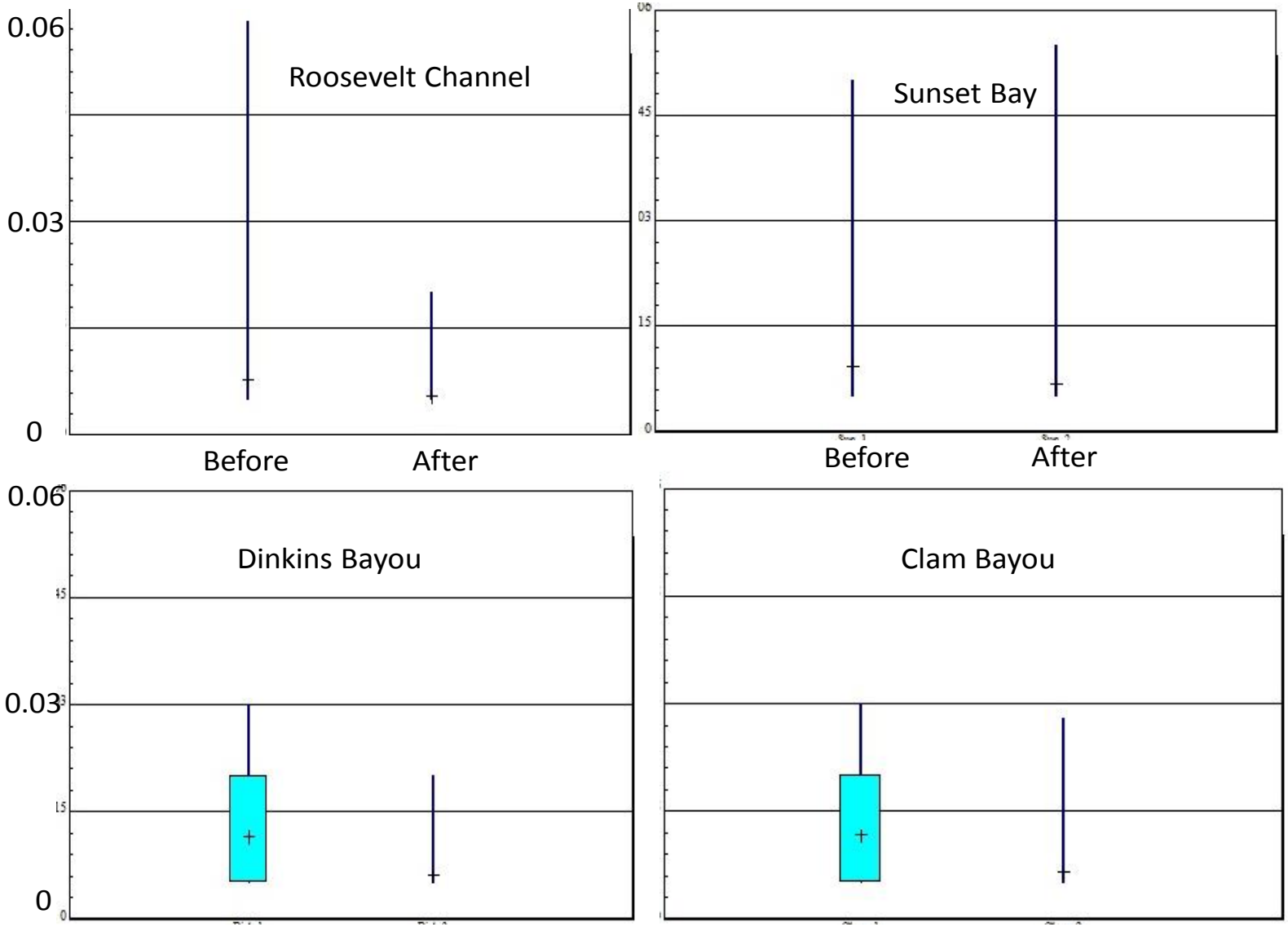


Figure 15: Whisker plot showing mean nitrate-nitrite nitrogen values (mg/l) the monitoring period before and after the opening of Blind Pass. No significant difference could be seen in NOx values before and after the dredging of Blind Pass. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

### *Total Phosphorus (TP)*

Monthly TP values for the four study sites are plotted in Figure 16. Overall, the mean TP of 0.033 mg/l for the study period after the opening was significantly lower than before the opening (0.055 mg/l) (Table 6, GLM ANOVA, F= 46.8, $p < 0.001$; n = 63). The reduction in TP after the opening of Blind Pass was found to be significant for both wet season (T = 6.7, $p < 0.001$) and dry season (T = 3.1 $p = 0.01$). When compared by station, Sunset Bay (GLM ANOVA, T = -3.5, $p = 0.04$; n = 63), and Dinkins Bayou (GLM ANOVA, T = -3.5, $p = 0.05$; n = 63) had significantly reduced TP after the opening (Figure 17, Table 6). Wet season mean TP (0.048 mg/l) was significantly greater than dry season TP (0.037 mg/l) (GLM ANOVA, F= 5.58, $p = 0.004$; n = 63). No significant differences could be seen for TP between sites (GLM ANOVA, F= 1.1, $p = 0.04$; n = 63).

Overall, variability in TP was not found to be significantly different after the dredging compared to before (Levene's test, F = 2.1, p = 0.14) (Table 6). No differences in before vs. after TP variance were seen for any of the four stations.

In the 30 months before the opening of Blind Pass, TP was trending downward at Clam Bayou (Seasonal Kendall, z = 2.2, $p < 0.05$, n = 33) and Dinkins Bayou (Seasonal Kendall, z = 2.5, $p < 0.05$, n = 33) while after the opening no statistically significant trends were found (Seasonal Kendall, $p > 0.05$, n = 33).

### *Orthophosphate (OP)*

Before and after Blind Pass opening comparisons for inorganic phosphorus were not made because collection of OP began late in 2009 as initial analyses indicated it may be an important predictor of algal blooms around developed areas. For the period after the pass was re-opened, there were no significant trends was seen in OP values after the opening of Blind Pass (Seasonal Kendall, z = 1.0, $p > 0.05$, n = 33) (Table 7).

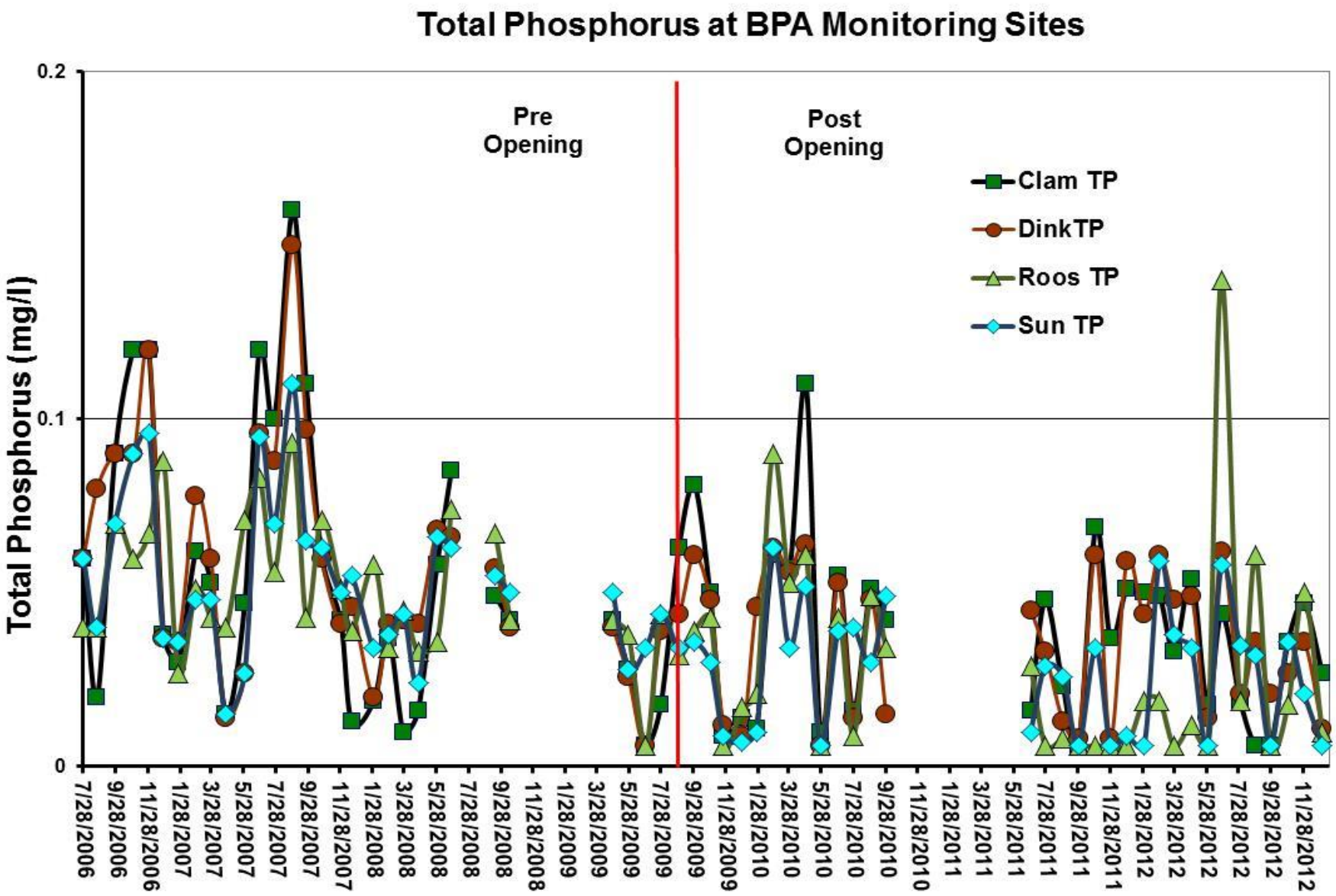


Figure 16: Monthly TP values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 6 Summary of monthly total phosphorus (TP) monitoring result analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall, mean TP was found to be significantly reduced after the opening but the variation in TP did not change. NST = No significant Trend.

| Total Phosphorus | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | 0.052 | 0.0004 | NST | 0.028 | 0.009 | NST | No significant change. | Not significantly different. | No Change. |
| Sunset Bay | 0.054 | 0.005 | NST | 0.027 | 0.003 | NST | Significantly less after. | Not significantly different. | No Change. |
| Dinkens Bayou | 0.06 | 0.001 | Decreasing | 0.04 | 0.0004 | NST | Significantly less after. | Not significantly different. | Decreasing trend interrupted. |
| Clam Bayou | 0.056 | 0.0016 | Decreasing | 0.039 | 0.0006 | NST | Not significantly different. | Not significantly different. | Decreasing trend interrupted. |
| Overall | 0.055 | 0.0009 | Mixed | 0.033 | 0.006 | NST | Significantly less after. | Not significantly different. | Mixed results. |

Table 7. Summary of monthly orthophosphate (OP) monitoring results analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Orthophosphate was added in 2009 as existing data suggested that it may be a predictor of chlorophyll in estuarine water. Therefore, no data was collected for this parameter before the opening of Blind Pass and no significant trends were observed for the period after the opening. NST = No significant Trend. ND = No data available.

| Orthophosphate | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | ND | ND | ND | 0.006 | 0 | NST | Cannot test | Cannot test | Cannot test |
| Sunset Bay | ND | ND | ND | 0.005 | 0 | NST | Cannot test | Cannot test | Cannot test |
| Dinkens Bayou | ND | ND | ND | 0.01 | 0 | NST | Cannot test | Cannot test | Cannot test |
| Clam Bayou | ND | ND | ND | 0.009 | 0.00009 | NST | Cannot test | Cannot test | Cannot test |
| Overall | ND | ND | ND | 0.007 | 0.00006 | NST | Cannot test | Cannot test | Cannot test |

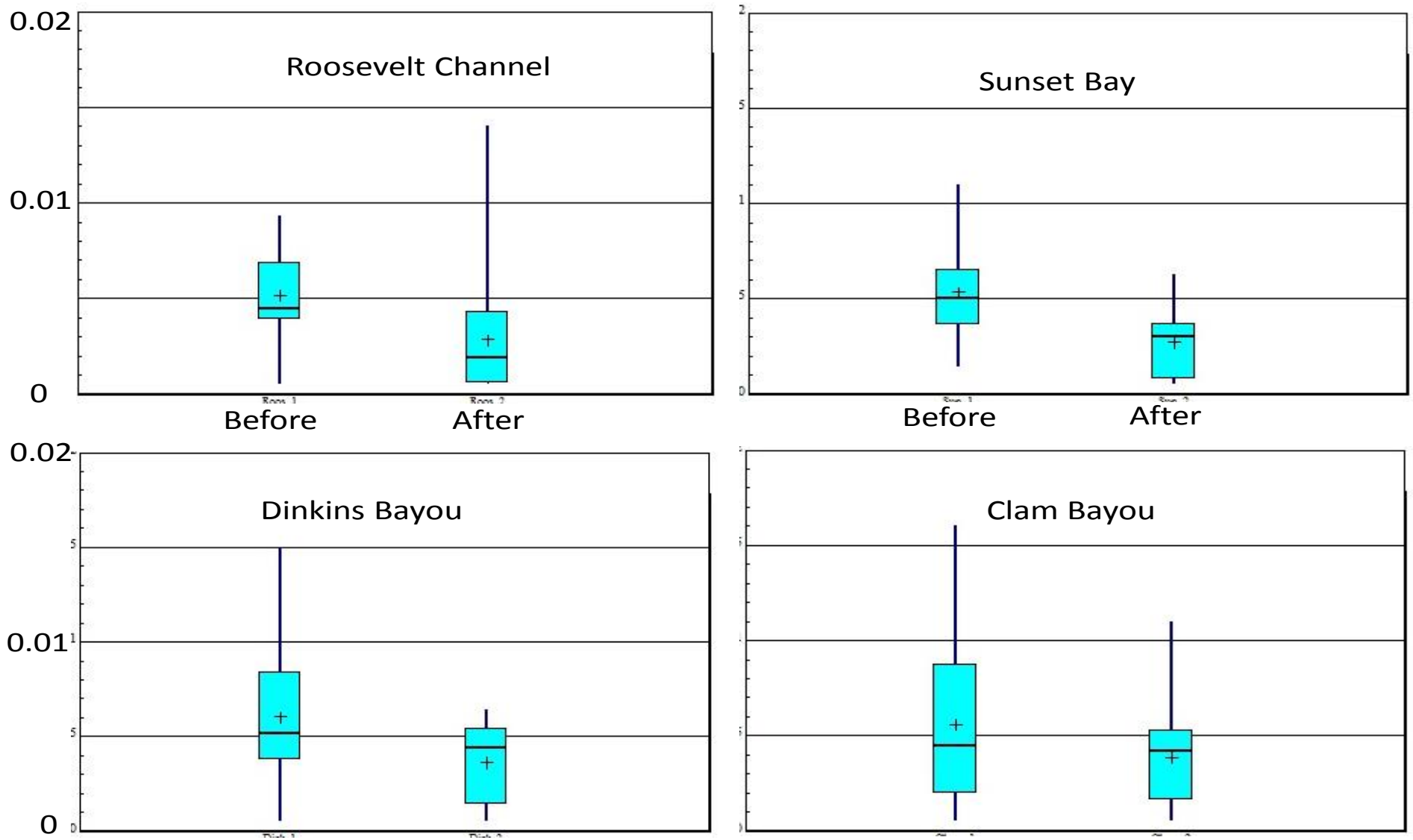


Figure 17. Whisker plot showing mean TP values for the monitoring period before and after the opening of Blind Pass. Overall, GLM ANOVA detected significantly reduced mean TP after the opening versus before the opening. Site specific analyses showed Sunset Bay and Dinkins Bayou to have statistically significant lower TP after the opening of Blind Pass. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

***Dissolved Oxygen (DO)***

Monthly DO values for the four study sites are plotted in Figure 18. Overall, the mean DO of 4.0 mg/l after the opening was significantly greater than the mean DO before the pass was opened (3.4 mg/l) (Table 8, GLM ANOVA, F= 12.2, $p < 0.001$; n = 63). A significant increase in DO was found after the opening of Blind Pass for the dry season (GLM ANOVA, T = 3.0, $p = 0.02$) but not for the wet season (GLM ANOVA, T = 1.9, $p = 0.21$). When analyzed by station, Roosevelt Channel (GLM ANOVA, T = -3.5, $p = 0.05$; n = 63) had significantly greater DO after the opening (Figure 19, Table 8), while before/after differences were insignificant at the other 3 stations. Dry season mean DO (4.3 mg/l) was significantly greater than wet season DO (3.1 mg/l) (GLM ANOVA, F= 46.4, $p < 0.001$; n = 63). Mean DO was significantly less at Clam Bayou after the opening in dry season compared to Roosevelt Channel (GLM ANOVA, T = 3.9, $p = 0.01$; n = 63), but no significant differences could be seen for DO between the other combinations of site comparisons.

Overall, variability in DO was not found to be significantly different after the dredging compared to before (Levene's test, F = 2.4, p = 0.12) (Table 8). No differences in before versus after DO variance were seen for any of the four stations.

In the 30 months before the opening of Blind Pass, a downward trend in DO was found at the Sunset Bay site (Seasonal Kendall, z = 2.6, $p < 0.05$, n = 33) while after the opening no statistically significant trends were found at any of the four stations (Seasonal Kendall, $p > 0.05$, n = 33) (Table 8).

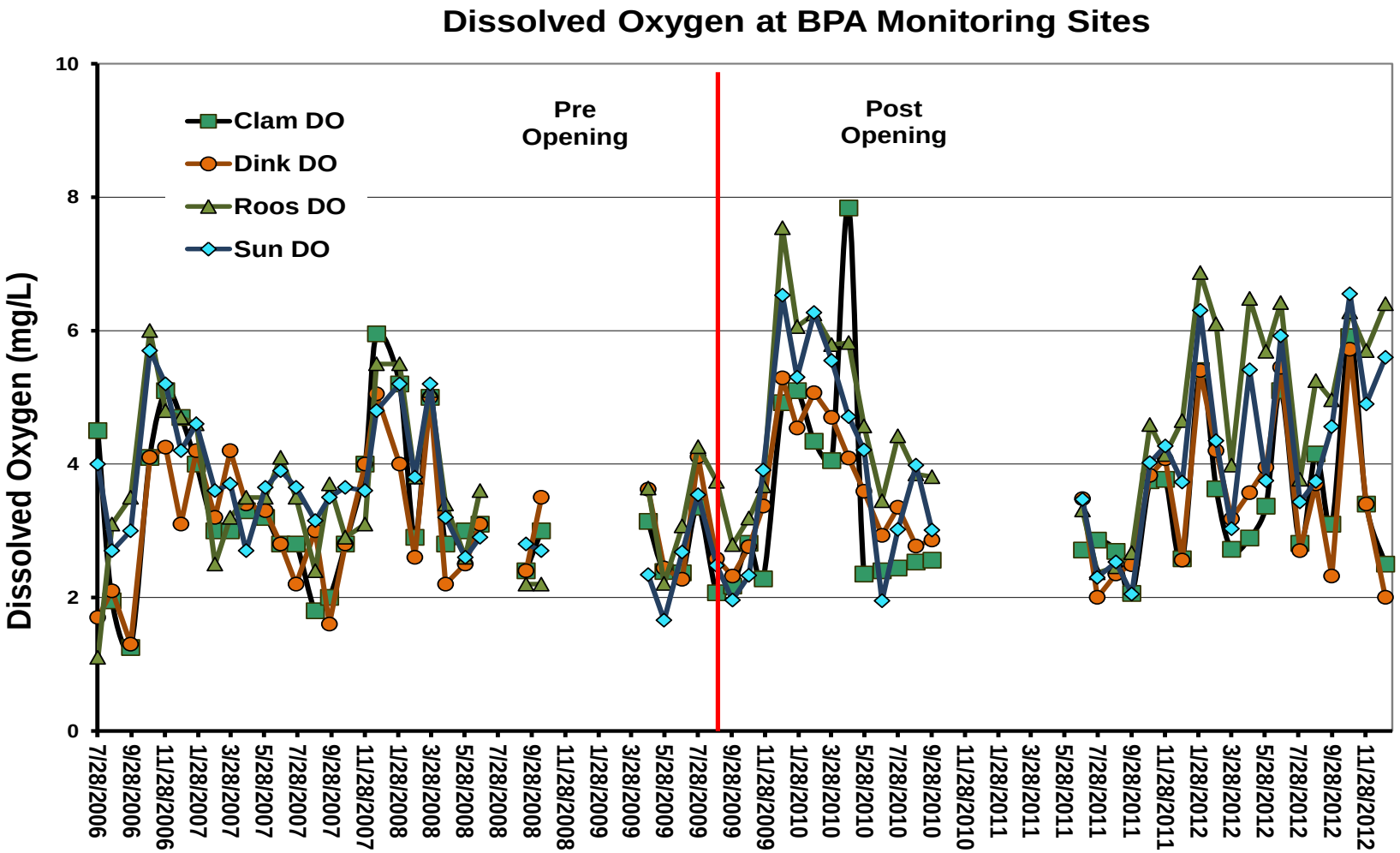


Figure 18: Monthly dissolved oxygen values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 8. Summary of monthly dissolved oxygen monitoring result analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. Overall mean DO was found to be significantly greater after the opening but the variation in DO was not significantly different. NST = No significant Trend.

| Dissolved Oxygen | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | 3.6 | 1.3 | NST | 4.8 | 2 | NST | Significantly greater after. | Not significantly different. | No Change. |
| Sunset Bay | 3.6 | 0.9 | Decreasing | 4.1 | 2 | NST | Not significantly different. | Not significantly different. | Decreasing trend interrupted. |
| Dinkens Bayou | 3.2 | 1 | NST | 3.5 | 1.1 | NST | Not significantly different. | Not significantly different. | No Change. |
| Clam Bayou | 3.3 | 1.2 | NST | 3.4 | 1.7 | NST | Not significantly different. | Not significantly different. | No Change. |
| Overall | 3.4 | 1.1 | NST | 4 | 2 | NST | Significantly greater after. | Not significantly different. | No Change. |

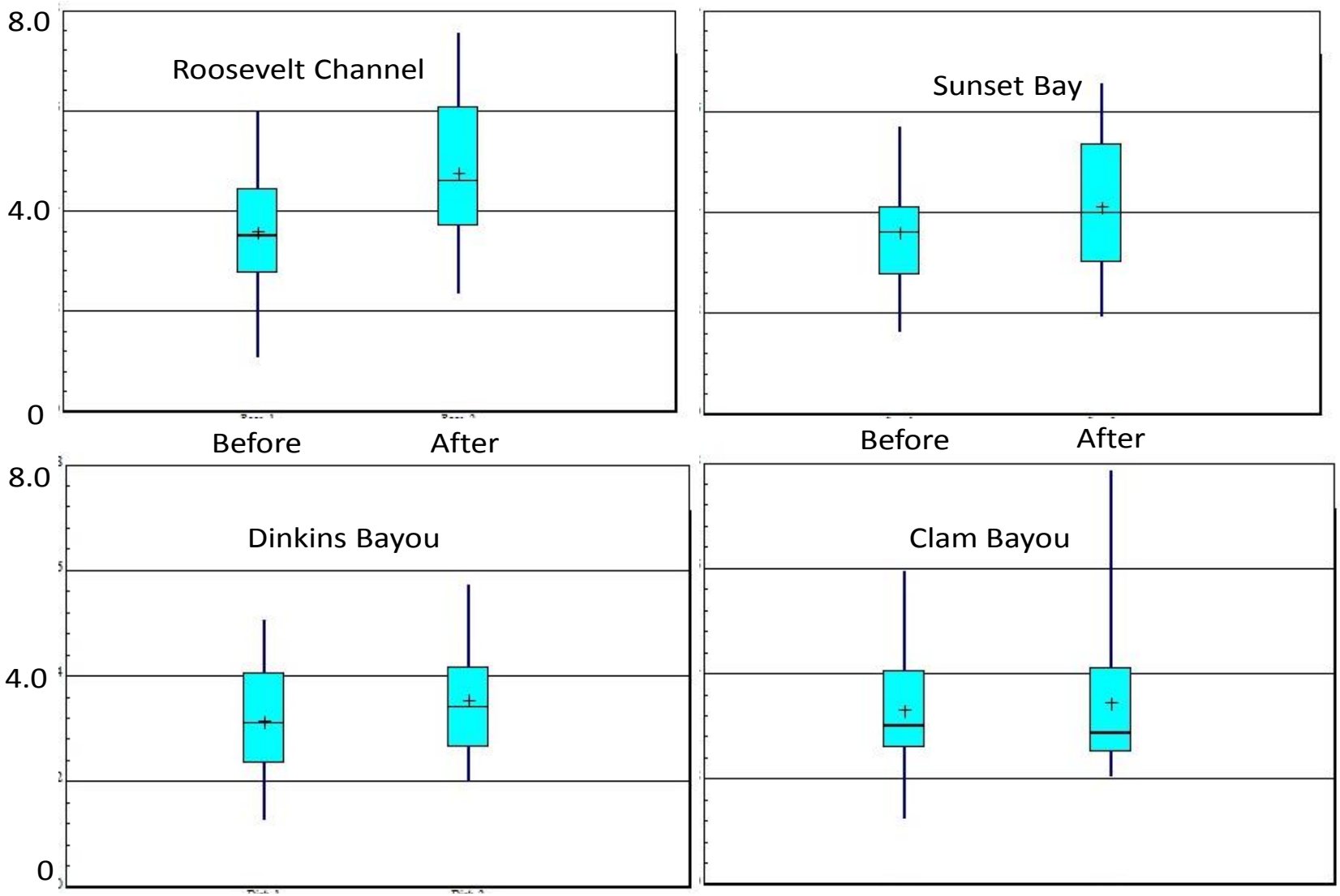


Figure 19: Whisker plot showing mean dissolved oxygen values for the monitoring period before and after the opening of Blind Pass. Overall GLM ANOVA found significantly higher mean DO after the opening. Individual station analyses showed Roosevelt Channel had significantly greater DO after the opening. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

***Water Temperature***

Monthly water temperature values for the four study sites are plotted in Figure 20. Overall, no significant differences could be found between after the re-opening (24.8° C) compared to the before period (24.9° C; Figure 21; Table 9, GLM ANOVA, F= 0.69, $p < 0.41$; n = 63). In addition, no site-specific differences were found in the before period compared to after the pass was re-opened. Temperature differences between sites were also not significant. As expected, mean dry season temperature (20.8 C) was significantly lower than wet season temperature (28.3 C) (GLM ANOVA, F= 15.5, $p < 0.001$; n = 252).

Overall, variability in temperature was not found to be significantly different after the dredging compared to before (Levene's test, F = 1.8, p = 0.19) (Table 9). No site-specific differences before versus after differences were found.

Additionally no temperature trends were observed before or after the opening of Blind Pass (Seasonal Kendall, z = 0.6, p > 0.05) (Table 9).

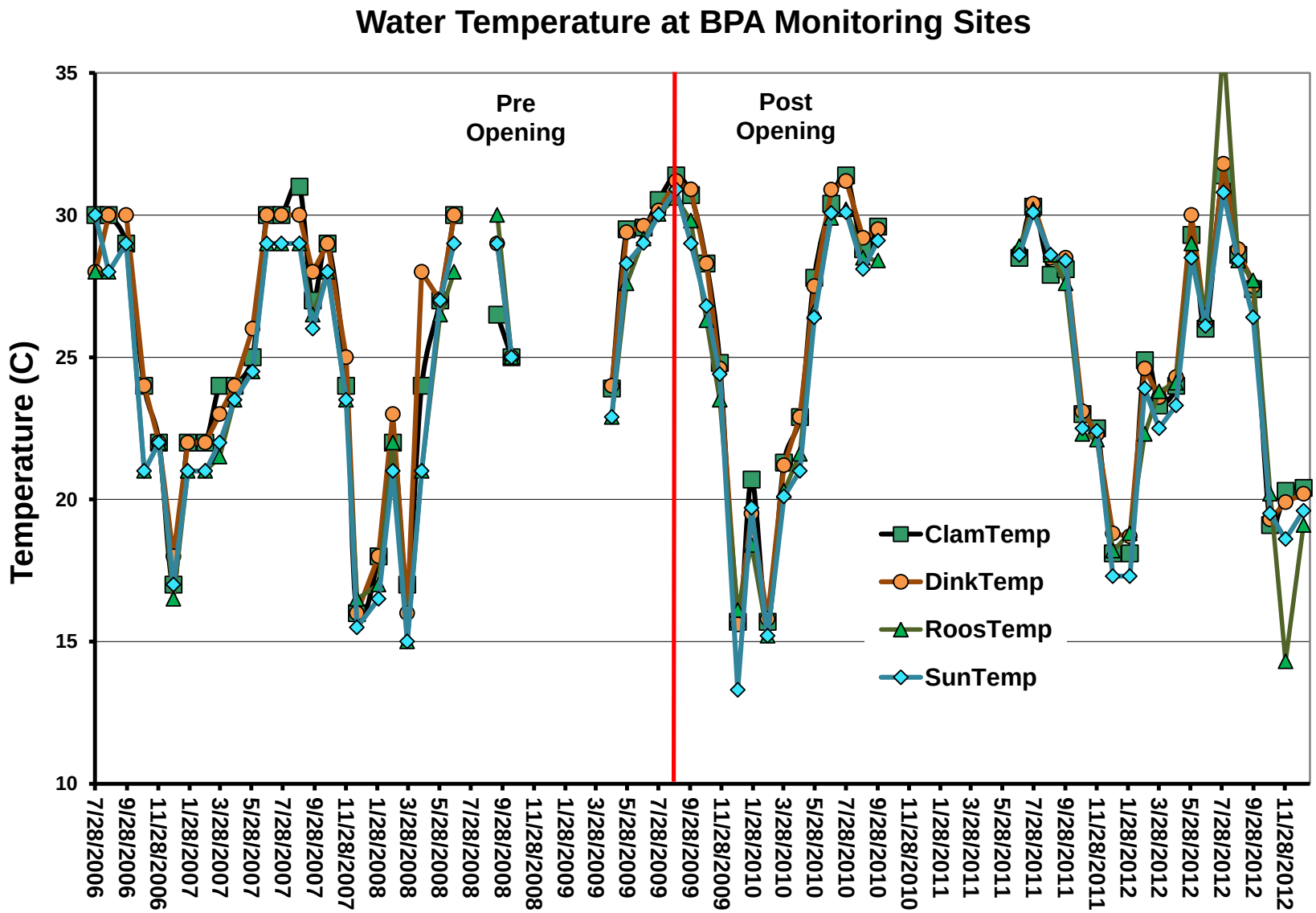


Figure 20: Monthly water temperature values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

Table 9. Summary of monthly temperature monitoring result analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. No significant changes were seen in temperature or the variation in temperature after the opening. NST = No significant Trend.

| Temperature | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | 24.4 | 24.5 | NST | 24.5 | 24.9 | NST | Not significantly different. | Not significantly different. | No Change. |
| Sunset Bay | 24.4 | 21.4 | NST | 24.5 | 24.8 | NST | Not significantly different. | Not significantly different. | No Change. |
| Dinkens Bayou | 25.5 | 19.7 | NST | 25.3 | 23.6 | NST | Not significantly different. | Not significantly different. | No Change. |
| Clam Bayou | 25.3 | 19.7 | NST | 25.2 | 22.2 | NST | Not significantly different. | Not significantly different. | No Change. |
| Overall | 24.9 | 19.9 | NST | 24.8 | 23.6 | NST | Not significantly different. | Not significantly different. | No Change. |

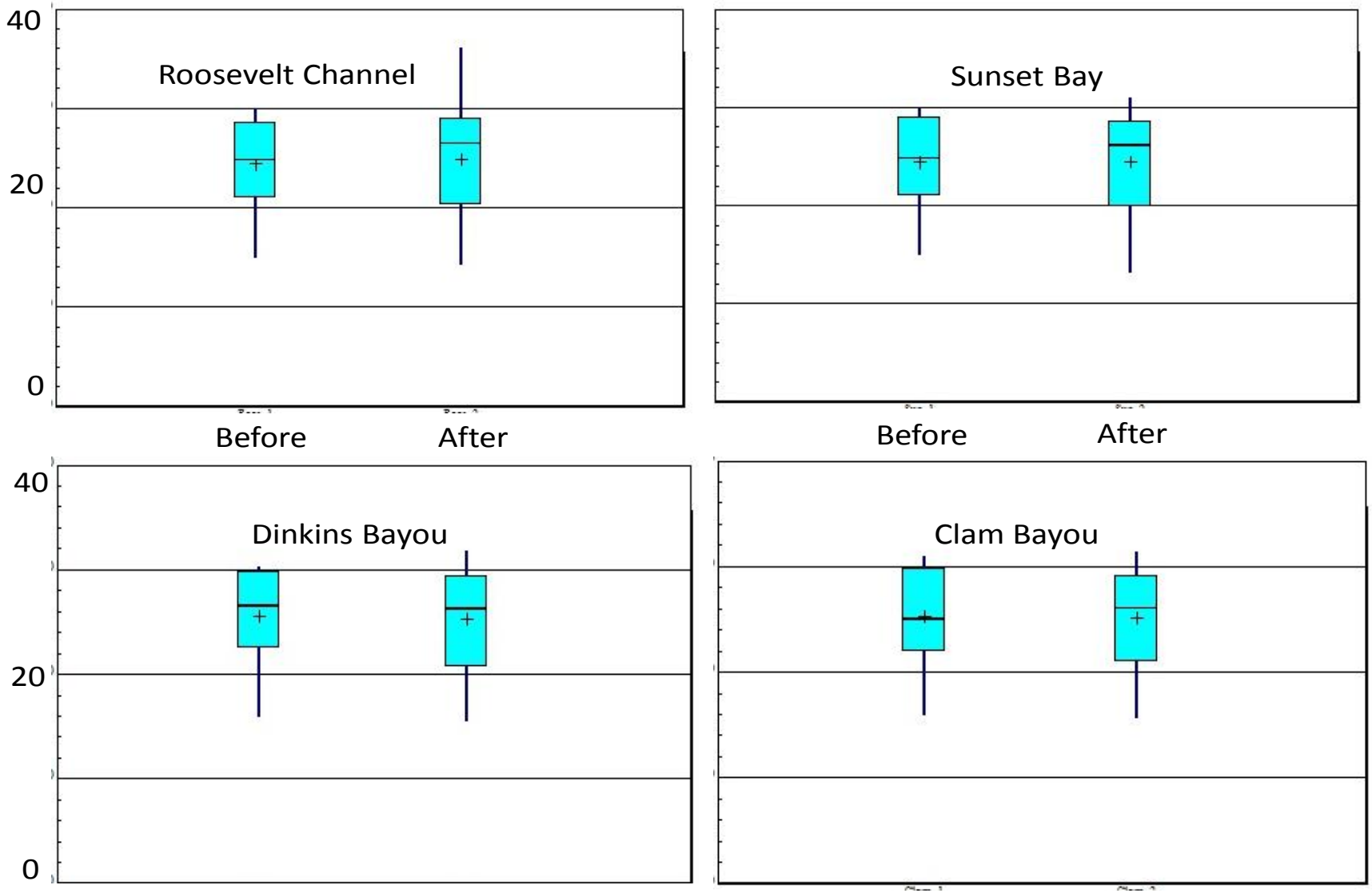


Figure 21: Whisker plot showing mean water temperature for the monitoring period before and after the opening of Blind Pass. No significant differences were found in temperature before vs. after the opening. Note: cross indicates average, horizontal line equals median, upper boundary of box is 75$^{th}$ percentile and lower boundary of box is 25$^{th}$ percentile value.

### *Fecal Coliform*

Fecal coliform (FC) data were discontinued in 2010 because Enterococcus analysis was determined from other studies to be a better indicator of bacterial concentrations. The data collected during the study are presented in Figure 22. For the pooled data, mean FC (12 col./100 ml) values were not found to be significantly different after the opening than values before (23 colonies/100 ml) the opening of Blind Pass (Figure 23; ANOVA, $F = 2.75$, $p = 0.099$). However, FC was significantly lower in wet season than dry season (ANOVA, $F = 13.96$, $p < 0.001$) and also significantly lower at the Roosevelt Channel site compared to the other three sites (ANOVA, $F = 3.27$, $p = 0.023$).

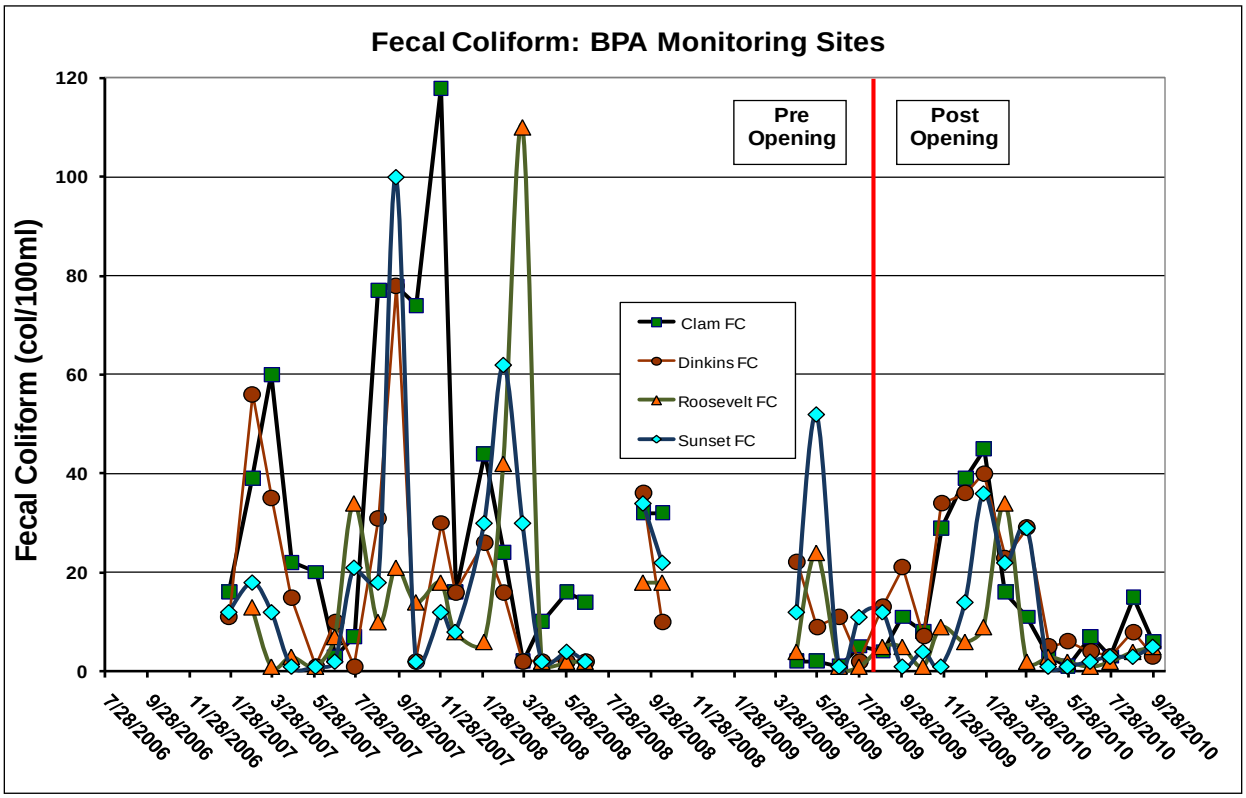


Figure 22. Monthly fecal coliform values at BPA monitoring sites over the duration of the study period showing period before and after opening of Blind Pass.

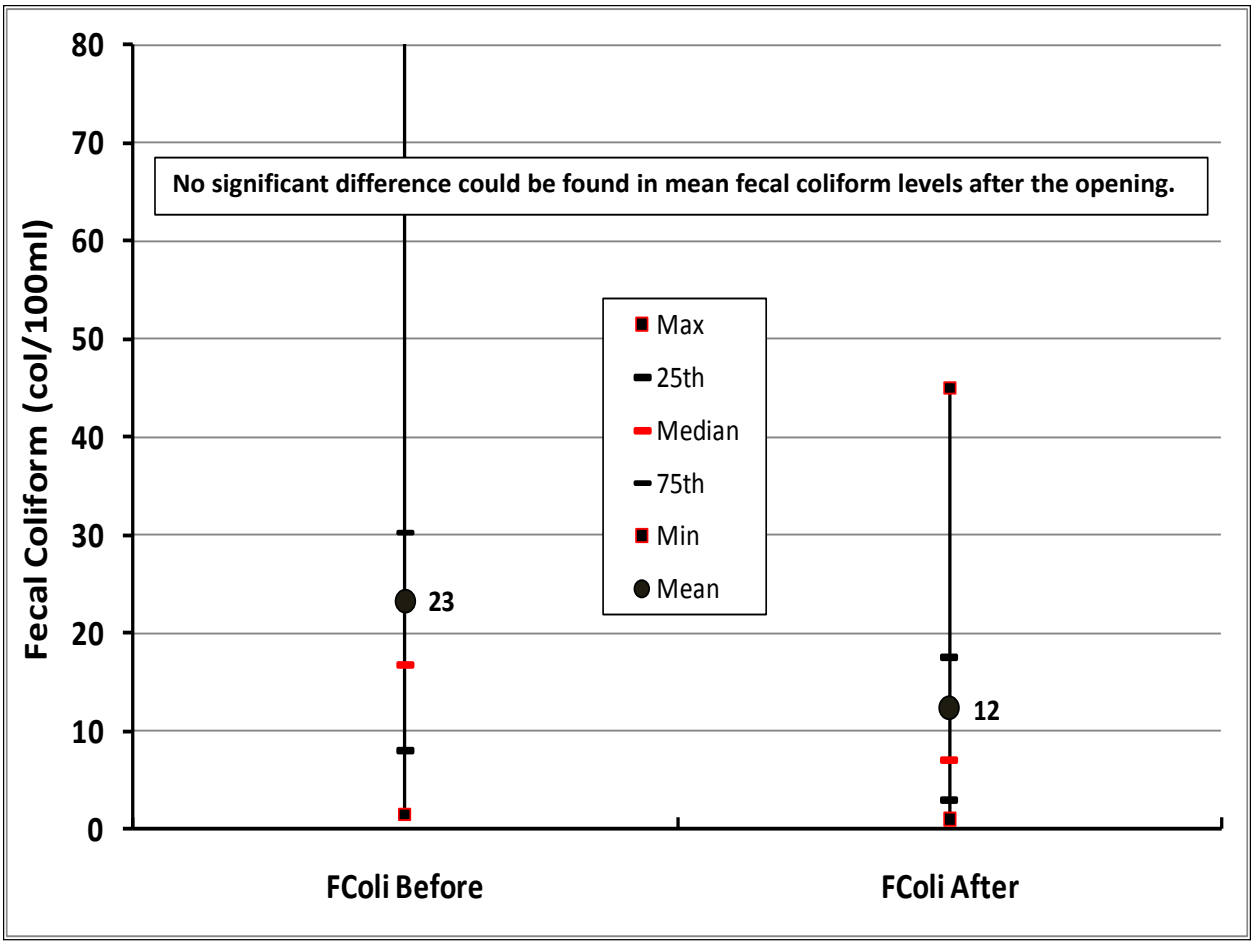


Figure 23. Whisker plot showing mean fecal coliform values for pooled data for the monitoring period before and after the opening of Blind Pass. ANOVA could not find a difference for mean F. coli after the opening.

### *CDOM and Enterococci Bacteria*

Statistical analyses assessing before and after differences were not performed on CDOM or enterococci bacteria because there was insufficient data.

After the opening of Blind Pass a significant decreasing trend was found in CDOM values at both the Dinkins (Spearman's correlation, $p = 0.045$, r = .788, n = 33) and Clam Bayou sites (Spearman's correlation, $p = 0.05$, r = .771, n = 33) (Table 10).

No significant trends were found for enterococci bacteria after the opening of blind pass (Table 11).

Table 10. Summary of CDOM monitoring result analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. No data was collected for this parameter before the opening of Blind Pass. A significant decreasing trend in CDOM was found after the opening of Blind Pass at the two bayous stations. NST = No significant Trend. ND = No data available.

| CDOM | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | ND | ND | ND | 18.8 | 76.1 | NST | Cannot test | Cannot test | Cannot test |
| Sunset Bay | ND | ND | ND | 17.8 | 65.2 | NST | Cannot test | Cannot test | Cannot test |
| Dinkens Bayou | ND | ND | ND | 29.2 | 82.7 | Decreasing | Cannot test | Cannot test | Cannot test |
| Clam Bayou | ND | ND | ND | 34.8 | 184.9 | Decreasing | Cannot test | Cannot test | Cannot test |
| Overall | ND | ND | ND | 25.2 | 150.9 | NST | Cannot test | Cannot test | Cannot test |

Table 11. Summary of monthly enterococci bacteria monitoring results analyses for period prior (n = 30) and after (n = 33) the opening of Blind Pass. No data was collected for this parameter before the opening of Blind Pass and no significant trends were observed for the period after the opening. NST = No significant Trend. ND = No data available.

| Enterococci | Before Dredging | | | After Dredging | | | Comparison After vs. Before | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Variance | Trend | Mean | Variance | Trend | Mean | Variance | Trend |
| Roosevelt Channel | ND | ND | ND | 25.1 | 2315 | NST | Cannot test | Cannot test | Cannot test |
| Sunset Bay | ND | ND | ND | 30.8 | 5876 | NST | Cannot test | Cannot test | Cannot test |
| Dinkens Bayou | ND | ND | ND | 37.5 | 5238 | NST | Cannot test | Cannot test | Cannot test |
| Clam Bayou | ND | ND | ND | 27.6 | 2298 | NST | Cannot test | Cannot test | Cannot test |
| Overall | ND | ND | ND | 32.7 | 3863 | NST | Cannot test | Cannot test | Cannot test |

### *Regional Data for Comparison*

A summary of data collected at SCCF's four real-time River, Estuary and Coastal Observing Network (or RECON) water quality monitoring stations nearest the study area (Figure 24) is presented in Figures 25-28 for one year before and after the opening. Mean salinity at all four RECON stations decreased in the one year period after the opening of Blind Pass compared to the preceding year (Figure 25).

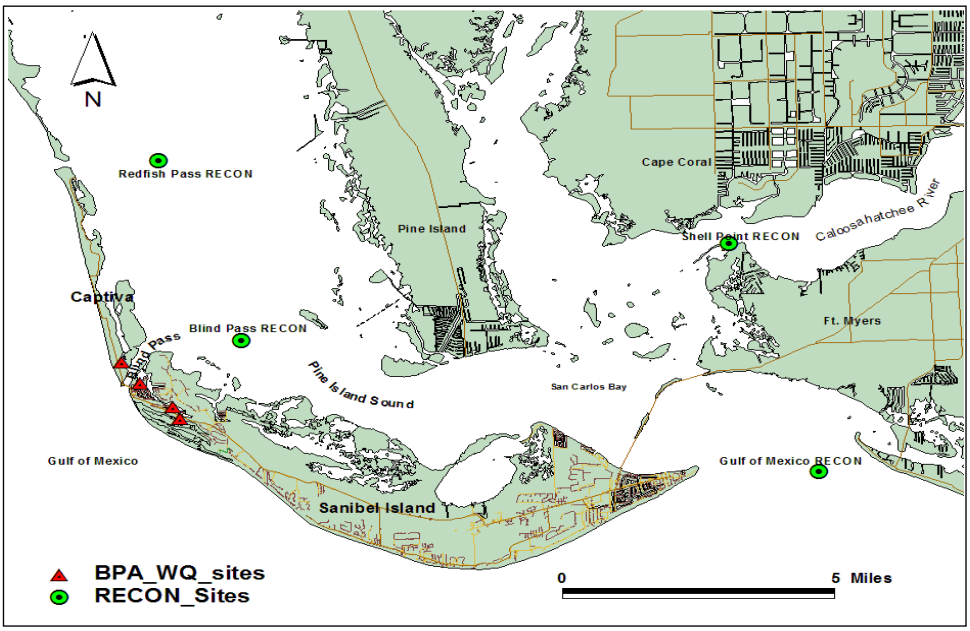


Figure 24. RECON stations from which data was evaluated for this study are shown by green points. BPA stations are shown with red triangles.

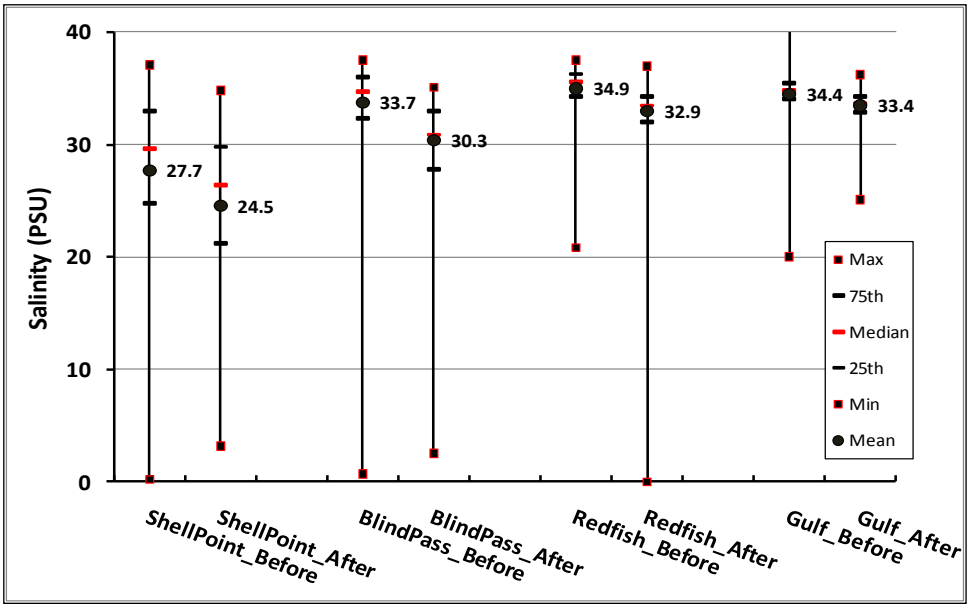


Figure 25. Mean salinity at four SCCF RECON monitoring stations for the one year period before and after the opening of Blind Pass.

Mean turbidity at the Blind Pass and Redfish Pass RECON stations decreased in the year after the opening of Blind Pass compared to the year before while the Gulf of Mexico and Shell Point Stations had greater mean turbidity in the year after the opening (Figure 26).

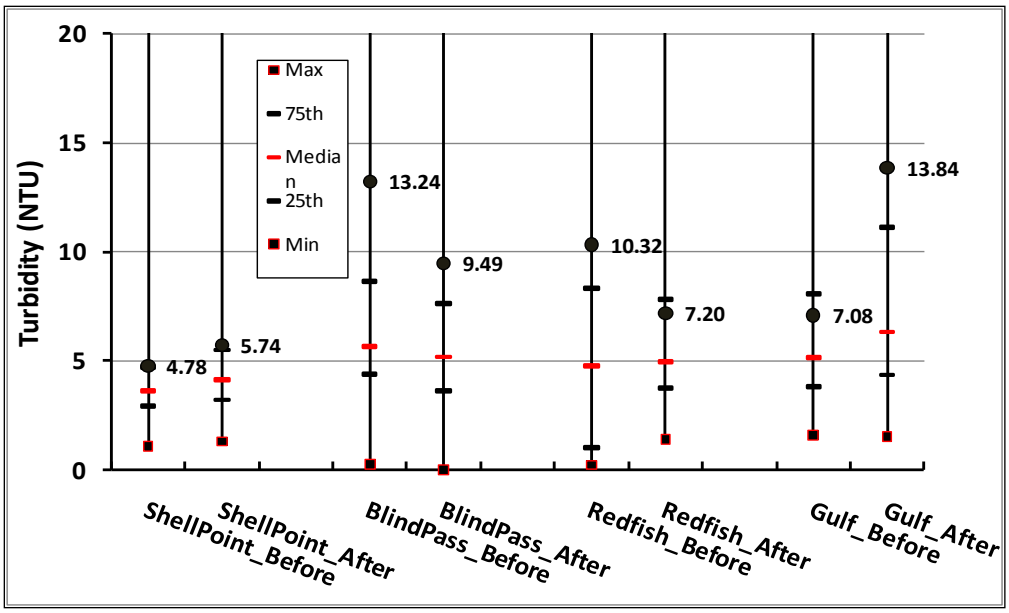


Figure 26. Mean turbidity at four SCCF RECON monitoring stations for the one year period before and after the opening of Blind Pass.

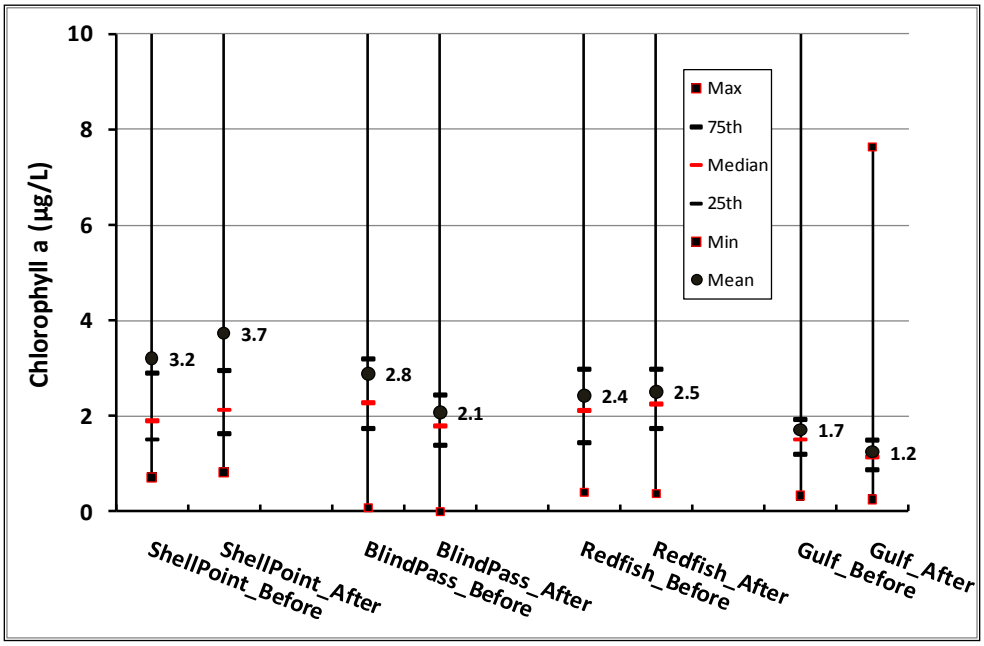


Figure 27. Mean chlorophyll *a* at the four RECON stations one year before and after the opening of Blind Pass.

Mean chlorophyll *a* did not change much for the four RECON stations evaluated during this study in the year after the opening of Blind Pass. Slightly higher chlorophyll *a* was found at the Shell Point and Redfish Pass sites while slightly lower mean chlorophyll *a* was found at the Blind Pass and Gulf of Mexico sites (see Figure 27).

Mean dissolved oxygen at the four RECON stations also did not vary much between the immediate years before and after the opening of Blind Pass. All four stations exhibited slight increases in DO in the year following the opening of Blind Pass, but the increases were insignificant at the Blind Pass, Shell Point and Gulf of Mexico stations (Figure 28).

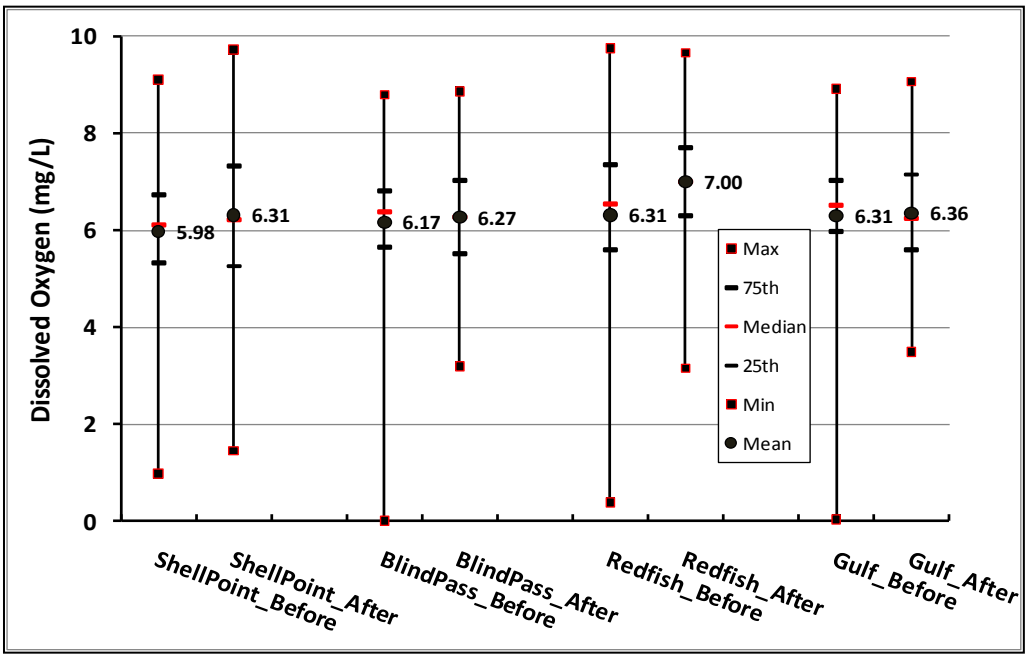


Figure 28. Mean dissolved oxygen at the four RECON stations one year before and after the opening of Blind Pass.

We include below plots (Figure 29) of water depth and temperature logged every 15 minutes from a YSI 6600 datasonde mounted on Dr. Edward Miller's dock in Clam Bayou.

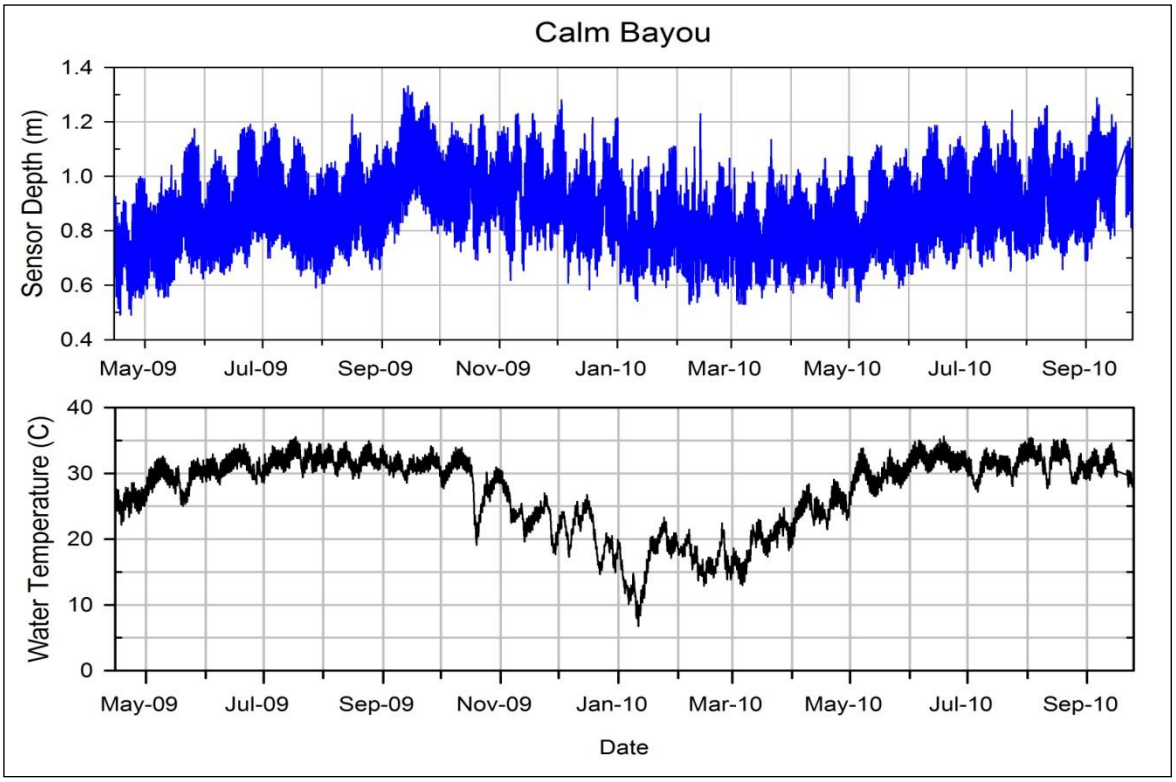


Figure 29. Water level and temperature as recorded by logging sensor in Clam Bayou (Note: these data correspond very well with the YSI logger on the same dock).

This is a temporary installation made possible by the J.N. "Ding" Darling Refuge who purchased this instrument and are allowing us to use it as needed in and around Sanibel and Captiva. Using the information collected by this data logger, we can see clearly see daily, diurnal, seasonal and annual variation for several important water quality parameters (Figures 30-32). These data will be used in conjunction with other biological monitoring associated with the oyster reef and mangrove restoration efforts in Clam Bayou.

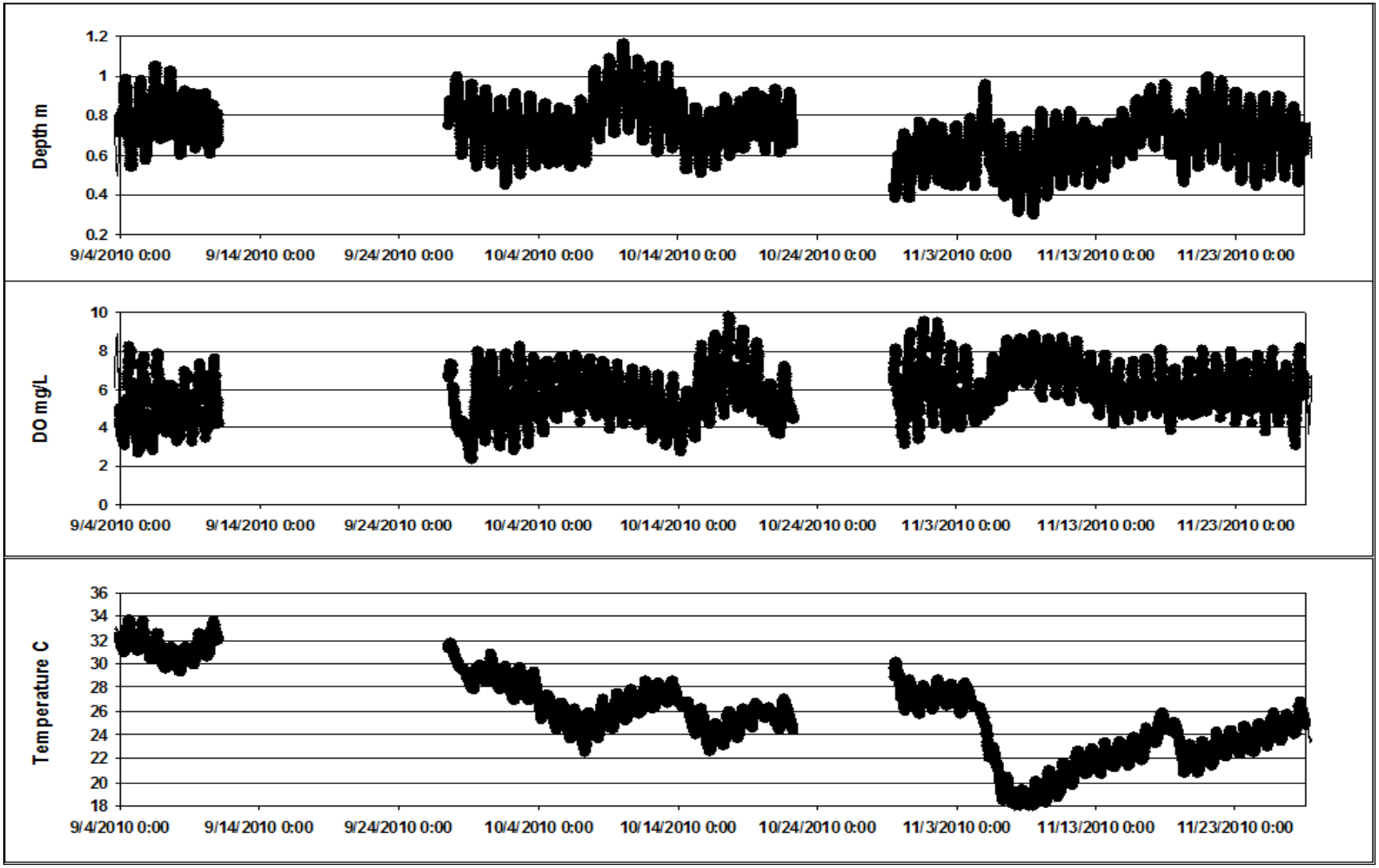


Figure 30. Data collected by a YSI water quality datasonde deployed in Clam Bayou. These data show daily, diurnal, seasonal and annual variation in several important water quality parameters.

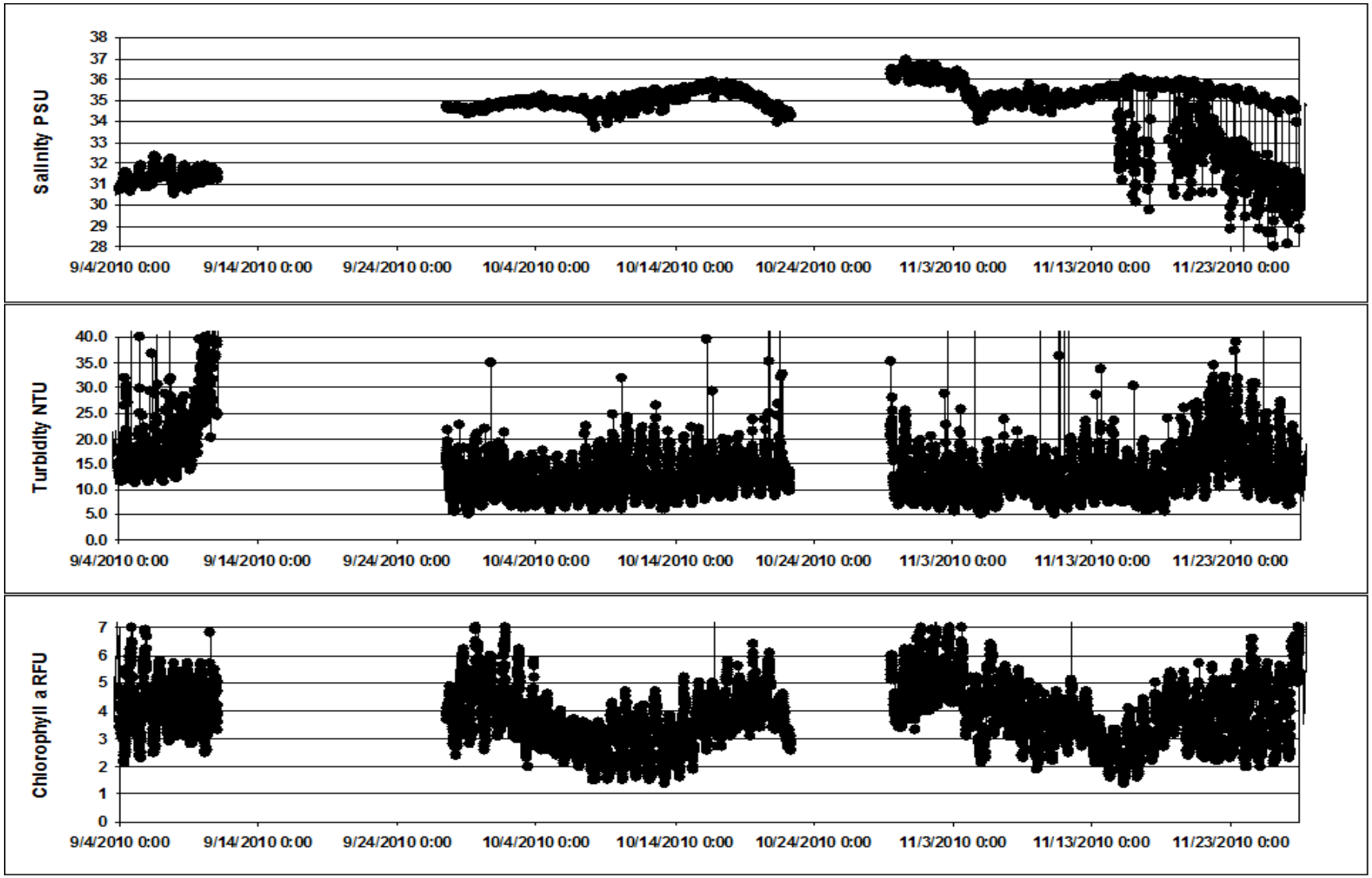


Figure 31. Data collected by a YSI 6600 water quality datasonde deployed in Clam Bayou. These data show daily, diurnal, seasonal and annual variation in several important water quality parameters.

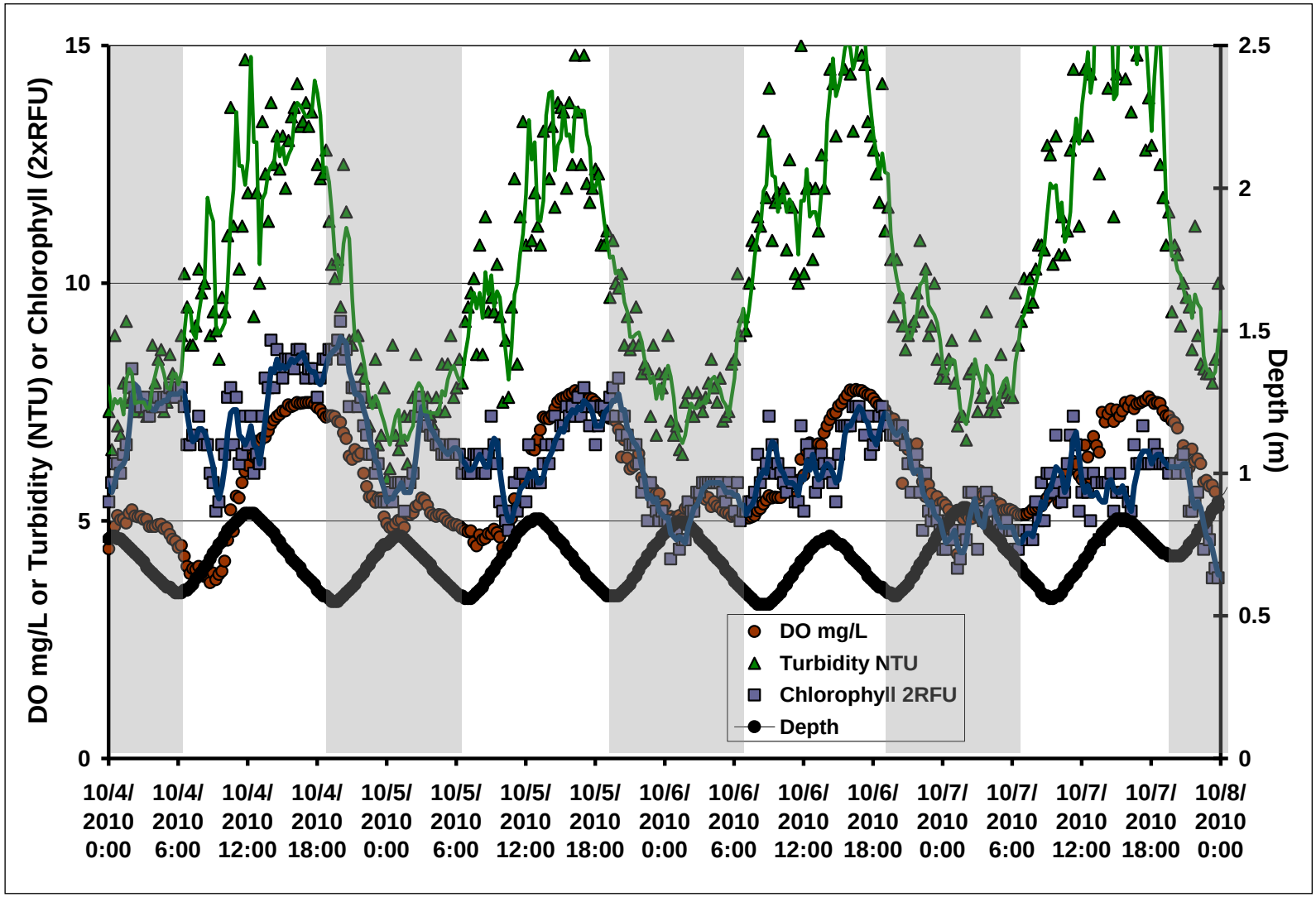


Figure 32. A four day sample of the data from a YSI water quality datasonde deployed in Clam Bayou. Dark shading represents night time hours. Each of the three water quality parameters shown here exhibited significant daily fluctuations.

## Discussion

Water quality is increasingly important around Sanibel and Captiva Islands. The Sanibel-Captiva Conservation Foundation in partnership with the Bayous Presearvation Association(BPA) have gathered a valuable dataset for determining the status of the waters around Blind Pass. There were significant improvements in water quality within the study area after the opening of Blind Pass. For example, total nitrogen (TN) and total phosphorus (TP) concentrations were found to be significantly reduced and dissolved oxygen was found to be significantly higher after the opening. The variation in TN was also reduced after the opening. Salinity was found to be significantly less after the opening with much less variability. There was also increased turbidity with greater variability after the pass was re-opened which was probably caused by increased tidal currents. Related to increases in turbidity, chlorophyll *a* was significantly greater after the opening.

Decreases in salinity were due to improved tidal exchange which reduced the frequency of hypersaline conditions. Hypersaline conditions were common in the back-bay areas in dry season due to weak tidal flushing. Analyses showed that the reduction in salinity was significant only in the dry season, corresponding to the time of year when hypersaline conditions were likely. Before the dredging project, a significant increasing trend in salinity was found at the Sunset Bay, Dinkins Bayou and Clam Bayou sites. These increasing trends were interrupted by the opening of Blind Pass and no significant trends were found after the initial dredging was completed. Reduced salinity variability after the opening also supports the idea that increased tidal flushing now buffers the back bay sites against hypersaline conditions. Data from a RECON station located in Pine Island Sound 2.17 miles east of the study area (Blind Pass RECON, Figure 24) suggests an overall decrease in mean salinity occurred in the year following the opening of the pass due to increased precipitation and Caloosahatchee River discharges. Regional influences may have had some effect on the overall decrease in salinity within the study area; however, the reduced variability in salinity suggests the increased tidal flushing associated with the re-opening of Blind Pass had a positive impact. The more stable salinities created by the re-opening can be a benefit for marine habitats and organisms. Red mangrove growth and oyster survivability can be negatively influenced by hypersaline conditions (Patel et al. 2010; Barnes et al. 2007) while fish and benthic organism biodiversity is positively affected by a more stable salinity regime (Uwadiae, 2009; Sime 2005; Barletta et al. 2005).

Another of the most noticeable differences observed after completion of the dredging project was an increase in turbidity at the study sites. The increase in the turbidity variability found during this study also suggests real changes occurred in this characteristic in the study area. Increased turbidity was seen in both the wet and dry seasons after the opening. In contrast, when we analyzed turbidity data from the “Blind Pass” RECON station located in Pine Island Sound we found no detectable increase in turbidity in the one year period after compared to the one year period before the opening of the pass. Similarly, no increase in turbidity was seen at the RECON station located further north in Pines Island Sound near Redfish Pass. This suggests the turbidity increases found in this study are localized and are not detectable in Pine Island Sound.

A study undertaken by SCCF Marine Lab in 2009-2010 focused on taking a large number of sample sites in the Blind Pass area and Redfish Pass area just before Blind Pass was open and again just after it was opened (Milbrandt et al. 2011). Although a large number of samples were taken, sampling occurred over a very short time period (3 days) before and after the opening. The before-after control impact (BACI) analyses done during that study confirmed a significant increase in

turbidity occurred within a year after the opening of Blind Pass and corroborate the findings in this study.

The increase in turbidity may be a short-term effect caused by increased tidal flows through the sediment-rich bayous resulting in re-suspension of fine sediments which had accumulated in the back bays over time. The BACI study conducted by SCCF Marine Lab included short term monitoring of current velocity at the Clam Bayou culvert. Maximum velocities increased from 0.3 - 0.4 meters/second before the opening to 0.4 - 0.8 meters/second after the opening of Blind Pass (Milbrandt et al. 2011). The significant increase in velocity likely increased the amount of re-suspended fine sediment. In addition to re-suspending local sediments, the newly opened pass advects water from the Gulf of Mexico carrying suspended carbonate silts from nearshore Gulf waters into the Blind Pass study area. The newly dredged opening for Blind Pass was engineered to provide sand scouring water velocities greater than 2 kt. to prevent a quick re-closure of the pass (Lee County 2011). The possibility that the turbidity increase is a short-term consequence of the dredging project is supported by the significant decreasing trend in turbidity found for Dinkins and Clam Bayou after the opening even though turbidity values after the opening were greater.

Median turbidity values for two different data sets (SCCF ML BACI study and BPA monitoring) suggest the water in this study area were within the typical values for Florida estuaries (3-7 NTU's, Hand 2010) and very low compared to other estuaries worldwide (e.g., SWMP, NERR). Median turbidity values after Blind Pass was opened were well above 90th percentile values for Florida estuaries (Hand 2010). Southwest Florida is an ebb-dominated micro-tidal coast with numerous protected estuaries lined with sediment trapping mangrove communities. These characteristics produce estuaries naturally low in turbidity. It appears that the opening of Blind Pass has produced a temporary increase in turbidity related to a dramatic change in hydrodynamic or other characteristics. We speculate that fine sediments accumulated in flow starved areas near Blind Pass and reopening the pass has allowed them to be transported to other areas within the estuary through tidal exchange. The fine sediments will eventually be relocated and result in a dynamic equilibrium with lower turbidity, similar to those more characteristic of a micro-tidal, sediment-trapping coastal morphology.

Another influence on turbidity is "bioturbation", which is the re-suspension of sediments resulting from the activity of benthic (bottom sediment residing) or bottom-feeding organisms. The foraging activity of large numbers of mullet and other benthic foragers in these shallow waters may be re-suspending fine sediments and thus increasing turbidity. The opening of Blind Pass may have enhanced the abundance fish and invertebrate organisms, resulting in higher bioturbation activity associated turbidity. In this case, an increase in turbidity over the study period may be an indicator of increased utilization of these habitats by aquatic organisms. Studies of fishes, manatees, and other benthic organisms before and after the opening of Blind Pass could be used to determine whether this is an important factor influencing turbidity.

Along with favoring an increase in fish and macroinvertebrate biodiversity, a more stable salinity regime results in environmental conditions which encourage increased phytoplankton growth. Phytoplankton mass is directly related to chlorophyll *a* concentrations. The significant increase in chlorophyll *a* overall after the opening, (even though we saw a decrease in TN and TP) may be correlated to the more stable salinity regime. Turbidity can be composed of several components including suspended sediments and phytoplankton. An increase in phytoplankton brought on by a more stable salinity regime would cause an associated increase in turbidity. The turbidity increase after the opening can be partly explained by an increase in mean chlorophyll *a*. However, it is just as likely that increased turbidity is the causative factor for greater amounts of

chlorophyll *a*. If benthic algae are re-suspended with sediments it would be measured as chlorophyll *a* in the water column. After the opening, decreasing trends in turbidity and chlorophyll *a* were found at the Clam and Dinkins Bayou sites. This strengthens the case for a relationship between the two parameters. However, the variability in turbidity increased drastically after the opening while the variability in chlorophyll *a* values decreased significantly. If increases in mean turbidity and chlorophyll *a* were solely the product of re-suspension of benthic sediments and its associated algae, then we would suspect variability of chlorophyll *a* would have increased concurrently with turbidity variability. Several factors are likely causative including a possible increase in chlorophyll due to a more stable salinity regime and lower CDOM.

Chlorophyll *a* is an indicator of the biomass of phytoplankton present in the water column. Chlorophyll values can be significantly influenced by a multitude of factors including tide, precipitation, flow rate, CDOM, turbidity, nutrient concentrations, seagrass community, sediment type and salinity (Boyer et al. 2009). Analysis of over 1100 chlorophyll *a* samples in near shore Gulf of Mexico waters verses chlorophyll *a* in local estuary waters showed a significantly greater chlorophyll *a* exists in estuarine waters (Milbrandt et al. 2011). Conservative mixing and increased dilution of estuarine water near Blind Pass with lower chlorophyll-containing Gulf waters would intuitively suggest chlorophyll *a* concentrations should decrease after the inlet was opened. However, the increase in chlorophyll *a* detected here is due to the great variety of environmental conditions which influence chlorophyll *a* and to the variability on a diurnal time scale. For example, the increase in turbidity at the Blind Pass estuarine stations associated with re-suspension of fine sediment particles may increase the amount of available nutrients in the water column and cause an increase in phytoplankton growth (chlorophyll *a*) (Corbett, 2010) or increase the amount of benthic algae in suspension (Shimeta et al. 2003). Additionally, decreased CDOM levels after the opening (Milbrandt et al. 2011) could cause greater light availability to support water column primary production and a deeper photic zone.

Often there is an inverse relationship between the amount of chlorophyll and dissolved oxygen (DO) in the water column. This can usually be explained by the higher productivity associated with greater levels of chlorophyll. The more living material, the greater the oxygen demand and the lower overall mean concentration. However in this study we found that DO increased concurrently with chlorophyll. A slight increase in DO was also seen at the RECON stations in the Pine Island Sound area. In general the waters from the Gulf of Mexico have lower organic content with a lower oxygen demand and experience higher turbulence resulting in well aerated waters higher in DO than less well-mixed, high organic content estuary waters. It is logical that DO increased due to improved tidal exchange, although the increase in DO at all RECON stations in the vicinity of Pine Island Sound during the study period suggests annual variation also played a role in the results. Temperature has a strong influence on DO, cooler temperatures allow greater amounts of oxygen to dissolve in water.

Mean concentrations of nitrogen, were lower after the opening compared to before. Total nitrogen can be divided into several major components: one, inorganic nitrogen and the other, organic nitrogen. Inorganic nitrogen is more easily used by microalgae (phytoplankton) for growth than organic nitrogen which is incorporated within larger-chained molecules. Before and after the opening of the Pass most of the nitrogen in the water column was bound-up as organic matter such as CDOM. The inorganic component of nitrogen was not found to be significantly different after the opening of the Pass. This suggests that the decrease in TN seen after the opening of the Pass is due to a decrease in organic nitrogen. The decrease in organic nitrogen is most likely due to the dilution effects of increased tidal flushing. The Blind Pass BACI study by SCCF ML found significantly less CDOM as well as TN after the opening (Milbrandt 2011). A significant

decreasing trend in CDOM (at Dinkins and Clam Bayou) after the opening of the Pass, also suggests organic nitrogen is being diluted by the improved tidal flushing.

The significantly lower total phosphorus (TP) concentration seen after the opening of Blind Pass is a dilution effect due to increased tidal flushing by Gulf waters. Although TP concentrations can vary greatly in near shore Gulf Waters, in general, the mean TP concentrations in the Caloosahatchee Estuary and Pine Island Sound are greater than the mean TP concentrations found in near shore Gulf water in this area (SCCF Marine Lab, Mark Thompson et al., other data including the Lee County Environmental Lab, The Captiva WQ Monitoring Project). Increased tidal mixing due to the opening of the Pass would be expected to dilute TP concentrations. Decreased TP may result in lower probability of nutrient enrichment causing overgrowth of algae in the study area

No significant change was seen in fecal coliform concentrations within the study area, although of note there was the final closure of the Bayous wastewater treatment plant (WWTP) adjacent to Clam Bayou and the dilution effect of better flushing with Gulf waters in the study area. The Bayous WWTP's wastewater pond adjacent to Clam Bayou was filled with material dredged from the opening of Blind Pass decreasing the probability that this pond would continue to be a possible source of contamination in the area. Most coliform contamination in estuaries and near shore waters comes from terrestrial sources. Gulf waters are generally lower in fecal coliforms due to their greater distance from human runoff sources and greater water volume (dilution effect) compared to local back bays such as Clam or Dinkins Bayou.

Although no measurable decrease was observed in fecal coliforms during the study period, a better measure of human bacteriological contamination of marine waters is enterococci bacteria. The EPA ruled that using enterococci bacteria as an indicator organism is more sensitive than using coliforms for testing in marine and estuarine waters. SCCF Marine Lab began monitoring for enterococci bacteria when it took over sampling for this project in April 2009, however there was not enough data to do a before and after opening comparison. The enterococci data collected after the opening of Blind Pass revealed the Dinkins Bayou and Clam Bayou sites had about 30% of samples above the level of regulatory concern (35 colonies per 100 milliliter of sample), while about 20% of samples from the Roosevelt Channel site and 7% of the Sunset Bay samples were of concern. Probable sources of enterococci bacteria are non-human as well as human sources. An extensive three-year water quality study funded through the Captiva Community Panel (CCP) by the Lee County Tourist Development Council (Captiva WQ Monitoring Project) found that enterococci concentrations in near shore waters of Sanibel and Captiva were directly related to precipitation (Thompson et al. 2011). The sources of bacteria were not septic or sewer-influenced groundwater discharges but instead surface water discharges carrying bacteria from terrestrial vegetation, soils and impervious surfaces. In short, these indicator bacteria were found proliferating in nearly every lawn and soil and parking lot, having been inoculated from most probably non-human sources such as birds and mammals (Thompson et al. 2011).

Unfortunately, there are a number of confounding factors which contribute to the variability of water quality data and decrease the degree to which we may form conclusions about the effects of opening Blind Pass. Variability caused by natural seasonal and annual cycles is a major consideration. The monitoring period before the opening of Blind Pass was drier than the period monitored after the opening. Many water quality parameters are greatly influenced by rainwater run-off, and differences in mean values for many parameters before and after the opening may have been in small or large part due to differences in rainfall amounts. In addition, freshwater releases from S-79 into the estuarine portion of the Caloosahatchee River were greater during the monitoring

period after the opening than before (Figures 4 and 6). These releases have been shown to impact water quality parameters in our area (Thompson et al. 2012). Variability due to tidal stage is another factor which is important to consider. Samples obtained at low tide are more likely to show greater influence from terrestrial runoff while samples taken during high tide are influenced by Gulf waters. The monthly monitoring design does not adequately address the influences of tidal variation.

Water quality measurements will vary significantly even over the course of a day. For example, measurement of turbidity, dissolved oxygen and chlorophyll *a* over a four day period using a YSI datasonde deployed in Clam Bayou show significant diurnal (daily) variation for all three parameters (Figure 32). In any typical day, DO values will increase 50% by late afternoon from an early morning low, turbidity will increase by over 60% and chlorophyll *a* will increase by over 40% during the day. The diurnal fluctuations for these three parameters are interrelated. During the day, chlorophyll a-containing phytoplankton give off oxygen, driving the concentration of DO up, while during the night time, these plankton and other organisms, use oxygen thus lowering the concentration of DO in the water.

Another possible factor in the cyclic behavior of chlorophyll and turbidity concentrations in Clam Bayou is the grazing behavior of zooplankton. Zooplankton generally feed more heavily on phytoplankton during the night (nocturnally) to avoid predation during daytime hours (Cuker and Watson 2002). During the daytime phytoplankton reproduce and are not as heavily grazed upon by zooplankton so their concentrations (and chlorophyll *a* measured) increase. During the night, grazing zooplankton reduce phytoplankton populations to lower concentrations. Since phytoplankton are a component of turbidity, turbidity would also follow the same daily (day night or diurnal) cycle as phytoplankton. During the day, phytoplankton protect their photosynthetic apparatus by transferring photons to non photosynthetic pathways. This is called "non-photochemical quenching." Concentrations of chlorophyll measured by RECON and YSI instruments often underestimate chlorophyll concentrations because of this phenomenon. Regardless of the reasons driving this diurnal cyclical variation in Clam Bayou, this example demonstrates the short-term variability (monthly vs. every 15 min) and the great number of interrelated factors affecting water quality.

All data collected during this study are comparable to other datasets, but there have been changes in instrumentation used to take measurements during the study and are noted below. When sampling was initiated, salinity was measured using a hydrometer, DO was measured using a Winkler method test kit, and chlorophyll *a* was analyzed at Lee County Laboratory per Standard Methods 10200H using a spectrophotometer. When SCCF Marine Lab began monitoring in April 2009, TN and DO measurements were then taken in-situ using a calibrated Hydrolab® Quanta or YSI 6297 sonde unit, and chlorophyll *a* was analyzed at SCCF Marine Lab per Standard Methods 10200H, but using a fluorometer (a more sensitive instrument at low concentrations) in place of the spectrophotometer (both EPA approved instruments).

## Summary

Comparisons of parameter values before and after the opening of Blind Pass were made using appropriate statistical tests. From these analyses it appears that several significant changes occurred in water quality values after the opening of Blind Pass. Positive changes include less salinity variability, increased dissolved oxygen, lower CDOM concentrations (Milbrandt el al. 2011), lower TN with less variability, and lower TP after the opening of the Pass. These changes can be predominantly attributed to the increased influence (dilution effects) of Gulf waters which now circulate all the way into the back bayous. Also as a consequence of increased tidal exchange came increased flow velocities resulting in re-suspension of sediments and higher turbidity and chlorophyll *a* (benthic algae). The increased turbidity may also be a reflection of increased habitat usage by benthic foragers (fish and invertebrates). Overall the opening of the Pass seems to have improved water quality conditions in the study area and likely will positively affect seagrass, and oyster reef communities as well as invertebrate and fish populations.

We hope this summary is informative and will serve a useful purpose to those who have an interest in the water quality of the area.

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