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# Florida Keys National Marine Sanctuary Water Quality Monitoring Project 1999 Annual Report

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## Water Quality Monitoring Project

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# Table of Contents

# I. Executive Summary

This report serves as a summary of our efforts to date in the execution of the water quality monitoring project for the FKNMS. Since initiation we have added 4 sampling sites and adjusted 6 others to increase cover in the Sanctuary Preservation Areas and Ecological Reserves. We have received 21 requests for data by outside researchers working in the FKNMS of which one has resulted in a master's thesis. Two scientific manuscripts have been submitted for publication: one is a book chapter in Linkages Between Ecosystems: the South Florida Hydroscape, St. Lucie Press; the other is in special issue of Estuarine, Coastal and Shelf Science on visualization in coastal marine science. Two other manuscripts are being prepared; one in conjunction with the FKNMS seagrass monitoring program. We maintain a website where data from the FKNMS is integrated with the other parts of the SERC water quality network (Florida Bay, Whitewater Bay, Biscayne Bay, Ten Thousand Islands, and SW Florida Shelf) and displayed as downloadable contour maps - http://www.fiu.edu/~serc/jrpp/wqmn/datamaps/datamaps.html

The period of record for this report is Mar. 1995 - Oct. 1999 and includes data from 17 quarterly sampling events at 154 stations within the FKNMS including the Dry Tortugas National Park. Field parameters at each station include salinity, temperature, dissolved oxygen (DO), turbidity, relative fluorescence, and light attenuation ($K_d$). Water chemistry variables measured at each station include the dissolved nutrients nitrate ($NO_3^-$), nitrite ($NO_2^-$), ammonium ($NH_4^+$), dissolved inorganic nitrogen (DIN), and soluble reactive phosphate (SRP as $PO_4^{3-}$). Total unfiltered concentrations of organic nitrogen (TON), organic carbon (TOC), phosphorus (TP), and silicate ($Si(OH)_4$) were also measured. The monitored biological parameters included chlorophyll *a* (Chl *a*) and alkaline phosphatase activity (APA).

Grouping stations by depth showed that temperature, DO, TOC, and TON were generally higher at the surface while salinity, $NO_3^-$, $NO_2^-$, $NH_4^+$, TP, and turbidity were higher in bottom waters. This slight stratification is indicative of a weak pycnocline which is maintained by freshwater inputs and solar heating at the surface. Elevated nutrients in the bottom waters is due to benthic flux and some upwelling. Stations grouped by to geographical region showed that the Tortugas and the Upper Keys had lower nutrient concentrations than the Middle Keys or Lower Keys. In the Lower Keys DIN was elevated in the Backcountry. TP concentrations in the Lower

Keys transects decreased with distance offshore but increased along transects in the Upper Keys, mostly because of low concentrations alongshore. The Sluiceway had lowest salinity and highest TOC, TON, and $Si(OH)_4$ concentrations. The north Marquesas area exhibited highest phytoplankton biomass for any segment of the FKNMS. Declining inshore to offshore trends were observed for $NO_3^-$, $NH_4^+$, $Si(OH)_4$, TOC, TON, and turbidity for all oceanside transects. Stations grouped by shore type showed that those stations situated along channels/passes possessed higher nutrient concentrations, phytoplankton biomass, and turbidity than those stations off land. These differences were very small but it is not known if they are biologically important. However, the fact that the benthic communities are different between these two habitats indicates that there may be some long term effects.

Probably the most interesting result of our data analysis was the elucidation of temporal trends in TP for much of the FKNMS. Trend analysis showed statistically significant increases in TP for the Tortugas, Marquesas, Lower Keys, and portions of the Middle and Upper Keys. These trends were remarkably linear and show little seasonality. The increases in TP were system wide and occurred outside the FKNMS on the SW Shelf as well. Rates of increase ranged from 0.01-0.07 $\mu M\ yr^{-1}$ which was significant considering initial concentrations to be ~0.1-0.2 µM. No trends in TP were observed in Florida Bay or in those FKNMS sites most influenced by transport of Florida Bay waters. The effect of increased TP on the phytoplankton biomass has not been shown to be significant; i.e. no concurrent increases in Chl a were observed.

At this time we can only speculate as to the cause of these increases in TP concentrations but it is clear that the increases are driven by regional circulation patterns arising from the Loop and Florida Currents. We have begun the process of gathering information as to potential TP sources and transport mechanisms.

## II. Project Background

The Florida Keys are a archipelago of sub-tropical islands of Pleistocene origin which extend in a NE to SW direction from Miami to Key West and out to the Dry Tortugas (Fig. 1). In 1990, President Bush signed into law the Florida Keys National Sanctuary and Protection Act (HR5909) which designated a boundary encompassing >2,800 square nautical miles of islands, coastal waters, and coral reef tract as the Florida Keys National Marine Sanctuary (FKNMS). The Comprehensive Management Plan (NOAA 1995) required the FKNMS to have a Water Quality Protection Plan (WQPP) thereafter developed by EPA and the State of Florida (EPA 1995). The contract for the water quality monitoring component of the WQPP was subsequently awarded to the Southeast Environmental Research Program at Florida International University and the field sampling program began in March 1995.

The waters of the FKNMS are characterized by complex water circulation patterns over both spatial and temporal scales with much of this variability due to seasonal influence in regional circulation regimes. The FKNMS is directly influenced by the Florida Current, the Gulf of Mexico Loop Current, inshore currents of the SW Florida Shelf (Shelf), discharge from the Everglades through the Shark River Slough, and by tidal exchange with both Florida Bay and Biscayne Bay. Advection from these external sources has significant effects on the physical, chemical, and biological composition of waters within the FKNMS, as may internal nutrient loading and freshwater runoff from the Keys themselves. Water quality of the FKNMS may be directly affected both by external nutrient transport and internal nutrient loading sources. Therefore, the geographical boundary of the FKNMS must not be thought of as enclosing a distinct ecosystem but rather as being one of political/regulatory definition.

Ongoing quarterly sampling of >200 stations in the FKNMS and Shelf, as well as monthly sampling of 100 stations in Florida Bay, Biscayne Bay, and the mangrove estuaries of the SW coast, has provided us with a unique opportunity to explore the spatial component of water quality variability. By stratifying the sampling stations according to depth, regional geography, distance from shore, proximity to tidal passes, and influence of Shelf waters we report some preliminary conclusions as to the relative importance of external vs. internal factors on the ambient water quality within the FKNMS.

# III. Methods

*Site Characteristics and Sampling Design*

A spatial framework for FKNMS water quality management was proposed on the basis of geographical variation of regional circulation (Klein and Orlando, 1994). The final implementation plan (EPA, 1995) partitioned the FKNMS into 9 segments which was collapsed to 7 for routine sampling (Fig. 1). Station locations were developed using a stratified random design along onshore/offshore transects in Seg. 5, 7, and 9 or within EMAP grid cells in Seg. 1, 2, 4, and 6.

Segment 1 (Tortugas) includes the Dry Tortugas National Park and surrounding waters and is most influenced by the Loop Current and Dry Tortugas Gyre. Segment 2 (Marquesas) includes the Marquesas Keys and a shallow sandy area between the Marquesas and Tortugas called the Quicksands; Segment 4 (Backcountry) contains the shallow, hard-bottomed waters of the gulfside Lower Keys. Segments 2 and 4 are both influenced by water moving south from the Shelf. Segment 6 can be considered as part of western Florida Bay. This area is referred to as the Sluiceway as it heavily influenced by transport from Florida Bay and Shark River Slough (Smith, 1994). Segment 5 (Lower Keys), 7 (Middle Keys), and 9 (Upper Keys) include the inshore, Hawk Channel and reef tract of the Atlantic side of the Florida Keys. The Lower Keys are most influenced by cyclonic gyres spun off of the Florida Current, the Middle Keys by exchange with Florida Bay, while the Upper Keys are influenced by the Florida Current frontal eddies and to a certain extent by exchange with Biscayne Bay. All three oceanside segments are also influenced by wind and tidally driven lateral Hawk Channel transport (Pitts, 1997).

*Spatial Analysis*

Stations were grouped four different ways for statistical analysis: by surface or bottom samples, surface by segment, surface by transect distance, and surface by shore type. These groupings were subjectively defined using best available knowledge in an effort to provide information as to source, transport, and fate of water quality components. For the first grouping, stations were selected as being >3 m depth where both surface and bottom samples were collected and stratified by depth. The second grouping included surface samples stratified by segment (Fig. 1) in accordance with the implementation plan (EPA, 1995). The third grouping consisted of those surface stations situated on ocean-side transects being aggregated according to their distance from shore: Alongshore, Hawk Channel, or Reef Tract. In addition, we initiated a transect of stations in the Tortugas off Loggerhead Key to serve as a reference. Since sampling at these locations in the Tortugas were only recently set up to address this question, the data is more sparse. Also there are only two "channel" stations in the Tortugas which makes the data more susceptible to outlier conditions.

One of the concerns of this program is to determine the contribution of water movement through the passes of the Keys to the water quality of the reef. To this end we decided to characterize the last grouping of transects as to shore type: those that are adjacent to land off Biscayne National Park off Old Rhodes Key, Elliot Key and the Safety Valve (BISC), those that abut land in Key Largo, Middle, and Lower Keys (LAND), and those transects which are aligned along an open channel or pass through the Keys (PASS). These grouping strategies may be changed when enough data is collected (ca. 5-7 yr) to be analyzed using a statistically objective, multivariate approach as has been done previously for Florida Bay and Ten Thousand Islands (Boyer et al., 1997; Boyer and Jones, 1998).

Typical water quality variables are usually skewed to the left resulting in non-normal distributions. Therefore it is more appropriate to use the median as the measure of central tendency. Data distributions of selected water quality variables are reported as box-and-whiskers plots. The box-and-whisker plot is a powerful statistic as it shows the median, range, the data distribution as well as serving as a graphical, nonparametric ANOVA. The center horizontal line of the box is the median of the data, the top and bottom of the box are the $25^{th}$ and $75^{th}$ percentiles (quartiles), and the ends of the whiskers are the $5^{th}$ and $95^{th}$ percentiles. The notch in the box is the 95% confidence interval of the median. When notches between boxes do not overlap, the medians are considered significantly different. Outliers ($<5^{th}$ and $>95^{th}$ percentiles) were excluded from the graphs to reduce visual compression. Differences in variables were also tested between groups using the Wilcoxon Ranked Sign test (comparable to *t*-test) and among groups by the Kruskall-Wallace test (ANOVA) with significance set at $P<0.05$.

In an effort to elucidate the contribution of external factors to the water quality of the FKNMS and to visualize gradients in water quality over the region, we combined data from other portions of our water quality monitoring network: Florida Bay, Biscayne Bay, Whitewater Bay, Ten Thousand Islands, and the Shelf (Fig. 1). Data from these 153 additional stations was collected during the same month as the FKNMS surveys and analyzed by the SERC laboratory using similar methodology and quality control as previously described.

*Time Series Analysis*

Data for the complete period of record were plotted as time series graphs (see separate Data Appendix) to illustrate any temporal trends that might have occurred. Trends were quantified by simple regression with significance set at $P<0.10$.

# IV. Results and Discussion

*Spatial Analysis*

Summary statistics for all measured parameters split out by segment are shown in Table 2. This summary includes data from all sampling dates and stations for the period of record listed by median value (Median), minimum value (Min.), maximum value (Max.), and number of samples (*n*). Typical water quality data is skewed to the low end which results in a non-normal distribution, therefore, it is more appropriate to use the median as the measure of central tendency.

Distinguishing internal from external sources of nutrients in the FKNMS is a difficult task. The finer discrimination of internal sources into natural and anthropogenic inputs is even more difficult but most important as anthropogenic inputs may be regulated and possibly controlled by management activities. Advective transport of nutrients through the FKNMS was not measured by the existing fixed sampling plan. However, nutrient distribution patterns may be compared to the regional circulation regimes in an effort to visualize the contribution of external sources and advective transport to internal water quality of the FKNMS.

Circulation in coastal South Florida is dominated by regional currents such as the Loop Current, Florida Current, and Tortugas Gyre and by local transport via Hawk Channel and along-shore Shelf movements (Klein and Orlando, 1994). Regional currents may influence water quality over large areas by the advection of external surface water masses into and through the FKNMS (Lee et al., 1994) and by the intrusion of deep offshore ocean waters onto the reef tract as internal bores (Leichter et al., 1996). Local currents become more important in the mixing and transport of freshwater and nutrients from terrestrial sources (Smith, 1994; Pitts, 1997).

Spatial patterns of salinity in coastal South Florida show these major sources of freshwater to have more than just local impacts (see salinity figures in Appendix 1). In Biscayne Bay, freshwater is released through the canal system operated by SFWMD; the impact is clearly seen to affect northern Key Largo by causing a depression in median salinity coupled with high variability in alongshore sites. Freshwater entering NE Florida Bay via overland flow from Taylor Slough and C-111 basin in ENP can be seen to mix in a SW direction. The extent of influence of freshwater from Florida Bay on alongshore salinity in the Keys is less than that of Biscayne Bay but it is more episodic. Transport of low salinity water from Florida Bay does not affect the Middle Keys sites enough to depress the median salinity in this region but is manifested as increased variability. On the west coast, the large influence of the Shark River Slough, which drains the bulk of the Everglades and exits through the Whitewater Bay - Ten Thousand Islands mangrove complex, is clearly seen as impacting the Shelf waters. The mixing of Shelf waters with the Gulf of Mexico produces a salinity gradient in a SW direction which extends out to Key West. This freshwater source does not seem to impact the Backcountry because of its shallow nature but instead follows a trajectory of entering western Florida Bay and exiting out through the channels in the Middle Keys (Smith, 1994). This net transport of lower salinity water from mainland to reef in open channels through the Keys is observed more so as an increase in the range and variability of salinity than as a large depression in salinity.

In addition to surface currents there is evidence that internal tidal bores regularly impact the Key Largo reef tract (Leichter et al. 1996). Internal bores are episodes of higher density, deep water intrusion onto the shallower shelf or reef tract. Depending on their energy, internal tidal bores can promote stratification of the water column or cause complete vertical mixing as a breaking internal wave of sub-thermocline water. To determine the extent of stratification we calculated the difference between surface and bottom density, delta sigma-t ($\Delta\sigma_t$), where positive values denoted greater density of bottom water relative to the surface. The resulting graph of $\Delta\sigma_t$ (Fig. 2), shows that the SW area of the Tortugas segment tends to experience the greatest frequency of stratification events. The decreased temperature and increased salinity in bottom waters from intrusion of deeper denser oceanic waters to this region may also account for increases in $NO_3^-$, TP, and SRP in these bottom waters as well. For example, in April 1998 a mass of colder, nutrient laden water from the Gulf of Mexico moved up onto the Tortugas reefs and fueled a large benthic macroalgae bloom (J. Porter, personal comm.). This event was observed throughout most of the eastern Gulf as far north as Pensacola. At the two most SW stations, temperatures dropped ~4°C, $NO_3^-$ increased 3 orders of magnitude, SRP and $Si(OH)_4$ increased by a factor of 100, while TP, turbidity, and in vivo Chl *a* specific fluorescence (measured via CTD) all doubled. As there was only a small increase in $NH_4^+$ during this event we believe the general case of elevated $NH_4^+$ and turbidity found in bottom waters throughout the FKNMS is most probably due to benthic flux and resuspension and not to subthermocline advection.

Surface $Si(OH)_4$ concentrations exhibited a pattern similar to salinity. The source of $Si(OH)_4$ in this geologic area of carbonate rock and sediments is from siliceous periphyton (diatoms) growing in the Shark River Slough, Taylor Slough, and C-111 basin watersheds. Unlike the Mississippi River plume with Chl *a* concentrations of 76 $\mu g\ l^{-1}$ (Nelson and Dortch 1996), phytoplankton biomass on the Shelf (1-2 $\mu g\ l^{-1}$ Chl *a*) was not sufficient to account for the depletion of $Si(OH)_4$ in this area. Therefore, $Si(OH)_4$ concentrations on the Shelf were rapidly depleted by mixing and by chemical precipitation (Moore et al., 1986) allowing $Si(OH)_4$ to be used as a semi-conservative tracer of freshwater in this system (Ryther et al. 1967). Unlike Florida Bay and the west coast, there was very little $Si(OH)_4$ loading to southern Biscayne Bay, mostly because the source of freshwater to this system is from canals which drain agricultural and urban areas of Dade County.

In the Lower and Middle Keys, it is clear that the source of $Si(OH)_4$ to the nearshore Atlantic waters is through the Sluiceway and Backcountry. $Si(OH)_4$ concentrations near the coast were elevated relative to the reef tract with much higher concentrations occurring in the Lower and Middle Keys than the Upper Keys (Fig. 5). There is an interesting peak in $Si(OH)_4$ concentration in an area of the Sluiceway which is densely covered with the seagrass, *Syringodium* (Fourqurean et al., in press). We are unsure as to the source but postulate that it may be due to benthic flux.

Visualization of spatial patterns of $NO_3^-$ concentration over South Florida waters provide an extended view of source gradients over the region (Appendix 1). Biscayne Bay, Florida Bay, and the Shark River area of the west coast exhibited high $NO_3^-$ concentrations relative to the FKNMS and Shelf. Elevated $NO_3^-$ in Biscayne Bay is the result of loading from both the canal drainage system and from inshore groundwater (Alleman et al., 1995; Meeder et al., 1997). The source of $NO_3^-$ to Florida Bay is the Taylor Slough and C-111 basin (Boyer and Jones, 1999; Rudnick et al., 1999) while the Shark River Slough impacts the west coast mangrove rivers and out onto the Shelf. The oceanside transects off Biscayne Bay in Seg. 9 exhibited the lowest $NO_3^-$ alongshore compared to the Middle and Lower Keys. A similar pattern was observed in a previous transect survey from these areas (Szmant and Forrester, 1996). They also showed an inshore elevation of $NO_3^-$ relative to Hawk Channel and the reef tract which is also demonstrated in our analysis. Interestingly, $NO_3^-$ concentrations in all stations in the Tortugas transect were similar to those of reef tract sites in the mainland Keys; there was no inshore elevation of $NO_3^-$ on the transect off uninhabited Loggerhead Key.

A distinct intensification of $NO_3^-$ occurs in the Backcountry region. Part of this increase may due to a local sources of $NO_3^-$, i.e. septic systems and stormwater runoff around Big Pine Key (Lapointe and Clark, 1992). However, there is another area, the Snipe Keys, that exhibits high $NO_3^-$ which is uninhabited by man. This rules out the premise of septic systems being the only source of $NO_3^-$ in this area. It is important to note that the Backcountry area is very shallow (~0.5 m) and hydraulically isolated from the Shelf and Atlantic which results in its having a relatively long water residence time. Elevated $NO_3^-$ concentrations may be partially due to simple evaporative concentration as is seen in salinity.

Dissolved $NH_4^+$ concentrations were distributed in a similar manner as $NO_3^-$ with highest concentrations occurring in Florida Bay, the Ten Thousand Islands, and the Backcountry (Appendix 1). $NH_4^+$ concentrations were very low in Biscayne Bay because it is not a major component of loading from the canal drainage system. $NH_4^+$ also showed similarities with $NO_3^-$ in its spatial distribution, being lowest in the Upper Keys and highest inshore relative to offshore. There was no alongshore elevation of $NH_4^+$ concentrations in the Tortugas where levels were similar to those of reef tract sites in the mainland Keys. That the least developed portion of the Upper Keys in Biscayne National Park and uninhabited Loggerhead Key (Tortugas) exhibited lowest $NO_3^-$ and $NH_4^+$ concentrations is evidence of a local anthropogenic source for both of these variables along the ocean side of the Upper, Middle, and Lower Keys. This pattern of decline implies an onshore source which is diluted with distance from land by low nutrient Atlantic Ocean waters.

Elevated DIN concentrations in the Backcountry, on the other hand, are not so easily explained. We postulate that the high concentrations found there are due to a combination of anthropogenic loading, physical entrapment, and benthic $N_2$ fixation. The relative contribution of these potential sources is unknown. Lapointe and Matzie (1996) have shown that stormwater and septic systems are responsible for increased DIN loading in and around Big Pine Key. The effect of increased water residence time in DIN concentration is probably small. Salinities in this area were only 1-2 ppt higher than local seawater which resulted in a concentration effect of only 5-6%. Benthic $N_2$ fixation may potentially be very important in the N budget of the Backcountry. Measured rates of $N_2$ fixation in a *Thalassia* bed in Biscayne Bay, having very similar physical and chemical conditions, were 540 $\mu$mol N $m^{-2}$ $d^{-1}$ (Capone and Taylor, 1980). Without the plant community N demand, one day of $N_2$ fixation has the potential to generate a water column concentration of >1 $\mu$M $NH_4^+$ (0.5 m deep). Much of this $NH_4^+$ is probably nitrified and may help account for the elevated $NO_3^-$ concentrations observed in this area as well. Clearly, $N_2$ fixation may be a significant component of the N budget in the Backcountry and that it may be a exported as DIN to the FKNMS in general.

Spatial patterns in TP in South Florida coastal waters were strongly driven by the west coast outputs (Appendix 1). A declining gradient in TP extended from the inshore waters of Whitewater Bay - Ten Thousand Islands mangrove complex out onto the Shelf and Tortugas. A declining gradient also extended from north central Florida Bay to the Middle Keys. Brand (1997) has postulated that groundwater from a subterranean Miocene quartz sand channel, "the river of sand", containing high levels of phosphorus is the source of TP in this region. However, no evidence of this source exists to date and the data from Florida Bay does not indicate a subterranean source either (Boyer and Jones unpublished data). A very small TP gradient was seen NE Florida Bay signifying that Taylor Slough and the C-111 basin contribute little TP to the system. Finally, there was no evidence of a significant terrestrial source of TP to Biscayne Bay.

In the Keys, there was evidence of elevated TP in alongshore stations of the Middle and Lower Keys but the differences were very small. The Upper Keys actually showed higher TP concentrations on the reef tract than inshore implying an offshore source. Interestingly, the Tortugas area had higher TP concentrations than the Upper Keys as a result of Shelf water advection.

In South Florida coastal waters, very little of TP is found in the inorganic form (SRP - $PO_4^{3-}$); most is organic P (TOP). The distribution of SRP on the west coast and Shelf was similar to that of TP with the general gradient from the west coast to Tortugas remaining. However, the SRP distribution was distinctly different from that of TP in Florida Bay, Whitewater Bay, and Biscayne Bay. In central Florida Bay the N-S gradient previously observed for TP was highly diminished for SRP indicating that almost all the TP in central Florida Bay was in the form of TOP. It is unlikely that the source of TOP to this region is from overland flow or groundwater as this is also the region that expresses highest salinity. Alternately, we hypothesize that the presence of the Flamingo channel, running parallel to the southern coastline of Cape Sable, acts as a tidal conduit for episodic advection of inshore Shelf water to enter north central Florida Bay. Subsequent trapping and evaporation then may act to concentrate TOP in this region. The second difference in P distributions was that there was a significant SRP gradient present in NE Florida Bay that was not observed for TP. The sources of SRP to this area are the Taylor Slough and C-111 basin (W. Walker per. communication; Boyer and Jones, 1999; Rudnick et al., 1999).

Whitewater Bay displayed an east-west gradient in SRP concentrations which increased with salinity leading us to conclude that the freshwater inputs from the Everglades were not a source of SRP to this area. Finally, there was evidence of a significant onshore-offshore SRP gradient in southern Biscayne Bay; most probably as a direct result of canal loading and groundwater seepage to this region (Meeder et al., 1997).

Concentrations of TOC (Appendix 1) and TON (not shown) were remarkably similar in pattern of distribution across the South Florida coastal hydroscape. The decreasing gradient from west coast to Tortugas was very similar to that of TP. A steep gradient with distance from land was observed in Biscayne Bay. Both these gradients were due to terrestrial loading. On the west coast, the source of TOC and TON was from the mangrove forests. Our data from this area shows that concentrations of TOC and TON increased from Everglades headwaters through the mangrove zone and then decrease with distance offshore. In Biscayne Bay, much of the TOC and TON is from agricultural land use. The high concentrations of TOC and TON found in Florida Bay were due to a combination of terrestrial loading (Boyer and Jones, in press), *in situ* production by seagrass and phytoplankton, and evaporative concentration (Fourqurean et al., 1993).

Advection of Shelf and Florida Bay waters through the Sluiceway and passes accounted for this region and the inshore area of the Middle Keys as having highest TOC and TON of the FKNMS. Strong offshore gradients in TOC and TON existed for all mainland Keys segments but not for the Tortugas transect. Part of this difference may be explained by the absence of mangroves in the single Tortugas transect. The higher concentrations of TOC and TON in the inshore waters of the Keys then implies a terrestrial source rather than simply benthic production and sediment resuspension. Main Keys reef tract concentrations of TOC and TON were similar to those found in the Tortugas.

Much emphasis has been placed on assessing the impact of episodic phytoplankton blooms in Florida Bay on the offshore reef tract environment. Spatial patterns of Chl *a* concentrations (Appendix 1) showed that NW Florida Bay, Whitewater Bay, and the Ten Thousand Islands exhibited high levels of Chl *a* relative to Biscayne Bay, Shelf, and FKNMS. The highest Chl *a* concentrations were found in west coast mangrove estuaries (up to 45 $\mu g\ l^{-1}$ in Alligator Bay, TTI). Chl *a* is also routinely high (~2 $\mu g\ l^{-1}$) in NW Florida Bay along the channel connecting the Shelf to Flamingo, ENP. It is interesting that Chl *a* concentrations are higher in the Marquesas (0.36 $\mu g\ l^{-1}$) than in other areas of the FKNMS. When examined in context with the whole South Florida ecosystem, it is obvious that the Marquesas zone should be considered a continuum of the Shelf rather than a separate management entity. This shallow sandy area (often called the Quicksands) acts as a physical mixing zone between the Shelf and the Atlantic Ocean and is a highly productive area for other biota as well as it encompasses the historical Tortugas shrimping grounds. A Chl *a* concentration of 1 $\mu g\ l^{-1}$ in the water column of a reef tract is considered a problem as it indicates potential of eutrophication. On the other hand, a similar Chl *a* level in the Quicksands indicates a productive shrimp fishery.

The oceanside transects in the Upper Keys (Seg. 9) exhibited the lowest overall Chl *a* concentrations of any zone in the FKNMS. Ocean transects showed a slight increase in Chl *a* on the reef tract in this area. Transects off the Middle and Lower Keys showed that a drop in Chl *a* occurred only in the reef tract sites; there was no linear decline with distance from shore (data not shown). alongshore compared to the Middle and Lower Keys. Interestingly, Chl *a* concentrations in the Tortugas transect showed a similar pattern as the mainland Keys. Inshore and Hawk Channel Chl *a* concentrations among Middle Keys, Lower Keys and Tortugas sites were not significantly different. As inshore Chl *a* concentrations in the Tortugas were similar to those in the Middle and Lower Keys, we see no evidence of phytoplankton bloom transport from Florida Bay under this type of sampling design. There was however some slight evidence of increased Chl *a* in those stations along the major passes in the Keys relative to those abutting land. The differences between these two groupings were very small (0.25 vs. 0.20 $\mu g\ l^{-1}$).

Along with P concentration, turbidity is probably the second most important determinant of local ecosystem health. The fine, low density carbonate sediments in this area are easily resuspended, rapidly transported, and have high light scattering potential per gram of material. High water column turbidity and transport directly affects filter feeding organisms by clogging their feeding apparatus and by increasing local sedimentation rate. Sustained high turbidity of the water column indirectly affects benthic community structure by decreasing light penetration, promoting seagrasses extinction. Large scale observations of turbidity clearly show patterns of onshore-offshore gradients which extend out onto the Shelf to the Marquesas (Appendix 1). In the last seven years, turbidities in Florida Bay have increased dramatically in the NE and central regions (Boyer et al. 1998) potentially as a consequence of destabilization of the sediment from seagrass die-off (Robblee et al., 1991).

Strong turbidity gradients were observed for all Keys transects but reef tract levels were remarkably similar regardless of inshore levels. High alongshore turbidity is most probably due to the shallow water column being easily resuspended by wind and wave action. Inshore stations in the Middle Keys had higher turbidity than other segments. Transects aligned with major passes had slightly greater turbidity than those against land but the difference was not statistically significant. Light extinction ($K_d$) was highest alongshore and improved with distance from land (data not shown). This trend was expected as light extinction is directly related to the turbidity of the water.

Using the DIN:TP ratio is a relatively simple method of determining phytoplankton nutrient limitation status of the water column (Redfield, 1967). Most of the FKNMS was shown to have DIN:SRP values < 16:1, indicating the potential for phytoplankton to be limited by N at these sites. The bulk of Florida Bay and both southern and northern Biscayne Bay were severely P limited, mostly as a result of high DIN concentrations. The south-north shift from P to N limitation observed in the west coast estuaries has been ascribed to changes in landuse and bedrock geochemistry of the watersheds (Boyer and Jones, 1998). The west coast south of 25.4 N latitude is influenced by overland freshwater flow from the Everglades and Shark River Slough having very low P concentrations relative to N. Above 25.7 N latitude the bedrock geology of the watershed changes from carbonate to silicate based and landuse changes from relatively undeveloped wetland (Big Cypress Basin) to a highly urban/agricultural mix (Naples, FL).

*Time Series Analysis*

We did not expect to see any temporal trends in the data because of the short data record (only 17 points on the graph), the usually high variability of the data, and the potential interference of a poorly resolved seasonal signal. This was true for all measured variables except TP. Trend analysis showed statistically significant increases in TP for the Tortugas, Marquesas, Lower Keys, and portions of the Middle and Upper Keys (Fig. 3). These trends were remarkably linear and showed little seasonality. Rates of increase ranged from 0.01-0.07 µM $yr^{-1}$ which was especially significant considering initial concentrations to be ~0.1-0.2 µM (Table 2). The effect of increased TP on the phytoplankton biomass was not shown to be significant; i.e. no concurrent increases in Chl a were observed.

The trend in TP was system wide and occurred outside the FKNMS on the SW Shelf as well (Fig. 4). It is important to emphasize that this trend was a regional phenomena and was not due to local inputs from the Florida Keys alone. These increases must also be put in perspective with other ecological changes occurring in the region. No trends in TP were observed in the western Florida Bay/Inner Shelf zone or in those FKNMS sites most influenced by transport of Florida Bay waters. During the same time period as this study, TP concentrations in Florida Bay proper were declining (Boyer et al. 1999). The absence of TP trends in the Middle and Lower Keys may have been due to the influence of low TP Florida Bay waters. This is a marked departure from the more alarmist thinking of some scientists and public that Florida Bay is source of nutrients to the reef and a major cause of reef decline.

A simple model of potential forcing functions on TP concentration (or any other non-conservative species) is shown in Fig. 5. The local concentration of a biologically reactive nutrient such as TP may be affected by advective transport into or out of the compartment (tides, currents, etc.), benthic flux into or out of the water column (including sedimentation), biological uptake and remineralization in the water column, and atmospheric input.

At this time we can only speculate as to the cause of these increases in TP concentrations but it is clear that much of the trend is driven by regional circulation patterns arising from the Loop Current which entrains water from other coastal estuaries such as the Caloosahatchee River and Tampa Bay as well as the Mississippi. That the increases have occurred in deep and shallow water stations at both the surface and bottom over a consistent period of time rules out episodic upwelling as a major factor.

We know of no data which addressed changes in internal cycling processes (benthic flux or water column cycling) over this period. However, there is some preliminary evidence that seagrass may be responsible for some of the trend patterns. Areas where TP trends were absent were also described as areas of dense seagrass beds (Fourqurean personal comm.). One hypothesis is that the potential increase in TP concentration in these areas was modulated by uptake by the seagrass community and therefore showed no significant change.

## *Summary*

The large scale of this monitoring program has allowed us to assemble a much more holistic view of broad physical/chemical/biological interactions occurring over the South Florida hydroscape. Much information has been gained by inference from this type of data collection program: major nutrient sources have be confirmed, relative differences in geographical determinants of water quality have been demonstrated, large scale transport via circulation pathways have been elucidated and temporal trends are becoming evident. In addition we have shown the importance of looking "outside the box" for questions asked within. Rather than thinking of water quality monitoring as being a static, non-scientific pursuit it should be viewed as a tool for answering management questions and developing new scientific hypotheses.

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## List of Tables

Table 1.

| Variable | Segment | Median | Minimum | Maximum | *n* |
|---|---|---|---|---|---|
| Surface | 1 | 0.015 | 0.000 | 0.713 | 239 |
| $NO_3^-$ | 2 | 0.022 | 0.000 | 1.153 | 303 |
| (µM) | 4 | 0.141 | 0.000 | 4.418 | 368 |
| | 5 | 0.090 | 0.000 | 1.550 | 452 |
| | 6 | 0.055 | 0.000 | 2.940 | 235 |
| | 7 | 0.066 | 0.000 | 2.094 | 278 |
| | 9 | 0.058 | 0.000 | 1.658 | 506 |
| Bottom | 1 | 0.072 | 0.000 | 4.455 | 239 |
| $NO_3^-$ | 2 | 0.033 | 0.000 | 1.455 | 303 |
| (µM) | 4 | | | | |
| | 5 | 0.091 | 0.000 | 1.483 | 356 |
| | 6 | 0.073 | 0.007 | 0.138 | 2 |
| | 7 | 0.045 | 0.000 | 2.305 | 202 |
| | 9 | 0.060 | 0.000 | 0.627 | 350 |
| Surface | 1 | 0.028 | 0.000 | 0.325 | 239 |
| $NO_2^-$ | 2 | 0.035 | 0.000 | 0.223 | 303 |
| (µM) | 4 | 0.065 | 0.007 | 0.347 | 368 |
| | 5 | 0.050 | 0.003 | 0.273 | 457 |
| | 6 | 0.063 | 0.007 | 0.255 | 235 |
| | 7 | 0.050 | 0.000 | 0.258 | 282 |
| | 9 | 0.040 | 0.000 | 0.190 | 506 |
| Bottom | 1 | 0.040 | 0.003 | 1.732 | 240 |
| $NO_2^-$ | 2 | 0.035 | 0.000 | 0.613 | 303 |
| (µM) | 4 | | | | |
| | 5 | 0.045 | 0.000 | 0.200 | 360 |
| | 6 | 0.033 | 0.033 | 0.033 | 2 |
| | 7 | 0.043 | 0.000 | 0.688 | 205 |
| | 9 | 0.037 | 0.000 | 0.167 | 347 |
| Surface | 1 | 0.297 | 0.022 | 1.893 | 239 |
| $NH_4^+$ | 2 | 0.324 | 0.025 | 1.703 | 302 |
| (µM) | 4 | 0.504 | 0.130 | 9.097 | 368 |
| | 5 | 0.333 | 0.000 | 2.160 | 457 |
| | 6 | 0.355 | 0.000 | 10.320 | 235 |
| | 7 | 0.390 | 0.005 | 2.442 | 282 |
| | 9 | 0.300 | 0.000 | 2.450 | 506 |

| | | | | | |
|---|---|---|---|---|---|
| Bottom $NH_4^+$ (µM) | 1 | 0.287 | 0.007 | 1.320 | 240 |
| | 2 | 0.302 | 0.028 | 1.255 | 303 |
| | 4 | | | | |
| | 5 | 0.334 | 0.000 | 2.377 | 360 |
| | 6 | 0.330 | 0.253 | 0.407 | 2 |
| | 7 | 0.307 | 0.000 | 1.885 | 205 |
| | 9 | 0.295 | 0.022 | 1.880 | 347 |
| Surface TON (µM) | 1 | 7.730 | 3.638 | 24.118 | 239 |
| | 2 | 8.859 | 3.809 | 24.928 | 302 |
| | 4 | 15.054 | 8.628 | 33.054 | 368 |
| | 5 | 11.097 | 3.557 | 27.278 | 452 |
| | 6 | 15.236 | 6.039 | 32.100 | 235 |
| | 7 | 11.470 | 4.693 | 42.682 | 276 |
| | 9 | 8.925 | 3.702 | 24.855 | 505 |
| Bottom TON (µM) | 1 | 7.163 | 2.254 | 18.825 | 238 |
| | 2 | 8.438 | 4.444 | 16.537 | 303 |
| | 4 | | | | |
| | 5 | 9.742 | 4.013 | 22.927 | 355 |
| | 6 | 11.968 | 7.673 | 16.264 | 2 |
| | 7 | 9.755 | 3.788 | 26.637 | 201 |
| | 9 | 8.340 | 3.900 | 28.200 | 346 |
| Surface TP (µM) | 1 | 0.185 | 0.083 | 0.350 | 240 |
| | 2 | 0.205 | 0.049 | 0.660 | 303 |
| | 4 | 0.230 | 0.092 | 0.621 | 368 |
| | 5 | 0.175 | 0.000 | 0.382 | 457 |
| | 6 | 0.228 | 0.119 | 0.843 | 235 |
| | 7 | 0.170 | 0.010 | 0.576 | 282 |
| | 9 | 0.153 | 0.000 | 0.295 | 503 |
| Bottom TP (µM) | 1 | 0.192 | 0.085 | 0.638 | 239 |
| | 2 | 0.208 | 0.033 | 0.518 | 303 |
| | 4 | | | | |
| | 5 | 0.173 | 0.000 | 0.395 | 358 |
| | 6 | 0.240 | 0.135 | 0.345 | 2 |
| | 7 | 0.169 | 0.010 | 0.391 | 204 |
| | 9 | 0.157 | 0.000 | 0.350 | 346 |
| Surface SRP (µM) | 1 | 0.007 | 0.000 | 0.087 | 236 |
| | 2 | 0.010 | 0.000 | 0.092 | 303 |
| | 4 | 0.010 | 0.000 | 0.297 | 368 |
| | 5 | 0.005 | 0.000 | 0.203 | 457 |
| | 6 | 0.007 | 0.000 | 0.258 | 235 |
| | 7 | 0.007 | 0.000 | 0.098 | 282 |
| | 9 | 0.005 | 0.000 | 0.120 | 506 |

| | | | | | |
|---|---|---|---|---|---|
| Bottom SRP (µM) | 1 | 0.010 | 0.000 | 0.390 | 238 |
| | 2 | 0.007 | 0.000 | 0.193 | 303 |
| | 4 | | | | |
| | 5 | 0.007 | 0.000 | 0.195 | 360 |
| | 6 | 0.006 | 0.003 | 0.010 | 2 |
| | 7 | 0.007 | 0.000 | 0.092 | 206 |
| | 9 | 0.007 | 0.000 | 0.090 | 347 |
| Surface APA (µM $hr^{-1}$) | 1 | 0.031 | 0.010 | 0.195 | 180 |
| | 2 | 0.038 | 0.013 | 0.840 | 230 |
| | 4 | 0.086 | 0.007 | 1.286 | 365 |
| | 5 | 0.050 | 0.014 | 0.370 | 454 |
| | 6 | 0.080 | 0.010 | 0.552 | 235 |
| | 7 | 0.062 | 0.010 | 0.434 | 273 |
| | 9 | 0.056 | 0.009 | 0.450 | 483 |
| Bottom APA (µM $hr^{-1}$) | 1 | 0.029 | 0.010 | 0.080 | 179 |
| | 2 | 0.039 | 0.008 | 0.261 | 230 |
| | 4 | | | | |
| | 5 | 0.046 | 0.000 | 0.428 | 358 |
| | 6 | 0.020 | 0.000 | 0.040 | 3 |
| | 7 | 0.053 | 0.000 | 0.491 | 198 |
| | 9 | 0.050 | 0.000 | 0.206 | 331 |
| Surface Chl a (µg $l^{-1}$) | 1 | 0.232 | 0.000 | 1.347 | 236 |
| | 2 | 0.373 | 0.011 | 6.810 | 303 |
| | 4 | 0.289 | 0.000 | 6.388 | 368 |
| | 5 | 0.271 | 0.000 | 1.676 | 455 |
| | 6 | 0.247 | 0.067 | 1.970 | 234 |
| | 7 | 0.237 | 0.000 | 1.792 | 282 |
| | 9 | 0.202 | 0.000 | 2.698 | 506 |
| Surface TOC (µM) | 1 | 178.573 | 86.979 | 1054.792 | 238 |
| | 2 | 200.194 | 88.480 | 501.750 | 302 |
| | 4 | 242.552 | 136.000 | 1653.542 | 368 |
| | 5 | 203.560 | 93.438 | 674.042 | 453 |
| | 6 | 271.104 | 122.170 | 970.167 | 235 |
| | 7 | 211.688 | 98.083 | 805.310 | 281 |
| | 9 | 193.896 | 92.646 | 512.479 | 505 |
| Bottom TOC (µM) | 1 | 169.625 | 89.375 | 883.104 | 238 |
| | 2 | 195.521 | 94.940 | 847.708 | 303 |
| | 4 | | | | |
| | 5 | 191.806 | 92.771 | 332.896 | 357 |
| | 6 | 286.386 | 126.730 | 446.042 | 2 |
| | 7 | 197.583 | 102.396 | 760.770 | 204 |
| | 9 | 187.792 | 92.833 | 482.500 | 346 |

| | | | | | |
|---|---|---|---|---|---|
| Surface | 1 | 0.310 | 0.000 | 3.902 | 209 |
| $SI(OH)_4$ | 2 | 0.537 | 0.000 | 4.992 | 265 |
| (µM) | 4 | 1.680 | 0.000 | 20.015 | 319 |
| | 5 | 1.337 | 0.000 | 16.035 | 397 |
| | 6 | 5.672 | 0.078 | 127.110 | 206 |
| | 7 | 1.027 | 0.000 | 37.362 | 246 |
| | 9 | 0.307 | 0.000 | 12.990 | 446 |
| Bottom | 1 | 0.555 | 0.000 | 5.777 | 209 |
| $SI(OH)_4$ | 2 | 0.675 | 0.000 | 6.923 | 265 |
| (µM) | 4 | | | | |
| | 5 | 1.053 | 0.000 | 11.110 | 311 |
| | 6 | 0.273 | 0.273 | 0.273 | 1 |
| | 7 | 0.590 | 0.000 | 30.195 | 181 |
| | 9 | 0.284 | 0.000 | 11.360 | 306 |
| Surface | 1 | 0.295 | 0.000 | 3.000 | 223 |
| Turbidity | 2 | 0.853 | 0.000 | 18.800 | 285 |
| (NTU) | 4 | 1.010 | 0.000 | 11.345 | 357 |
| | 5 | 0.465 | 0.000 | 4.885 | 455 |
| | 6 | 0.825 | 0.000 | 37.000 | 234 |
| | 7 | 0.458 | 0.000 | 17.350 | 282 |
| | 9 | 0.345 | 0.000 | 8.800 | 505 |
| Bottom | 1 | 0.385 | 0.000 | 2.626 | 223 |
| Turbidity | 2 | 1.100 | 0.000 | 9.100 | 285 |
| (NTU) | 4 | 0.650 | 0.150 | 1.477 | 13 |
| | 5 | 0.475 | 0.000 | 4.885 | 366 |
| | 6 | 1.012 | 0.095 | 7.295 | 17 |
| | 7 | 0.270 | 0.000 | 16.900 | 211 |
| | 9 | 0.280 | 0.000 | 7.950 | 356 |
| Surface | 1 | 36.200 | 32.300 | 36.600 | 237 |
| Salinity | 2 | 36.200 | 33.600 | 37.000 | 297 |
| (ppt) | 4 | 36.000 | 30.500 | 38.600 | 368 |
| | 5 | 36.200 | 33.600 | 38.600 | 436 |
| | 6 | 35.800 | 29.900 | 40.300 | 234 |
| | 7 | 36.100 | 33.100 | 38.400 | 264 |
| | 9 | 36.100 | 22.244 | 37.800 | 493 |
| Bottom | 1 | 36.200 | 34.000 | 37.000 | 238 |
| Salinity | 2 | 36.200 | 34.600 | 37.400 | 297 |
| (ppt) | 4 | 36.000 | 33.400 | 38.700 | 365 |
| | 5 | 36.208 | 33.400 | 38.600 | 433 |
| | 6 | 35.800 | 29.900 | 39.700 | 232 |
| | 7 | 36.130 | 33.000 | 38.900 | 266 |
| | 9 | 36.100 | 21.738 | 37.800 | 471 |

| | | | | | |
|---|---|---|---|---|---|
| Surface Temperature ($^oC$) | 1 | 26.100 | 21.100 | 31.100 | 239 |
| | 2 | 26.500 | 19.287 | 32.300 | 298 |
| | 4 | 27.900 | 19.100 | 36.100 | 368 |
| | 5 | 27.400 | 20.300 | 33.600 | 439 |
| | 6 | 28.500 | 20.900 | 32.700 | 234 |
| | 7 | 26.150 | 19.500 | 39.600 | 264 |
| | 9 | 25.900 | 17.300 | 32.200 | 494 |
| Bottom Temperature ($^oC$) | 1 | 24.700 | 18.200 | 30.600 | 239 |
| | 2 | 25.695 | 19.000 | 32.200 | 298 |
| | 4 | 28.000 | 18.700 | 36.800 | 365 |
| | 5 | 27.000 | 20.100 | 33.400 | 435 |
| | 6 | 28.500 | 20.300 | 32.700 | 232 |
| | 7 | 25.800 | 19.400 | 32.900 | 267 |
| | 9 | 25.621 | 17.100 | 32.100 | 473 |
| $K_d$ ($m^{-1}$) | 1 | 0.126 | 0.037 | 0.700 | 240 |
| | 2 | 0.208 | 0.030 | 0.961 | 299 |
| | 4 | 0.326 | 0.026 | 2.562 | 326 |
| | 5 | 0.180 | 0.005 | 1.090 | 434 |
| | 6 | 0.370 | 0.021 | 1.389 | 177 |
| | 7 | 0.188 | 0.009 | 1.546 | 269 |
| | 9 | 0.203 | 0.007 | 1.573 | 443 |
| Surface DIN:TP | 1 | 2.189 | 0.000 | 11.026 | 239 |
| | 2 | 2.077 | 0.211 | 11.563 | 302 |
| | 4 | 3.215 | 0.584 | 32.306 | 368 |
| | 5 | 2.980 | 0.261 | 61.250 | 447 |
| | 6 | 2.203 | 0.333 | 35.390 | 235 |
| | 7 | 3.275 | 0.325 | 85.500 | 278 |
| | 9 | 2.723 | 0.149 | 71.250 | 501 |
| Surface $DO_{sat}$ (%) | 1 | 92.495 | 0.000 | 150.029 | 234 |
| | 2 | 92.623 | 0.000 | 114.926 | 294 |
| | 4 | 93.896 | 43.526 | 169.865 | 368 |
| | 5 | 91.783 | 46.935 | 153.343 | 431 |
| | 6 | 94.867 | 65.021 | 148.204 | 234 |
| | 7 | 92.553 | 68.049 | 124.391 | 262 |
| | 9 | 92.989 | 38.130 | 126.051 | 483 |
| Bottom $DO_{sat}$ (%) | 1 | 91.678 | 0.000 | 107.570 | 224 |
| | 2 | 92.546 | 0.000 | 113.452 | 295 |
| | 4 | 94.194 | 43.526 | 171.438 | 365 |
| | 5 | 91.969 | 46.935 | 143.602 | 427 |
| | 6 | 95.310 | 62.684 | 149.616 | 232 |
| | 7 | 93.061 | 46.915 | 127.425 | 261 |
| | 9 | 93.817 | 0.000 | 128.710 | 463 |

| | | | | | |
|---|---|---|---|---|---|
| $\Delta\sigma_t$ | 1 | 0.197 | -0.190 | 5.552 | 236 |
| | 2 | 0.059 | -0.188 | 27.173 | 297 |
| | 4 | 0.000 | -4.424 | 6.528 | 365 |
| | 5 | 0.076 | -0.383 | 3.343 | 430 |
| | 6 | 0.000 | -0.370 | 3.590 | 232 |
| | 7 | 0.070 | -1.440 | 4.762 | 263 |
| | 9 | 0.031 | -3.185 | 1.522 | 466 |

Table 2.

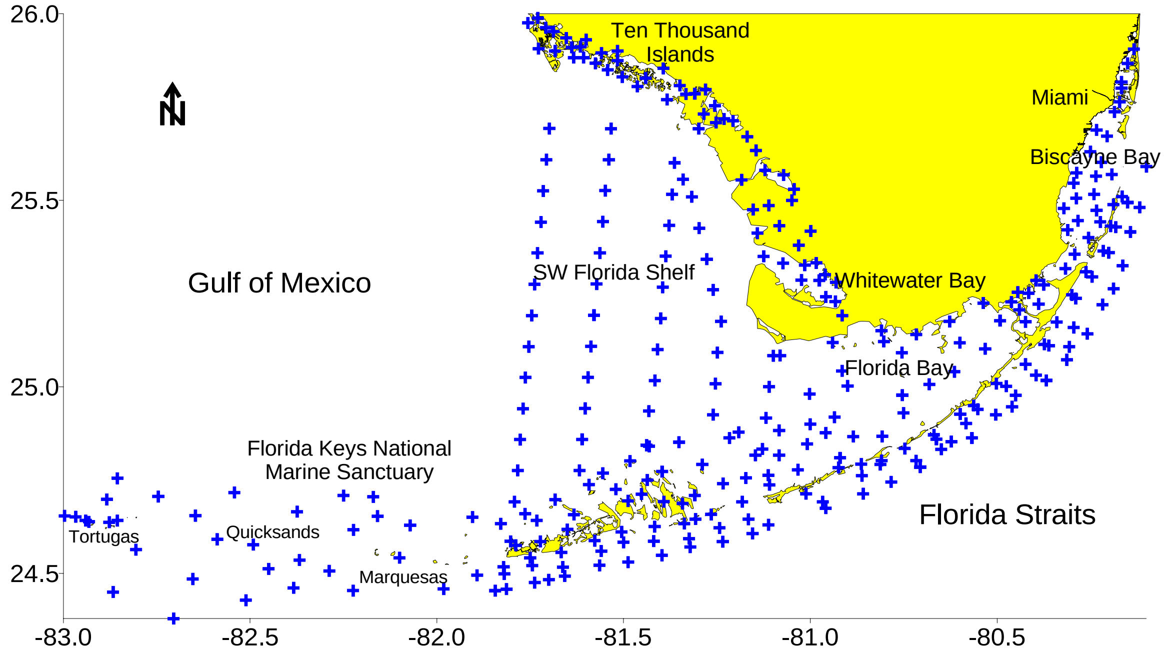
| Station | Site | Slope | P |
|---|---|---|---|
| **200** | **Fowey Rocks** | **0.033** | **0.030** |
| **201** | **Sands Key** | **0.017** | **0.016** |
| 202 | Bowles Bank | 0.009 | 0.430 |
| 203 | Triumph Reef | 0.017 | 0.118 |
| 204 | Elliott Key | 0.012 | 0.270 |
| 205 | Margo Fish Shoal | 0.011 | 0.330 |
| **206** | **Ajax Reef** | **0.022** | **0.018** |
| **207** | **Old Rhodes Key** | **0.017** | **0.059** |
| 208 | Old Rhodes Key Channel | 0.014 | 0.187 |
| **209** | **Channel Key** | **0.028** | **0.004** |
| **210** | **Old Rhodes Key Reef** | **0.028** | **0.006** |
| 211 | Pennikamp G27 | 0.013 | 0.313 |
| 212 | Turtle Harbor | 0.011 | 0.273 |
| **213** | **Turtle Reef** | **0.020** | **0.045** |
| 214 | Port Elizabeth | 0.003 | 0.720 |
| 215 | Carysfort Channel | 0.007 | 0.450 |
| 216 | Carysfort Reef | 0.016 | 0.125 |
| 217 | Rattlesnake Key | 0.012 | 0.120 |
| **218** | **White Bank** | **0.021** | **0.020** |
| 219 | The Elbow | 0.009 | 0.440 |
| 220 | Radabob Key | 0.024 | 0.374 |
| **221** | **Radabob Key Channel** | **0.019** | **0.067** |
| **222** | **Dixie Shoal** | **0.014** | **0.091** |
| **223** | **Mosquito Bank** | **0.017** | **0.057** |
| **224** | **Molasses Reef Channel** | **0.023** | **0.025** |
| **225** | **Molasses Reef** | **0.023** | **0.011** |
| **226** | **Tavernier Harbor** | **0.025** | **0.004** |
| **227** | **Triangles** | **0.034** | **0.001** |
| **228** | **Conch Reef** | **0.029** | **0.001** |
| **229** | **Plantation Point** | **0.035** | **0.001** |
| **230** | **The Rocks** | **0.027** | **0.006** |
| **231** | **Davis Reef** | **0.031** | **0.001** |
| **232** | **Upper Matecumbe Key** | **0.026** | **0.007** |
| **233** | **Upper Matecumbe Chnl** | **0.054** | **0.013** |
| **234** | **Fish Haven** | **0.029** | **0.004** |
| **235** | **Indian Key** | **0.036** | **0.005** |
| **236** | **Indian Key Channel** | **0.034** | **0.000** |
| **237** | **Indian Key Offshore** | **0.016** | **0.091** |
| **238** | **Matecumbe Harbor** | **0.025** | **0.018** |
| **239** | **Lower Matecumbe Chnl** | **0.025** | **0.019** |

| | | | |
|---|---|---|---|
| **240** | **Matecumbe Offshore** | **0.034** | **0.003** |
| **241** | **Long Key** | **0.029** | **0.013** |
| 242 | Long Key Channel | 0.025 | 0.045 |
| **243** | **Tennessee Reef** | **0.039** | **0.001** |
| **244** | **Long Key Pass Inshore** | **0.042** | **0.000** |
| **245** | **Long Key Pass Channel** | **0.029** | **0.001** |
| **246** | **Long Key Pass Offshore** | **0.022** | **0.004** |
| **247** | **Key Colony Beach** | **0.026** | **0.021** |
| 248 | Coffins Patch Channel | 0.007 | 0.253 |
| 249 | Coffins Patch Offshore | 0.014 | 0.105 |
| **250** | **Seven Mile Bridge** | **0.028** | **0.062** |
| 251 | Seven Mile Br. Channel | 0.014 | 0.103 |
| 252 | Seven Mile Br. Offshore | 0.018 | 0.123 |
| 253 | Spanish Harbor Keys | 0.012 | 0.433 |
| 254 | Bahia Honda Key | 0.008 | 0.447 |
| 255 | Bahia Honda Channel | 0.006 | 0.547 |
| **256** | **Bahia Honda Offshore** | **0.015** | **0.051** |
| **257** | **Long Beach** | **0.018** | **0.055** |
| **258** | **Big Pine Channel** | **0.015** | **0.078** |
| **259** | **Big Pine Shoal** | **0.016** | **0.081** |
| 260 | Newfound Harbor Keys | 0.015 | 0.143 |
| 261 | American Shoal Channel | 0.013 | 0.139 |
| **262** | **Looe Key Channel** | **0.017** | **0.025** |
| **263** | **Looe Key** | **0.024** | **0.015** |
| **264** | **Aquarius** | **0.026** | **0.025** |
| **265** | | **0.020** | **0.059** |
| 266 | Tarpon Creek | 0.013 | 0.221 |
| **267** | **American Shoal** | **0.014** | **0.032** |
| **268** | **Saddlebunch Keys** | **0.026** | **0.026** |
| **269** | **West Washerwoman** | **0.023** | **0.060** |
| 270 | Maryland Shoal | 0.016 | 0.118 |
| **271** | **Boca Chica Key** | **0.028** | **0.041** |
| **272** | **Eastern Sambo** | **0.025** | **0.019** |
| **273** | **Eastern Sambo Offshore** | **0.030** | **0.000** |
| **274** | **Boca Chica Channel** | **0.053** | **0.001** |
| **275** | **Boca Chica Mid** | **0.041** | **0.004** |
| **276** | **Boca Chica Offshore** | **0.034** | **0.021** |
| **277** | **Key West Cut A** | **0.028** | **0.024** |
| **278** | **Western Head** | **0.026** | **0.066** |
| **279** | **Main Ship Channel** | **0.032** | **0.009** |
| **280** | **Eastern Dry Rocks** | **0.033** | **0.021** |
| **281** | **Middle Ground** | **0.040** | **0.002** |

| | | | |
|---|---|---|---|
| 282 | Arsenic Bank | 0.006 | 0.710 |
| 283 | | -0.027 | 0.423 |
| 284 | Tripod Bank | -0.010 | 0.489 |
| **285** | **Channel Key Pass** | **0.034** | **0.023** |
| **286** | **Toms Harbor Cut** | **0.032** | **0.046** |
| **287** | **Bamboo Banks** | **0.032** | **0.037** |
| 288 | | 0.016 | 0.321 |
| **289** | **Bamboo Key** | **0.036** | **0.035** |
| 290 | Bluefish Bank | -0.007 | 0.790 |
| 291 | Bullard Bank | 0.012 | 0.456 |
| 292 | John Sawyer Bank | 0.021 | 0.144 |
| **293** | **Bethel Bank** | **0.024** | **0.075** |
| 294 | Red Bay Bank | 0.015 | 0.212 |
| 295 | Bullfrog Banks | 0.022 | 0.395 |
| 296 | W. Bahia Honda Key | 0.012 | 0.393 |
| 297 | Cocoanut Key | 0.014 | 0.378 |
| 298 | Harbor Key Bank | 0.001 | 0.949 |
| 299 | Bogie Channel | 0.013 | 0.145 |
| 300 | Little Pine Key | 0.010 | 0.356 |
| 301 | Cutoe Key | 0.004 | 0.690 |
| 302 | Content Passage | 0.014 | 0.310 |
| **303** | **Pine Channel** | **0.022** | **0.005** |
| **304** | **Toptree Hammock Chan.** | **0.030** | **0.006** |
| 305 | Cudjoe Key | 0.016 | 0.284 |
| 306 | Johnson Key Channel | 0.016 | 0.215 |
| 307 | Tarpon Belly Keys | 0.010 | 0.314 |
| **308** | **Kemp Channel** | **0.019** | **0.070** |
| 309 | Snipe Point | 0.015 | 0.241 |
| **310** | **Snipe Keys** | **0.030** | **0.026** |
| 311 | Shark Key | 0.008 | 0.370 |
| 312 | E. Harbor Key Channel | 0.010 | 0.512 |
| 313 | Lower Harbor Keys | 0.022 | 0.110 |
| **314** | **Howe Key Channel** | **0.037** | **0.003** |
| **315** | **Calda Channel** | **0.026** | **0.026** |
| **316** | **Man of War Harbor** | **0.026** | **0.000** |
| **317** | **Garrison Bight** | **0.025** | **0.002** |
| **318** | **KY Northwest Channel** | **0.021** | **0.017** |
| 319 | N Boca Grande Channel | 0.021 | 0.137 |
| 320 | Loggerhead Marker | 0.018 | 0.163 |
| **321** | **Loggerhead Channel** | **0.021** | **0.045** |
| **322** | **Satan Shoal** | **0.030** | **0.007** |
| **323** | | **0.027** | **0.023** |
| **324** | **Ellis Rock** | **0.024** | **0.054** |

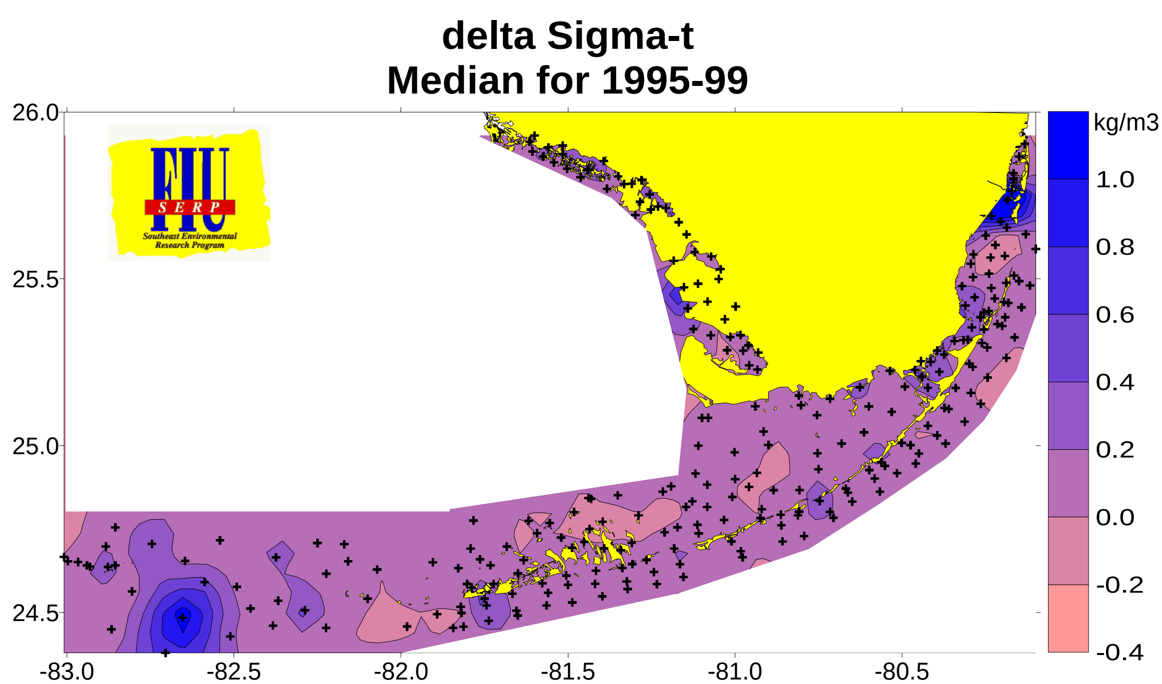
| | | | |
|---|---|---|---|
| 325 | SE Marquesas | 0.043 | 0.140 |
| **326** | | **0.045** | **0.034** |
| **327** | **N Quicksands** | **0.031** | **0.010** |
| **328** | **Marquesas Rock** | **0.032** | **0.000** |
| **329** | | **0.035** | **0.004** |
| **330** | **New Ground** | **0.036** | **0.009** |
| **331** | | **0.039** | **0.026** |
| **332** | **S Quicksands** | **0.034** | **0.031** |
| **333** | **Half Moon Shoal** | **0.038** | **0.009** |
| **334** | | **0.022** | **0.037** |
| **335** | | **0.028** | **0.032** |
| **336** | | **0.037** | **0.001** |
| **337** | **Rebecca Shoal** | **0.034** | **0.000** |
| **338** | **Garden Key** | **0.038** | **0.000** |
| **339** | | **0.045** | **0.005** |
| **340** | | **0.041** | **0.000** |
| **341** | **Northwest Channel** | **0.043** | **0.000** |
| **342** | **NE DTNP** | **0.041** | **0.000** |
| **343** | **N DTNP** | **0.041** | **0.000** |
| **344** | **Southwest Channel** | **0.036** | **0.001** |
| **345** | | **0.039** | **0.001** |
| **346** | **W DTNP** | **0.045** | **0.000** |
| **347** | **Loggerhead Offshore** | **0.037** | **0.001** |
| **348** | **Hospital Key** | **0.035** | **0.002** |
| **349** | **Logerhead Inshore** | **0.037** | **0.000** |
| **350** | | **0.032** | **0.000** |

## List of Figures



26.0
25.5
25.0
24.5
-83.0
-82.5
-82.0
-81.5
-81.0
-80.5
N
Ten Thousand
Islands
Miami
Biscayne Bay
Gulf of Mexico
SW Florida Shelf
Whitewater Bay
Florida Bay
Florida Keys National
Marine Sanctuary
Tortugas
Quicksands
Marquesas
Florida Straits


Fig. 1



delta Sigma-t
Median for 1995-99
26.0
25.5
25.0
24.5
-83.0
-82.5
-82.0
-81.5
-81.0
-80.5
kg/m3
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
FIU
S E R P
Southeast Environmental
Research Program


Fig. 2

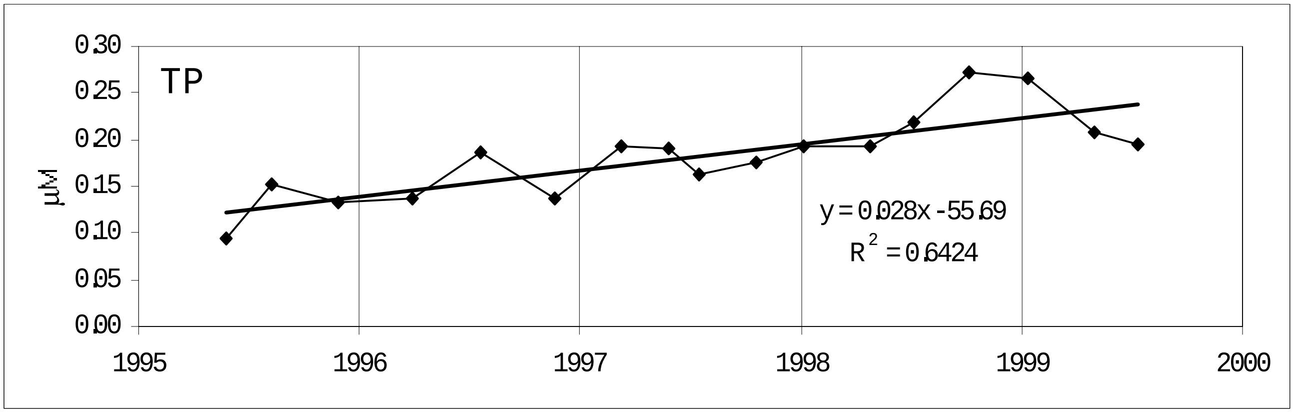

TP
µM
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1995
1996
1997
1998
1999
2000
y = 0.028x - 55.69
R2 = 0.6424

Fig. 3

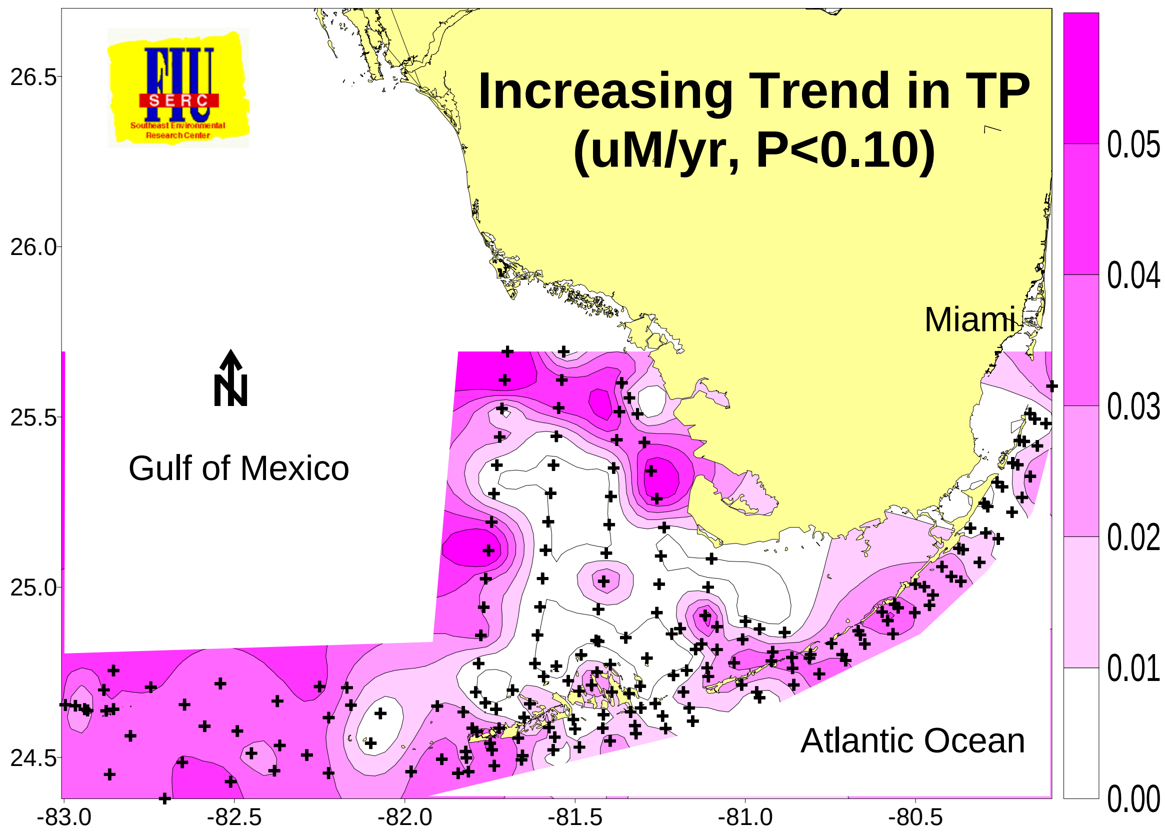

Increasing Trend in TP
(uM/yr, P<0.10)
FIU
SERC
Southeast Environmental Research Center
N
Gulf of Mexico
Miami
Atlantic Ocean
26.5
26.0
25.5
25.0
24.5
-83.0
-82.5
-82.0
-81.5
-81.0
-80.5
0.05
0.04
0.03
0.02
0.01
0.00

Fig. 4

## V. List of Appendices

Appendix 1. Color contour maps of selected water quality variables by sampling event. These maps encompass all 354 stations of the SERC Water Quality Monitoring Network which includes the FKNMS, Biscayne Bay, Florida Bay, Whitewater Bay, Ten Thousand Islands, and Southwest Florida Shelf. The data was collected over a period of a month so care should be taken in interpreting these maps as they are not truly synoptic.

# Appendix 1 - Contour Maps