Nitrogen and Phosphorus trends of three rivers along the southwest coast of Everglades National Park (2001-2008)

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I. Abstract

Anthropogenic activities have altered the water quality of the Everglades ecosystem. Nutrients from the upstream inflows are linked to phytoplankton blooms and altered vegetative communities throughout Everglades National Park (ENP). Monthly total nitrogen (TN) and total phosphorus (TP) concentrations during an eight year period (2001 – 2008) from three rivers within the estuarine zone of ENP were analyzed for interannual variability and long term trends. The three rivers chosen for the analysis receive freshwater from Big Cypress National Park, Lostmans Slough, or Shark River Slough. Variability among seasons was examined using the non-parametric Wilcoxon sign-rank test, while long-term trends were studied utilizing the non-parametric Seasonal Mann-Kendall test with flow adjusted concentrations. Significant increasing trends were found for TP in all three rivers at approximately 0.001 mg P L^{-1} yr^{-1}, while TN showed no significant trends in two of the rivers and a significant decreasing trend in one river of -0.013 mg N L^{-1} yr^{-1}. Analysis of seasonal variability of TP showed a significant difference between wet and dry concentration in all three rivers. TP concentrations were greater during wet than dry season for two of the rivers while one river yielded higher concentrations during the dry season than the wet season. TN concentrations were not significantly different between seasons for any of the three rivers. The increasing trend in TP in the three rivers leads us to presume phosphorus concentrations throughout the ENP are increasing and will meet or exceed the established criteria. The results from the study suggest trend analyses of water quality constituents in downstream water bodies could provide additional tools for the evaluation of best management practices and anthropogenic influences on water resources.

II. Introduction:

Eutrophication of coastal waterways caused by point and non-point sources is a growing concern. Water bodies such as Chesapeake Bay, the coastal waters of South America, and the Everglades are being threatened by eutrophication due to nitrogen and phosphorus loading. Phytoplankton blooms have been linked to coastal eutrophication, which cause increased turbidity reducing sea grass beds, anoxic conditions leading to fish mortality, and human health issues (Nixon, 1995; Paerl, 2009). A decrease in sea grass beds and submerged aquatic vegetation can also lead to the re-suspension of sediment and release of nutrients, increasing the severity of the phytoplankton bloom. Multiple studies have associated nitrogen and phosphorus loading and eutrophication (Boesch et al., 2001; Rudnick et al., 1999; Van Der Struijk & Kroeze, 2010). In most cases, the cause of the nitrogen and phosphorus loading is anthropogenic land alteration and water conveyance systems.

ENP Background

Everglades National Park (ENP), located in the southern peninsula of Florida, has been subjected to anthropogenic changes in the upstream watersheds since before 1919 (Miller et al. 2004. The Everglades was once a naturally flowing oligotrophic wetland stretching from Lake Okeechobee to the Gulf of Mexico, slowly transitioning from fresh to saline conditions. Currently, the Everglades system is regulated by 1000 miles of upstream canals, 720 miles of levees, and 200 control systems and gated structures. The current land area is half the size it once was. Water flowing from Lake Okeechobee is conveyed south, through the Everglades Agricultural Area (EAA) and Water Conservation Areas (WCAs) before entering ENP. Water entering the ENP is regulated in the west by culverts passing under US 41 and in the south by four gated structures, denoted as the S12A through D structures.

Hydrology, Land Use, and Water Quality

Land use upstream of ENP consists primarily of agriculture and residential development. Water managers have constructed a series of storm water treatment areas (STAs) and WCAs to improve water quality before input to ENP. Several best management practices (BMPs) have also been adopted in the agricultural areas in an attempt to decrease nutrient loading caused by runoff. The current proposed numeric nutrient criteria for the mangrove zone of the ENP is 0.021 mg L^{-1} for total phosphorus and 0.69 mg L^{-1} for total nitrogen (Florida Department of Environmental Protection, 2012).

Water passing through the S12 structures flows through Shark River Slough southwest toward the Gulf of Mexico (Figure 1). Shark River Slough consists of five rivers located in the ENP: Lostmans River, Broad River, Harney River, Shark River, and North River (Levesque, 2004). Broad River and Lostmans River accounted for 46% of the mean annual discharge for the five rivers (Levesque, 2004). Water outflows from ENP and Shark River Slough to the Gulf of Mexico and Florida Bay. The S12 structures generally have larger discharges than the culverts located to the west (Miller et al., 2004). One of the goals of the Comprehensive Everglades Restoration Plan (CERP) is to increase freshwater flows to ENP. Rainfall and evapotranspiration are the largest inputs and outputs of water to ENP, but the two components cancel each other out causing upstream water management to have greater impacts on the water flow and storage (Saha et al., 2012). Freshwater flows to the ENP are needed to maintain lower salinity levels in the estuarine zones to foster habitat for marine organisms using this area for refuge and early development.

Linear relationships between nutrient concentrations (total nitrogen and total phosphorus) and discharge have been observed at the inflows to Shark River Slough with differences in the variability between flow and concentration. Increases in total phosphorus and total nitrogen concentrations at the inflows to ENP occur with increases in discharge, but the variability of flow is greater than the variability of the nutrient concentrations (Rudnick et al., 1999). An increase in discharge does not always correspond with an increase in nutrient concentrations. Direct linkages to the increases in discharge to phytoplankton blooms have also been noted. The phytoplankton blooms generally increase during the wet season and decrease during the dry season, with nitrogen being the limiting nutrient (Juradoet al., 2007).

Trends in Nitrogen and Phosphorus

Walker (1997) found spatially decreasing phosphorus concentrations from Lake Okeechobee to the S12s. The trend analysis completed by Walker (1997) spanning years 1978 to 1996 found decreasing total phosphorus concentrations at the major structures within the EAA and Water Conservation Areas. Two other trend analyses were also completed both in the EAA and the Water Conservation Areas. One from 1992 to 2002 found decreasing phosphorus loads in the S8 and S7 sub basins of the EAA (Daroub et al., 2009). A study further downstream found from 1975 to 2005 total nitrogen at the S12 structures decreased by approximately 2.3% to 3.33 % per year, while total phosphorus Increased by 3.9% to 6% per year (Hanlon et al., 2010). The agreement of the three studies suggests positive results from the implementation of agricultural BMPs and STAs in the EAA and WCA's for nitrogen reductions. Phosphorous trends vary slightly among the studies and have not begun to decrease in the areas downstream, such as the S12s.

Objective

This study aims to (i) examine total nitrogen and total phosphorus trends for 8 years, 2001 through 2008, within the coastal gradient of ENP, (ii) analyze the seasonal trends and (iii) compare results of previous research occurring in the upstream sub basins and the current data set along the coastal gradient. The trend analysis was limited to eight years due to a change in sampling techniques after 2008.

Hypothesis statements

H_o: Total phosphorus and total nitrogen concentrations will not change from 2001 to 2008 in each of the three rivers.

The result of no trend in the study area could be due to the source of the nutrients being an artifact of the geomorphology the study area. Boyer (2006) suggested the cause of the nutrient gradients throughout ENP were brought about by changes in the coastal geomorphology.

H_o: Total phosphorus and total nitrogen concentrations during the dry season will be the same as concentrations in the wet seasons.

As water containing higher concentrations of nutrients is released from the upstream watersheds during the wet seasons, increased rainfall within ENP will dilute the nutrient concentrations causing the net concentration within the rivers to be the same as during the dry season.

III. Material and Methods:

Site Description

The study area consists of three rivers located within the coastal gradient of ENP. Water quality data were collected in Chatham River, Lostmans River, and Broad River (Figure 1) in close proximity to U.S. Geological Survey flow monitoring stations. The majority of the freshwater flows into Chatham River are input from Big Cypress National Park, while Broad River's primary freshwater input is Shark River Slough. Lostmans River represents the transition between the two upstream sources and receives freshwater flows from both Big Cypress National Park and Shark River Slough. The freshwater inputs to Chatham River are less restricted and anthropogenically controlled compared to the Shark River Slough inputs. As mentioned earlier, the inputs to Shark River Slough are controlled by gated structures, while the inputs into Chatham River and the northern portion of ENP flows freely through open culverts.

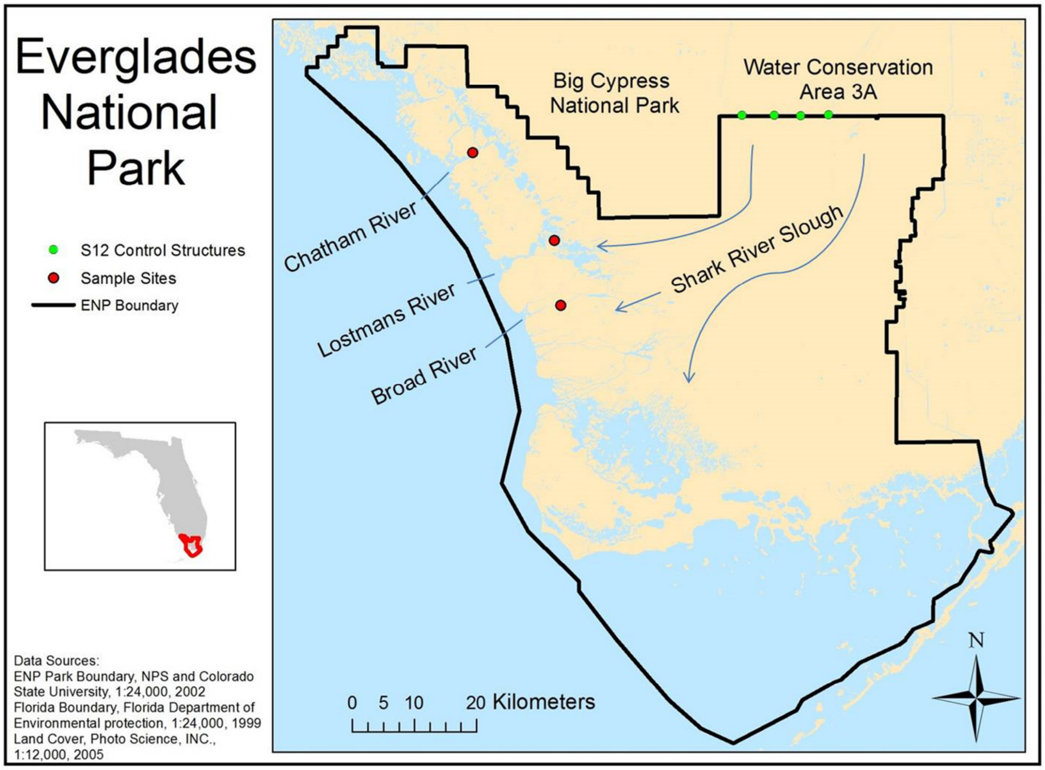

Figure 1: Map showing the boundary of ENP, major features, and locations of the three sampling sites.

Data Sources

Mean daily filtered flow data were retrieved from SOFIA database (sofia.usgs.gov) (**Error! Reference source not found.**). The period of retrieved records was 2001 to 2008. The US Geological Survey (USGS) computes discharge using index velocity methodology described in Levesque & Oberg (2012) and Ruhl & Simpson (2005). Continuous discharge for the three rivers was calculated by generating linear relationships between velocities obtained from an Acoustic Velocity Meter (AVM) mounted at each station and physical flow measurements made with an Acoustic Doppler Velocity Profiler (ADCP). Discharge is computed at fifteen minute intervals and filtered using the Godin low-pass filter to remove tidal frequencies. The USGS then calculated mean daily filtered discharge for each station listed in Table 1.

Table 1: Flow data used in the analysis listed in order of location North to South.

USGS Station Number	Site Name	Data Type	Source	Inflow	Outflow
02290888	Chatham River Near the Watson Place, Fl	Mean Daily Filtered Discharge	U.S. Geological Survey	Big Cypress National Park	Gulf of Mexico
02290918	Lostmans River Below Second Bay, Fl	Mean Daily Filtered Discharge	U.S. Geological Survey	Big Cypress National Park and Shark River Slough	Gulf of Mexico
02290878	Broad River Near the Cutoff, Fl	Mean Daily Filtered Discharge	U.S. Geological Survey	Shark River Slough	Gulf of Mexico

Water quality data were retrieved from South Florida Water Management's DBHYDRO database (http://www.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu) for the sample locations listed in Table 2. The water quality data were collected by Florida International University in conjunction with the Southeast Environmental Research Center. The samples were collected as grab samples on a monthly frequency. Total nitrogen and total phosphorus were used in trend analysis.

Table 2: Nutrient sample locations within each river.

Sample Location				
Latitude	Longitude	Associated River	Data Source	Sample Frequency
25 19' 54.73"	-80 59' 1.31"	Chatham River	FIU	Monthly
25 34' 48.61"	-81 7' 15.34"	Lostmans River	FIU	Monthly
25 29' 59.02"	-81 2' 56.32"	Broad River	FIU	Monthly

Data Exploration

Both the nutrient and flow data were tested for normality with the Shapiro-Wilk W test using SPSS version 21 (SPSS 2012). The data sets were non normal even after attempting a natural log transformation (p-value >0.05). Due to the non-normal distribution of the data the nonparametric Seasonal Mann-Kendall test was used for the trend analysis. Effects of seasonality on nitrogen and phosphorus were investigated using scatterplots of concentration versus time. Strong seasonal effects were present, so both total nitrogen and total phosphorus were adjusted for flow using LOWESS (Locally Weighted Scatterplot Smooth) smooth lines for each river. Other studies in south Florida have also seen strong seasonal influences caused by wet and dry seasons (Qian et al., 2007). Box and whisker plots were created in SPSS version 20 showing the median, quartiles, and outliers for the water quality data in each river. The box and whisker plots illustrate the seasonal comparisons and summarize concentrations of the constituents for the period of record.

Seasonal Analysis

Seasonal boundaries are defined where wet season is classified as June to October and dry season as November to May. Water budgets for 2002 to 2008 have shown the highest rainfall to occur during the period of June to October (Saha et al., 2012). The non-parametric Wilcoxon sign-rank test was then applied to each parameter for each river using the SPSS statistical package (SPSS 2012). The Wilcoxon sign-rank test is a non-parametric test that determines whether the median difference between paired observations is significantly different (B. D. R. Helsel & Hirsch, 1992).

Trend Analysis

The nonparametric Seasonal Mann-Kendall test in the program Kendall.exe (USGS 2005) was used to test for trends in flow adjusted nutrient concentrations for each river. The seasonal Mann-Kendall test examines monotonic trends for the period of record by comparing only like seasons then combining the results (Helsel et al., 2006). The Mann-Kendall test is considered robust and was designed to handle skewed data with outliers (Hirsch et al., 1982). For the analysis, each month was selected as a season. Grouping monthly collected data into monthly seasons is an approach recommended by Hirsch et al. (1982). Nutrient concentrations were adjusted for flow using the mean daily filtered discharge for the day the sample was collected. The adjusted flow was calculated using LOWESS. Once the nutrient concentrations were adjusted, the trend test was conducted on the residuals of the LOWESS.

IV. Results and Discussion

Seasonal Analysis

Total nitrogen concentrations during the wet season were not significantly different from the dry season for any of the rivers (Chatham River p value = 0.080, Lostmans River p value = 0.195, Broad River p value = 0.385) (Figure 2). This finding supports the hypothesis that the concentrations would be similar during both wet and dry season. The median total nitrogen concentration was similar for each of the three rivers ranging from 0.40 to 0.43 mg N L^{-1} (Figure 3). Extreme outliers were documented for the three rivers primarily in the wet season. These outliers were most likely due to large rain events causing a flushing effect in the upstream reaches.

Total phosphorus concentrations were significantly different between seasons among all three rivers (Chatham River p value = 0.030, Lostmans River p value = 0.000, Broad River p value = 0.014), rejecting the hypothesis that the concentrations would be the same between wet and dry season. The median total phosphorus concentration for the three rivers ranged from 0.016 to 0.028 mg P L^{-1} with Chatham River having the highest median concentration for the period of record (Figure 3). The median total phosphorus concentrations in Chatham and Lostmans River were greater during the wet season compared to dry season, while dry season concentrations were greater than wet season in Broad River. These results suggest upstream inputs are a larger source of phosphorus compared to the Gulf of Mexico for Chatham and Lostmans River. The Gulf of Mexico may still be a significant source of phosphorus in Broad River. During the dry season, sea water residence times increase with less freshwater inputs, increasing time for phosphorus cycling to ensue. Potential changes in the vegetative community structure along the coast may also be a reason for different interannual trends between the three rivers. Vegetation in one area may assimilate more phosphorus or add more phosphorus through decomposition compared to another. Phosphorus inputs from Big Cypress National Park may also be greater than in Shark River Slough.

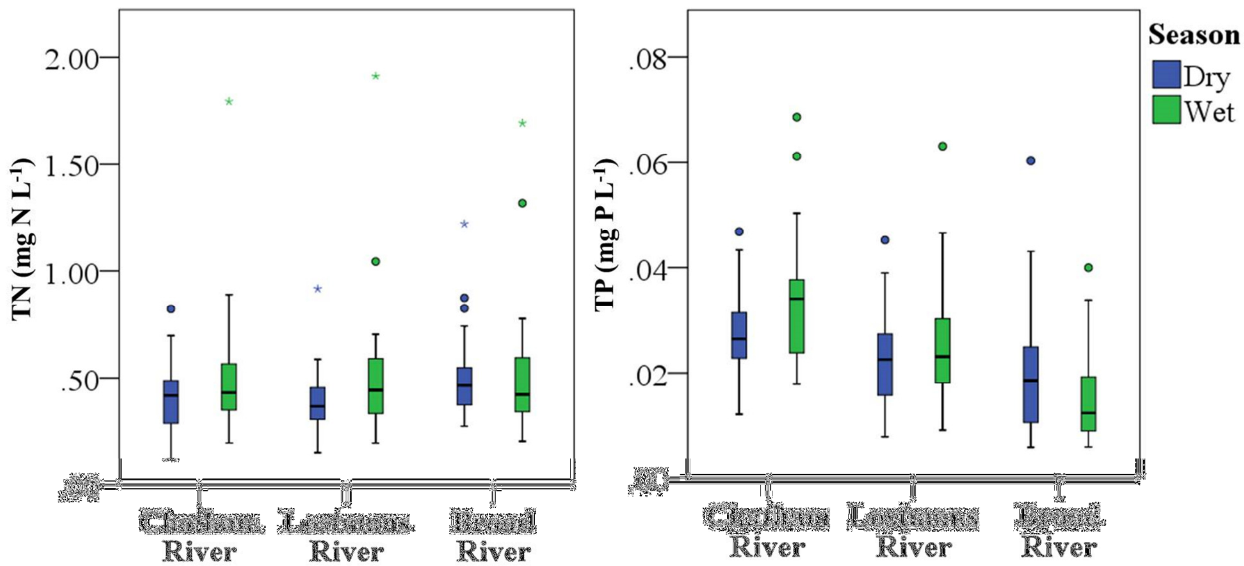

Figure 2: Box and whisker plots showing total nitrogen (left) concentrations and total phosphorus (right) in each river grouped by season. The bold center line represents the median of the data, top and bottom represent the 25th and 75th quartiles, the whiskers are the 5th and 95th quartiles, and the circles and stars are outliers and extreme outliers.

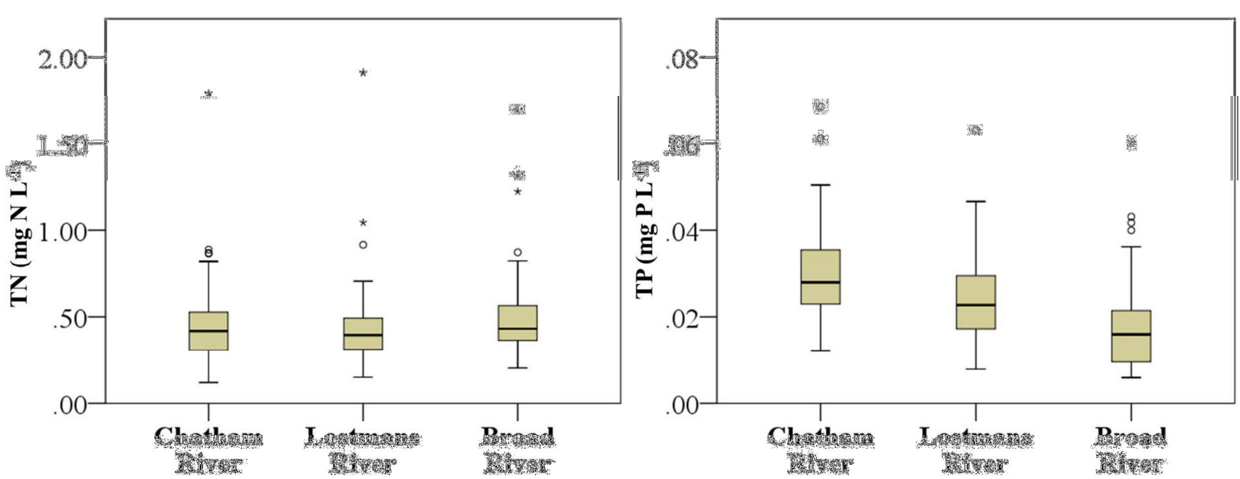

Figure 3: Box and whisker plots showing total nitrogen (left) concentrations and total phosphorus (right) in each river for the period of record (2001 to 2008). The bold center line represents the median of the data, top and bottom represent the 25th and 75th quartiles, the whiskers are the 5th and 95th quartiles, and the circles and stars are outliers and extreme outliers.

Trend Analysis

Chatham and Lostmans River both showed trends that were not significant for total nitrogen (p value = 0.357; 0.244) (Table 3). Broad River displayed a significantly decreasing trend of 0.013 mg N L^{-1} yr^{-1}. Studies such as Basu et al. (2010) have shown biogeochemical stationarity with nutrients in some catchments despite alterations in loading rates. In these instances concentrations can remain unchanged until the nutrients have been removed from the system via biogeochemical processes such as denitrification. Another explanation for the decreasing trends could be a decreasing trend in precipitation. Decreasing precipitation trends were seen from 1996 to 2005 in the upstream reaches (Hanlon et al., 2010). Other studies have suggested during drier years, sea water with lower nitrogen concentrations mix and dilute the estuarine waters of the coastal gradient (Rudnick et al., 1999).

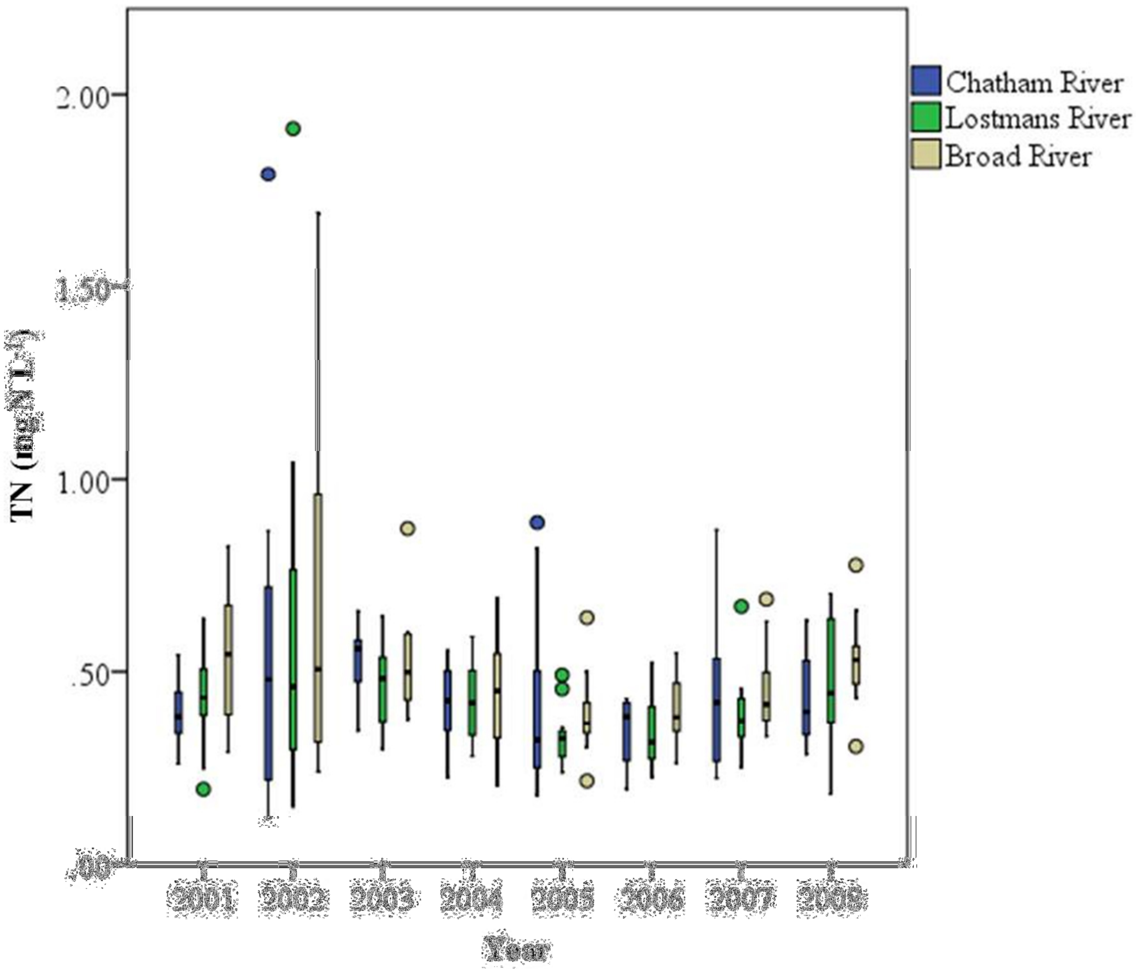

Figure 4: *Box and whisker plots showing total nitrogen concentrations for each river for the period of record (2001 to 2008). The bold center line represents the median of the data, top and bottom represent the 25th and 75th quartiles, the whiskers are the 5th and 95th quartiles, and the circles are outliers.*

All three rivers showed significant increasing trends in total phosphorus (p value < 0.01), which agrees with previous studies at the inflows to ENP. The slope of the trend for all three rivers was 0.001 mg P L^{-1} yr^{-1} (Table 3). Currently the median total phosphorus concentration for Chatham River and Lostmans River is equal to or exceeds the proposed numeric nutrient criteria (Figure 3), while Broad River will most likely exceed the proposed criteria within the next five years based on the slope of current trend (Table 3).

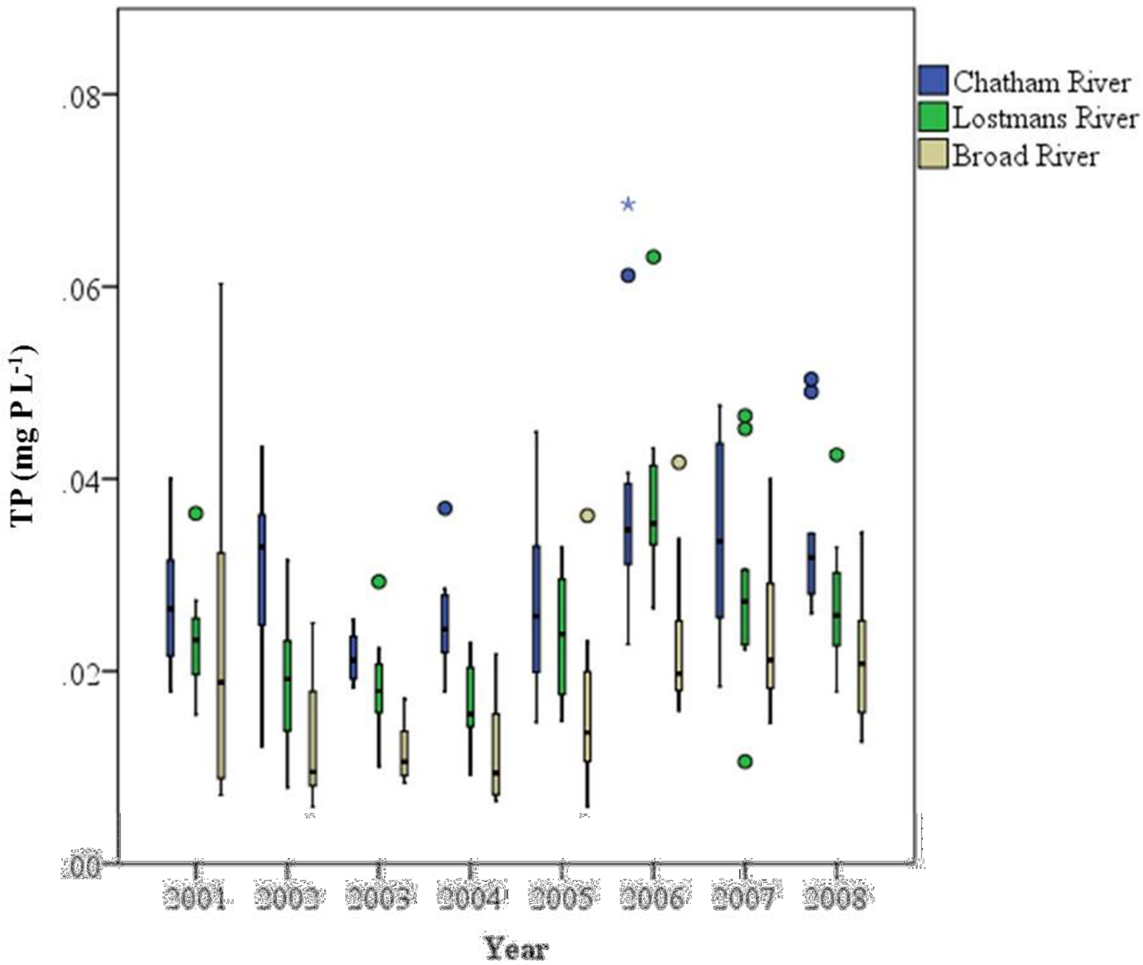

Figure 5: *Box and whisker plots showing total phosphorus in each river for the period of record (2001 to 2008). The bold center line represents the median of the data, top and bottom represent the 25^th^ and 75^th^ quartiles, the whiskers are the 5^th^ and 95^th^ quartiles, and the circles and stars are outliers and extreme outliers.*

The cause of the increasing trend could be related to several factors. One possible element influencing the trend is loading from the Gulf of Mexico during incoming tides. Other studies have shown the Gulf of Mexico to be a significant source of phosphorus for the ENP during the dry season(Rudnick et al., 1999). From 1996 to 2005 annual precipitation upstream of the S12 structures decreased (Hanlon et al., 2010). A decrease in precipitation reduces freshwater inputs to the ENP coastal gradient leading to increased sea water intrusion. Previous studies have shown increased total phosphorus concentrations when the S12 gates were closed, as well as strong relationships between increasing salinity and increasing total phosphorus (Childers et al., 2006). Groundwater discharge during times of reduced freshwater inputs could also affect the increasing trend by acting as a phosphorus source. During periods of reduced freshwater input groundwater has been shown to become a significant input in other areas within the ENP (Sutula et al., 2001). Lastly, the trend could be due to phosphorus legacy downstream of the areas where the BMPs are being implemented. Phosphorus tends to flux from areas of higher concentration to areas of lower concentration, such as the soil/water interface. Phosphorus assimilated by vegetation can also reenter the water column and soil during decomposition.

Table 3: Results from the Seasonal Mann-Kendall trend analyses.

Site	Constituent	Sig. Trend	p-value	Rate ($mg\ L^{-1}\ yr^{-1}$)
Chatham River	Total Phosphorus	Up	0.001	0.001
Chatham River	Total Nitrogen	None	0.357	-0.007
Lostmans River	Total Phosphorus	Up	0.002	0.001
Lostmans River	Total Nitrogen	none	0.244	-0.008
Broad River	Total Phosphorus	Up	0.001	0.001
Broad River	Total Nitrogen	Down	0.043	-0.013

Overall, the trend analysis compared well with previous trend analyses completed at the inflow to the ENP. The study results indicate upstream water management still plays a role in the nutrient concentrations in the estuarine zone despite additional loading from the Gulf of

Mexico. The decreases in total nitrogen will most likely coincide with decreases in the severity of phytoplankton blooms within the ENP and the Gulf of Mexico. As mentioned earlier, the increases in total phosphorus concentrations could be a result of loading from the Gulf of Mexico. Decreasing the phosphorus levels may require an increased in freshwater flows, especially as sea level continues to rise. More research is needed to investigate this phenomenon.

The sampling frequency was the main limiting factor of the study. Each river was sampled once per month. A more beneficial approach would have been to include event-driven sampling to better characterize the relationship of flow on concentration. In this design, sampling would take place based on both time and events. The increase in sampling would allow the capture of nutrient concentrations resulting from runoff upstream. Larger flows caused by increased rainfall can cause both increased runoff from upstream land use areas and a flushing of nutrients present in the water column. A study examining 22 different rivers in Central and Northern Florida showed 90% of flows happen in approximately 15% of the time (Jawitz & Mitchell, 2011). When using the discrete sampling approach seen in this study, constituents may have higher or lower levels depending on the hydroclimatic or anthropogenic conditions during the sampling, such as the operation of the S12 structures in the Shark River Slough. Sample frequency and the resolution of the data could influence the interannual trends, such as wet and dry season concentrations. Other studies have had great success within the coastal gradient using automated samplers coupled with flow stations. Levesque (2004) found strong correlations between flow and solute fluxes of total nitrogen and total phosphorus in Lostmans Creek (R^2= 0.96, 0.80). Levesque’s study revealed large changes in flow resulted in small changes in nutrient concentrations. Increasing the resolution of the data would improve the understanding of the short term trends.

V. Conclusion

The water quality trend analysis of the estuarine zone of ENP compared well with previous studies conducted upstream. All three rivers also showed significant increasing trends in total phosphorus during the study period. Lostmans and Chatham River showed no significant trends in total nitrogen, while Broad River was found to have significant decreasing trends. Significant seasonal variances in total phosphorus concentrations were found within ENP during the 2001 to 2008 period, while total nitrogen concentrations were not significantly different.

Upstream BMPs do not appear to be assisting in phosphorus reductions to the estuarine zone of ENP. This finding could be due to phosphorus legacy downstream of the areas where the BMPs are being implemented. Documentation of the lag time associated with phosphorus reductions at the inflows to ENP would assist in the understanding of the temporal delay related to the implementation of BMPs and downstream responses to nutrient loading. The Gulf of Mexico is also a significant source of phosphorus to the estuarine zone of ENP. To control loading from the Gulf, larger freshwater releases will be needed.

The findings discussed in this study are vital to nutrient management for the ENP. Two of the rivers examined met or exceeded the current numeric nutrient criteria. All three rivers were found to have increasing trends of 0.001 mg P L^{-1} yr^{-1}. The similar trends among the three rivers suggest total phosphorus throughout the ENP is increasing and has the possibility of exceeding water quality criteria throughout the region. Results from this study can be used to assess the efficiency of the BMPs and STAs located upstream of the ENP.

VI. References

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