6-2014

Relating Freshwater Flow with Estuarine Water Quality in the Southern Everglades Mangrove Ecotone

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Recommended Citation

Briceno, H.O., G. Miller, S.E. Davis. 2013. Relating freshwater flow with estuarine water quality in the southern Everglades mangrove ecotone. Wetlands DOI: 10.1007/s13157-013-0430-0

This material is based upon work supported by the National Science Foundation through the Florida Coastal Everglades Long-Term Ecological Research program under Cooperative Agreements #DBI-0620409 and #DEB-9910514. Any opinions, findings, conclusions, or recommendations expressed in the material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Introduction

As has been the case with many wetland ecosystems around the globe, the Everglades has endured more than a century of drainage, reduced water flow, agricultural pollution, and urban development (Mitsch & Gosselink 2009). With increased understanding of the value of wetland ecosystems over the past few decades, we have seen a shift towards restoration and conservation of these remaining landscapes. Today, the greater Everglades ecosystem represents one of the largest ecosystem restoration undertakings in the world. As such, it provides an ideal opportunity for scientists to develop, apply, and adapt tools for projecting ecological change in response to different restoration (and even climate change) scenarios (Clark et al. 2001).

South Florida and the Everglades were once synonymous as a mosaic of hydrologically interconnected landscapes and communities comprising the largest single marsh system in the United States (Ogden et al 2005). Today, remaining subtropical wetlands and their drainages are disconnected, over-drained, and managed by a complex network of canals (2,300 Km) and structures. As a result, there has been extensive soil loss due to subsidence and peat oxidation, an increase in algal bloom frequency and magnitude, decreases in bird and mammal populations, shifts in vegetative community structure, and saltwater intrusion (Lorenz, 1999; Sklar et al., 2001; Marshall et al. 2009).

In Everglades National Park, located at the southernmost tip of the Florida Peninsula, decreased flow and increased nutrient loading (especially phosphorus), can lead to loss of periphyton—the base of the Everglades food web—and irreversible change in vegetative community structure, both of which lead to diminished habitat quality (Davis, 1994; McCormick et al. 1996; Childers et al., 2001; Durako et al., 2001; Gaiser et al., 2004). Therefore restoring the natural flow and quality of water to the Everglades is critical to protecting the remaining “River of Grass”, mangrove forests, and estuaries such as Florida Bay.

To date, few modeling or quantitative tools exist to help us understand how restoring the quantity and quality of flows to Florida Bay will affect its health. This is partly due to the complexity of these dynamic coastal environments and difficulty in accurately predicting ecosystem behavior—let alone responses to different management decisions (Stow et al. 2003). Marshall et al. (2011) recently developed a set of multi-variate linear regression models that link Everglades stage and regional climatic conditions to salinity. When coupled to habitat suitability indices developed for species such as Roseate spoonbills (*Ajaja ajaja*; Lorenz 1999) and the American crocodile (*Cocodrylus acutus*; Green et al. 2001), these tools can be effective in projecting habitat improvement with hydrologic restoration. However, there are currently no means for projecting change in other water quality parameters, such as nitrogen or phosphorus that affects the productivity and carbon dynamics in the mangrove ecotone. This is particularly important given the progress of restoration in the C-111 canal basin of south Florida and the continual press of sea-level rise.

The C-111 provides flood control for much of southeast Miami-Dade County. Its effectiveness in flood control is equaled by its impact on Florida Bay, as it not only drains much of the developed landscape in South Florida, it also siphons water away from Taylor Slough—the most important source of freshwater to eastern Florida Bay

(Figure 1). The seepage barrier of the C-111 Spreader Canal project, a Comprehensive Everglades Restoration Program (CERP) project, has recently become operational and will serve to minimize water loss from Taylor Slough to the C-111 canal drainage system. Phase 2 of this effort, will eventually result in the filling-in of this canal and will restore natural flows of freshwater into Florida Bay.

In anticipation of these restoration efforts, we utilized statistical techniques to understand the relationships between flow and water quality in this region of Everglades National Park. Such relationships are difficult to detect with naturally high variability in water quality data as well as the confounding effects of natural versus human-induced control over water flow in this region. Specifically, we sought to determine the relationships between salinity, nutrients, and flow in the mangrove ecotone of lower Taylor Slough. The motivation for this is that the restoration of flows into Taylor Slough and the C-111 basin will result in substantially increased flows of freshwater to Florida Bay. Based on past research looking at seasonal patterns of water quality in this region (Childers et al. 2006), we expected that total phosphorus (TP) would show a general increase with salinity, reflecting a downstream marine source and negatively correlated with freshwater flow through the mangrove ecotone. On the other hand, nitrogen likely increases as freshwater flow passes through the mangrove ecotone, reflecting a possible internal source (Davis et al. 2003; Childers et al. 2006; Liu et al. this issue).

Site Description

Taylor Slough is located in Everglades National Park and functions as the southeastern watershed that historically channeled water from the Everglades to Florida

Bay (Figure 1). Along with Shark River Slough, it is one of the most important watersheds in Everglades National Park, and it is of vital importance to the overall health of the park—especially Florida Bay. The southern Everglades mangrove ecotone lies at the interface between the freshwater Everglades marshes of lower Taylor Slough and eastern Florida Bay and one of the major distributaries of flow along this path is Taylor River (Figure 1).

Two sites were considered in this analysis: the Taylor River mouth site and the Taylor River upstream site (Figure 1). The Taylor River mouth site exhibits a daily tidal range of about 10 cm or less. The daily tidal signature at the upstream site is considerably more muted. Inputs of water to this ecotone are primarily from direct precipitation, local runoff, releases from water-management structures, and tidal flow from the Florida Bay into the ecotone, and flow direction and magnitude at both sites are influenced by seasonal discharge from the freshwater Everglades, wind, and storm events.

The salinity and nutrient dynamics of this mangrove ecotone illustrate fundamental ecosystem responses to the natural seasonal rainfall pattern but also to the imposed (i.e., managed) hydrological regime (Rudnick et al. 1999; Sutula et al., 2003). Nutrient exchange in Taylor Slough affects the water quality of Florida Bay and therefore, the Florida Keys (Lapointe et al., 2001). Taylor Slough, as part of the Everglades, is considered an oligotrophic environment such that—in its natural state—has very low nutrient availability and efficient biogeochemical cycles (Noe et al., 2003; Childers et al., 2006). As a result, oligotrophic Everglades wetlands are particularly vulnerable to invasion and habitat transformation if additional nutrients are loaded (Davis 1994; McCormick et al., 1996).

Taylor Slough currently operates in a diminished hydrologic capacity, largely due to a reduced watershed and its proximity to agriculture, given the reduced groundwater levels legally mandated during the fall and early winter produce-growing season, precisely during the natural times for highest freshwater flows (Oct-Nov). The downstream consequence of diminished flow has been increased salinity in parts of the mangrove ecotone and Florida Bay resulting in loss of habitat and reduced density of pink shrimp and wading birds in Florida Bay (Robblee et al., 1991; McIvor et al., 1994; Lorenz 1999; Brand 2001). In turn, this has led to the landward expansion of the ‘white zone’—a low productivity zone between the mangrove ecotone and the sawgrass-dominated landscape of the southern Everglades—by about 1.5 kilometers between 1940 and 1994 (Ross et al., 2001).

The major direct agent that has altered the hydrology of Taylor Slough is the C-111 canal, which siphons water away from Taylor Slough and routes it into lower Biscayne Bay/Manatee Bay (via the S-197 structure) and far eastern Florida Bay (Light and Dineen, 1994). As such, restoration efforts are centering on the C-111 canal to increase freshwater flow into Taylor Slough, thus returning the timing of the flows to a semblance of its natural state. The seepage barrier component of the C-111 Spreader Project will create a hydrological head in the surrounding area, keeping more water in Taylor Slough and allowing for more of that freshwater to enter into Florida Bay (USACE, 2011).

Methods

Data Sources and Analyses

Discharge data for the Taylor River mouth and Taylor River upstream sites came from the USGS (http://fl.water.usgs.gov/Miami/hurricane/) and water quality data were derived from the Florida Coastal Everglades Long-Term Ecological Research (FCE-LTER) program (http://fcelter.fiu.edu/data/core/). Water quality parameters included total nitrogen (TN), total phosphorus (TP), and salinity values. Sampling intervals were tri-daily from Jan 1996 to Sept 2009 (POR). Unfiltered water samples were analyzed for total nitrogen (TN) and total phosphorus (TP). TN was measured using an ANTEK 7000N Nitrogen Analyzer using O_2 as carrier gas to promote complete recovery of the nitrogen in the water samples (Frankovich and Jones 1998). TP was determined using a dry ashing, acid hydrolysis technique (Solórzano and Sharp 1980). Data sets were manipulated to remove null data points and discharge data was 3-day averaged to match the intervals of the FCE LTER water quality sampling program.

Cumulative sum charts

We used statistical techniques developed primarily for industrial processes (standardized cumulative sum) to envision linkages between four base variables: salinity, total phosphorus (TP) and total nitrogen (TN) concentrations, daily discharge, and the ratio of total nitrogen (TN) to total phosphorus (TN:TP), a key indicator of the biological availability of these ecologically important nutrients. In doing so, we sought to predict the direction and likely consequences of hydrologic restoration of the Taylor Slough ecosystem through the implementation of the C-111 spreader project.

We explored the structure of time-series to identify and characterize their components (trend, cycles and seasonality) with standardized cumulative sum charts (Cusum; Manly and MacKenzie 2000). A standardized Cusum chart is a plot of the cumulative sum of standardized deviations from a target specification (in our case the time-series grand mean), against n, the sample number (or date if regularly sampled) (Ewan, 1963). Standardization is performed as follows:

$$z_i = [(x_i - m)/ \sigma] + z_{i-1}; \quad m = \text{mean and } \sigma = \text{standard deviation}$$

As such, the Cusum procedure sums up the deviations around the mean and provides a visual representation of smoothed data used to infer trends or change points in a time series. The key elements in Cusum charts are the slopes and slope breaks. We should keep in mind that interpretation of Cusum line-plots is different from the usual interpretation of scatter-plots. A segment with a positive slope in the Cusum graph represents a period where most of the values in the original series (x_i) are above-average, and not necessarily that values are increasing, as we usually interpret positive slopes in scatter-plots. Segments with negative slopes in Cusum space indicate below-average values (not necessarily an indication of a decline in the original series). Likewise, horizontal segments in the Cusum represent average conditions. Finally, monotonically increasing secular trends in the dataset produce positive parabolic

Cusum curves (cup- or V-shape) and monotonically decreasing trends produce negative parabolic curves (dome- or peak-shape).

Cusum charts and Cusum analysis are standard procedure in the field of industrial process control (Duncan 1974; Grant and Leavenworth 1980; Montgomery 2001), and the direct connection between Cusum and process performance, has driven increasing applications to the earth sciences, especially for the analysis of time-series data in oceanography, geology, climate change and ecology (Ibanez et al. 1993; Adrian et al. 2006; Molinero et al. 2008; Briceño and Boyer 2010; Wachnicka et al. 2013), especially when identifying cause-effect (driver-response) relationships. In our case, Cusum analyses were first run to identify temporal changes in salinity, nutrients (TN and TP), and discharge time series. Then, Cusum charts were used to assess changes in TN, TP, salinity and TN:TP molar ratios relative to discharge gradients.

Results

The mouth of Taylor River is considerably more saline and influenced by tide and wind-driven shifts in discharge compared with the upstream site (Table 1). Both Taylor River sites exhibited similar TP concentrations, but median TN concentrations were about 4 µM higher at the mouth site compared with the upstream site during the period of record (7/30/99 to 9/30/09). This is reflected in slightly higher TN:TP ratios at the mouth site (Table 1).

As with other areas of the Everglades, temporal patterns in coastal Everglades water quality reflect the intra-annual seasonality of hydrologic conditions (Davis et al.

2003; Childers et al. 2006). Considering hydrologic conditions at Taylor River mouth and using this as a surrogate for conditions throughout the region, we found a clear seasonal pattern of discharge coinciding with wet season rainfall that begins in late May/early June and typically runs through November (Figure 2a). Mean daily stage in Taylor River corresponded with this (Figure 2b), likely as a result of upland runoff backing up against the Buttonwood Ridge—a sediment embankment running along the interface between the mangrove ecotone and eastern Florida Bay. As expected, salinity at Taylor River mouth is inversely related to discharge, with lowest values in the wet season and highest values at the height of the dry season in May (Figure 2c). However, surface water TP concentrations, which are variable throughout the year, seemed to track salinity with highest minimum and median concentrations occurring at the peak of the dry season (Figure 2d).

Temporal trends

Cusum charts were constructed by plotting standardized cumulative data for each variable along the y-axis, and time on the x-axis (see panels in Figure 3). Results show that rainfall at NOAA's Everglades Station (Figure 3a and 3b) and discharge (Figure 3c and 3d) follow similar patterns until mid 2005, with discharge lagging rainfall by about 1-3 months. Relative low discharges prevailed until June 1997 (steep negative slope), then a more obvious seasonal pattern with two 4-year cycles were experienced, followed by a strong departure towards high discharges during the 2005 hurricane season (i.e., Katrina, Rita, Wilma). Since then, we have seen a seasonal pattern of discharge superimposed on a below-average discharge tendency (Figure 3d), while rainfall follows an above-average tendency. Salinity exhibited a long-term increasing secular trend (Figure 3e; also note cup-shaped cusum in Figure 3f) in which well-defined seasonal cycles were superimposed (Figure 3e and 3f). For this record, salinity was below-average until early 1999 when an average tendency began and remained as such until 2001. It was followed by a below-average tendency until March 2004 (Figure 3f). Since then the general tendency has been one of above-average salinity values (>15.5 ppt). Concentrations of TN were relatively high until 2003, exhibiting two similar cycles of below-average to above-average values within that period (Figure 3g and 3h). After 2003, low TN prevailed at Taylor River mouth until early 2008. Since then TN has increased to above-average levels (Figure 3h). On the other hand, total phosphorus (TP; Figures 3i and 3j) showed irregular seasonal patterns until late 2000 when a sustained low TP period began, and lasted until the end of 2005 (Figure 3j). Since January 2006 TP concentrations have been relatively high. Relating these patterns of change in TN to TP, the TN:TP molar ratio experienced irregular oscillations until September 2000, followed by a significant departure towards high values (TN:TP=342) from October 2000 to April-2003 (Figure 3k and 3l). After a short period of close to average tendency (TN:TP=224), which extended to mid 2004, there was a sustained decline of TN:TP (=158) lasting until early 2009.

Discharge gradients

Slopes of ordinary linear regressions of salinity, TP, TN and TN:TP on discharge were calculated to estimate secular trends along discharge gradients (Table 2). Most slopes are statistically significant at $p<0.10$, except TN at upstream Taylor and TN:TP at Taylor Mouth.

Taylor River upstream:

As expected, salinity at the Taylor River upstream site was negatively correlated with discharge showing a clear declining secular trend (i.e., dome-shaped cusum; Figure 4a). The inflexion point for salinity, from below-average to above-average salinity occurred at 0.17 m^3/s. Cusum trend results for TN at the upstream site had two important breaks, which highlight the non-linear response of TN to discharge at this less tidally-influenced site: from below-to-above average TN at about -0.18 m^3/s, and from above-to-below average at 0.30 m^3/s (Figure 4b). Hence, very low TN concentrations prevailed during negative flows (e.g., during strong southerly wind or tidal events) as well as during extreme positive flows (e.g., wet season discharge events). TP exhibited a marked declining secular trend with increasing discharge (note clear dome-shaped cusum in Fig 4c). The most important breaks in TP occurred from above-average to average concentrations at 0.10 m^3/s discharge and from average to below-average at 0.16 m^3/s discharge (Figure 4c).

TN:TP ratios at the Taylor River upstream site were directly correlated with discharge (positive parabolic cusum; Figure 4d). Given this and the good negative correlation between TP and discharge, ratios at the upstream site seemed to be driven more by flow-related changes in TP concentrations than to TN values. Below-average

TN:TP values occurred below 0.11 m^3/s, and above-average TN:TP occurred for discharges above 0.25 m^3/s.

Taylor River mouth:

At the mouth of Taylor River, salinity declined with discharge and the inflexion point for above-to-below average salinity (13.46 ppt) occurred at 0.80 m^3/s (Figure 4e). TN and TP cusum patterns versus discharge were non-linear and similar up to 0.7 m^3/s discharge (Figure 4f and 4g). When considered separately, negative flows produced an increasing trend of TN and TP as discharge approached zero but overall below-average TN and TP concentrations of 54.5 and 0.33 uM, respectively. Between zero and 0.70 m^3/s discharge TN and TP concentrations increased to 60.1 and 0.36 uM respectively. Larger discharges resulted in TP decline to a mean of 0.31 uM. On the other hand, TN declined to 52.1 uM at discharges between 0.7 and 1.12 m^3/s. Beyond that, TN increased to 60.3 uM between 1.12 and 1.18 m^3/s and finally declined to an average of 52.9 uM for higher discharges (Figure 4f). The correlation coefficient for a power regression model between TP and TN:TP is 0.71, while the best for TN versus TN:TP is 0.15. Hence, although TN and TP cusum patterns are similar to TN:TP at the mouth site, TP seems to drive much of the discharge-related fluctuations in TN:TP ratios at the mouth site during the period of record (Figure 4h).

Discussion

Variations in tidal creek flow are known to affect patterns of estuarine water quality (Eyre and Balls 1999); however, these patterns can be greatly modified by short-term storm events, longer term variations in climate, and interactions with human activities (Childers et al. 1990; Paerl et al. 2006). This confounds our ability to effectively predict water quality fluctuations in sensitive coastal waters subjected to a range of natural and human-related drivers. The descriptive statistical approach we used, combined with evidence observed by others, can help establish the link between flow of water from Taylor Slough, phosphorus and nitrogen dynamics, and TN:TP ratios in the southern Everglades mangrove ecotone. Once those relationships are established, we can begin to unravel the effects of water management, restoration, climatic, and event-driven dynamics.

The period around 2004-2005 marked a series of distinct water quality changes at these sites (Figure 3; e.g., increase in salinity, decline in TN, increase in TP, and decline in TN:TP ratio). This is noteworthy, as it was a period of time marked by two very active hurricane seasons, and there is ample evidence showing that water quality, hydrology and sediment dynamics of this region are greatly influenced by such storm events (Davis et al. 2004; Woods and Zucker, 2007; Castañeda-Moya et al., 2009; Briceño and Boyer 2010). Furthermore, these trends gradually reverted to previous conditions by 2009, indicating the lasting effects of these types of events (Figure 3; e.g., Paerl et al. 2006). In south Florida, these lasting impacts are to be expected given the large volumes of seawater and P-rich marine/bay sediments brought to the mangrove forests by the storm surges (Davis et al. 2005; Castañeda-Moya et al. 2009).

Phosphorus concentrations along lower Taylor Slough were greatly influenced by hydrologic conditions affecting discharge and salinity, with highest TP concentrations found at lowest or negative discharge values and moderately high salinity values (10-31 ppt). This seemed clearest at the upstream site, where Everglades runoff and internal processes have prevailing control over nutrient availability. High TP under these low flow conditions may result through a number of processes including increased discharge of relatively high TP groundwater (Price et al. 2006), increased influence of the relatively high TP marine end-member (Childers et al. 2006), evaporative concentration of TP, or a decreased demand for surface water TP due to labile C limitation resulting from high hydrologic residence times (as suggested by Davis and Childers 2007). This supports findings from other water quality studies in this region indicating that increased freshwater flows from the C-111 will not only reduce hypersalinity events in the bay but will also lower surface water TP concentrations in the mangrove ecotone, thus contributing to a restoration of the oligotrophic character of this region.

Nitrogen dynamics are more complicated and perhaps indicate the influence of both external and internal sources of TN at different times of the year. Further, evidence suggests that the Everglades mangrove ecotone may be a hot spot for nitrogen dynamics driven by high organic matter accumulation and N immobilization (Rivera-Monroy et al. 2011). Relating flows and water quality, Davis et al. (2003) and Childers et al. (2006), respectively, suggested that a positive relationship between freshwater flow and TN concentrations reflected a possible upland source (i.e., freshwater marsh) of TN or an internal mangrove source (i.e., mangrove) of TN in response to wet season onset. An analysis of limited flux data from within the mangrove ecotone indicated a net release of TN from the mangrove to the water column at salinity values above about 27 ppt (Davis et al. 2003). More recent flux data by Liu and Davis (this issue) indicate consistent low-level soil/sediment uptake of nitrate + nitrite in combination with high-level release of ammonium in different ecotone habitats. The imbalance between these fluxes combined with seasonal re-wetting of the upstream marsh may represent a significant source of TN in this region driving up ratios of TN:TP early in the wet season.

In general, our approach showed that TN varied more over annual to inter-annual scales relative to TP that, despite exhibiting variation over longer time-scales, also showed a clearer relationship with seasonal discharge. Still, there were ranges of high discharge, perhaps at the outset of the wet season, when high discharge corresponded with high TN. This only speaks to the complex array of drivers affecting TN in this region and that more biogeochemical work needs to be done to understand nitrogen dynamics across the mangrove ecotone of Taylor Slough.

The Taylor Slough and C-111 restoration efforts are predicted to restore up to 87% of natural volume of flows according to the U.S. Army Corps of Engineers' best restoration alternative (USACE 2011). Assuming that current C-111 discharges to the coast will be retained in the Taylor Slough and adjacent marsh below the C-111 canal (i.e., the "C-111 basin") with full C-111 restoration, we could see 10% or more freshwater flowing into eastern Florida Bay each year relative to current conditions. With restored flows, increased freshwater passing through Taylor Slough and the C-111 basin could reduce phosphorus concentrations in the mangrove ecotone by reducing potential terrestrial sources and by minimizing the periods of time where Florida Bay is actively inputting phosphorus into the ecotone (Rudnick et al., 1999; Price et al. 2006; Childers et al. 2006). This will also shorten hydrologic residence times, which may also minimize local evaporative concentration and decrease periods of possible labile C limitation in the water column.

As a result of these actions and advanced states of Everglades restoration, we could anticipate a restored oligotrophic status to the lower Taylor Slough area of the Everglades. However, as we have shown, these assumptions may be too simplistic. Restored oligotrophic status is certainly the goal, but ecosystem responses are not linear and recent research suggests that elevated P availability and the associated changes in ecosystem structure will remain for extended periods following flow restoration (Herbert and Fourqurean 2008). This is due in part to the retention of P in sediments (Liu et al. this issue) of these strongly P-limited ecosystems that has occurred in the recent past combined with future changes in the availability of N across this ecotone. Further, it does not consider the continual effects of sea-level rise along the vulnerable south Florida coastline.

Our approach presented here is useful in that it provides a tool for revealing patterns, relationships, and change points in otherwise noisy water quality and hydrologic data. With the inclusion of more sites, longer time series, and process-specific information on fluxes of N and P, we hope to generate a better understanding of long-term trends in water quality. This will allow us to link major climatic events and cycles to regional hydro-ecological processes it will also be necessary to evaluate the long-term benefits of restored flows in Taylor Slough and throughout the Greater Everglades ecosystem.

Acknowledgements

The authors thank the National Fish and Wildlife Foundation (grant # 9934.12.029268) and the Florida Coastal Everglades Long-Term Ecological Research program (National Science Foundation cooperative agreements #DEB-1237517 and DBI-0620409) for their support of this research. The Everglades Foundation provided internship support for G. Miller's work on this study. This is contribution #608 from the Southeast Environmental Research Center at Florida International University.

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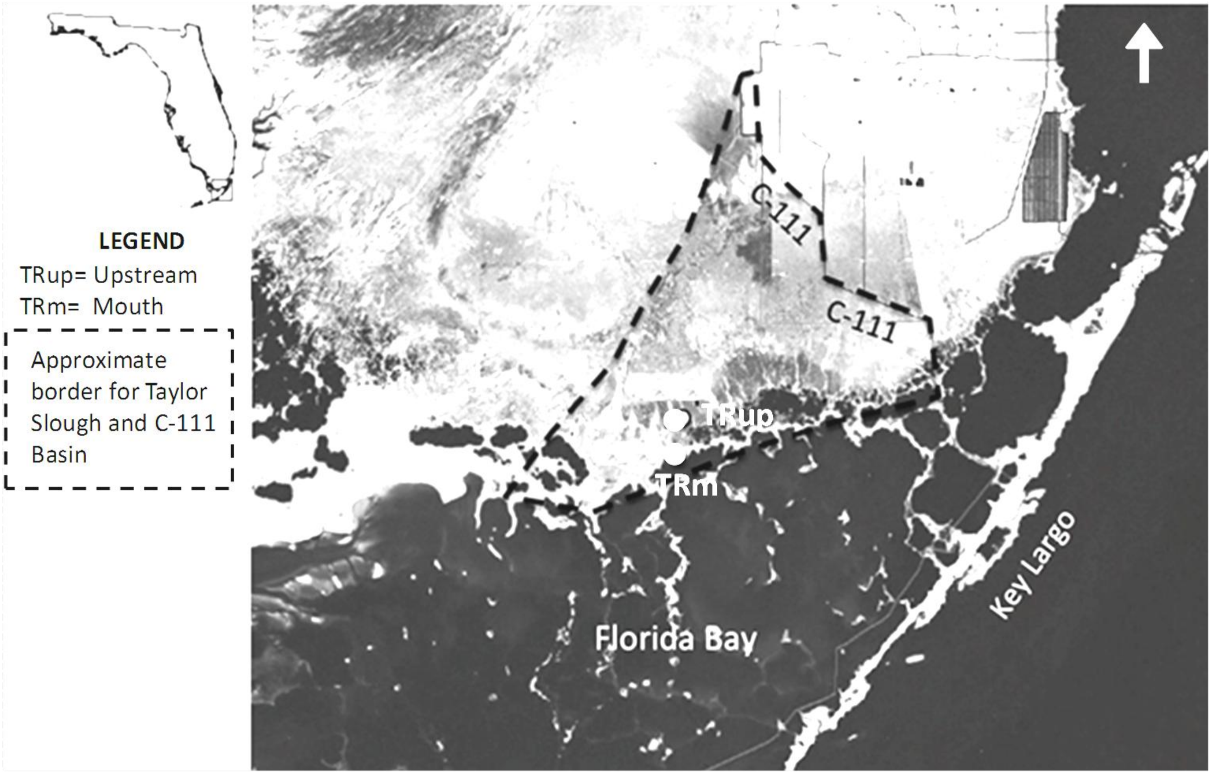
List of Figures

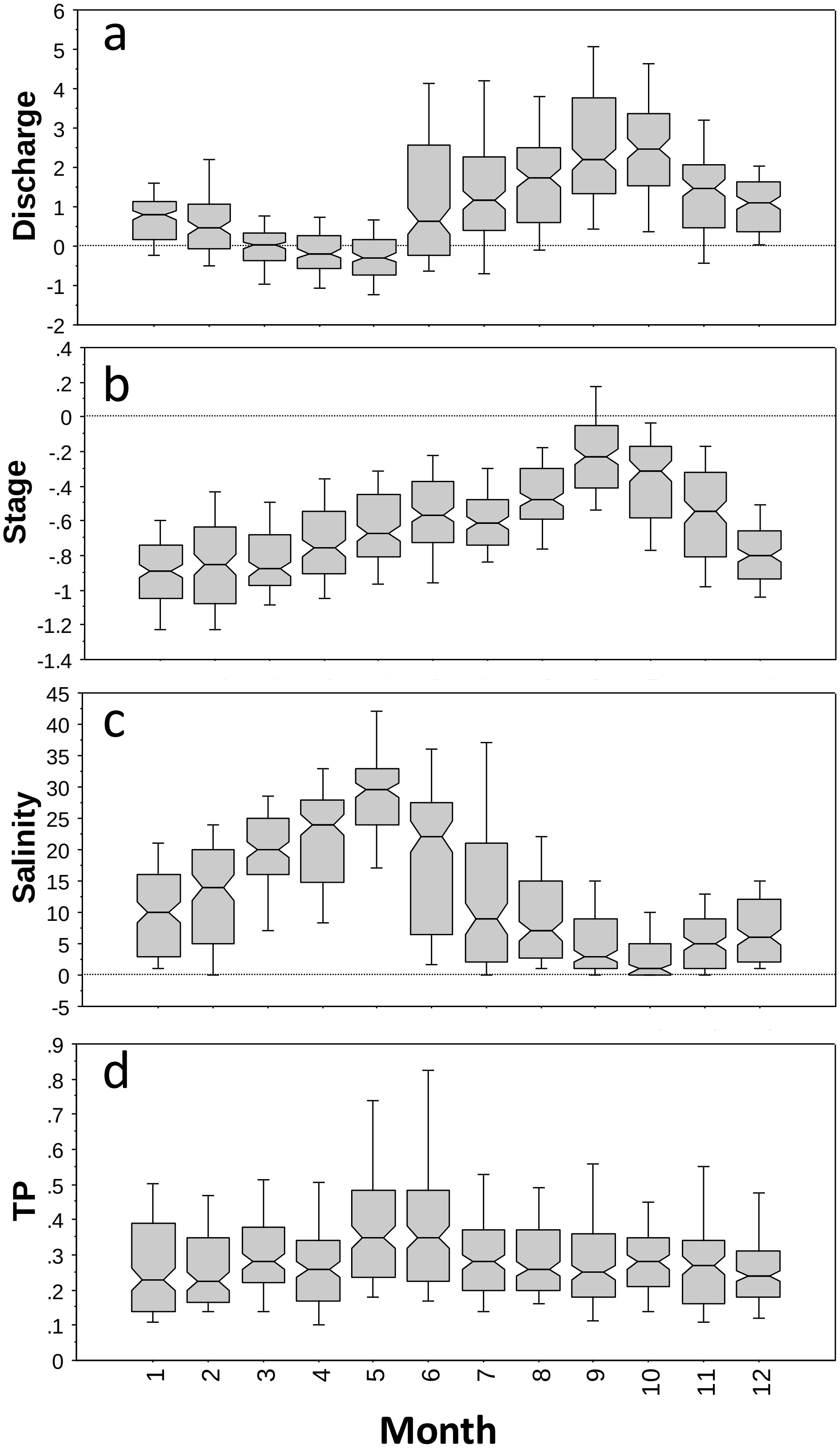
Figure 1: Map showing Florida Bay and location of water quality sampling sites considered in this analysis. C-111 canal basin and Taylor Slough are delineated. Sites in map are identified as follows TRup: Taylor River upstream, TRm: Taylor River mouth

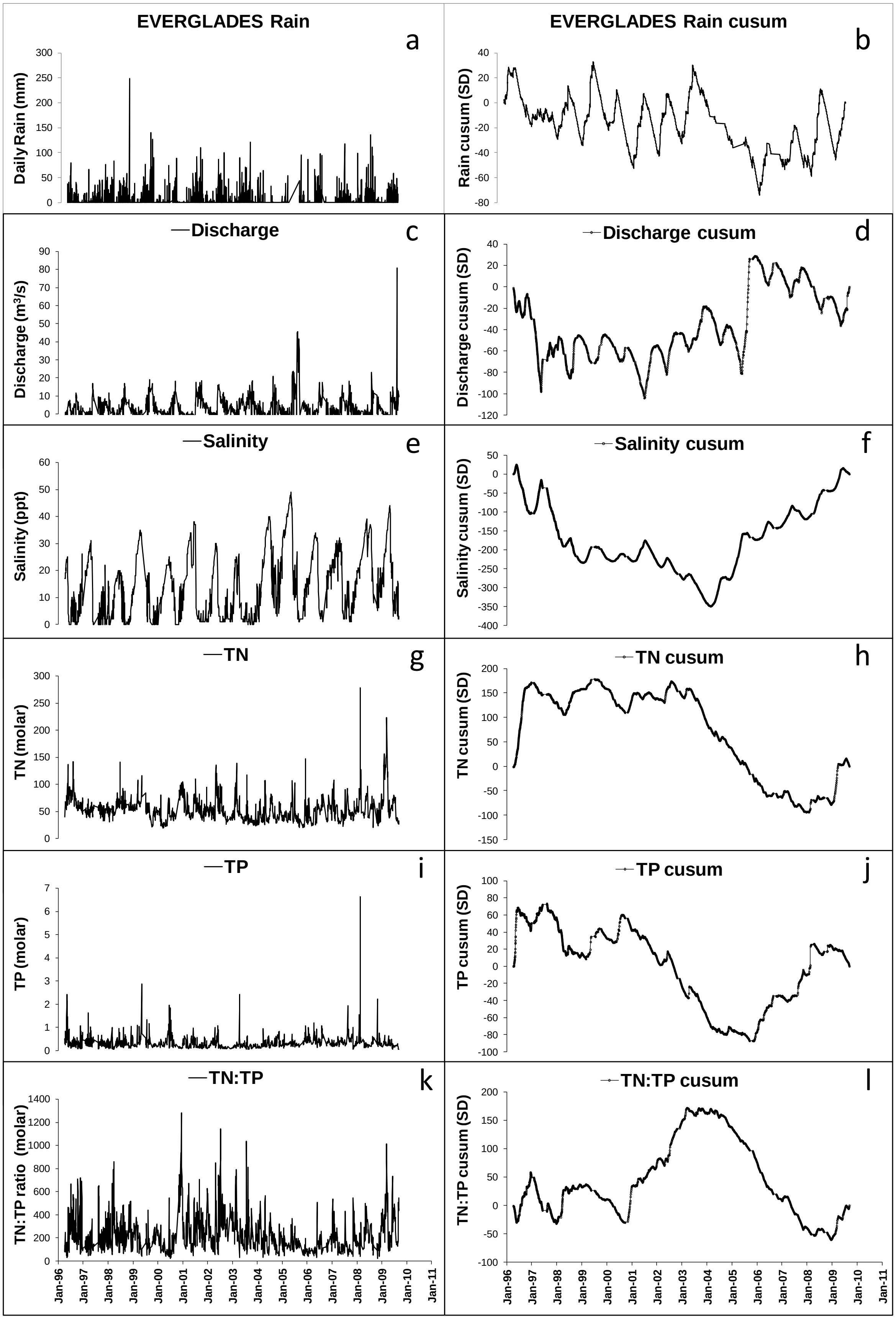
Figure 2: Box and whisker plots of (a) daily discharge (m^3 s^{-1};NAVD88), (b) mean daily stage (m), (c) mean daily salinity (ppt), and (d) tri-daily TP (µM) by month at Taylor River mouth during the period of record. The center horizontal line of the box is the median of the data, the top and bottom of the box are the 25th and 75th percentiles (quartiles), and the ends of the whiskers are the 5th and 95th 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 (<5th and >95th percentiles) were excluded from the graphs to reduce visual compression.

Figure 3: Temporal time series and their respective standardized cusum charts for Rainfall at NOAA's Everglades Station (N 25°51'; W81°23'), and Taylor River mouth station discharge, salinity, TN, TP, and TN:TP. General cup-shaped chart (i.e. salinity) indicates increasing secular trend, while dome-shaped line-plot indicates declining secular trend (i.e. TN:TP). Note the time-series and cusum seasonality in discharge and salinity, as well as cusum changes in salinity, TN, TP, and TN:TP around 2004-2005 in association with those strong hurricane seasons.

Figure 4: Discharge gradient cusum charts for salinity, TN, TP, and TN:TP in Taylor upstream (a-d) and Taylor mouth (e-h), respectively. TP in Taylor upstream and salinity in both stations display declining secular trends with discharge, while TN:TP trend in upstream station increases. TP and TN:TP in Taylor mouth and TN in both stations display non linear responses to discharge. Peak-shaped inflexion points highlight largest changes from above-average to below-average values, while V-shaped inflexion points indicate the opposite.


LEGEND
TRup= Upstream
TRm= Mouth
Approximate border for Taylor Slough and C-111 Basin
C-111
C-111
TRup
TRm
Florida Bay
Key Largo


a
Discharge
6
5
4
3
2
1
0
-1
-2
b
Stage
.4
.2
0
-.2
-.4
-.6
-.8
-1
-1.2
-1.4
c
Salinity
45
40
35
30
25
20
15
10
5
0
-5
d
TP
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1
2
3
4
5
6
7
8
9
10
11
12
Month


EVERGLADES Rain
a
Daily Rain (mm)
0
50
100
150
200
250
300
EVERGLADES Rain cusum
b
Rain cusum (SD)
-80
-60
-40
-20
0
20
40
Discharge
c
Discharge (m³/s)
0
10
20
30
40
50
60
70
80
90
Discharge cusum
d
Discharge cusum (SD)
-120
-100
-80
-60
-40
-20
0
20
40
Salinity
e
Salinity (ppt)
0
10
20
30
40
50
60
Salinity cusum
f
Salinity cusum (SD)
-400
-350
-300
-250
-200
-150
-100
-50
0
50
TN
g
TN (molar)
0
50
100
150
200
250
300
TN cusum
h
TN cusum (SD)
-150
-100
-50
0
50
100
150
200
TP
i
TP (molar)
0
1
2
3
4
5
6
7
TP cusum
j
TP cusum (SD)
-100
-80
-60
-40
-20
0
20
40
60
80
100
TN:TP
k
TN:TP ratio (molar)
0
200
400
600
800
1000
1200
1400
TN:TP cusum
l
TN:TP cusum (SD)
-100
-50
0
50
100
150
200
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11

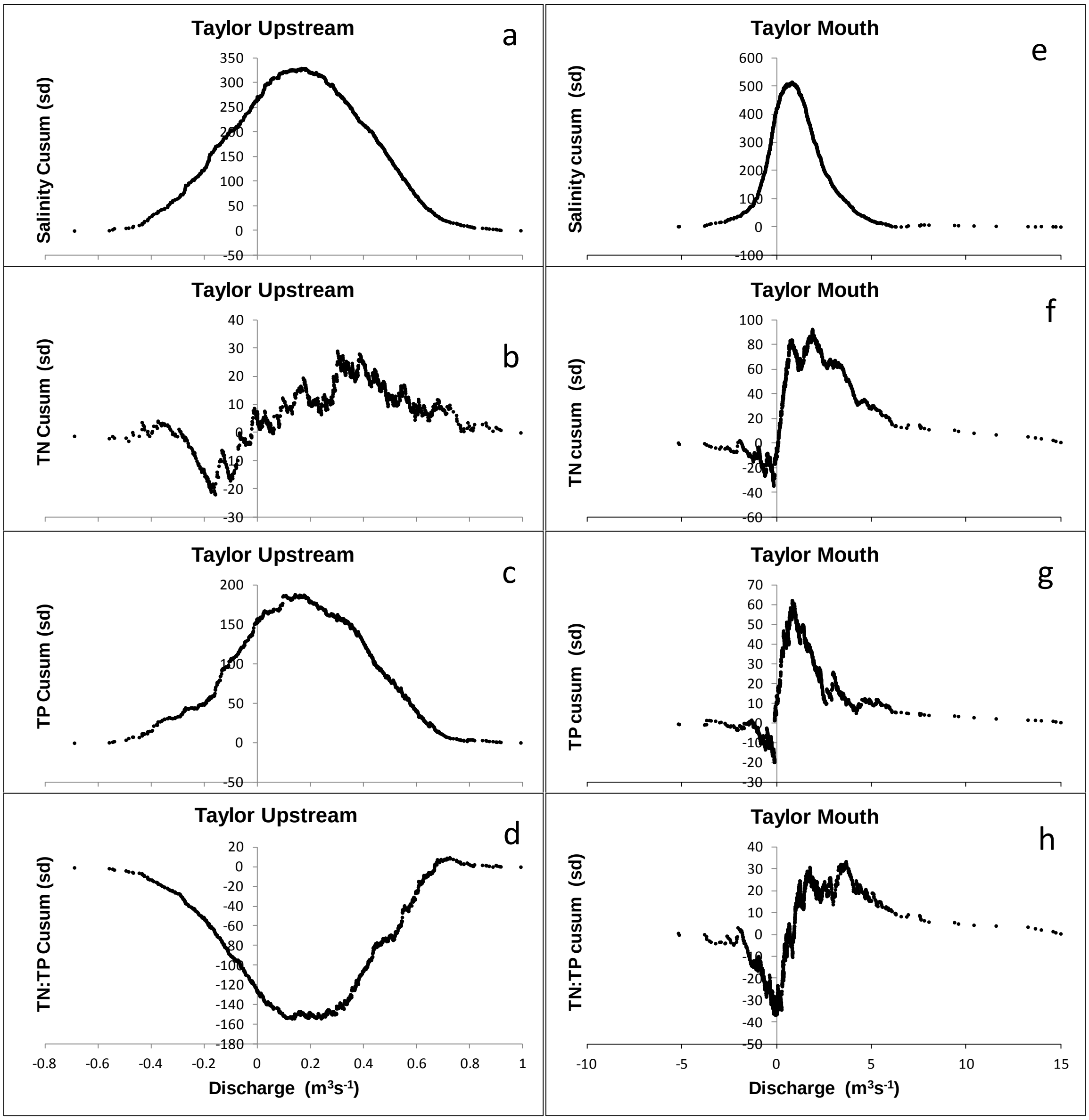

Taylor Upstream
a
Salinity Cusum (sd)
350
300
250
200
150
100
50
0
-50
Taylor Upstream
b
TN Cusum (sd)
40
30
20
10
0
-10
-20
-30
Taylor Upstream
c
TP Cusum (sd)
200
150
100
50
0
-50
Taylor Upstream
d
TN:TP Cusum (sd)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Discharge (m³s⁻¹)
Taylor Mouth
e
Salinity cusum (sd)
600
500
400
300
200
100
0
-100
Taylor Mouth
f
TN cusum (sd)
100
80
60
40
20
0
-20
-40
-60
Taylor Mouth
g
TP cusum (sd)
70
60
50
40
30
20
10
0
-10
-20
-30
Taylor Mouth
h
TN:TP cusum (sd)
40
30
20
10
0
-10
-20
-30
-40
-50
-10
-5
0
5
10
15
Discharge (m³s⁻¹)

Table 1: Basic statistics for relevant parameters at Taylor Mouth and Upstrean Taylor Stations. Units: TP and TN in uM; TN:TP in molar ratio; Salinity in ppt; Stage in m; and Discharge in cfs.

UPSTREAM TAYLOR	**TP**	**TN**	**TN:TP**	**Salinity**	**Stage**	**Discharge**
Average	0.36	49.01	209.77	8.51	-0.33	9.20
Stdev	0.29	23.49	175.45	11.94	0.44	10.53
Median	0.28	41.95	152.72	2.00	-0.38	10.78
Max	2.76	185.68	1304.80	49.00	1.47	35.05
Min	0.04	16.16	14.82	0.00	-1.26	-24.38

TAYLOR MOUTH	**TP**	**TN**	**TN:TP**	**Salinity**	**Stage**	**Discharge**
Average	0.32	51.48	225.14	15.56	-0.59	44.39
Stdev	0.30	24.09	161.80	12.36	0.37	81.30
Median	0.25	46.24	174.19	14.00	-0.59	27.95
Max	6.64	278.30	1284.89	49.00	0.88	935.94
Min	0.05	19.48	21.42	0.00	-1.65	-183.51

Table 2: Slopes of Line of Ordinary Regression as estimate of secular trends along discharge gradients

	TP	**TN**	**TN:TP**	**Stage**	**Salinity**
Upstream Taylor					
slope	-0.0096	-0.0491	4.8889	0.0061	-0.7317
p	<.0001	0.4691	<.0001	<.0001	<.0001
Taylor Mouth					
slope	-0.0002	-0.0323	-0.0661	0.0007	-0.0797
p	0.0582	<.0001	0.1955	<.0001	<.0001