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# 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.

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## 1 **Introduction**

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

12           South Florida and the Everglades were once synonymous as a mosaic of  
13 hydrologically interconnected landscapes and communities comprising the largest  
14 single marsh system in the United States (Ogden et al 2005). Today, remaining  
15 subtropical wetlands and their drainages are disconnected, over-drained, and managed  
16 by a complex network of canals (2,300 Km) and structures. As a result, there has been  
17 extensive soil loss due to subsidence and peat oxidation, an increase in algal bloom  
18 frequency and magnitude, decreases in bird and mammal populations, shifts in  
19 vegetative community structure, and saltwater intrusion (Lorenz, 1999; Sklar et al.,  
20 2001; Marshall et al. 2009).

21           In Everglades National Park, located at the southernmost tip of the Florida  
22 Peninsula, decreased flow and increased nutrient loading (especially phosphorus), can  
23 lead to loss of periphyton—the base of the Everglades food web—and irreversible

1 change in vegetative community structure, both of which lead to diminished habitat  
2 quality (Davis, 1994; McCormick et al. 1996; Childers et al., 2001; Durako et al., 2001;  
3 Gaiser et al., 2004). Therefore restoring the natural flow and quality of water to the  
4 Everglades is critical to protecting the remaining “River of Grass”, mangrove forests,  
5 and estuaries such as Florida Bay.

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

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

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

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

## 20 *Site Description*

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

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

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

15 The salinity and nutrient dynamics of this mangrove ecotone illustrate  
16 fundamental ecosystem responses to the natural seasonal rainfall pattern but also to  
17 the imposed (i.e., managed) hydrological regime (Rudnick et al. 1999; Sutula et al.,  
18 2003). Nutrient exchange in Taylor Slough affects the water quality of Florida Bay and  
19 therefore, the Florida Keys (Lapointe et al., 2001). Taylor Slough, as part of the  
20 Everglades, is considered an oligotrophic environment such that—in its natural state—  
21 has very low nutrient availability and efficient biogeochemical cycles (Noe et al., 2003;  
22 Childers et al., 2006). As a result, oligotrophic Everglades wetlands are particularly

1 vulnerable to invasion and habitat transformation if additional nutrients are loaded  
2 (Davis 1994; McCormick et al., 1996).

3 Taylor Slough currently operates in a diminished hydrologic capacity, largely due  
4 to a reduced watershed and its proximity to agriculture, given the reduced groundwater  
5 levels legally mandated during the fall and early winter produce-growing season,  
6 precisely during the natural times for highest freshwater flows (Oct-Nov). The  
7 downstream consequence of diminished flow has been increased salinity in parts of the  
8 mangrove ecotone and Florida Bay resulting in loss of habitat and reduced density of  
9 pink shrimp and wading birds in Florida Bay (Robblee et al., 1991; McIvor et al., 1994;  
10 Lorenz 1999; Brand 2001). In turn, this has led to the landward expansion of the 'white  
11 zone'—a low productivity zone between the mangrove ecotone and the sawgrass-  
12 dominated landscape of the southern Everglades—by about 1.5 kilometers between  
13 1940 and 1994 (Ross et al., 2001).

14 The major direct agent that has altered the hydrology of Taylor Slough is the C-  
15 111 canal, which siphons water away from Taylor Slough and routes it into lower  
16 Biscayne Bay/Manatee Bay (via the S-197 structure) and far eastern Florida Bay (Light  
17 and Dineen, 1994). As such, restoration efforts are centering on the C-111 canal to  
18 increase freshwater flow into Taylor Slough, thus returning the timing of the flows to a  
19 semblance of its natural state. The seepage barrier component of the C-111 Spreader  
20 Project will create a hydrological head in the surrounding area, keeping more water in  
21 Taylor Slough and allowing for more of that freshwater to enter into Florida Bay  
22 (USACE, 2011).

1

## 2 **Methods**

### 3 *Data Sources and Analyses*

4 Discharge data for the Taylor River mouth and Taylor River upstream sites came  
5 from the USGS (<http://fl.water.usgs.gov/Miami/hurricane/>) and water quality data were  
6 derived from the Florida Coastal Everglades Long-Term Ecological Research (FCE-  
7 LTER) program ( <http://fcelter.fiu.edu/data/core/>). Water quality parameters included  
8 total nitrogen (TN), total phosphorus (TP), and salinity values. Sampling intervals were  
9 tri-daily from Jan 1996 to Sept 2009 (POR). Unfiltered water samples were analyzed for  
10 total nitrogen (TN) and total phosphorus (TP). TN was measured using an ANTEK  
11 7000N Nitrogen Analyzer using O<sub>2</sub> as carrier gas to promote complete recovery of the  
12 nitrogen in the water samples (Frankovich and Jones 1998). TP was determined using  
13 a dry ashing, acid hydrolysis technique (Solórzano and Sharp 1980). Data sets were  
14 manipulated to remove null data points and discharge data was 3-day averaged to  
15 match the intervals of the FCE LTER water quality sampling program.

16

### 17 *Cumulative sum charts*

18 We used statistical techniques developed primarily for industrial processes  
19 (standardized cumulative sum) to envision linkages between four base variables:  
20 salinity, total phosphorus (TP) and total nitrogen (TN) concentrations, daily discharge,  
21 and the ratio of total nitrogen (TN) to total phosphorus (TN:TP), a key indicator of the

1 biological availability of these ecologically important nutrients. In doing so, we sought to  
2 predict the direction and likely consequences of hydrologic restoration of the Taylor  
3 Slough ecosystem through the implementation of the C-111 spreader project.

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

$$10 \quad z_i = [(x_i - m) / \sigma] + z_{i-1}; \quad m = \text{mean and } \sigma = \text{standard deviation}$$

11

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



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

3 Cusum charts and Cusum analysis are standard procedure in the field of  
4 industrial process control (Duncan 1974; Grant and Leavenworth 1980; Montgomery  
5 2001), and the direct connection between Cusum and process performance, has driven  
6 increasing applications to the earth sciences, especially for the analysis of time-series  
7 data in oceanography, geology, climate change and ecology (Ibanez et al. 1993; Adrian  
8 et al. 2006; Molinero et al. 2008; Briceño and Boyer 2010; Wachnicka et al. 2013),  
9 especially when identifying cause-effect (driver-response) relationships. In our case,  
10 Cusum analyses were first run to identify temporal changes in salinity, nutrients (TN and  
11 TP), and discharge time series. Then, Cusum charts were used to assess changes in  
12 TN, TP, salinity and TN:TP molar ratios relative to discharge gradients.

13

## 14 **Results**

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

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

1 2003; Childers et al. 2006). Considering hydrologic conditions at Taylor River mouth  
2 and using this as a surrogate for conditions throughout the region, we found a clear  
3 seasonal pattern of discharge coinciding with wet season rainfall that begins in late  
4 May/early June and typically runs through November (Figure 2a). Mean daily stage in  
5 Taylor River corresponded with this (Figure 2b), likely as a result of upland runoff  
6 backing up against the Buttonwood Ridge—a sediment embankment running along the  
7 interface between the mangrove ecotone and eastern Florida Bay. As expected, salinity  
8 at Taylor River mouth is inversely related to discharge, with lowest values in the wet  
9 season and highest values at the height of the dry season in May (Figure 2c). However,  
10 surface water TP concentrations, which are variable throughout the year, seemed to  
11 track salinity with highest minimum and median concentrations occurring at the peak of  
12 the dry season (Figure 2d).

13

#### 14 *Temporal trends*

15 Cusum charts were constructed by plotting standardized cumulative data for  
16 each variable along the y-axis, and time on the x-axis (see panels in Figure 3). Results  
17 show that rainfall at NOAA's Everglades Station (Figure 3a and 3b) and discharge  
18 (Figure 3c and 3d) follow similar patterns until mid 2005, with discharge lagging rainfall  
19 by about 1-3 months. Relative low discharges prevailed until June 1997 (steep negative  
20 slope), then a more obvious seasonal pattern with two 4-year cycles were experienced,  
21 followed by a strong departure towards high discharges during the 2005 hurricane  
22 season (i.e., Katrina, Rita, Wilma). Since then, we have seen a seasonal pattern of

1 discharge superimposed on a below-average discharge tendency (Figure 3d), while  
2 rainfall follows an above-average tendency. Salinity exhibited a long-term increasing  
3 secular trend (Figure 3e; also note cup-shaped cusum in Figure 3f) in which well-  
4 defined seasonal cycles were superimposed (Figure 3e and 3f). For this record, salinity  
5 was below-average until early 1999 when an average tendency began and remained as  
6 such until 2001. It was followed by a below-average tendency until March 2004 (Figure  
7 3f). Since then the general tendency has been one of above-average salinity values  
8 ( $>15.5$  ppt). Concentrations of TN were relatively high until 2003, exhibiting two similar  
9 cycles of below-average to above-average values within that period (Figure 3g and 3h).  
10 After 2003, low TN prevailed at Taylor River mouth until early 2008. Since then TN has  
11 increased to above-average levels (Figure 3h). On the other hand, total phosphorus  
12 (TP; Figures 3i and 3j) showed irregular seasonal patterns until late 2000 when a  
13 sustained low TP period began, and lasted until the end of 2005 (Figure 3j). Since  
14 January 2006 TP concentrations have been relatively high. Relating these patterns of  
15 change in TN to TP, the TN:TP molar ratio experienced irregular oscillations until  
16 September 2000, followed by a significant departure towards high values (TN:TP=342)  
17 from October 2000 to April-2003 (Figure 3k and 3l). After a short period of close to  
18 average tendency (TN:TP=224), which extended to mid 2004, there was a sustained  
19 decline of TN:TP (=158) lasting until early 2009.

20

21 *Discharge gradients*

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

5 Taylor River upstream:

6 As expected, salinity at the Taylor River upstream site was negatively correlated  
7 with discharge showing a clear declining secular trend (i.e., dome-shaped cusum;  
8 Figure 4a). The inflexion point for salinity, from below-average to above-average salinity  
9 occurred at  $0.17 \text{ m}^3/\text{s}$ . Cusum trend results for TN at the upstream site had two  
10 important breaks, which highlight the non-linear response of TN to discharge at this less  
11 tidally-influenced site: from below-to-above average TN at about  $-0.18 \text{ m}^3/\text{s}$ , and from  
12 above-to-below average at  $0.30 \text{ m}^3/\text{s}$  (Figure 4b). Hence, very low TN concentrations  
13 prevailed during negative flows (e.g., during strong southerly wind or tidal events) as  
14 well as during extreme positive flows (e.g., wet season discharge events). TP exhibited  
15 a marked declining secular trend with increasing discharge (note clear dome-shaped  
16 cusum in Fig 4c). The most important breaks in TP occurred from above-average to  
17 average concentrations at  $0.10 \text{ m}^3/\text{s}$  discharge and from average to below-average at  
18  $0.16 \text{ m}^3/\text{s}$  discharge (Figure 4c).

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

1 TN:TP values occurred below 0.11 m<sup>3</sup>/s, and above-average TN:TP occurred for  
2 discharges above 0.25 m<sup>3</sup>/s.

### 3 Taylor River mouth:

4 At the mouth of Taylor River, salinity declined with discharge and the inflexion  
5 point for above-to-below average salinity (13.46 ppt) occurred at 0.80 m<sup>3</sup>/s (Figure 4e).  
6 TN and TP cusum patterns versus discharge were non-linear and similar up to 0.7 m<sup>3</sup>/s  
7 discharge (Figure 4f and 4g). When considered separately, negative flows produced an  
8 increasing trend of TN and TP as discharge approached zero but overall below-average  
9 TN and TP concentrations of 54.5 and 0.33 uM, respectively. Between zero and 0.70  
10 m<sup>3</sup>/s discharge TN and TP concentrations increased to 60.1 and 0.36 uM respectively.  
11 Larger discharges resulted in TP decline to a mean of 0.31 uM. On the other hand, TN  
12 declined to 52.1 uM at discharges between 0.7 and 1.12 m<sup>3</sup>/s. Beyond that, TN  
13 increased to 60.3 uM between 1.12 and 1.18 m<sup>3</sup>/s and finally declined to an average of  
14 52.9 uM for higher discharges (Figure 4f). The correlation coefficient for a power  
15 regression model between TP and TN:TP is 0.71, while the best for TN versus TN:TP is  
16 0.15. Hence, although TN and TP cusum patterns are similar to TN:TP at the mouth  
17 site, TP seems to drive much of the discharge-related fluctuations in TN:TP ratios at  
18 the mouth site during the period of record (Figure 4h).

19

## 20 **Discussion**

21 Variations in tidal creek flow are known to affect patterns of estuarine water  
22 quality (Eyre and Balls 1999); however, these patterns can be greatly modified by short-

1 term storm events, longer term variations in climate, and interactions with human  
2 activities (Childers et al. 1990; Paerl et al. 2006). This confounds our ability to  
3 effectively predict water quality fluctuations in sensitive coastal waters subjected to a  
4 range of natural and human-related drivers. The descriptive statistical approach we  
5 used, combined with evidence observed by others, can help establish the link between  
6 flow of water from Taylor Slough, phosphorus and nitrogen dynamics, and TN:TP ratios  
7 in the southern Everglades mangrove ecotone. Once those relationships are  
8 established, we can begin to unravel the effects of water management, restoration,  
9 climatic, and event-driven dynamics.

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

21 Phosphorus concentrations along lower Taylor Slough were greatly influenced by  
22 hydrologic conditions affecting discharge and salinity, with highest TP concentrations  
23 found at lowest or negative discharge values and moderately high salinity values (10-31

1 ppt). This seemed clearest at the upstream site, where Everglades runoff and internal  
2 processes have prevailing control over nutrient availability. High TP under these low  
3 flow conditions may result through a number of processes including increased  
4 discharge of relatively high TP groundwater (Price et al. 2006), increased influence of  
5 the relatively high TP marine end-member (Childers et al. 2006), evaporative  
6 concentration of TP, or a decreased demand for surface water TP due to labile C  
7 limitation resulting from high hydrologic residence times (as suggested by Davis and  
8 Childers 2007). This supports findings from other water quality studies in this region  
9 indicating that increased freshwater flows from the C-111 will not only reduce  
10 hypersalinity events in the bay but will also lower surface water TP concentrations in the  
11 mangrove ecotone, thus contributing to a restoration of the oligotrophic character of this  
12 region.

13 Nitrogen dynamics are more complicated and perhaps indicate the influence of  
14 both external and internal sources of TN at different times of the year. Further,  
15 evidence suggests that the Everglades mangrove ecotone may be a hot spot for  
16 nitrogen dynamics driven by high organic matter accumulation and N immobilization  
17 (Rivera-Monroy et al. 2011). Relating flows and water quality, Davis et al. (2003) and  
18 Childers et al. (2006), respectively, suggested that a positive relationship between  
19 freshwater flow and TN concentrations reflected a possible upland source (i.e.,  
20 freshwater marsh) of TN or an internal mangrove source (i.e., mangrove) of TN in  
21 response to wet season onset. An analysis of limited flux data from within the  
22 mangrove ecotone indicated a net release of TN from the mangrove to the water  
23 column at salinity values above about 27 ppt (Davis et al. 2003). More recent flux data

1 by Liu and Davis (this issue) indicate consistent low-level soil/sediment uptake of nitrate  
2 + nitrite in combination with high-level release of ammonium in different ecotone  
3 habitats. The imbalance between these fluxes combined with seasonal re-wetting of the  
4 upstream marsh may represent a significant source of TN in this region driving up ratios  
5 of TN:TP early in the wet season.

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

13 The Taylor Slough and C-111 restoration efforts are predicted to restore up to  
14 87% of natural volume of flows according to the U.S. Army Corps of Engineers' best  
15 restoration alternative (USACE 2011). Assuming that current C-111 discharges to the  
16 coast will be retained in the Taylor Slough and adjacent marsh below the C-111 canal  
17 (i.e., the "C-111 basin") with full C-111 restoration, we could see 10% or more  
18 freshwater flowing into eastern Florida Bay each year relative to current conditions.  
19 With restored flows, increased freshwater passing through Taylor Slough and the C-111  
20 basin could reduce phosphorus concentrations in the mangrove ecotone by reducing  
21 potential terrestrial sources and by minimizing the periods of time where Florida Bay is  
22 actively inputting phosphorus into the ecotone (Rudnick et al., 1999; Price et al. 2006;  
23 Childers et al. 2006). This will also shorten hydrologic residence times, which may also



1 minimize local evaporative concentration and decrease periods of possible labile C  
2 limitation in the water column.

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

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

22

1 **Acknowledgements**

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

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1 **List of Figures**

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

6 Figure 2: Box and whisker plots of (a) daily discharge ( $\text{m}^3 \text{s}^{-1}$ ; NAVD88), (b) mean daily  
7 stage (m), (c) mean daily salinity (ppt), and (d) tri-daily TP ( $\mu\text{M}$ ) by month at  
8 Taylor River mouth during the period of record. The center horizontal line of the  
9 box is the median of the data, the top and bottom of the box are the 25th and 75<sup>th</sup>  
10 percentiles (quartiles), and the ends of the whiskers are the 5th and 95th  
11 percentiles. The notch in the box is the 95% confidence interval of the median.  
12 When notches between boxes do not overlap, the medians are considered  
13 significantly different. Outliers (<5th and >95th percentiles) were excluded from  
14 the graphs to reduce visual compression.

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

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

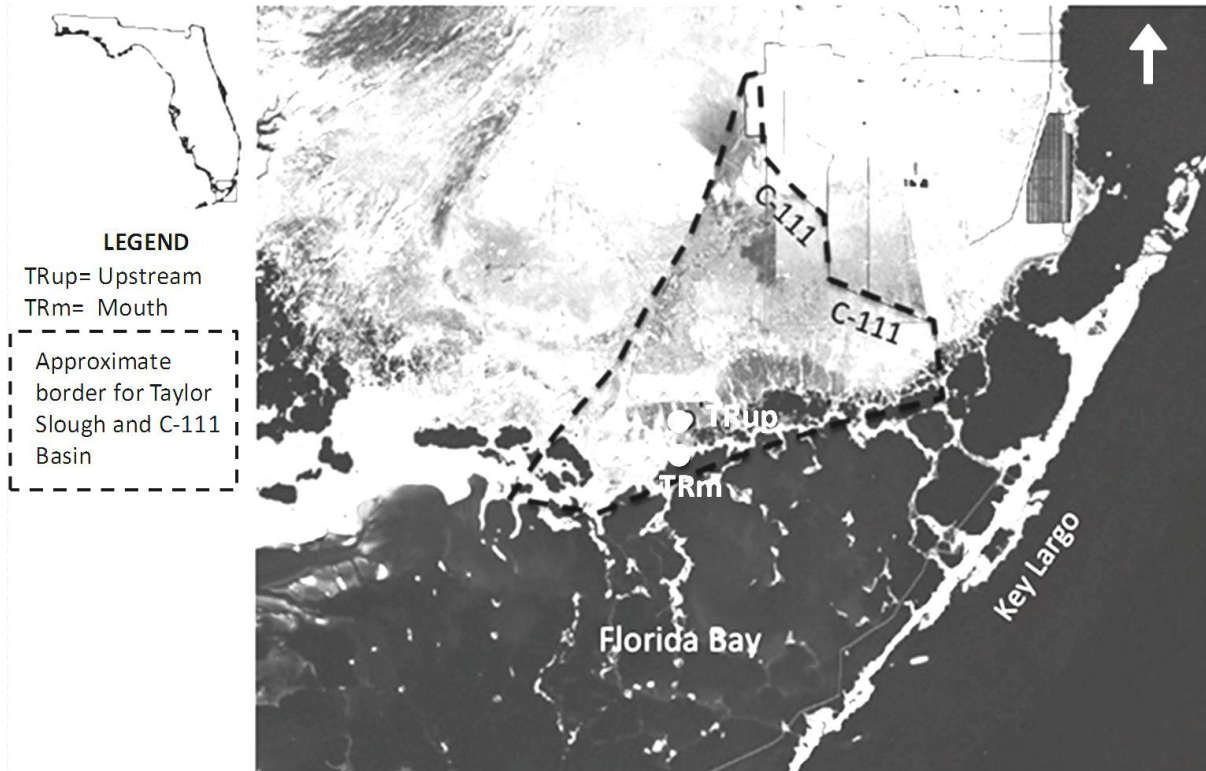
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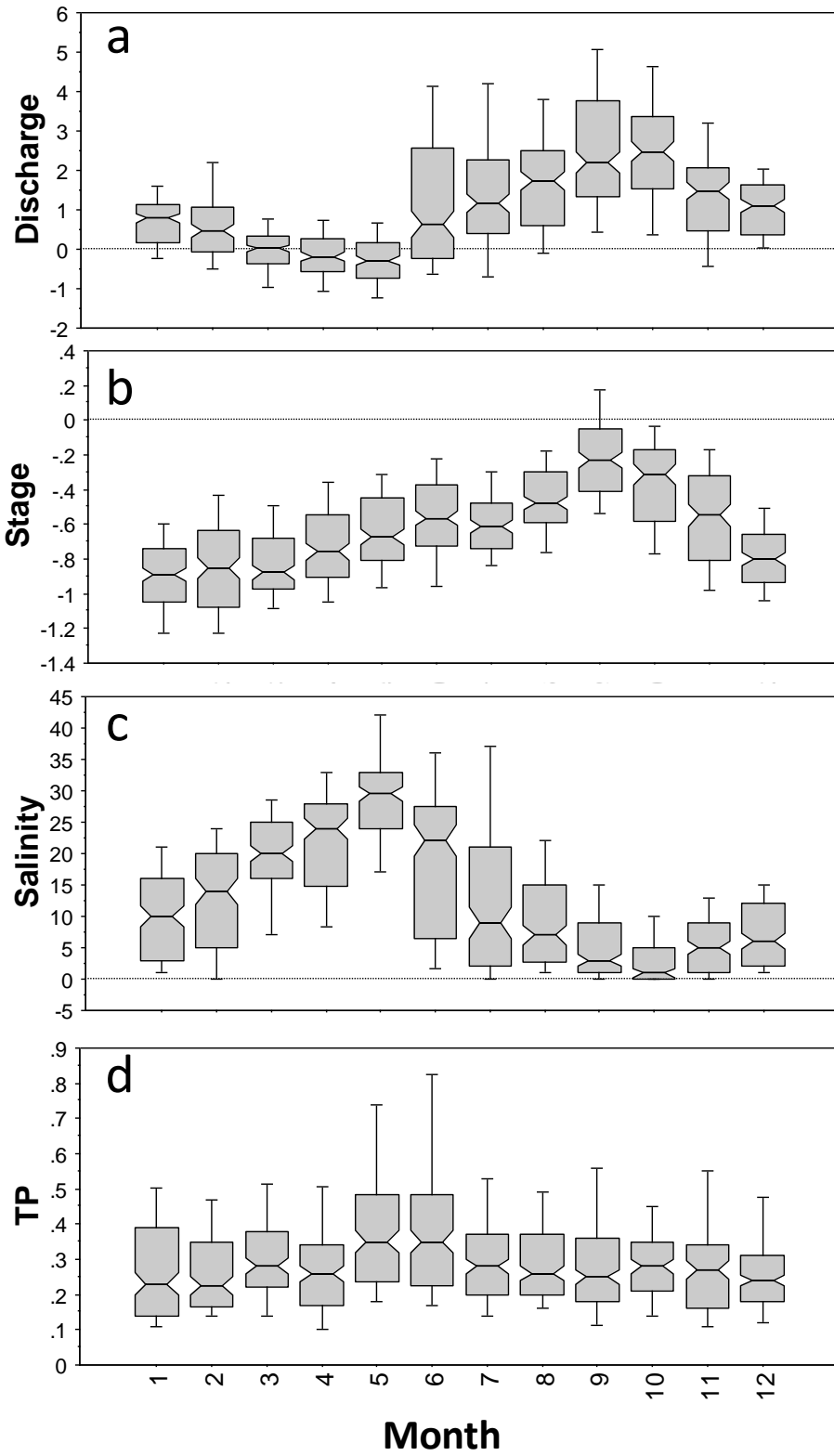
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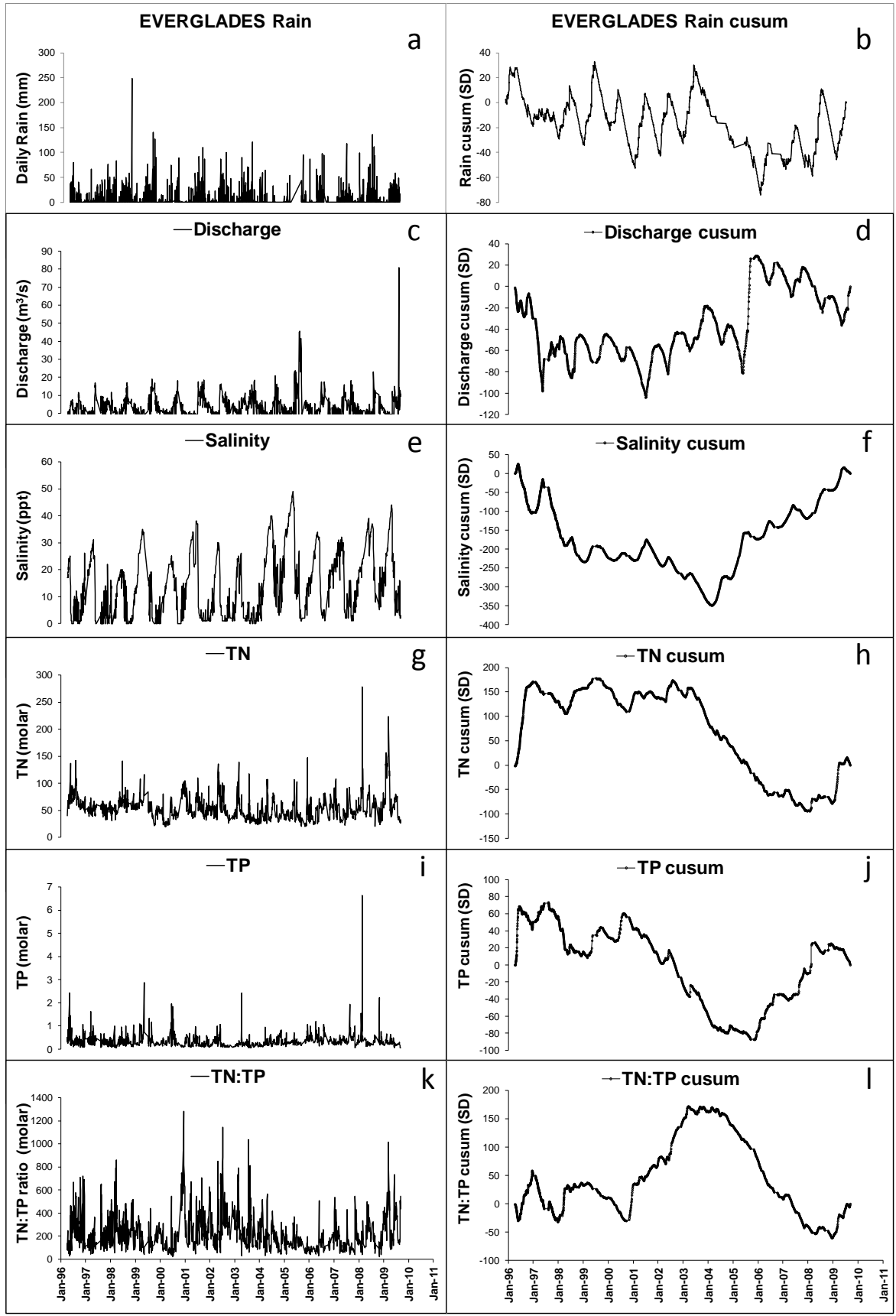
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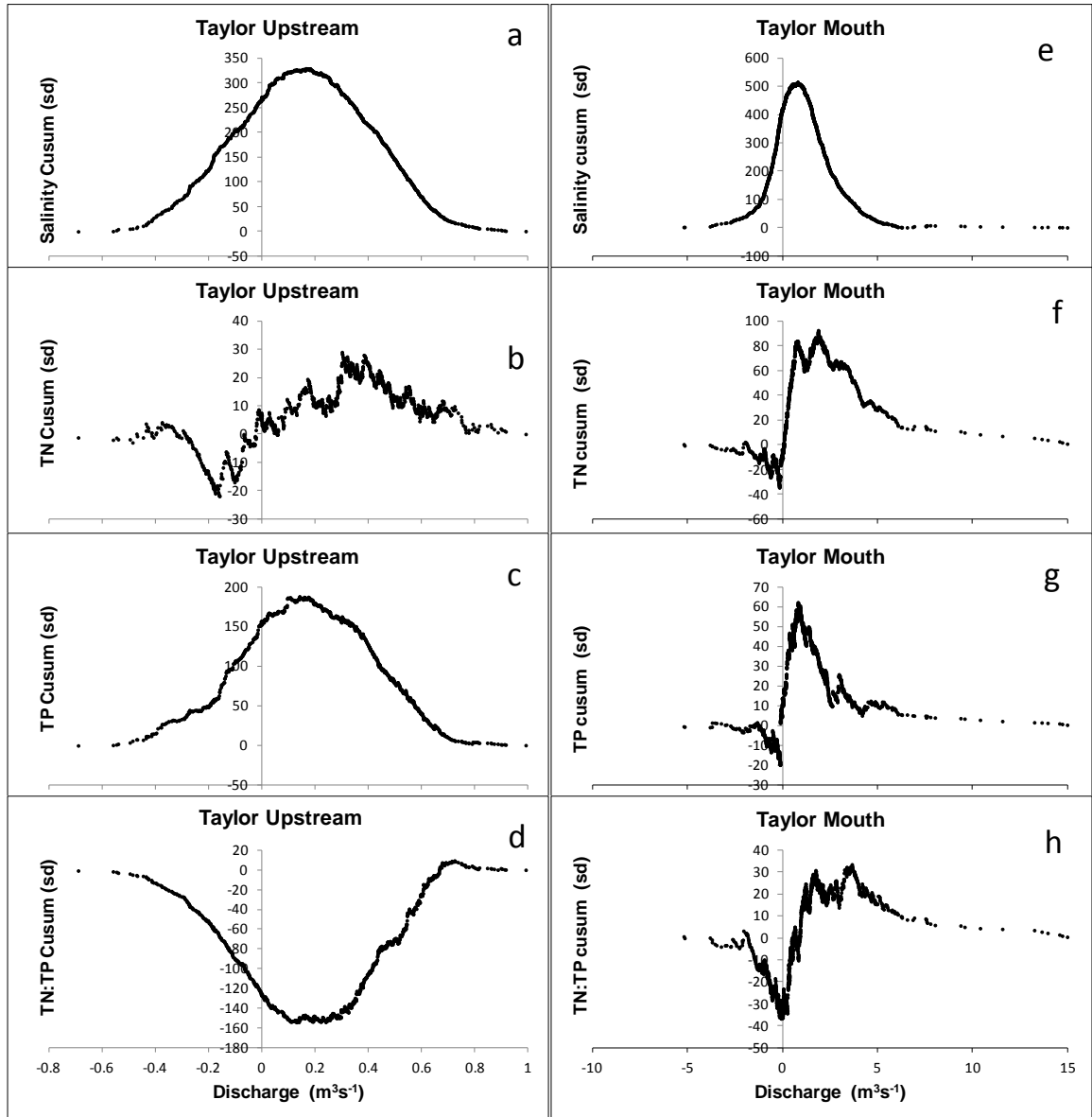
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1 Table 1: Basic statistics for relevant parameters at Taylor Mouth and Upstream Taylor  
 2 Stations. Units: TP and TN in uM; TN:TP in molar ratio; Salinity in ppt; Stage in m; and  
 3 Discharge in cfs.

4

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

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

5

6

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

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

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