CRITICAL ECOSYSTEMS SCIENCE INITIATIVE

Year 2 Interim Project Report

And

Final Project Report for:

Cooperative Agreement #H5284-05-0015

Submitted to:

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By

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Introduction and Objectives

Taylor Slough and the C-111 Basin represent significant contributors to water delivered to the freshwater and estuarine portions of eastern Everglades National Park (ENP). These drainages, and the downstream mangrove estuaries that form the northern shore of Florida Bay, collectively often referred to as the Southern Everglades, will be the site of significant hydrological changes as a result of the upcoming restoration activities. Most of the major environmental issues associated with the Southern Everglades and Florida Bay focus on three key parameters: hydroperiod, marsh water quality, and bay salinity. All are intimately tied to water delivery to Taylor Slough, the C-111 Basin and the Rocky Glades. This project was designed to address the need for monitoring and adaptive assessment of key environmental variables (nutrient levels, salinity regime, plant productivity) in the Greater Taylor Slough and C-111 Basin drainages during the restoration of the Southern Everglades. This Year 2 Report fulfills an annual obligation to the Critical Ecosystems Science Initiative (CESI) funding (COTAR: Mike Zimmerman) program to Everglades National Park. Some of this additional monitoring is continuing under South Florida Water Management District (SFWMD) funding for this long-term monitoring program.

In making decisions about restoration activities, it is important that ENP understands how changes in the quantity, timing, and quality of water delivery will affect Southern Everglades wetlands and the Florida Bay estuary. This integrated monitoring and science program continues to address questions relating to how hydrologic restoration impacts ecosystem dynamics in the entire Southern Everglades--from canal inflows to the Florida Bay shoreline. We accomplished this by integrating ongoing efforts in the ENP Panhandle (active since Fall 1997), in Taylor Slough (active since Summer 1999), and in the mangrove transition zone (active since Spring 1996). This work continues our long-term monitoring of water quality at eighteen marsh sites and four mangrove sites (Table 1). We also continued our long-term monitoring of: 1) rainfall in the freshwater marshes, 2) *Cladium jamaicense* productivity and *Eleocharis* sp. density. Additionally, we also began measuring marsh surface water levels in S332B-1 in late 2005. Much work conducted in the ENP Panhandle, Taylor Slough proper, and the southern Everglades mangrove zone was supported by a cooperative agreement from the SFWMD (Project Manager: Chris Madden) until December 31 2004 and under an additional agreement from October 2005 - October 2006. Since that time, the scope and funding of SFWMD support have been scaled back to basic monitoring of key sites in the C-111 Basin.

The primary goal of this extensive research and monitoring program has been to assess how increased movement of fresh water, nutrients, and organic matter from the S-332/S-332B and S-332D structures will affect the freshwater and mangrove wetlands of the Southern Everglades. Addressing these goals involves quantifying ecosystem processes and environmental controls that influenced water, mass, and nutrient exchange between canal inputs, freshwater wetlands, estuarine wetlands, and Florida Bay. The ecosystem-level interactions we continue to quanty in this monitoring and research are conceptualized below. We organized the research program into three components:

1. monitoring water quality dynamics in Southern Everglades watersheds;
2. quantifying responses of marsh ecosystem structure to changes in water management; and
3. quantifying responses of marsh ecosystem function to changes in water management.

This cooperative agreement focused on the following main tasks: 1) continuing to quantify water quality at the S-332B primary [west] retention pond outfall when surface water was

present; and 2) continuing to quantify water quality, when surface water was present, along a six site transect down Taylor Slough anchored at the S-332D site and extending to the mouth of Taylor River at Little Madeira Bay (Table 1, Fig. 1).

Site	**Monitoring parameters**						
Taylor Slough drainage	TN & TP	DIN & DOC	Salinity	H_2O level	Rainfall	ANPP	*Eleocharis* density
S332B-1	2a	2b		3	4		
S332B-2	2a	2b					
S332D (TS/Ph 1)	5a	5b		8	9	10	
S332	5a	5b					
MPR (TS/Ph 2)	5a	5b		8	9	10	
UE						10	
ME				8		10	
LC (TS/Ph 3)	5a	5b		8	9	10	13
AH (TS/Ph 6)*	6a	6b&c	6c,7			10	13
TM (TS/Ph 7)*	6a	6b&c	6c.7				
C-111 Basin drainage						12	
W1 (TS/Ph 4)	14a	14b		21	19	23	
W2 (TS/Ph 5)	14a	14b		21	19	23	
W3	14a	14b		21		23	
W4							25
E1	15a	15b				23	
E2	15a	15b				23	
Triangle (USC 1-3)	17	17		22	20	24	
N1	16a	16b		22	20	24	
N2	16a	16b				24	
N3	16a	16b		22		24	
N4	16a	16b				24	
JB*	18a	18c,d	18b				
TC*	18a	18c,d	18b				

Table 1. List of the sites monitored and the data collected for each site. The mangrove sites are marked with asterisks (*). Numbers within each cell correspond to the Figure showing the data.

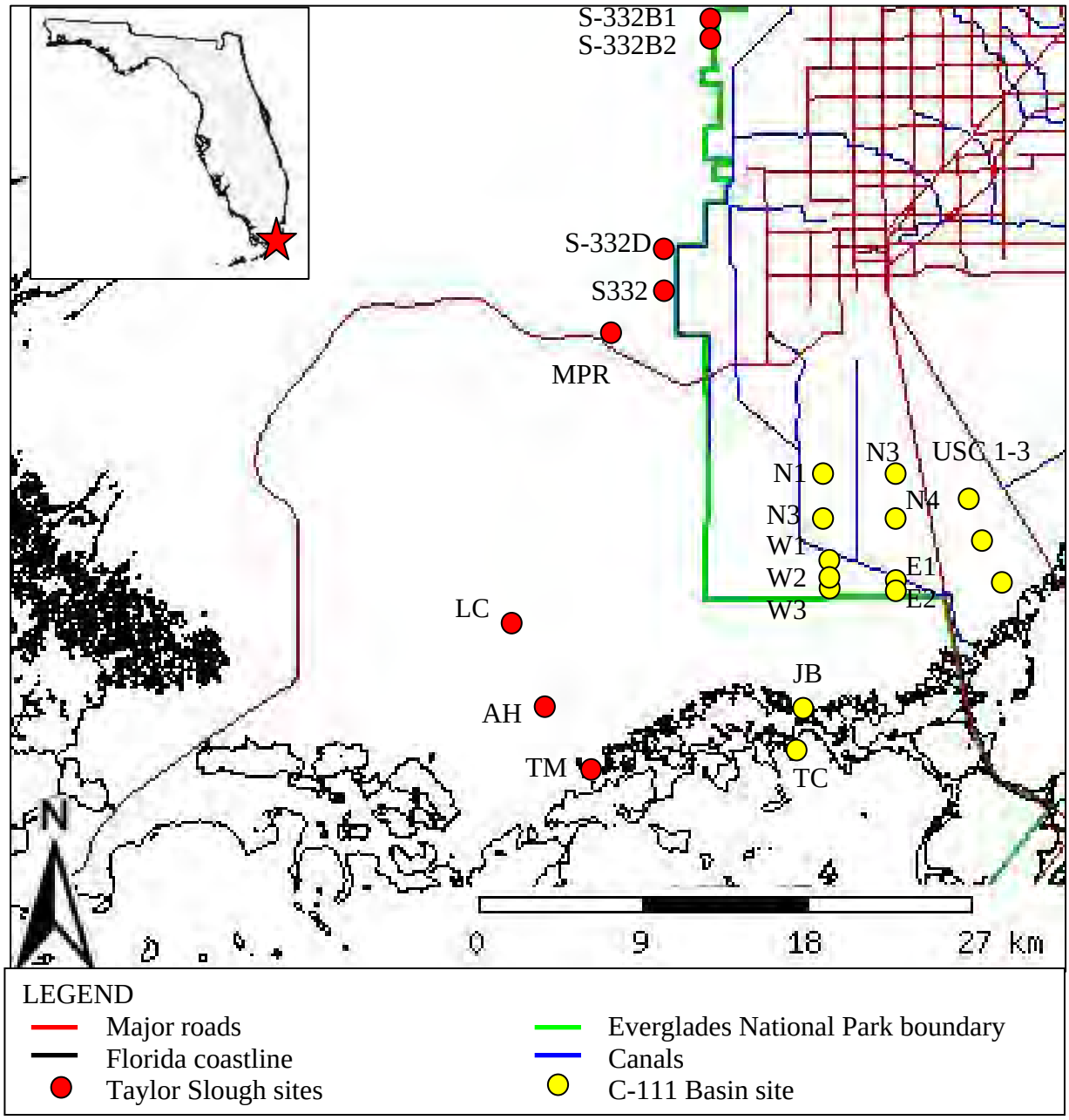

Figure 1. Map of Florida (inset) indicating the location of Everglades National Park (★). The map shows sites monitored along Taylor Slough and the C-111 Basin.

S332B Monitoring

1. **Water Quality**

In May 2003, we installed two new water quality stations in the ENP marshes just west and southwest of the S332B primary [west] retention pond overflow weir (hereafter referred to as S332B-1 and S332B-2, respectively). The S332B-1 site is approximately 10 m west of the concrete weir, towards its southern extent. The S332B-2 is approximately 300 m southwest of this first station, in short hydroperiod marshes of ENP. The stations include a rain level gauge at S332B-1. We began collecting surface water samples on May 23 2003.

The wet season in South Florida is from May to November while the dry season extends from November to late-May. In the seasonally flooded ENP marshes, we visit all water quality stations monthly to service equipment and pick up samples until the marsh had effectively gone dry (usually early January). Our sampling scheme involves tri-daily integrated samples that include four 250 ml subsamples collected every 18 hours. This generates a single 1L sample every 3 days that includes water collected roughly at dawn, dusk, noon, and midnight. Each sample is analyzed for salinity, total nitrogen (TN), and total phosphorus (TP). Every month, when the autosamplers are emptied, we also collect a grab sample. Grab samples are immediately placed on ice, filtered in the lab, and are analyzed for the full suite of dissolved inorganic nutrients (ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), soluble reactive phosphorus (SRP)) as well as dissolved organic carbon (DOC), TN, and TP. All analyses are conducted in the SERC Analytical Lab at FIU (which is a FDEP certified lab).

Average TP concentrations at the S332-B sites were lower in 2003 than in the out years (Fig. 2a). In 2005, we observed a pattern of increasing TP concentrations at both sites as the wet season progressed, and TP concentrations in 2006 remained somewhat high. In fact, in 2006 we observed few TP concentrations that were typically below the 0.2 µM (6.2 ppb) that typified the previous 3 years (Fig. 2a). The elevated TP levels we observed in 2003 and 2004 were storm related, as the observations were preceded 24-48 hours by either rainfall of over 2.5 cm/day and/or wind gusts of 35-72 km/hr (daily average: 15-40 km/hr). Higher concentrations in late 2005 and throughout 2006 could not be related to short-term rain events.

Total N concentrations were lower and less variable at both sites except in 2005, when we observed several high concentration events early in the wet season (Fig. 2a). Specifically, in 2005, there was an early wet season spike at S332B-2 where TN exceeded 60 µM on two days and 100 µM during a single event. Overall, though, there is a suggestion in these data of gradually declining TN concentrations from 2003 to 2006. Notably, however, both ammonium and nitrate concentrations (Fig. 2b) showed an increasing trend during this time that resembles the TP trend. Concentrations of NH_4^+ were higher than is typical for oligotrophic ENP marshes. Note: Soluble reactive P (SRP) concentrations were not presented here because they were nearly always very low (<0.05 µM) and were often near analytical detection (0.01µM).

To determine when surface water actually flowed from the S332B retention pond into ENP, we installed an acoustic water level gauge at the S332B-1 site that was surveyed to the fixed crest weir. The gauge became operational on October 4th 2005 (Fig. 3). Water level ranged from about 40-53 cm between October to mid December but declined sharply in late December, indicating that surface water was no longer entering the retention pond as

overflow from the concrete weir (Fig. 3). The marsh was completely dry by mid February, but was re-inundated during 2 high water overflow events very early in the 2006 wet season. Interestingly, water levels at S332B-1 after this time suggested little or no weir overflow through the rest of the 2006 wet season (Fig. 3).

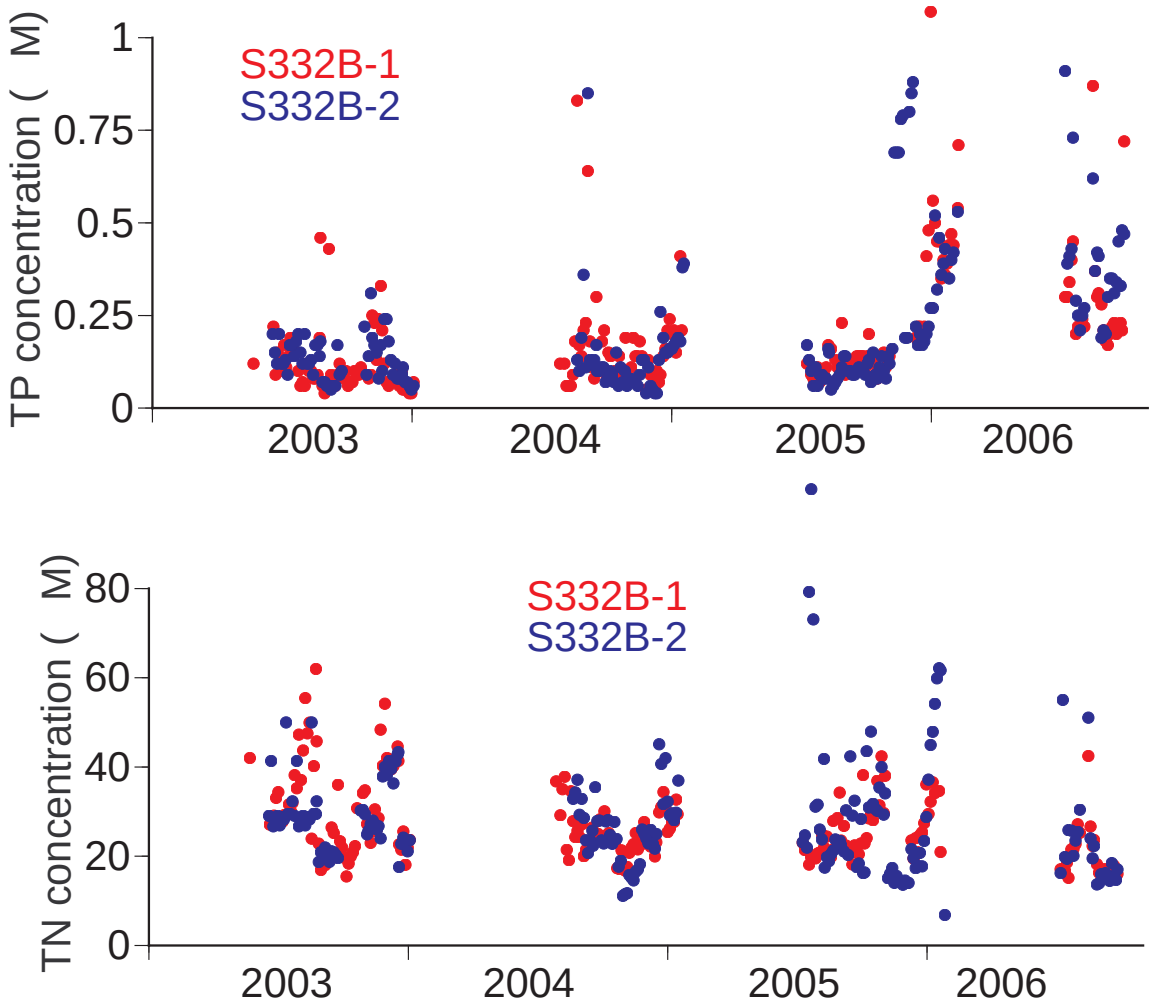

Figure 2a. Continuous water quality data from the two S332B marsh sites. The S332B-1 site is ~5 m west of the fixed crest weir overflow along the western boundary of the main S332B retention pond. S332B-2 is approximately 300 m SW of S332B-1 (1 µM TP = 31 ppb, 1 µM TN = 14 ppb).

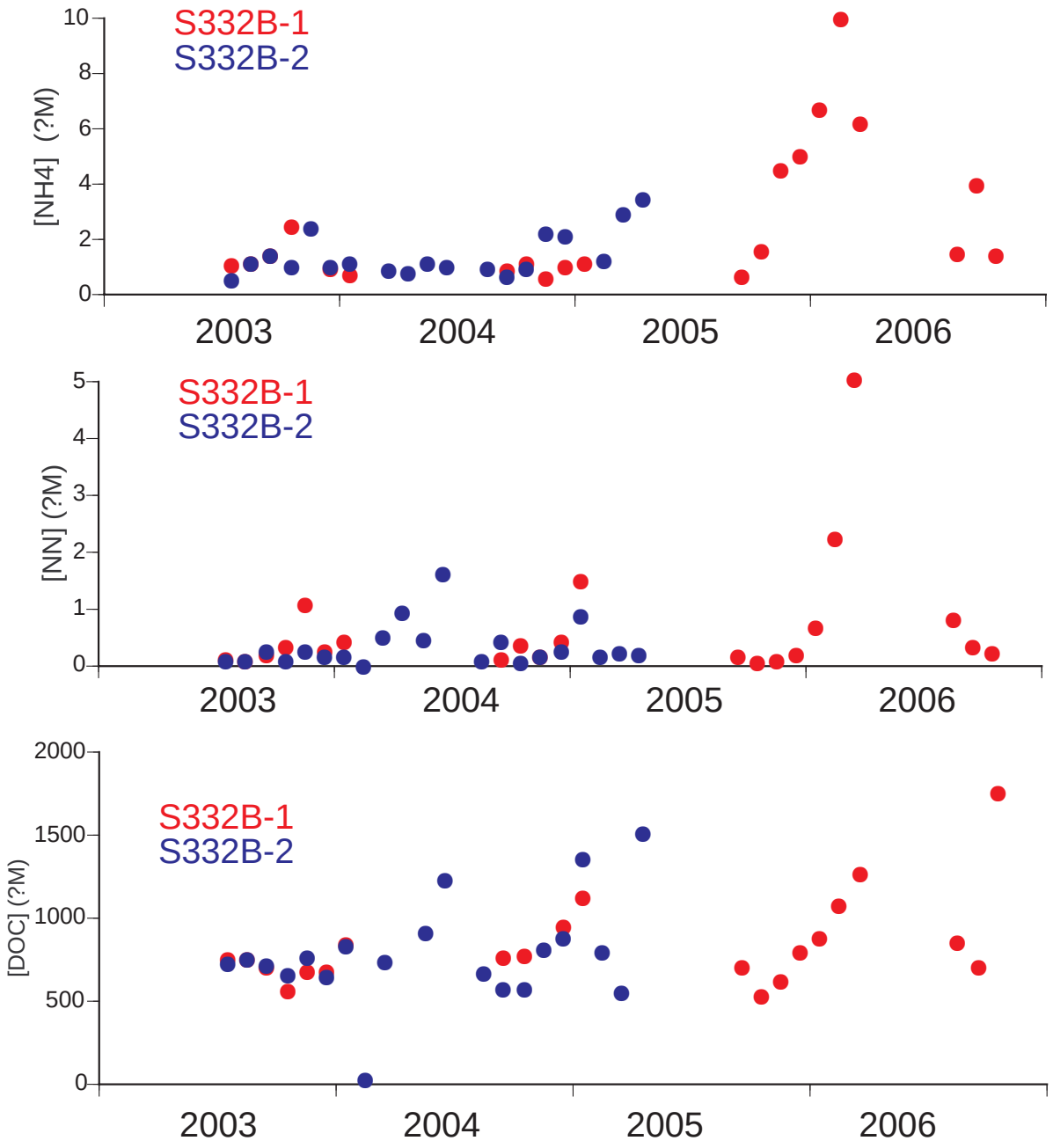

Figure 2b. Dissolved N concentrations from monthly grab samples at the S332B-1 and S332B-2 sites in upper Taylor Slough (note that 1 µM C = 12 ppb and 1 µM N = 14 ppb).

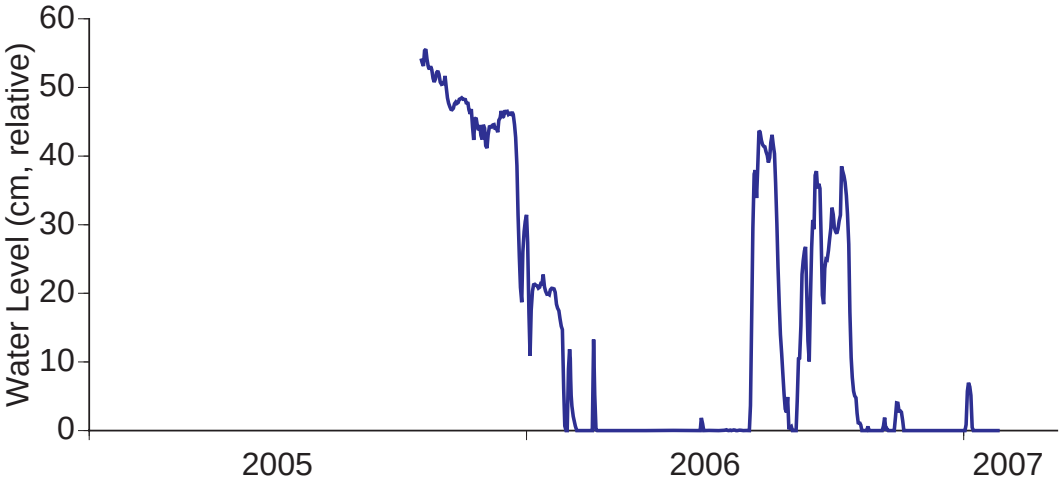

Figure 3. Surface water level at S332B-1. The water level gauge became operational on October 4th 2005.

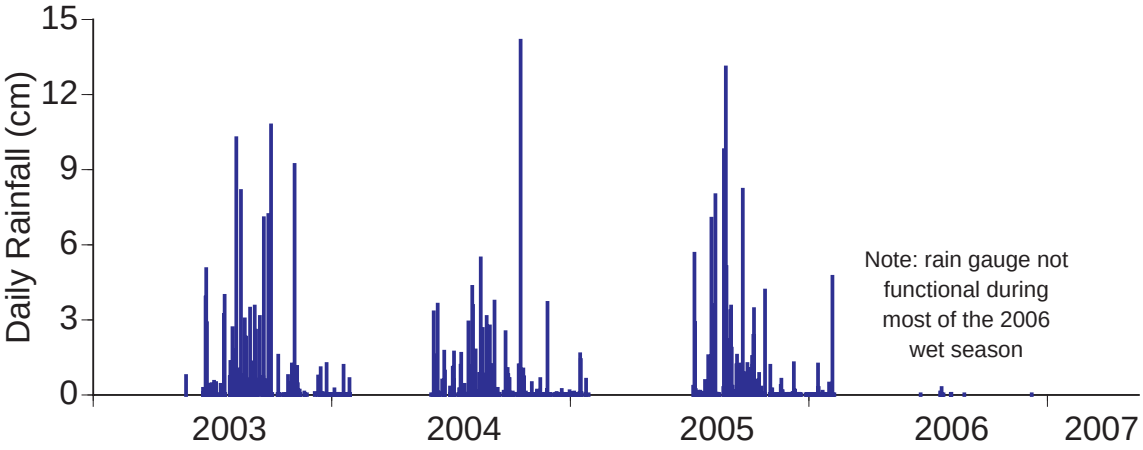

Figure 4. Daily rainfall at S332B-1 from 2003-2006.

For the three years of rainfall we have on record, 2004 had lower rainfall than either 2003 or 2005. There were two events of heavy rain in excess of 12 cm observed, once in 2004 and again in 2005 (Fig. 4).

SIGNIFICANT FINDINGS—S332B WATER QUALITY

There did not appear to be a consistent pattern of marsh nutrient uptake (P) or release (N and TOC) between the S332B-1 and S332B-2 sites. With over four years of nutrient data however, we begin to see some trends and patterns. From 2003 through most of 2005, water quality in the marsh immediately downstream from the S332B retention pond was comparable to other Everglades marshes. However, there were high concentration events in all years, of P and N, that may have been related storm events and quality of surface water inflows. There was also a trend of higher TP concentrations late in the 2005 wet season at both sites that lasted for several months and continued through the 2006 wet season. During the same four year time period TN concentrations appeared to be declining while dissolved inorganic N concentrations showed an increasing trend that resembled TP concentrations. Phosphorus inputs well in excess of 0.3 µM (10 ppb) may affect periphyton structure and dynamics in these freshwater marshes, and over longer time periods may be responsible for increasing soil nutrient content and, perhaps, changes in the emergent vegetation community. We are now monitoring water levels continuously at our site immediately downstream from the retention pond outfall weir. These data demonstrate the value of long-term monitoring to formulating an accurate assessment of the patterns and dynamics of the nutrient inputs, and the trajectory of ecosystem response to these inputs.

Taylor Slough Hydrologic Basin

1. Water quality and Hydrology

Water quality was continuously monitored at our S-332D, S-332, MPR, LC, AH, and TM sites in Taylor Slough (Fig. 1). These sites were sampled through 2004 and from October 2005 – October 2006 with funding from SFWMD (Chris Madden, Project Manager). When that funding expired in December 2004, sampling was continued with funds from this Cooperative Agreement. We also collected a grab sample every month, when autosamplers were serviced, and these samples were analyzed for the full suite of dissolved and total C, N, and P nutrients. We collected rain event water samples at all sites instrumented with rain gauges. All samples were analyzed for the full suite of dissolved and total C, N, and P nutrients. For detailed methods, see Childers et al. (2006a).

At our freshwater sites in Taylor Slough, the canalside water quality sites (S-332D and S-332) typically showed higher TP concentrations than did the MPR site during the wet season (May-Nov) (Fig. 5a). Total P concentrations down slough at the upper estuarine ecotone LC site were also always low (Fig. 5a). The marsh dried down during the dry season (Nov-May) for most years sampled, although we were able to sample all sites during the unusual El Niño dry season of 2003 (Fig. 5a; Childers et al. 2006a). High P events (where TP > 1.0 µM (31 ppb)) occurred every year in our 8 year record except 2000 and 2006 (Fig. 5a). There did not appear to be a seasonal pattern to when these high TP events occurred, and no apparent geographic rationale for them either.

Total N concentrations were usually below about 75 µM. However, there have been episodes of TN > 100 µM (Fig. 5a). These spikes did not appear to be consistent across sites or years, however, and none were observed in 2005 or 2006. In these years, however, there were several months with relatively high NH_4^+ concentrations, but NN concentrations were relatively consistent through the 2001-2007 period of record (Fig. 5b). We observed extremely high TN concentrations at the end of the 1999 wet season (January and February 2000) at S332, immediately after the pump structure was permanently shut down. It is likely that these two events were somehow related. From 1999-2001, TN at S332 was consistently higher relative to all other sites. We observed a significant decline in TN starting in 2000 at the S332 site (estimated TN decline of 15 µM yr^{-1} (210 ppb); $r^2 = 0.30$) but not at the S332-D site, suggesting that elimination of pumped inflows via the S332 in favor of overbank inflows near our S332-D site may have helped water quality in upper Taylor Slough. The high TN at LC in early 2004 coincided with the rewetting event at the onset of the wet season. It is not clear why this phenomenon only occurred at this site and only in 2004, although 2004 was a relatively dry year.

We were able to sample water quality at all four freshwater Taylor Slough sites through the 2003 dry season, with the exception of a brief interruption at LC—when the marsh was dry (Fig. 5). This is because of the moderate El Niño event (ENSO) that occurred in 2002-03. Childers et al. (2006a) showed that ENSO events tend to coincide with dryer wet seasons and wetter dry seasons, which results in a loss of the seasonality in precipitation that is typical of the south Florida climate. Because of the 2002-03 ENSO event, Taylor Slough marshes did not dry down during the 2003 dry season. Although the marshes did not dry down, the overlying water did get quite shallow and flow was minimal. During this period of low, relatively stagnant water, we observed higher TP concentrations at most sites but TN remained relatively low (Fig. 5a).

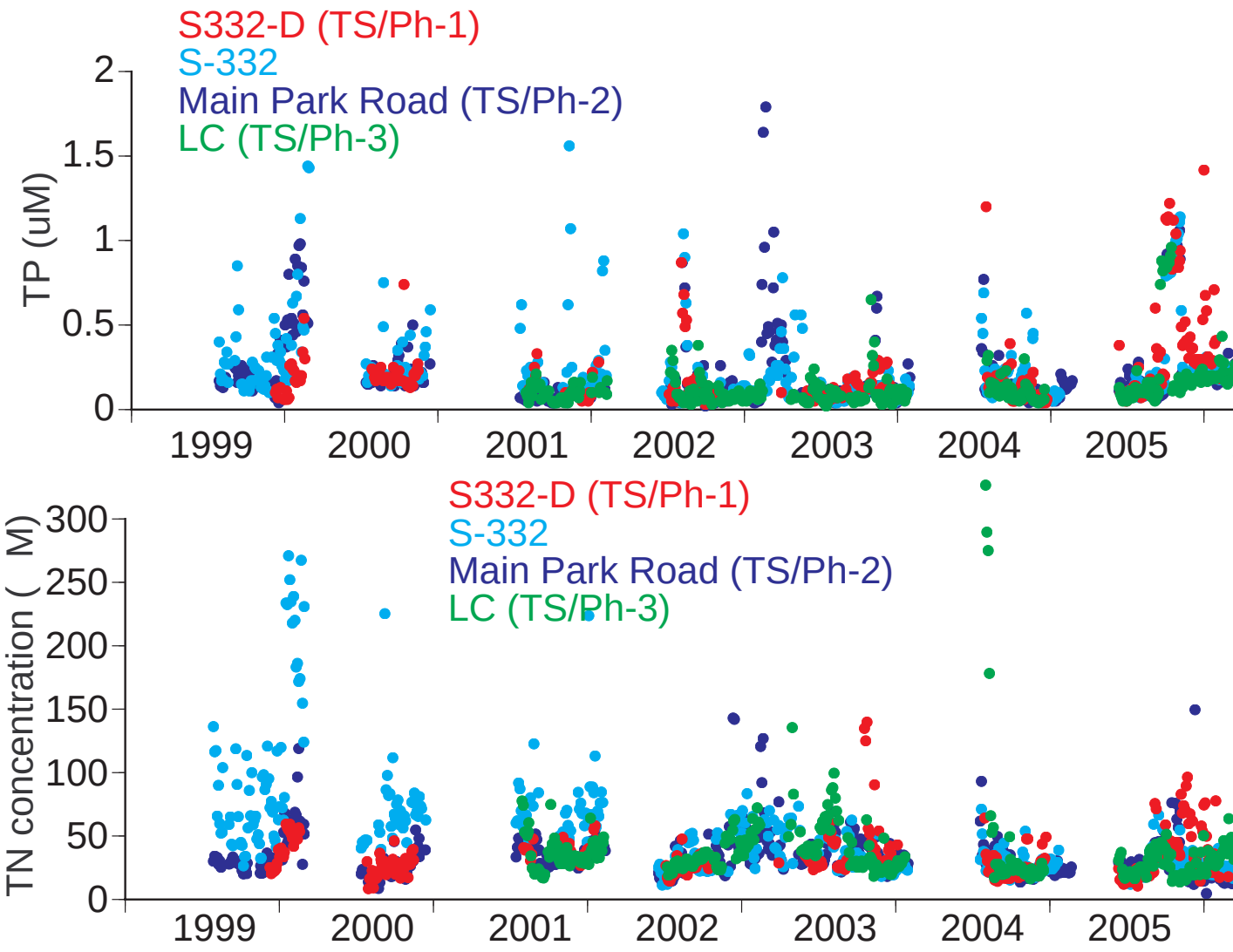

Figure 5a. Total nutrient concentrations at freshwater sites along the Taylor Slough transect for the period of record (1 µM TP = 31 ppb and 1 µM TN = 14 ppb).

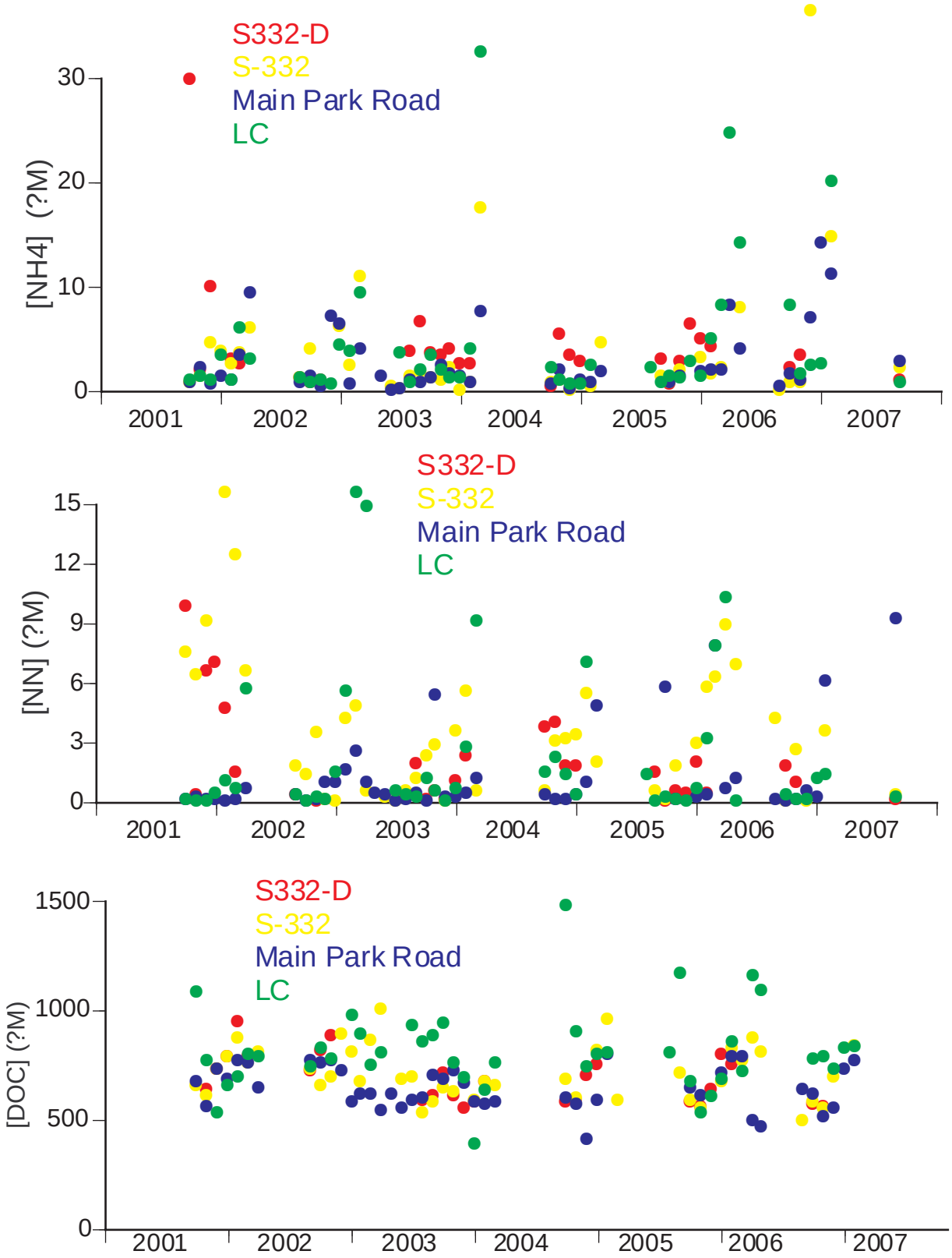

Figure 5b. Dissolved N concentrations from monthly grab samples at the S332D, S332, Main Park Road, and LC sites in Taylor Slough (note that 1 µM C = 12 ppb and 1 µM N = 14 ppb).

Our estuarine water quality program in Taylor Slough includes 2 sites (AH and TM). Phosphorus concentrations were generally <0.3 µM (10 ppb) at all sites, but higher values have regularly occurred in our 12 year dataset—particularly during the dry season when the estuarine influence is greatest and water residence times in the system are longer (Fig. 6a). Spikes in TP concentration to about 1 µM (31 ppb) occurred regularly at both sites, while values exceeding 2 µM (62 ppb) were less frequent. On an annual basis, mean and median TP concentrations were higher at the AH site compared with the TM site for most of the 12 years (Fig. 6a).

Concentrations of TN were similar at the estuarine sites, compared with the freshwater marsh sites in Taylor Slough, but rarely showed the very high TN concentrations seen up-basin (Fig. 6a). Ammonium and NN concentrations were roughly half those observed at the upstream sites (Fig. 6b), however, while DOC concentrations were considerably higher in the mangrove zone (Fig. 6c). Unlike with TP, there is no apparent wet/dry season pattern in the mangrove TN concentrations (Fig. 6). We did find a significant temporal decline in TN at both sites from 1996 to 2007, though, with the stronger concentration decrease at AH. Annual mean and median TN concentrations were higher at AH compared with TM for most of the years sampled.

Salinity patterns at the southern Everglades estuarine mangrove sites showed clear annual patterns, with lowest values during the wet season at AH (Figs. 6c & 7). We observed protracted hypersalinity events in 2001, 2004, and 2005 at both sites. These dry season hypersaline values coincided with low rainfall during the wet season that decreased freshwater flow from upstream. During the 2002-2003 ENSO year, increased dry season rainfall maintained salinity levels below 30 ppt during the dry season at both sites. In 2005, a second successive year of lower than normal rainfall resulted in several month of hypersalinity at both sites, with maximum values exceeding 50 psu during the late dry season. These hypersaline conditions have since been ameliorated by normal wet season rainfall—consequently dry season 2006 and 2007 values only reached a maximum of about ~32 ppt (Figs. 6c & 7).

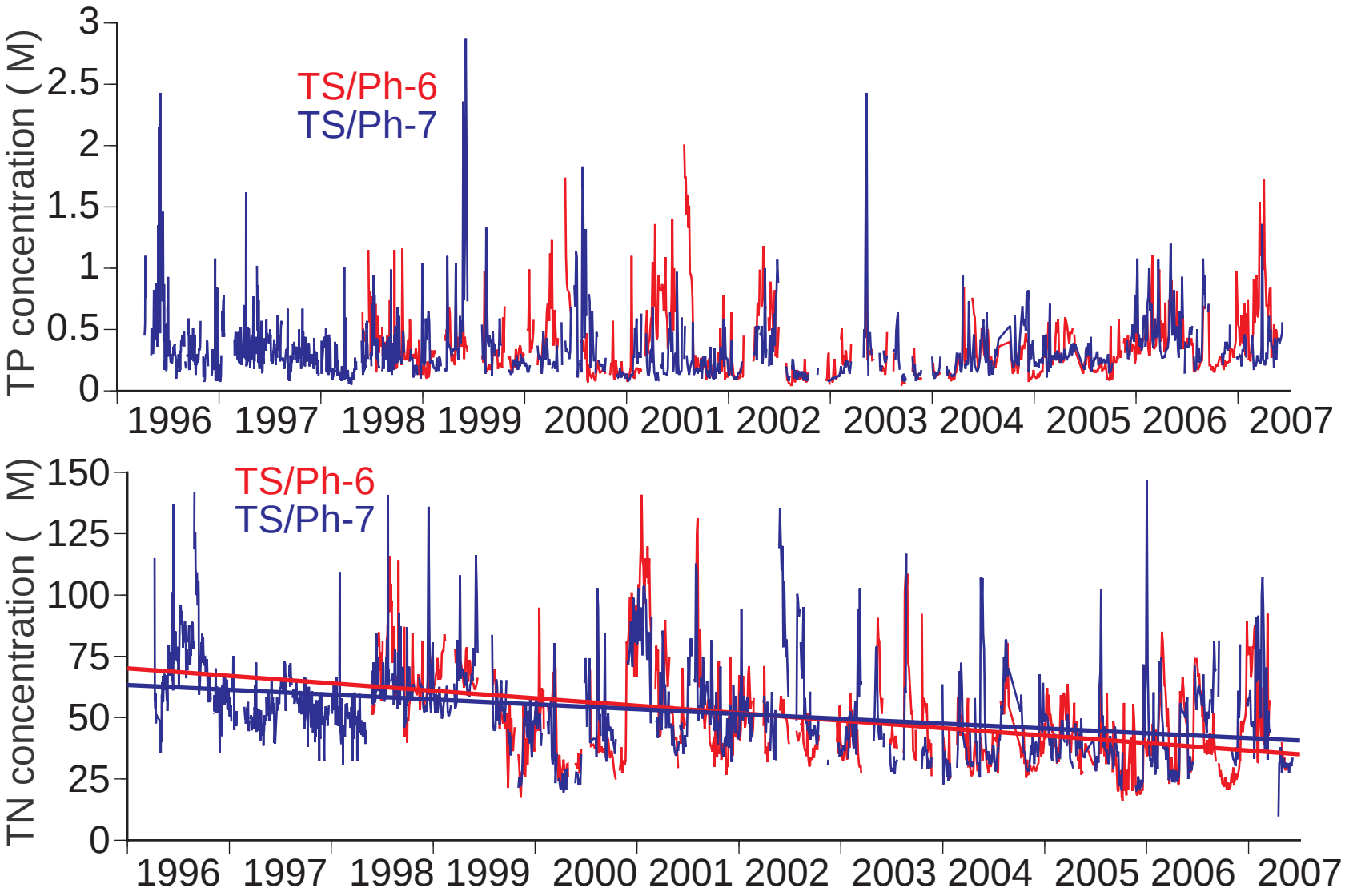

Figure 6a. Total nutrient concentrations at the Argyll Henry (AH = TS/ Ph 6) and Taylor Mouth (TM = TS/Ph 7) mangrove sites along Taylor Slough (note that 1 µM P = 31 ppb and 1 µM N = 14 ppb). Missing data are attributed to autosampler malfunction.

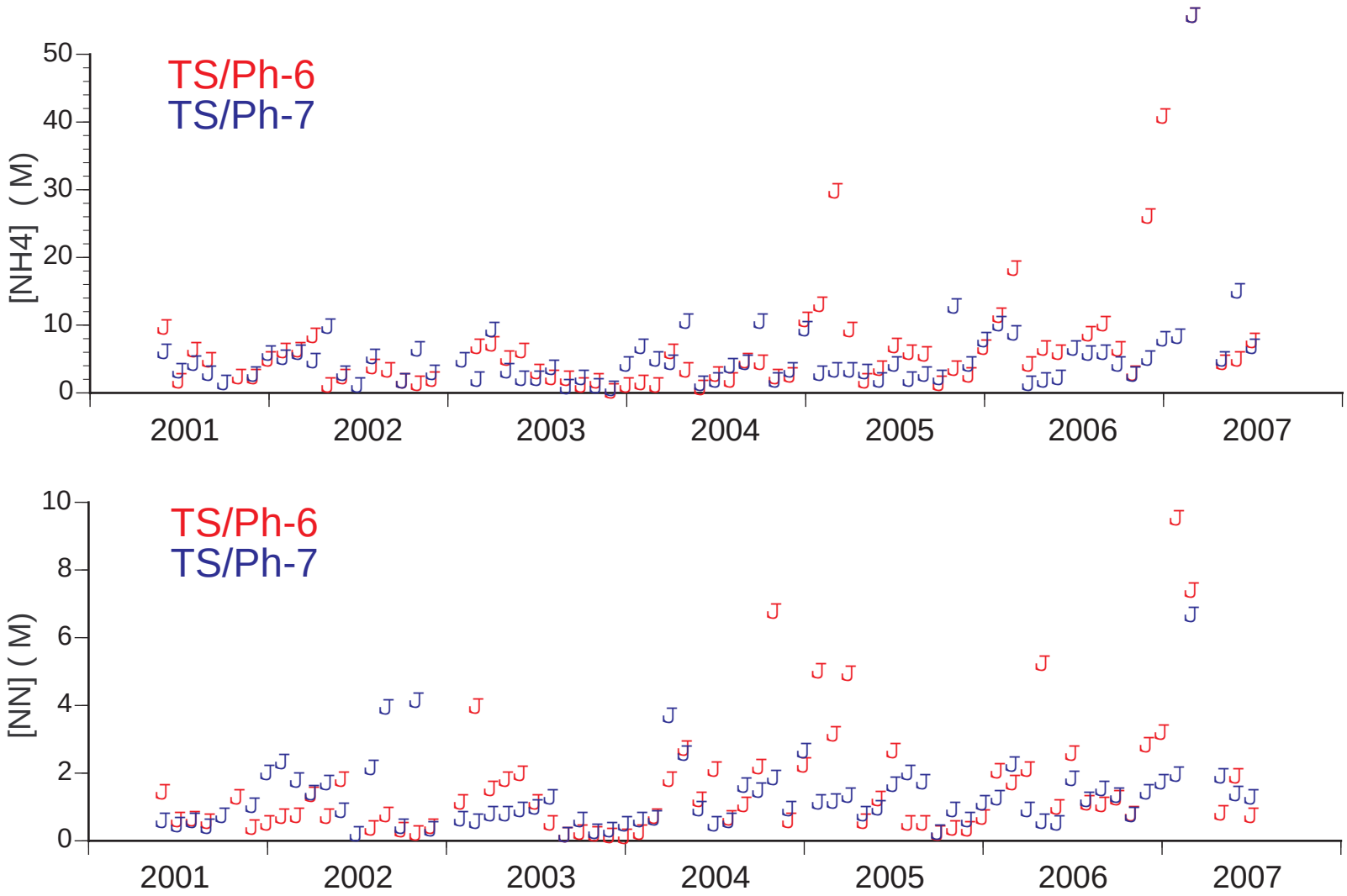

Figure 6b. Dissolved N concentrations from monthly grab samples at the Argyll Henry (AH = TS/ Ph 6) and Taylor Mouth (TM = TS/Ph 7) mangrove sites along Taylor Slough (note that 1 µM P = 31 ppb and 1 µM N = 14 ppb).

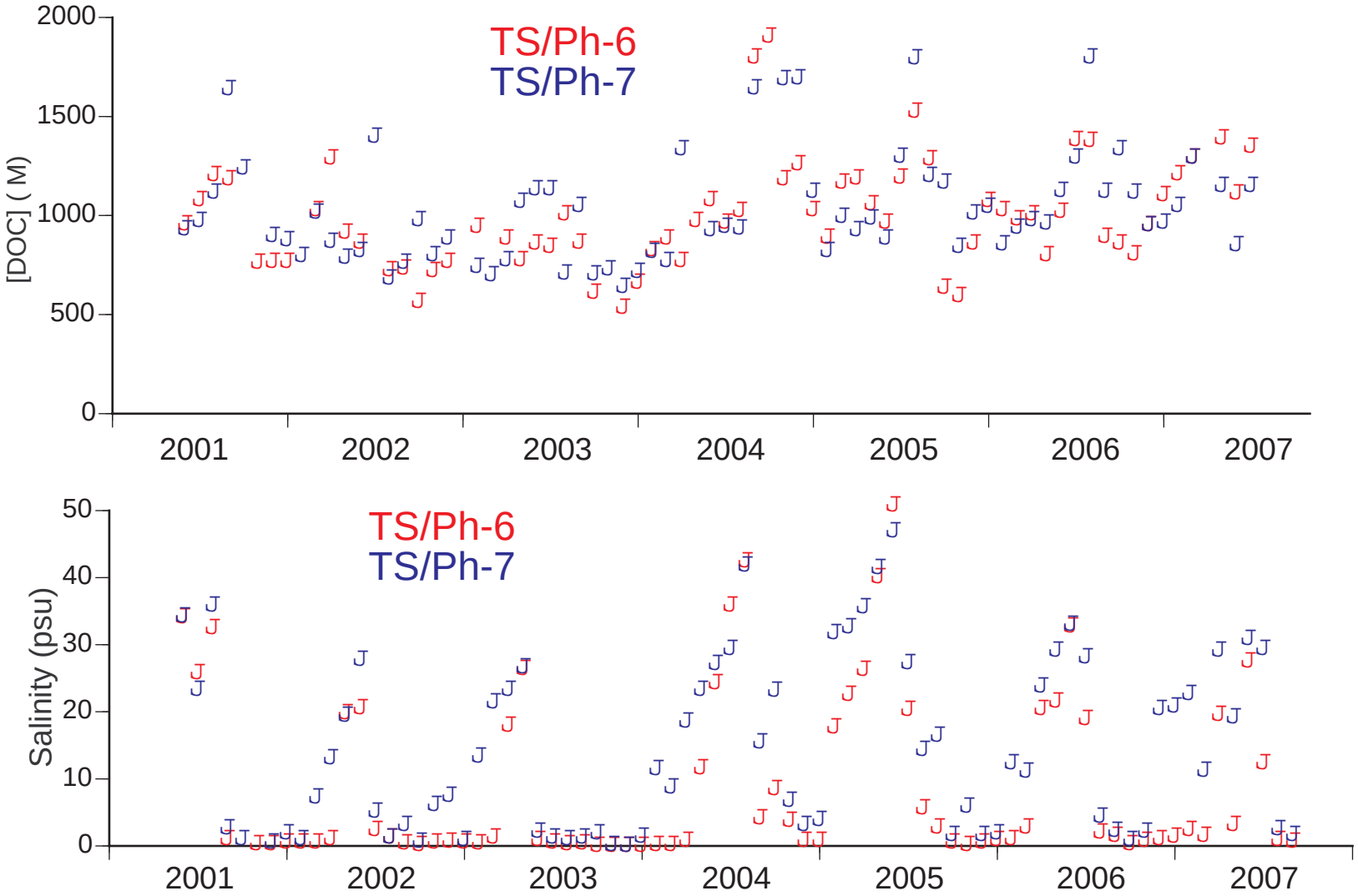

Figure 6c. Dissolved organic carbon concentrations and salinity from monthly grab samples at the Argyll Henry (AH = TS/ Ph 6) and Taylor Mouth (TM = TS/Ph 7) mangrove sites along Taylor Slough (note that 1 µM C = 12 ppb).

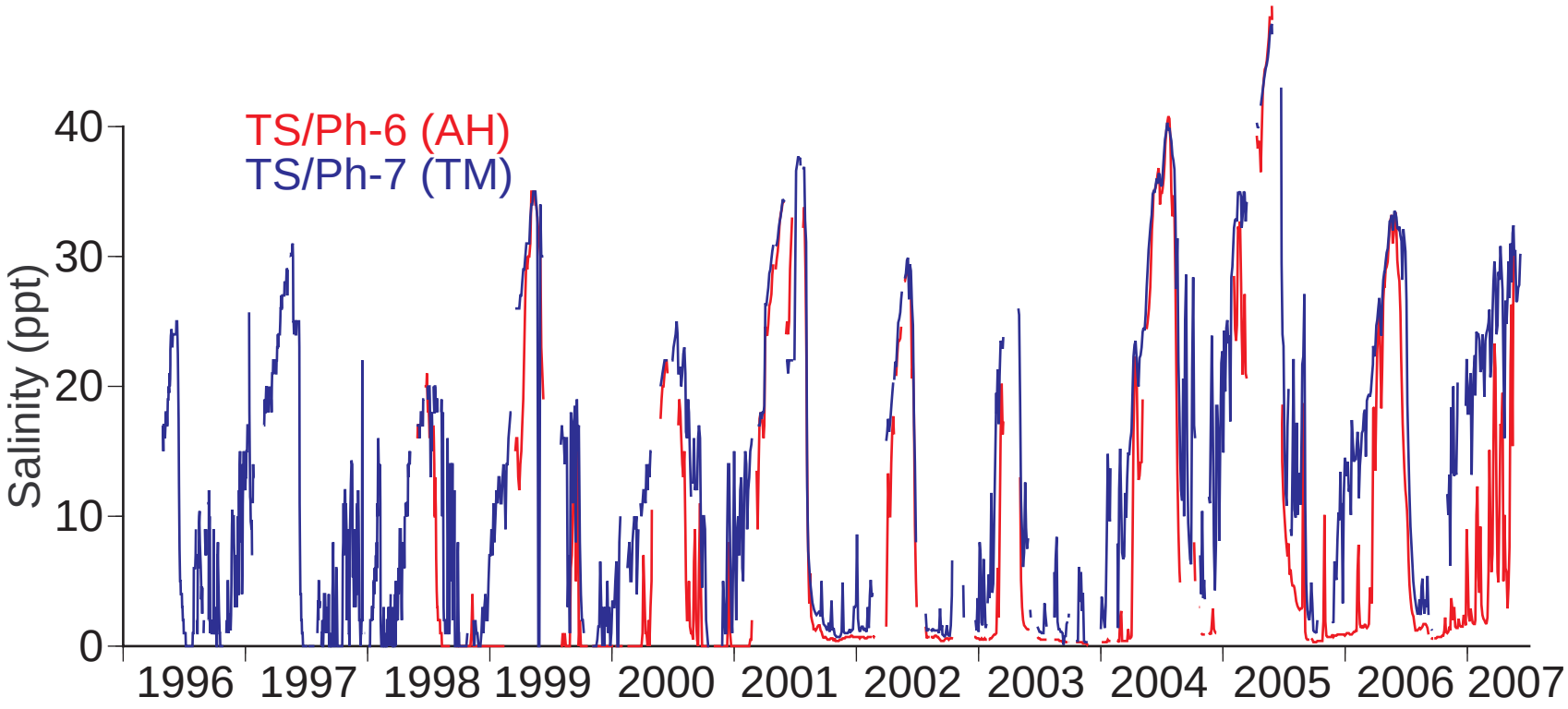

Figure 7. Salinity at mangrove sites along the Taylor Slough transect for the period of record. We started sampling at AH in mid 1998 but at TM since 1996. Missing data are from autosampler malfunctions.

We collected continuous water level data at most water quality sites and, at most autosampler sites, we collected continuous rainfall data. Although neither of these datasets are specifically required by the Cooperative Agreement, we provide the data as part of this annual report. Water level was highest at MPR relative to either ME or LC (Fig. 8). In the 7 years since we began keeping records, water levels clearly showed the unusual inundation patterns seen in El Niño years (2002-03; Fig. 8; Childers et al. 2006a). Water levels steadily declined through the 2002 wet season, which had below average precipitation, then increased steadily through the unusually wet 2003 dry season. In fact, the LC marsh site did not dry down at all during this ENSO event. Rapid declines in water levels at the end of the wet season, in most years, were largely driven by abrupt changes in structure management (Fig. 8)—namely, pump shutdown at the S-332 (pre-2000) and the shift to more diffuse water inflows associated with the S-332D pump. This was particularly evident at the Main Park Road site, which was closest to canal inflows. The interior marsh sites (ME and LC) typically dried down during the late dry season, but the duration of these drydown events varied considerably from year to year (Fig. 8). For example, in 2004 and 2005 (dry years), both MPR and LC remained dry for several months of the year.

We began measuring rainfall at S332-D and MPR in mid-2000 and added LC in mid 2001 (Fig. 9). Three observations emerge from this data. First, rainfall patterns were not consistent across the landscape as high rainfall observed at one sites was not always seen at the other two sites. Second, there are locally high rainfall events exceeding 20 cm/day. For example, in 2003 at LC, we observed several rainfall events of > 10 cm in April, May and November. In fact, on Nov 4th of that year, we observed 27 cm of rainfall not recorded at the other sites. A similar pattern occurred during Hurricane Wilma in late 2005, when precipitation at LC greatly exceeded that observed further up Taylor Slough. Third, the ENSO 2002-2003 year was clearly documented in our rainfall data as there was no apparent dry season that year.

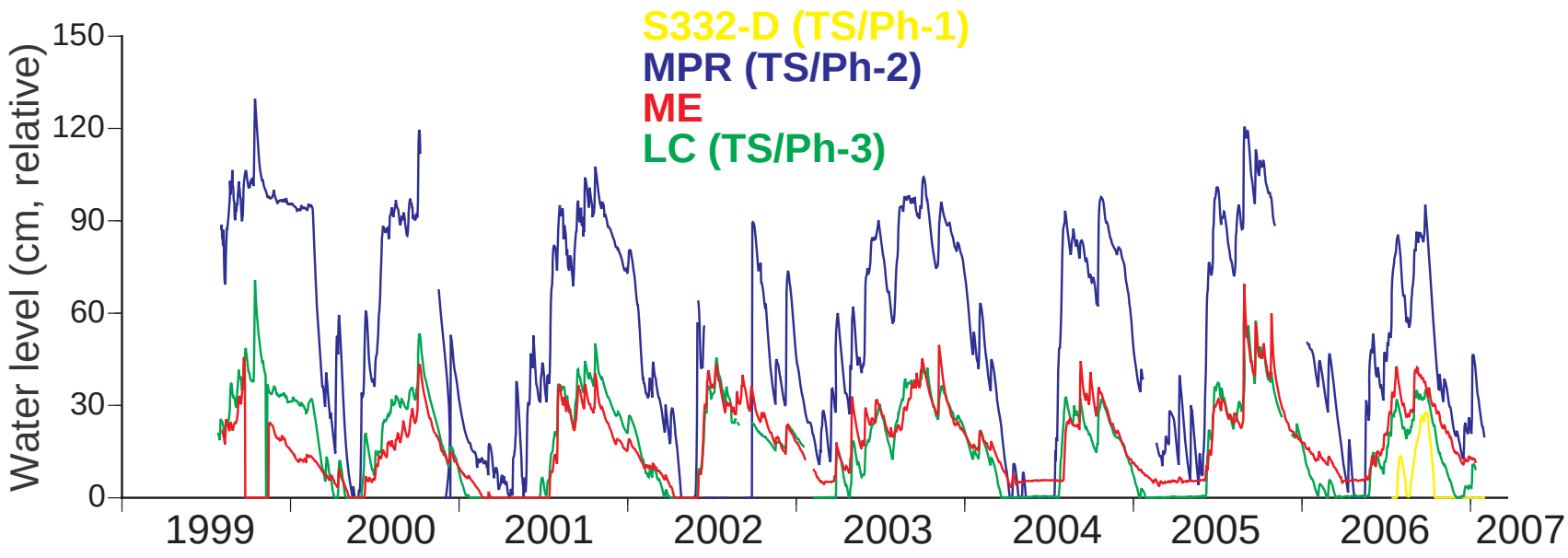

Figure 8. Mean daily water levels from the freshwater sites in Taylor Slough. All water levels are relative to site-specific datums. Missing data from MPR is the result of water level recorder malfunction.

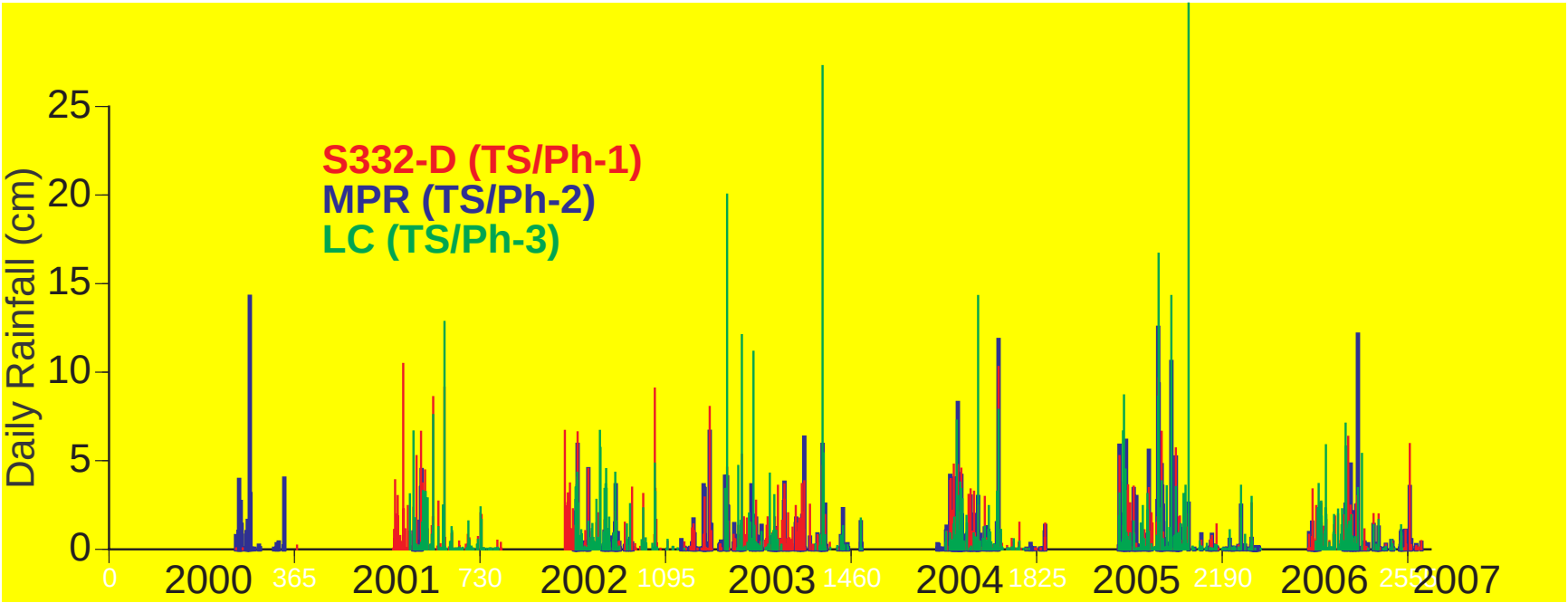

Figure 9. Daily rainfall at three upper marsh sites from 2000-2007.

SIGNIFICANT FINDINGS – TAYLOR SLOUGH WATER QUALITY AND HYDROLOGY

Water management is closely tied to water quality throughout the Everglades. This is particularly true in the southern Everglades, where recent modifications to the Taylor Slough headwaters (e.g. retention ponds) may have affected nutrient concentrations in water entering ENP. Taylor Slough TP data show occasional high concentration peaks, particularly at near-canal sites and particularly in 1999 and 2000. However, long-term mean TP content in Taylor Slough waters is nearly always below 0.3 µM (10 ppb) with the exception of a protracted period of higher TP concentrations during the 2005 wet season (which included 4 hurricanes). Total N levels have been high in upper Taylor Slough waters (≈700 ppb), particularly in water entering ENP marshes from the L-31W canal. This point of water inputs has changed several times over our period of record. Since 1999, we have observed a consistent and significant decline in TN concentrations at our site below the dormant S332 pump. The more passive water inputs, as groundwater seepage and overbank flooding driven by L-31W water levels controlled by S-332D pumping, appear to have resulted in lower N concentrations in water entering Taylor Slough. In 2002 or 2003, S-332D pump waters were diverted to a series of new retention ponds that control L-31W levels more passively. Water inputs to Taylor Slough were enhanced by removal of a low berm along the west L-31W canal just north of the dormant S-332 pump. Our sampling at this inflow point shows periodic high TN concentrations in 2003 and high TP concentrations in 2004, but lower concentrations of both since then.

Marsh water levels in Taylor Slough (MPR, ME, and LC) were controlled by *in situ* rainfall and by management of key structures (namely the S-332 and S-332D pumps). Water level recession into the dry season should be a gradual process, yet in many years water levels dropped precipitously. This was largely a function of abrupt changes in water delivery at the Taylor Slough pumps (water management decisions that have been controlled by IOP and ISOP for much of our period of record). Rapid declines in early dry season water levels are not natural, and lead to abrupt salinity increases in downstream estuarine wetlands. Rapid water level recession may also disrupt dry season faunal activity, including wading bird feeding dynamics. These problems have been somewhat ameliorated by the switch to S332-D detention pond water additions. Abrupt water level shifts were most evident at the Main Park Road (MPR) site, and modifications to this road during our period of data record (expanded bridges and larger culverts, reducing the “damming effect”) appear to have ameliorated these rapid changes somewhat. Finally, our long-term hydrologic dataset included the 2002-03 moderate El Niño event. El Niño events are typically associated with wet dry seasons and dry wet seasons, but with little change in total annual rainfall. Rainfall across the landscape was also quite heterogeneous and did not appear to be consistent over the different sites. Natural shifts in precipitation should be considered when future water management decisions are made for the southern Everglades.

2. Macrophyte Dynamics

We quantified macrophyte species composition and aboveground *Cladium* biomass at all plant quadrats in Taylor Slough (S-332D, UE, UC, UW, ME, MC, MW, LE, LC, LW, and AH). Rates of ANPP were relatively low in Taylor Slough, except at the upper estuarine ecotone (Fig. 10). We found no temporal trend in sawgrass ANPP at site nearest the L31-W canal, suggesting that productivity of this dominant macrophyte has not been stimulated by nutrient inputs from canal inflows. We found no within-transect [hydroperiod] biomass differences among the ME, MC, and MW sites, but did find that biomass at the short hydroperiod UW site was significantly lower than at UC (mid-transect; Fisher's PLSD $p=0.006$) and at UE (the longer hydroperiod site; Fisher's PLSD $p=0.042$). Across all years, biomass at the canalside site (S-332D) was either significantly lower than or not different from biomass at all other sites, with the exception of MW (a short hydroperiod site; Fisher's PLSD $p_{S332D>MW}=0.047$). Based on these data—and because of funding cuts—we terminated macrophyte monitoring at UW, UC, MW, MC, LW, and LE at the end of 2004.

Across all years, the lower transect upper estuarine ecotone sites (LW, LC, and LE) had significantly higher ANPP than the other Taylor Slough sites, with biomass at LC and LW higher than at LE (Fisher's PLSD $p_{LC>LE}=0.03$ and $p_{LW>LE}=0.045$) (Fig. 10). Here, ANPP ranged from 400 – 750 gdw m^{-2} y^{-1}. Aboveground NPP was significantly higher at the LC site that at any other Taylor Slough site except LW (RMANOVA site effect $F_{10,66}=15.81$; $p<0.0001$; Fisher's PLSD $p<0.03$ for all comparisons). Production at the upper and middle transects and at the S-332D canalside site was low, statistically similar, and temporally consistent, ranging from 200 – 350 gdw m^{-2} y^{-1} (Fig**.** 10).

We observed the most dramatic inter-annual variation in ANPP at the lower ecotone AH site, where production was significantly higher than all sites except those of the upper ecotone transect and the UC site (Fig. 10; Fisher's PLSD $p<0.008$). When we compared this pattern with surface water salinity at AH, we found ANPP responded negatively to higher average salinity, peak salinity, and number of days with measurable salinity (Fig. 11; Childers et al. 2006b). Sawgrass ANPP was highest in 2000, when all three measures of salinity were relatively low. In 2001, the lowest ANPP rates coincided with the highest annual average salinity (17.7 psu), (Fig. 11). All three salinity measures decreased through 2002 and 2003. Sawgrass ANPP increased somewhat during this time, but did not recover to pre-2001 levels (Fig. 11). Since 2003, all 3 measures of salinity at the AH site have been high (Fig. 11), and sawgrass ANPP has remained depressed (Fig. 10).

The importance of salinity as a potential environmental driver of sawgrass ANPP in oligohaline ecotone regions also has implications for restoration. Productivity at our AH site in Taylor Slough—the only estuarine ecotone with measurable salinity—showed a pattern that closely tracked salinity. Estuarine transgression and saltwater encroachment, driven by sea level rise and reduced freshwater inflows, have been formidable in the southern Everglades over the last 50 - 60 years (Ross et al. 2000). Increased freshwater flow (a restoration target in the southern Everglades) should counteract this phenomenon, at least temporarily. Sawgrass ANPP appears to be negatively affected by salinity, and appears to recover from high salinity years relatively slowly. As such, sawgrass production and extent in the estuarine ecotone may provide an important management tool to measure the effects of hydrologic restoration on the dynamics of the freshwater-estuarine boundary.

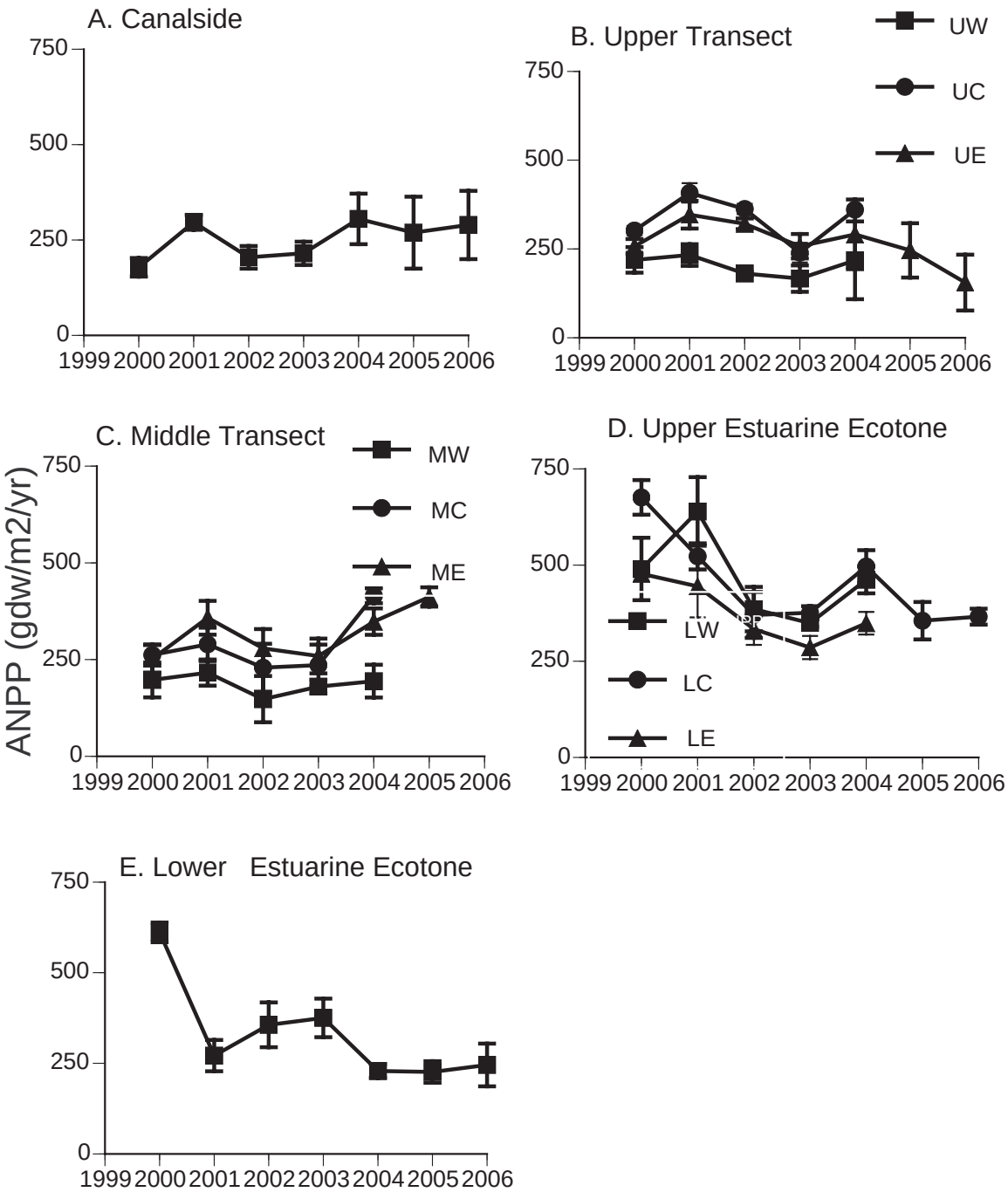

Figure 10. Sawgrass aboveground net primary productivity (ANPP) at Taylor Slough S-332D (a), upper transect (b), middle transect (c), lower transect (d), and AH (e) macrophyte monitoring plots.

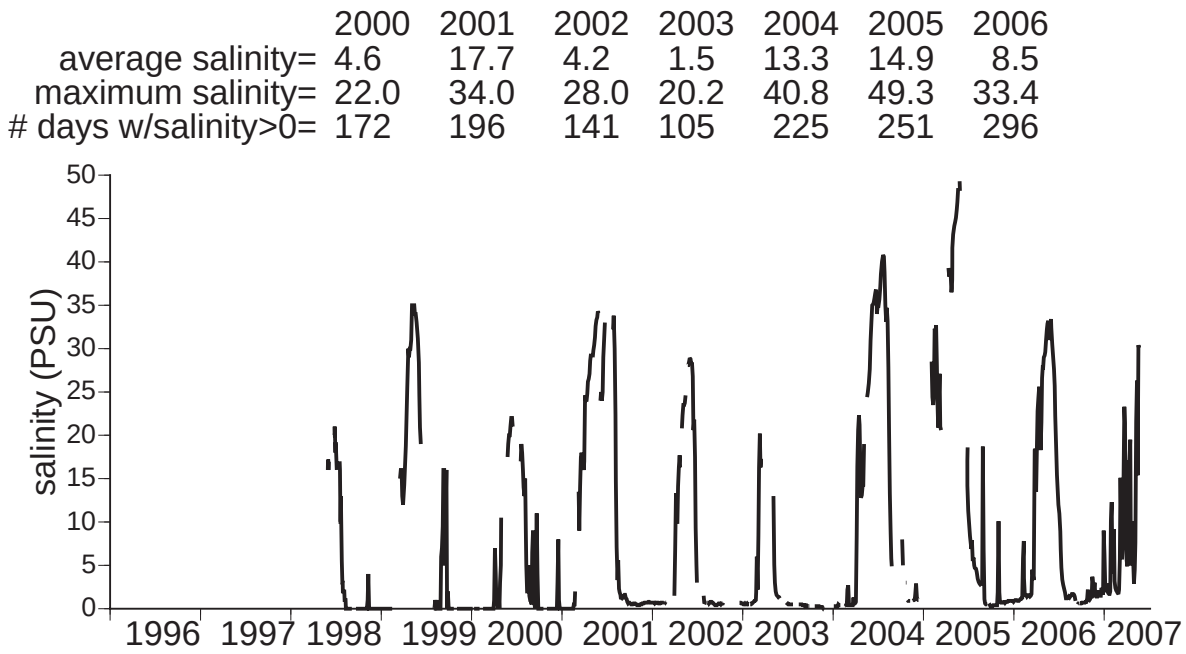

Figure 11. Average annual salinity, maximum recorded salinity and the number of days with salinity recorded at AH (TS/Ph 6).

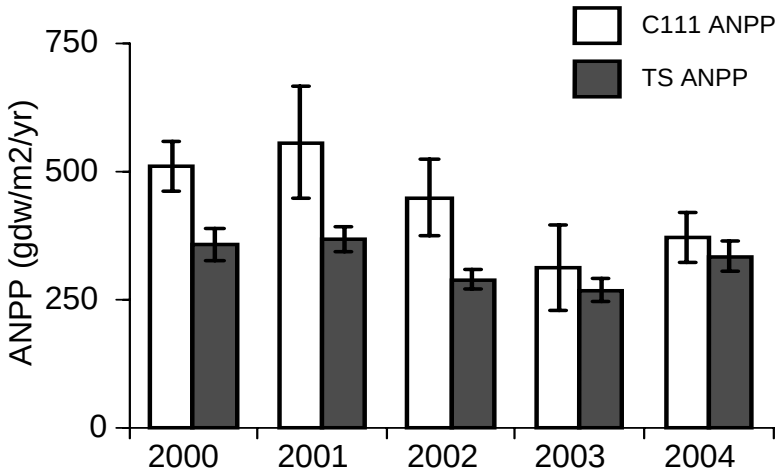

Figure 12. Basin-wide average sawgrass aboveground net primary productivity (ANPP) for the C-111 Basin (white bars) and Taylor Slough (shaded bars). Note that this cross-basin comparison was not continued after 2004 due to the discontinuation of sampling at various sites.

In late 2001, we installed new *Eleocharis* monitoring plots near our LC and AH sites, and began tracking *Eleocharis* stem densities in them. *Eleocharis* is a more prominent component of the plant community at the AH lower ecotone site, possibly because sawgrass densities are lower (reducing shading) and because of longer hydroperiods (which favor *Eleocharis* sp.; Fig. 13). *Eleocharis* is also much patchier in its distribution at the AH site (note the large variation among our 3 plots in Fig. 13). At both sites, stem densities tended to be highest in the wet season. While salinity may limit *Eleocharis* productivity during the dry season at the AH site, we never observed measurable salinities at the LC site—in fact, in most years the

LC site was dry for at least a portion of the dry season. Nonetheless, *Eleocharis* stem densities at both ecotone sites were considerably lower in 2006 and 2007 compared with pre-2004. As noted above, these years coincided with saltier conditions in the estuarine ecotone.

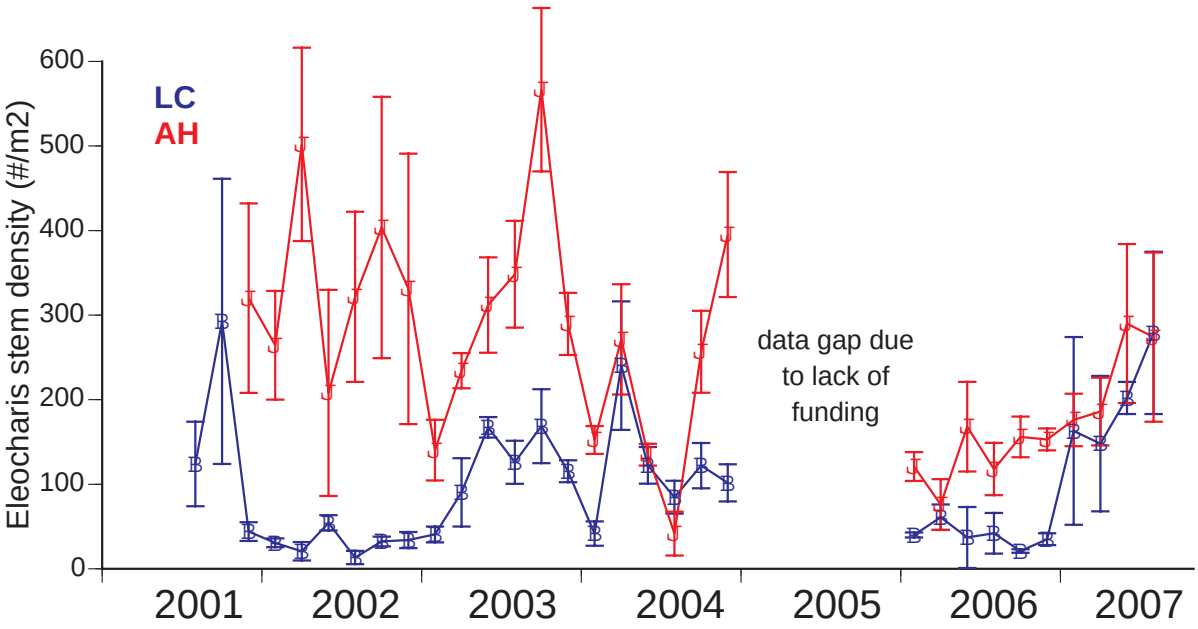

Figure 13. *Eleocharis* stem density in triplicate 1 m^2 plots at the LC and AH estuarine ecotone sites in Taylor Slough.

SIGNIFICANT FINDINGS: TAYLOR SLOUGH MACROPHYTE DYNAMICS

Everglades plant communities are vulnerable to changes in either water quality or hydrologic regime. Our data suggest that sawgrass productivity is not controlled by water quality in the southern Everglades but rather, negatively related to both mean annual water depth, depth-days, and salinity. This finding suggests that, as water depths and hydroperiods increase in the southern Everglades, sawgrass may decline. The former is a primary goal of Everglades Restoration, though, so we investigated how the plant community responded to this hydrologically-controlled reduction in productivity. The next most prominent component of this community at our sites was spikerush (*Eleocharis* sp.). We found that nearly 40% of the spatial and temporal variability in sawgrass productivityy was explained by depth-days (the product of hydroperiod and mean water depth) and *Eleocharis* density. If increased water depths or longer hydroperiods cause sawgrass production—and possibly sawgrass cover—to decline, spikerush densities will increase almost simultaneously. This has important implications for hydrologic restoration: A decline in the "charismatic macrophyte" of the Everglades—sawgrass—in some areas is not necessarily detrimental, and the nearly simultaneous replacement of sawgrass with deeper water species—such as spikerush—suggests that a decline in sawgrass will not be ecologically disruptive. This is a freshwater marsh model, though, as transgression will cause saltier conditions in the estuarine ecotone, which seems to have negative effects on both sawgrass and spikerush. Increased freshwater flows should slow this process, or possibly even reverse it—albeit a temporary reversal.

C-111 HYDROLOGIC BASIN

1. Water Quality

Water quality has been continuously monitored at our W-1, W-2, E-1, E-2, JB, and TC sites in the C-111 Basin, at our N-1, N-2, N-3, and N-4 sites in the North C-111 Basin, and at 3 sites in the "Triangle" area of the Model Lands between Highway US 1 and Card Sound Road. At all sites, we also collect a grab sample every month when autosamplers were serviced. These samples are analyzed for the full suite of dissolved and total C, N, and P nutrients. We collect rain event water samples at all sites instrumented with rain gauges.

Phosphorus concentrations (as TP) at our C-111 freshwater sites have typically been less than 0.5 µM (15.5 ppb) and often less than 0.2 µM (6.2 ppb) throughout the 10 years of record. Exceptions were high P events (concentrations >1µM) that occasionally have occurred during early and late wet seasons at W-1 (Fig. 14a). These spikes are most likely from initial wet season canal inputs or from storm-induced events. Phosphorus levels have typically been lower at the east transect sites (E1 and E2) where we have not measured TP levels above 1 µM (31 ppb) (Fig. 15a). Values at these sites rarely exceeded 0.25 – 0.3 µM (7.75 – 9.3 ppb) although annually, there have usually been one or several events of TP > 0.5 µM (Fig. 15a). Over the 10 year period of record, TP concentrations have shown a slight decreasing trend along the east transects. At the four C-111 North sites (N-1 through N-4), TP concentrations were generally <0.25 µM from 2001-2004, but have been considerably higher beginning in 2005 (Fig. 16a).

As with TP, TN concentrations were generally higher along the west transect (W-1 to W-3) compared with E-1 and E-2. Total N concentrations were, however, more variable along the east transect (Fig.s 14 and 15). Over the 10 years of record, TN was usually < 50 µM (700 ppb) at both W-1 and W-2 with the exception of high concentration events events in 1998, 2002 (during the 2002-03 moderate ENSO event), and 2006 (Fig. 14a). These spikes in TN are similar to findings from MPR in late 2002 (Fig. 5a). Data from the C-111 North sites all suggest a trend of increasing TN through time (Fig. 16a). Ammonium concentrations were generally lower than NN concentrations at all C-111 Basin sites, and NH_4^+ tended to be lower at W-1 and W-2 (Fig. 14b) than at E-1 and E-2 (Fig. 15b). In the C-111 North Basin, which is essentially ombrotrophic, both NH_4^+ and NN concentrations have been increasing since 2001—most dramatically for NN (Fig. 16b). The period of record from the 3 Triangle sites is shorter (Fig. 17). Concentrations of TP and TN are similar to at the sites to the west (N1 – N4) and to the southwest (W1 – W3, E1, and E2). Interestingly, NH_4^+ concentrations in the Triangle are somewhat higher than at other C-111 sites while NN concentrations are somewhat lower (Fig. 17).

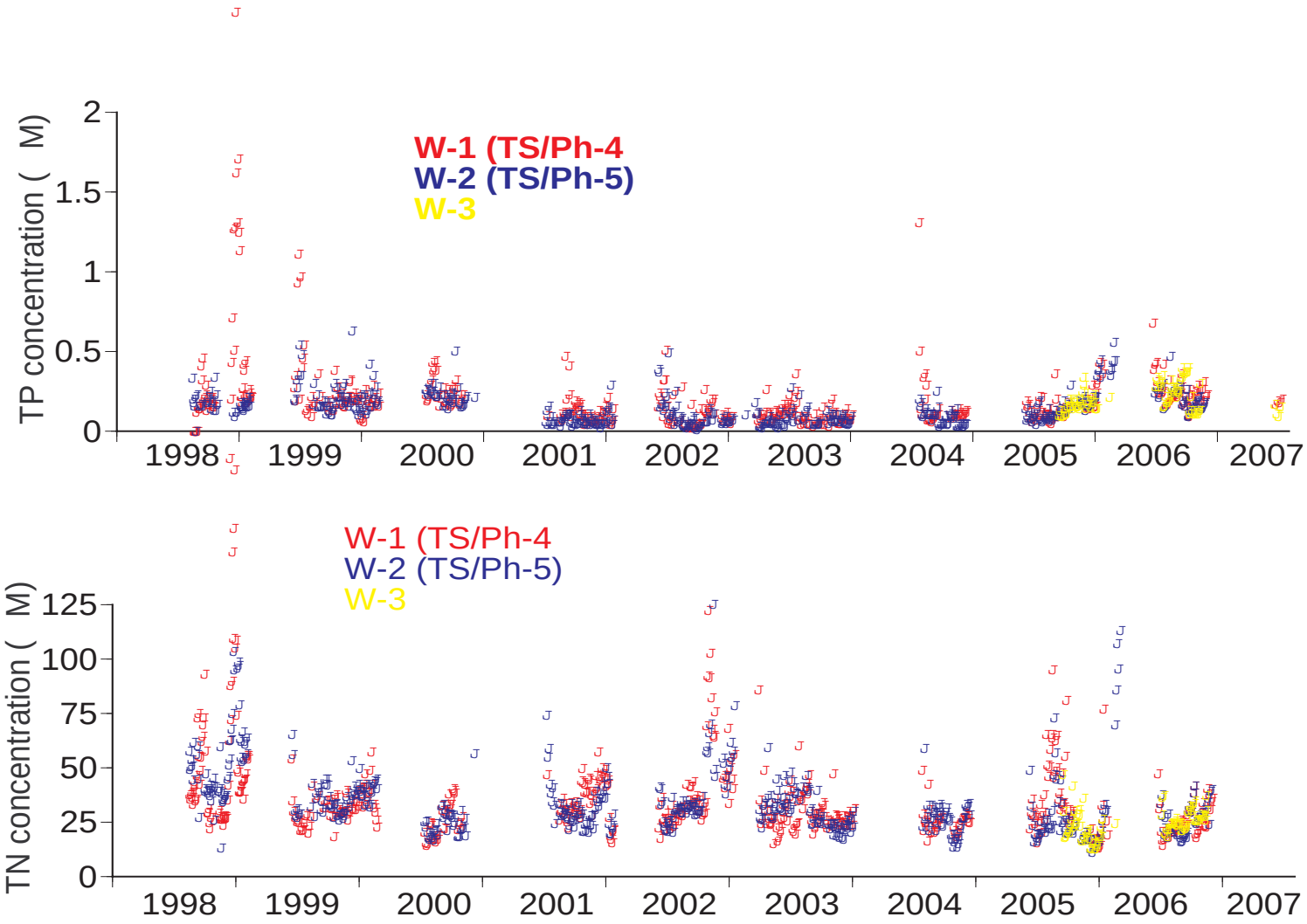

Figure 14a. Total nutrient concentrations along the C-111 west transect for the period of record. We started collecting TN and TP at W-3 in late 2005.

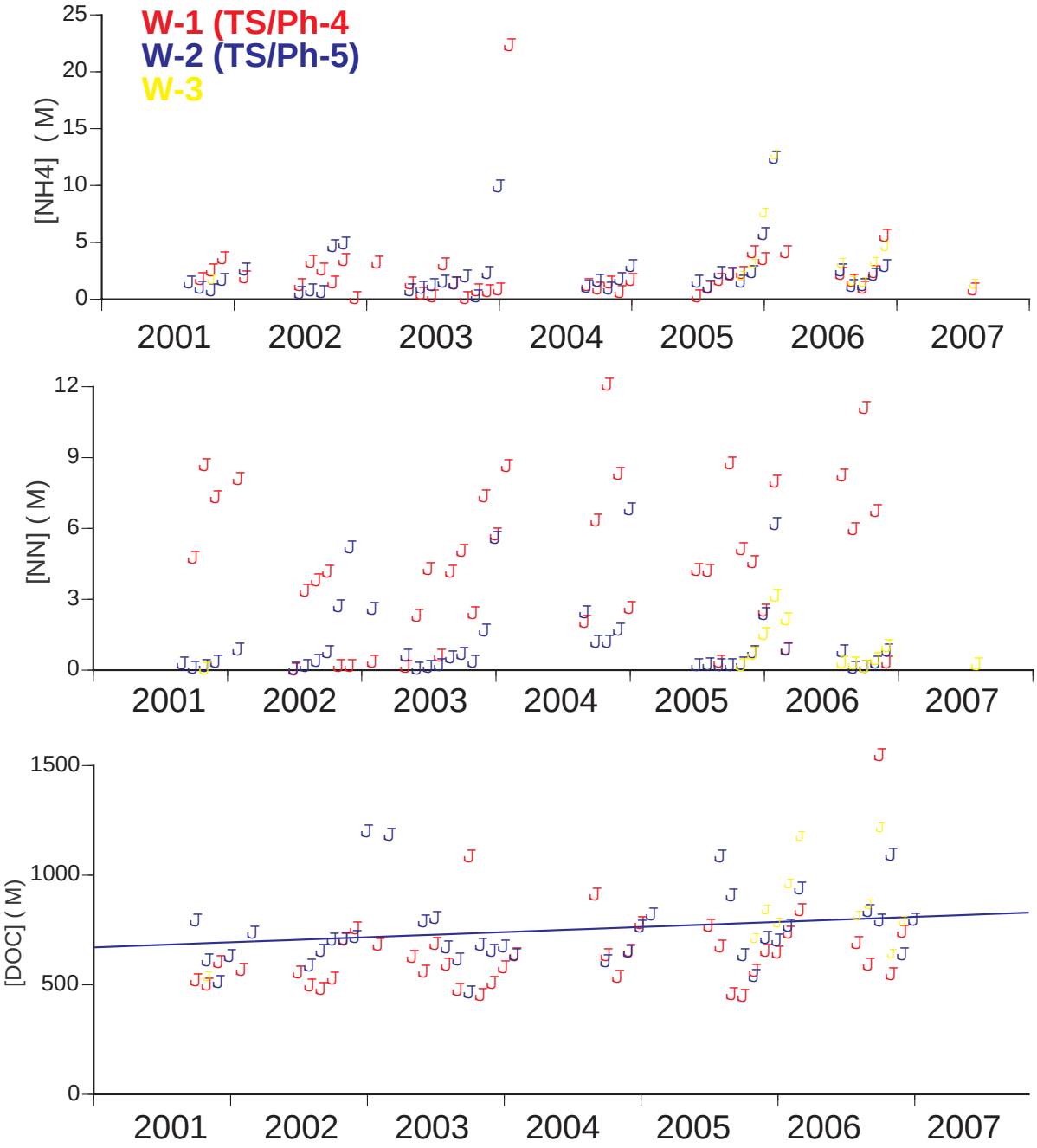

Figure 14b. Dissolved N concentrations, as ammonium (NH4) and nitrate + nitrite (NN), and dissolved organic carbon (DOC) from monthly grab samples at the W-1, W-2, and W-3 sites in the C-111 Basin (note that 1 µM C = 14 ppb and 1 µM N = 14 ppb).

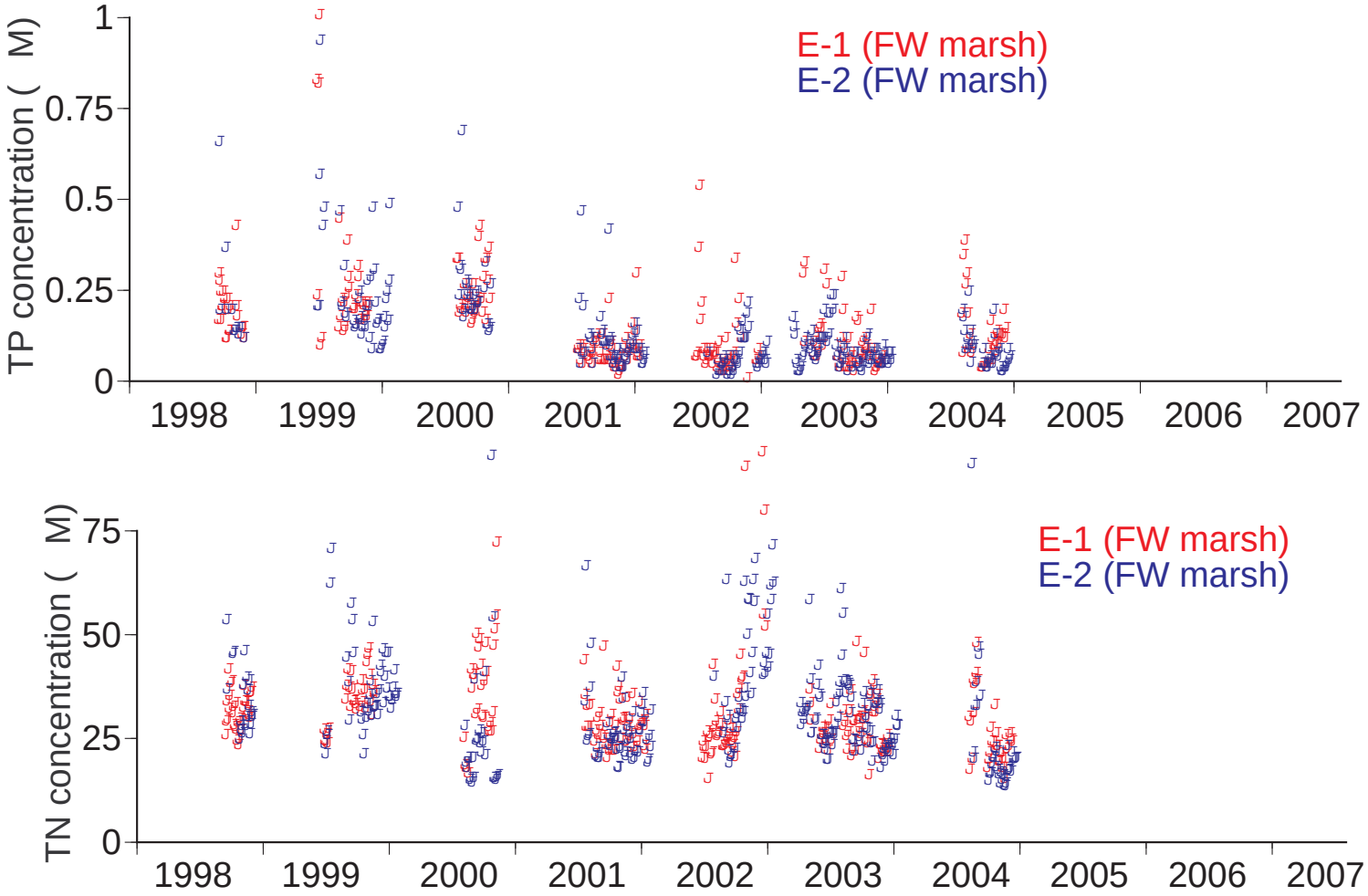

Figure 15a. Total nutrient concentrations along the C-111 east transect for the period of record. Data collection at both sites terminated at the end of 2004 due to a change in funding priorities.

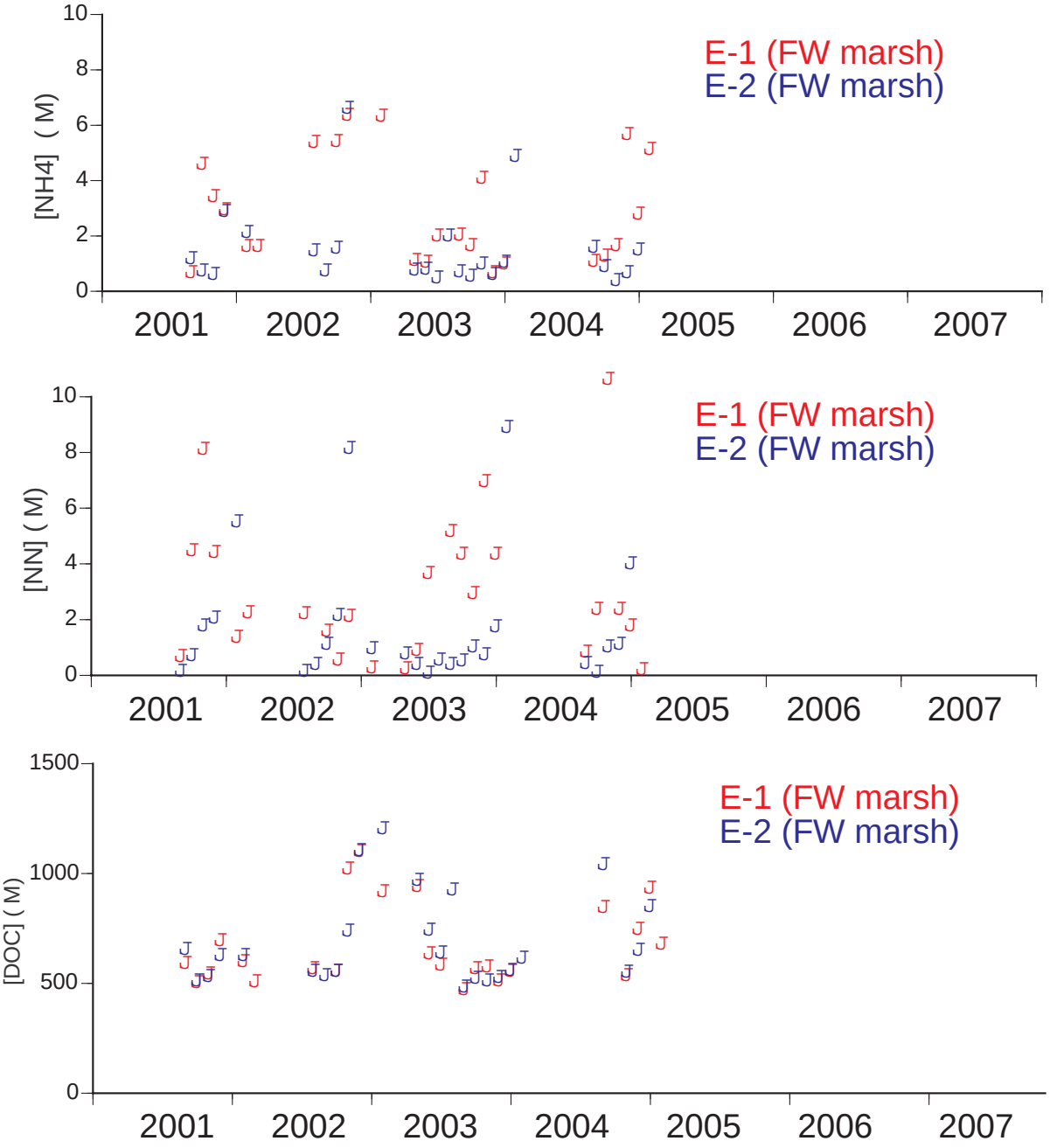

Figure 15b. Dissolved N concentrations, as ammonium (NH4) and nitrate + nitrite (NN), and dissolved organic carbon (DOC) from monthly grab samples at the E-1 and E-2 sites in the C-111 Basin (note that 1 µM C = 14 ppb and 1 µM N = 14 ppb). Data collection at both sites terminated at the end of 2004 due to a change in funding priorities.

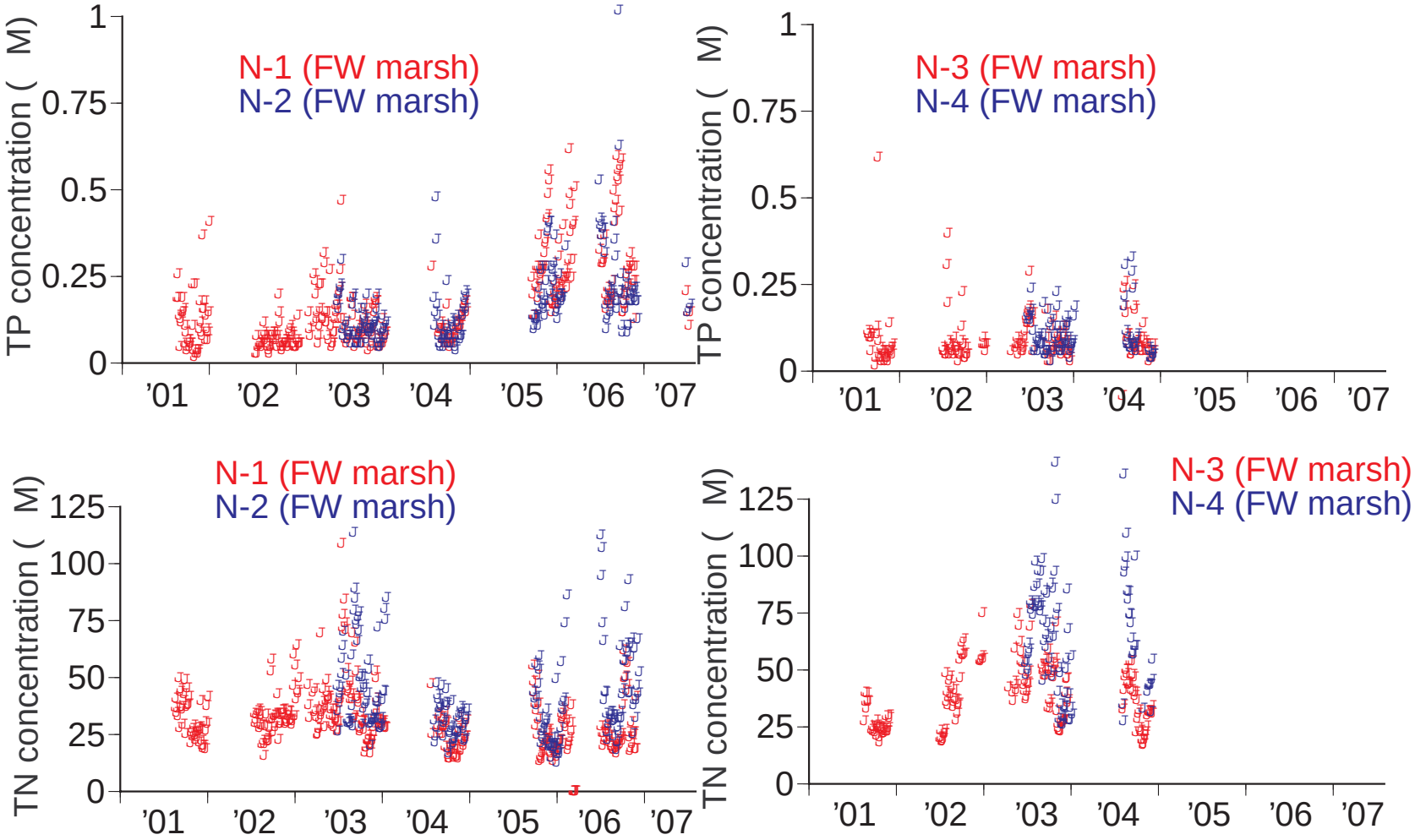

Figure 16a. Total nutrient concentrations along the east (N-3 and N-4) and west (N-1 and N-2) transects in the C-111 North region for the period of record. Data collection at the N-3 and N-4 sites terminated at the end of 2004 due to a change in funding priorities.

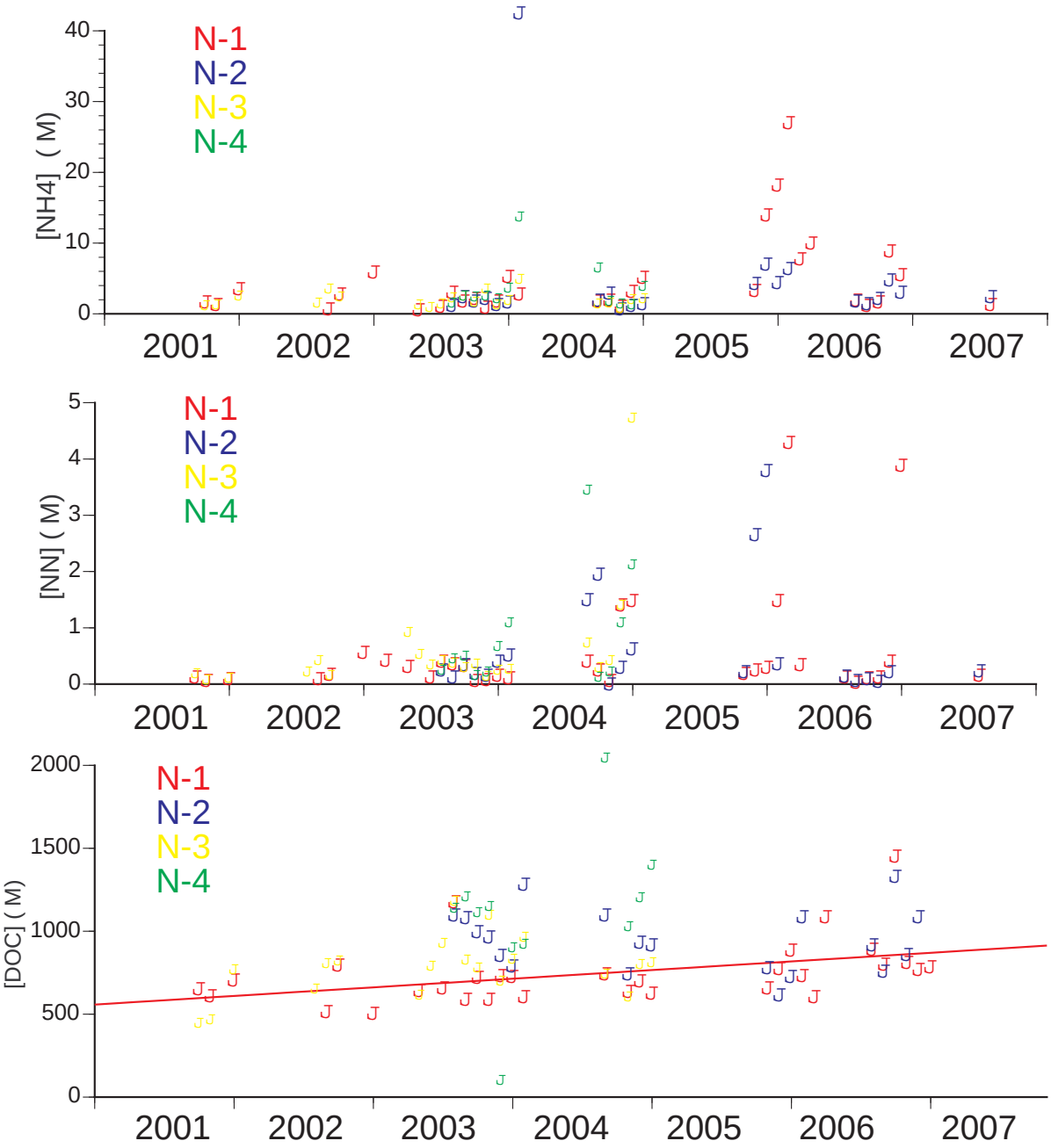

Figure 16b. Dissolved N concentrations, as ammonium (NH4) and nitrate + nitrite (NN), and dissolved organic carbon (DOC) from monthly grab samples at the N-1, N-2, N-3, and N-4 sites in the C-111 Basin (note that 1 µM C = 14 ppb and 1 µM N = 14 ppb). Data collection at the N-3 and N-4 sites terminated at the end of 2004 due to a change in funding priorities.

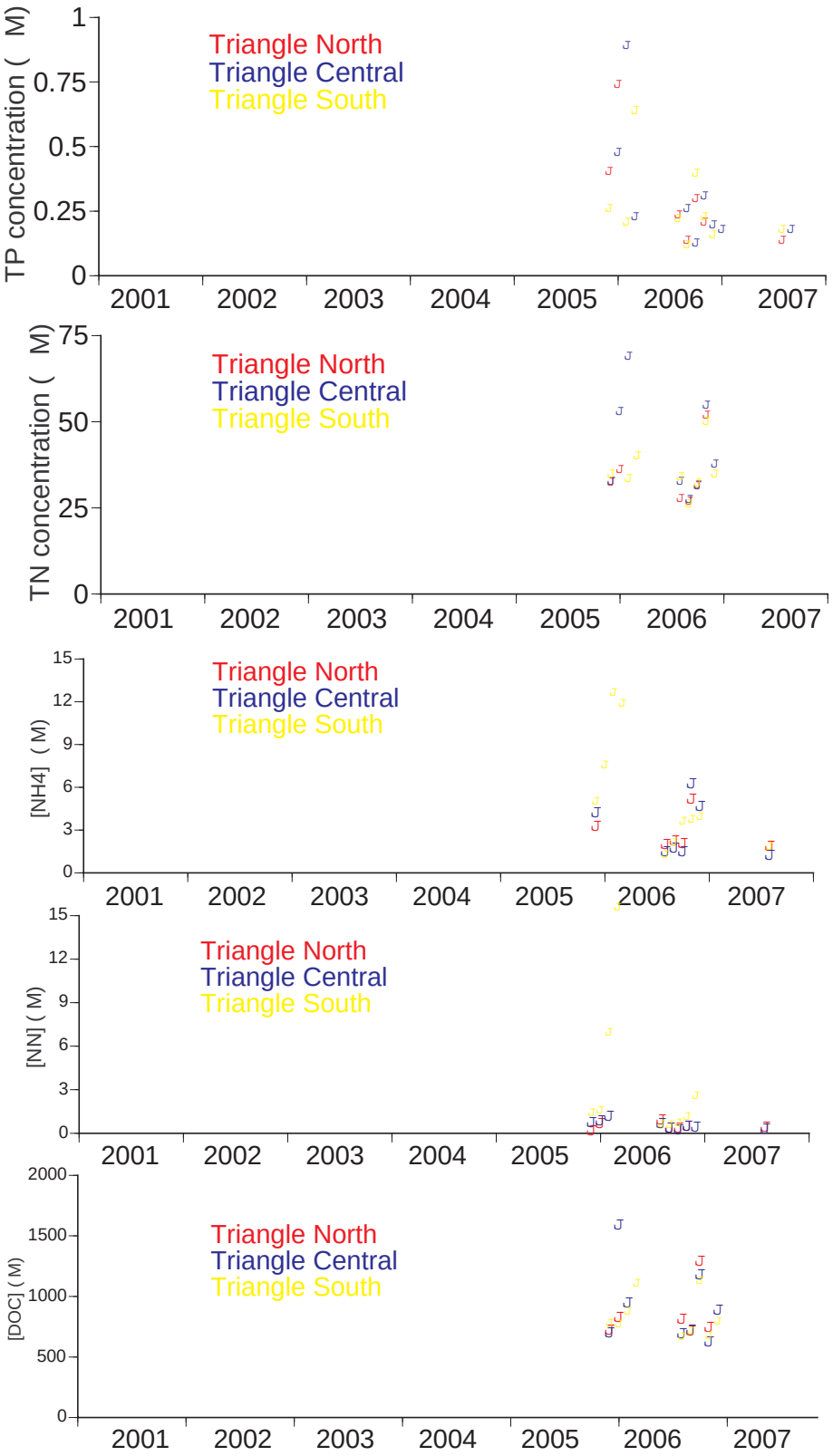

Figure 17. Total P and N, dissolved N concentrations, as ammonium (NH4) and nitrate + nitrite (NN), and dissolved organic carbon (DOC) from monthly grab samples at the US-1 & Card Sound Road Triangle sites in the C-111 Basin (note that 1 µM C = 14 ppb,1 µM N = 14 ppb, and 1 µM P = 31 ppb).

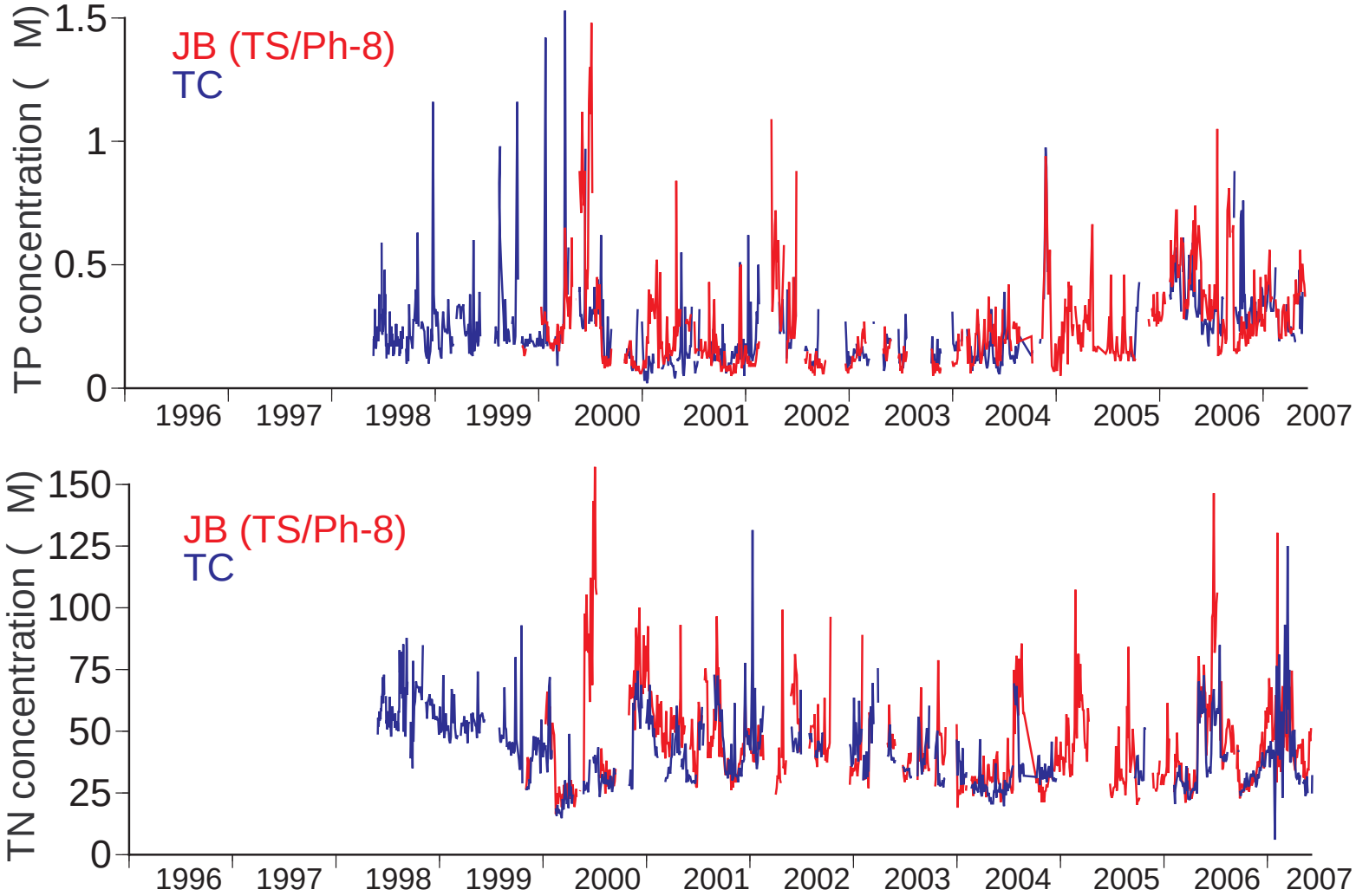

Figure 18a. Total nutrient concentrations at mangrove sites south of the C-111 transect for the period of record. We started collecting water from Trout Creek (TC) in mid 1998 and from Joe Bay (JB) in late 1999. Missing data indicate autosampler malfunction.

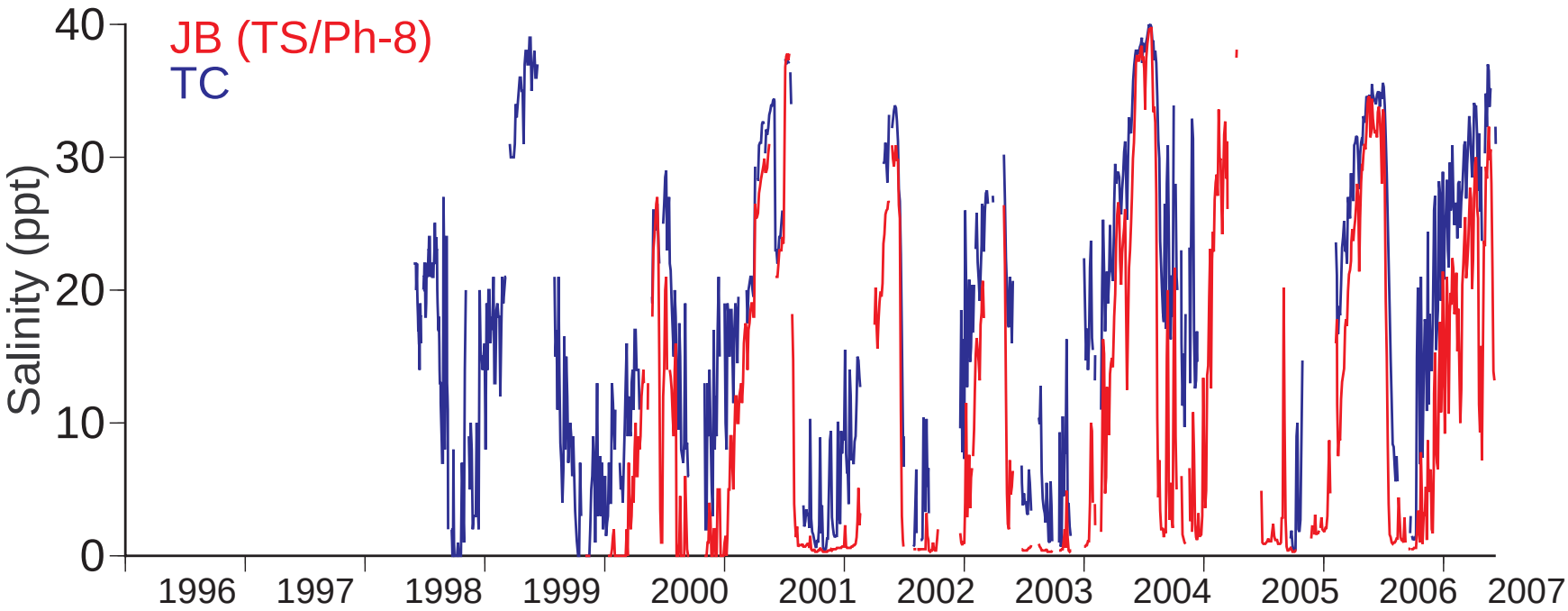

Figure 18b. Salinities at mangrove sites south of the C-111 transect for the period of record. Missing data indicate autosampler malfunction.

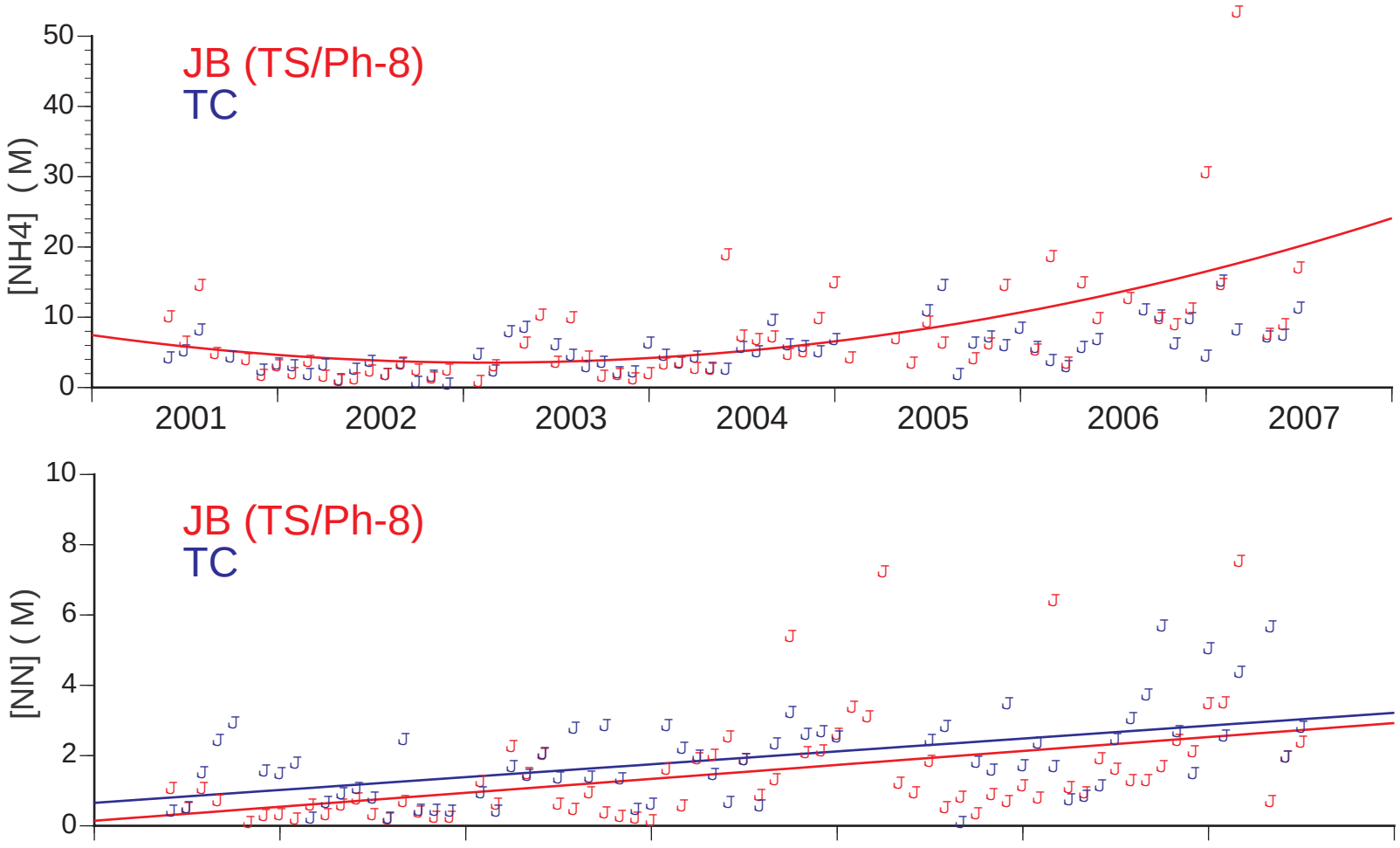

Figure 18c. Dissolved N concentrations from monthly grab samples at the Joe Bay (JB = TS/ Ph 8) and Trout Creek (TC) mangrove sites south of the C-111 Basin (note that 1 µM P = 31 ppb and 1 µM N = 14 ppb).

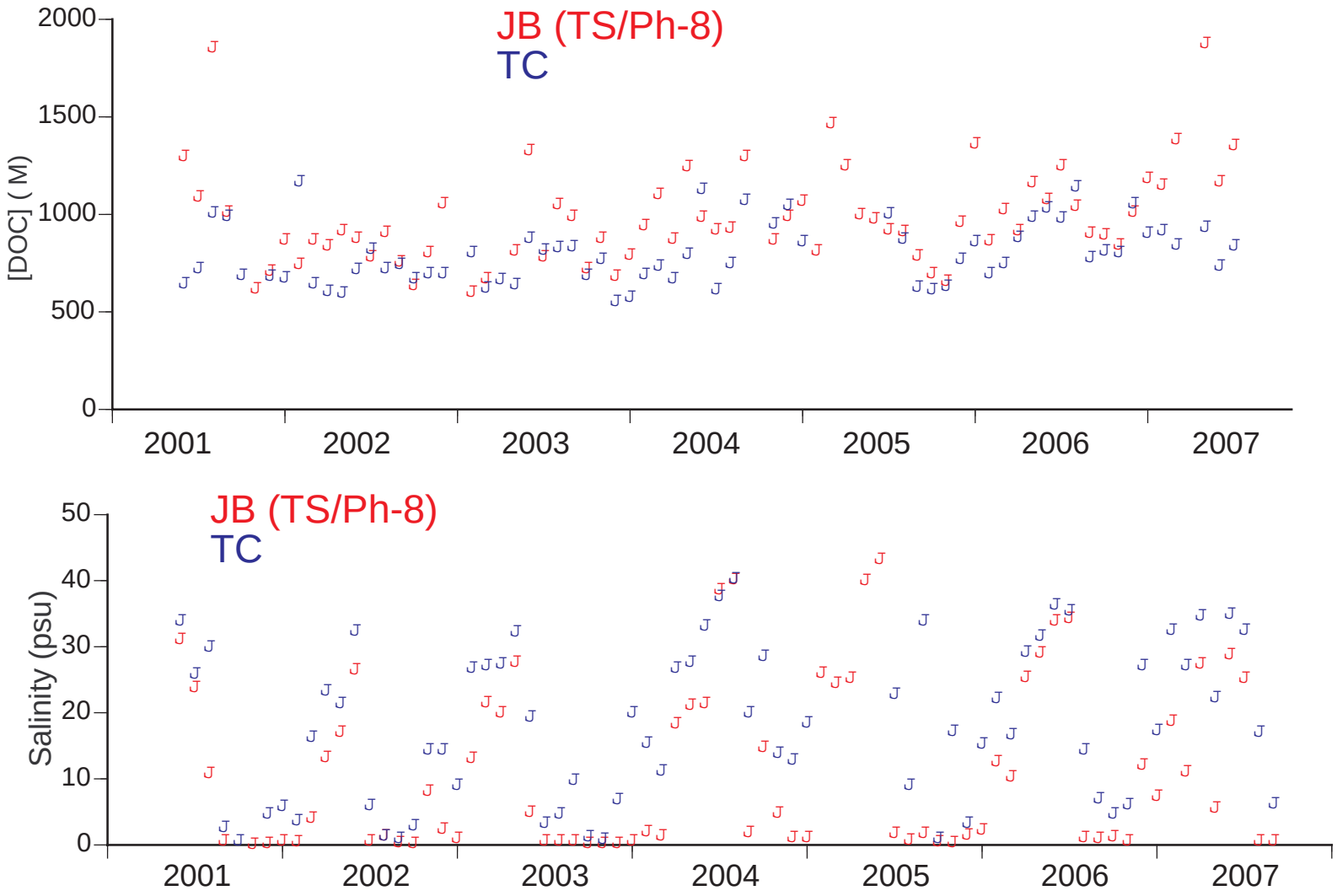

Figure 18d. DOC concentrations and salinity from monthly grab samples at the Joe Bay (JB = TS/ Ph 8) and Trout Creek (TC) mangrove sites south of the C-111 Basin (note that 1 µM P = 31 ppb and 1 µM N = 14 ppb).

In the C-111 Basin, 0ur estuarine water quality program includes two sites that we conceptualize as downstream from the C-111 west transect (Joe Bay (JB) and Trout Creek (TC)). Phosphorus concentrations were generally <0.3 µM at both sites, but spikes regularly occurr in our 10 year dataset—particularly during the dry season, when the estuarine influence was greatest (Fig. 18a). Periodic high TP concentration events, to about 1 µM, occurred regularly at both sites from 1998 to 2000 and in 2006. Most notable was the ENSO year of 2002 and 2003 when TP concentrations were quite low and never exceeded 0.5 µM (Fig. 18a). Concentrations of TN tended to be higher (generally 50 – 75 µM) at these estuarine sites compared with the freshwater marsh (Fig. 18a). Ammonium concentrations have shown a non-linear trend at the JB site, with an increase since about 2003 (Fig. 18c). Nitrate + nitrite content has been steadily increasing at both estuarine sites, though, since 2001 (Fig. 18c).

Over the 10 years of record-keeping, salinity at both sites ranged from fresh [or nearly fresh] in the wet season to slightly hypersaline at the end of the dry season in some years (Fig. 18b & d). The overall seasonal patterns are similar to trends observed in AH and TM. Salinities were often higher at the TC site compared with the JB site, except during the late dry season (when the influence of freshwater flow from the upstream C-111 Basin was lowest; Fig. 18b & d). Lower salinities at JB reflect the fact that this site is located along a mangrove creek that directly drains this landscape, while the TC site integrates freshwater inflows over the larger spatial domain of northeastern Florida Bay. The transition from dry season to wet season often shows an even more abrupt salinity decline in this area than was observed in the Taylor Slough drainage, while the wet season to dry season transitions tend to be more gradual.

In addition to our water quality sampling, we also collected continuous rainfall data at several sites and continuously monitored water levels at most water quality sites. Rainfall was measured at W-1, W-2, N-1 and the Model Lands Triangle (Fig. 19). In comparing W-1 and W-2, we found significant differences between the quantity and timing of rainfall although these sites are within a few kilometers of each other (Fig. 19). We measured rainfall at both sites through the dry season of 2003 during the ENSO event (2002-2003). In the wet season of 2005, we installed rain gauges at N-1 and the Model Land Triangle areas, both of which are relatively ombrotrophic sub-basins (Fig. 20). We observed low rainfall (< 3 cm) in these areas through much of the 2005 wet season, but considerably higher rainfall during the 2006 wet season (Fig. 20).

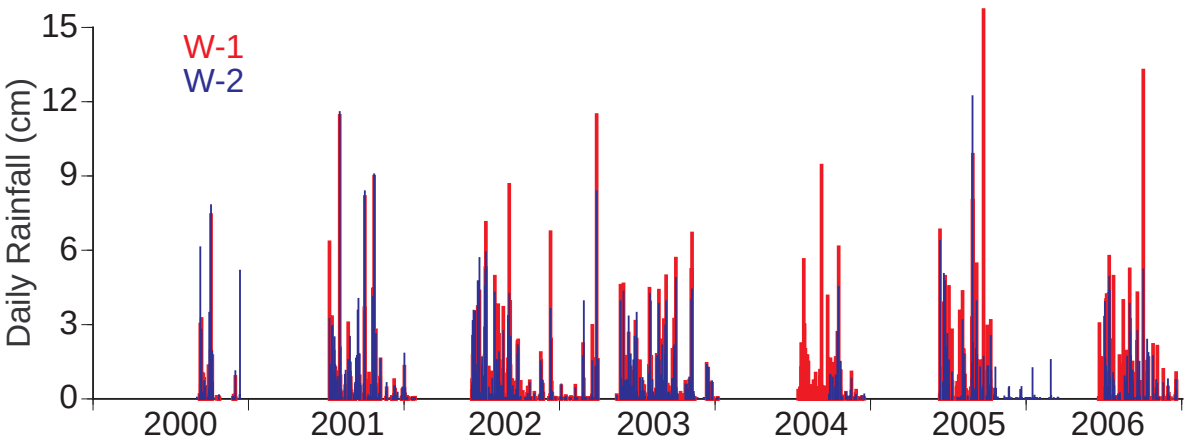

Figure 19. Daily rainfall for W-1 and W-2 from 2000-2006 in the C-111 Basin.

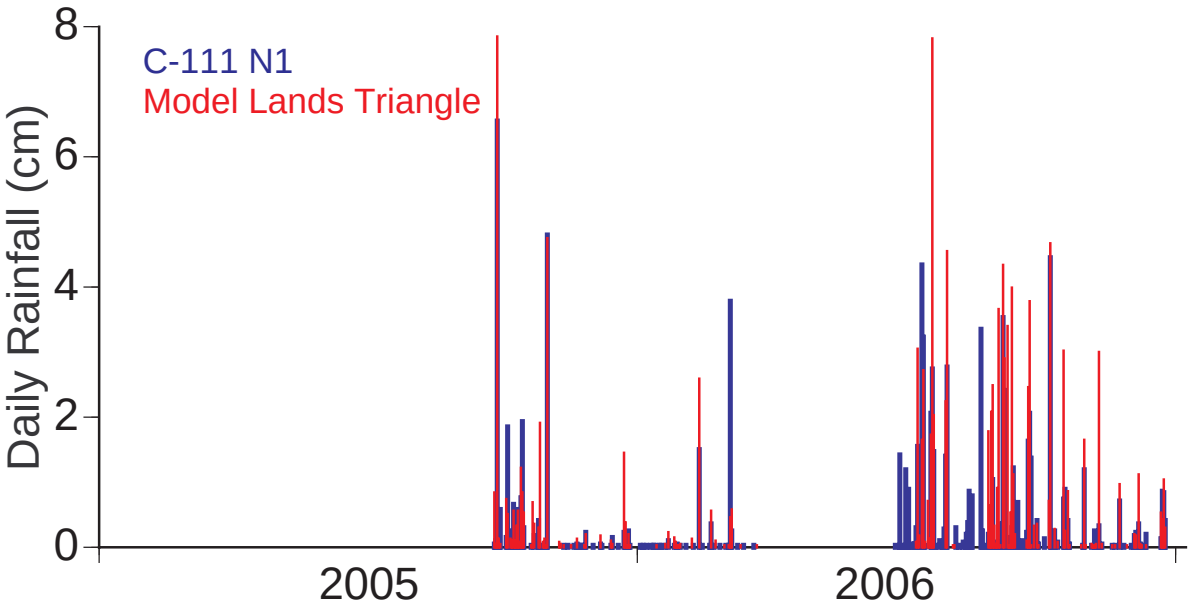

Figure 20. Rainfall at N-1 site and the Model Lands Triangle area in 2005 and 2006.

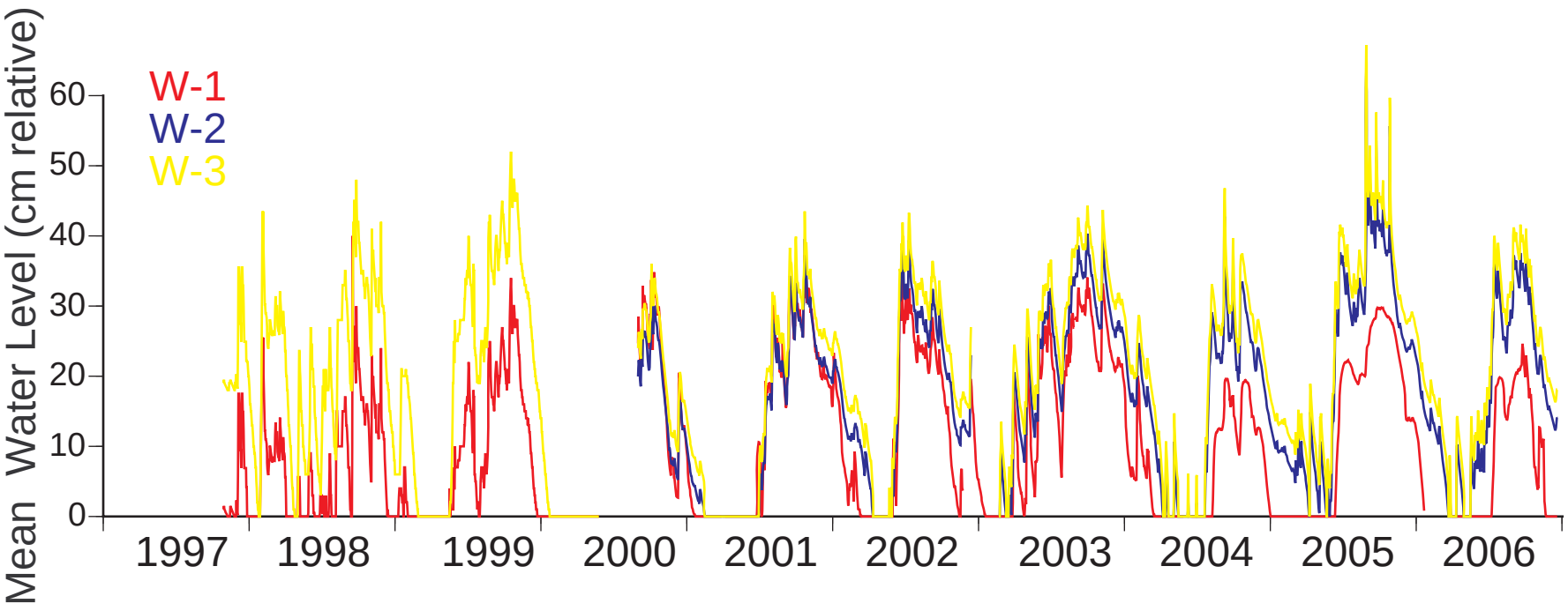

Figure 21. Mean daily water levels from the C-111 west transect. All water levels are relative to site-specific datums.

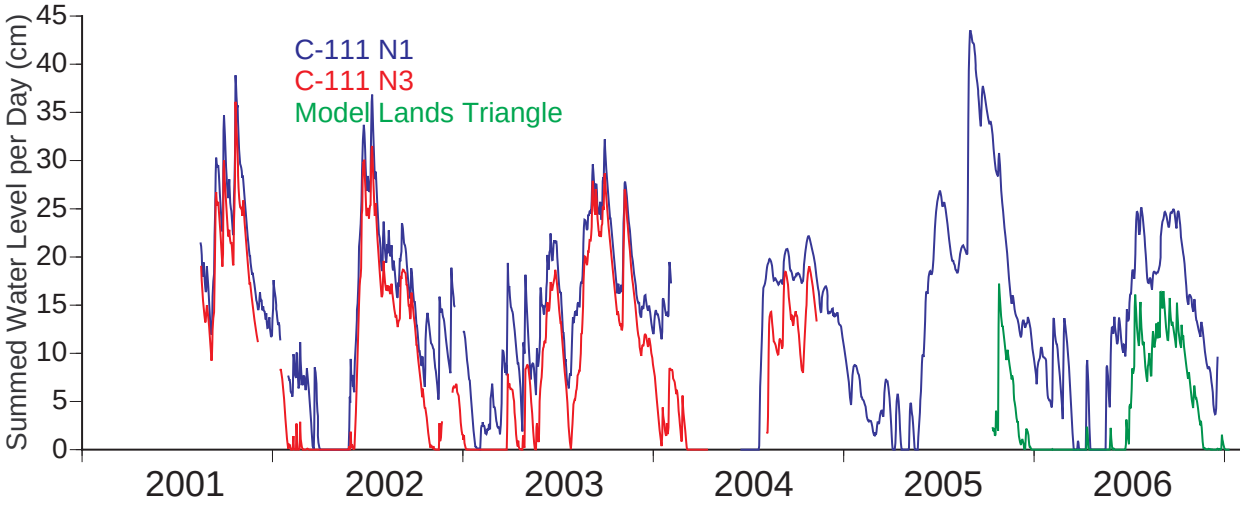

Figure 22. Daily water level at N-1, N-3, and the Model Lands Triangle. Monitoring at the C-111 Basin sites began in 2001 but we only started tracking water levels in the Model Lands in mid 2005. Water level monitoring at N-3 terminated at the end of 2004 due to a lack of funding.

Water level data from the C-111 west transect (W-1 to W-3) clearly show the unusual inundation patterns seen in El Niño years (1998 and 2002-03; Childers et al. 2006a; Fig. 21). During the strong 1998 ENSO event, the dry season was unusually wet and most of our marsh sites did not dry down. The 1998 wet season was somewhat dryer than normal, also, and ended early (Fig. 21). The moderate 2002-03 ENSO event coincided with water levels that steadily declined through the 2002 wet season, which had below average precipitation, and with water levels that increased steadily through the 2003 wet season, which was unusually wet. Since 2003, this landscape appears to have been wetter than in the late 1990s and early 2000s. In non-ENSO years, rapid declines in water levels at the end of the wet season were largely driven by abrupt changes in structure management—namely abrupt closure of the S-18C. The abrupt nature of this managed end to a typical C-111 Basin dry season caused water levels to drop rapidly, rather than to recede at a more natural rate into the dry season.

Although the water level patterns at N-1 and N-3 were similar to the western transect (W-1 to W-3), the decline in water levels at the end of the wet season were less abrupt (Fig. 22). This more gradual recession is expected in ombrotrophic basins where canal water inputs are not a dominant hydrologic driver. Water levels were also generally lower in this area relative to the western transect. In the mid wet season of 2005, water level in the Model Lands Triangle increased abruptly from ~2 cm to ~20 cm depth but receded immediately thereafter, in concert with N-1.

SIGNIFICANT FINDINGS – C-111 BASIN WATER QUALITY AND HYDROLOGY

Water management is closely tied to water quality throughout the Everglades. This is particularly true in the southern Everglades, where the removal of the southern levee along the C-111 canal between the S-18C and S-197 structures in 1997 increased water flow into the C-111 Basin and where plans for the C-111 spreader canal require knowledge of current water quality in the C-111 North basin. Our long-term data (beginning in 1997) suggest low P concentrations in water entering the C-111 Basin (8-10 ppb), and even lower P content in C-111 North and Triangle marshes (typically 5-8 ppb). Phosphorus concentrations in the C-111 Basin appear to have been declining since 1997. Since levee removal, N loads have largely been lower than in most pre-1996 years. There is some indication of a trend of declining TN concentrations at our estuarine mangrove sites since 2000. Our 10 year record suggests that water quality in the C-111 Basin is and has been good, particularly in the isolated C-111 North landscape. The one exception to this pattern is a trend of increasing TN concentrations along the C-111 North transect. This trend supports the importance of continuing to monitor water quality during C-111 Spreader Canal planning and project execution.

Marsh water levels in the C-111 Basin are controlled by *in situ* rainfall and by management of the S-18C structure. Water level recession into the dry season should be a gradual process, yet in many years water levels dropped precipitously. This is largely a function of abrupt changes in water delivery at the S-18C (water management decisions that have been controlled by IOP and ISOP for much of our period of record). Rapid declines in early dry season water levels are not natural, and lead to abrupt salinity increases in downstream estuarine wetlands. Rapid water level recession may also disrupt dry season faunal activity, including wading bird feeding dynamics. These problems could be largely eliminated if dry season changes in S-18C structure status were implemented gradually, over several months. Finally, our long-term hydrologic dataset includes two El Niño events (the strong 1998 event and the moderate 2002-03 event). El Niño events are typically associated with unusually wet dry seasons and by unusually dry wet season. These natural shifts in precipitation, which effectively dampen normal seasonality in precipitation, should be considered when future water management decisions are made for the southern Everglades.

2. Marsh Macrophytes

We quantified macrophyte species composition and aboveground *Cladium* biomass at all plant quadrats in the C-111 Basin (W-1, W-2, W-3, E-1, and E-2), in C-111 North Basin (N-1, N-2, N-3, and N-4), and in the Triangle Basin. Aboveground NPP was lower at the canalside W-1 site and at the upper ecotone W-3 site, relative to the mid-transect W-2 site, in all years prior to 2002 (Fig. 23). ANPP rarely exceeded 750 gdw m^{-2} y^{-1} along this transect. The eastern transect (E-1 and E-2) showed a different pattern, with consistently higher ANPP at the E-1 site [nearest the canal]. This site was also unique in the C-111 Basin in that it showed the highest ANPP in 2001 (Fig**.** 23). The E-1 site was significantly more productive than the other 4 sites across all years (RMANOVA, $F_{4,40}$=10.58; p=0.001; Fisher's PLSD p<0.002). Productivity has been relatively consistent from 2002 through 2006 in this canal-dominated basin. Sawgrass ANPP in the C-111 North Basin and Triangle Basin is quite similar in magnitude and lack of interannual variability (Fig. 24).

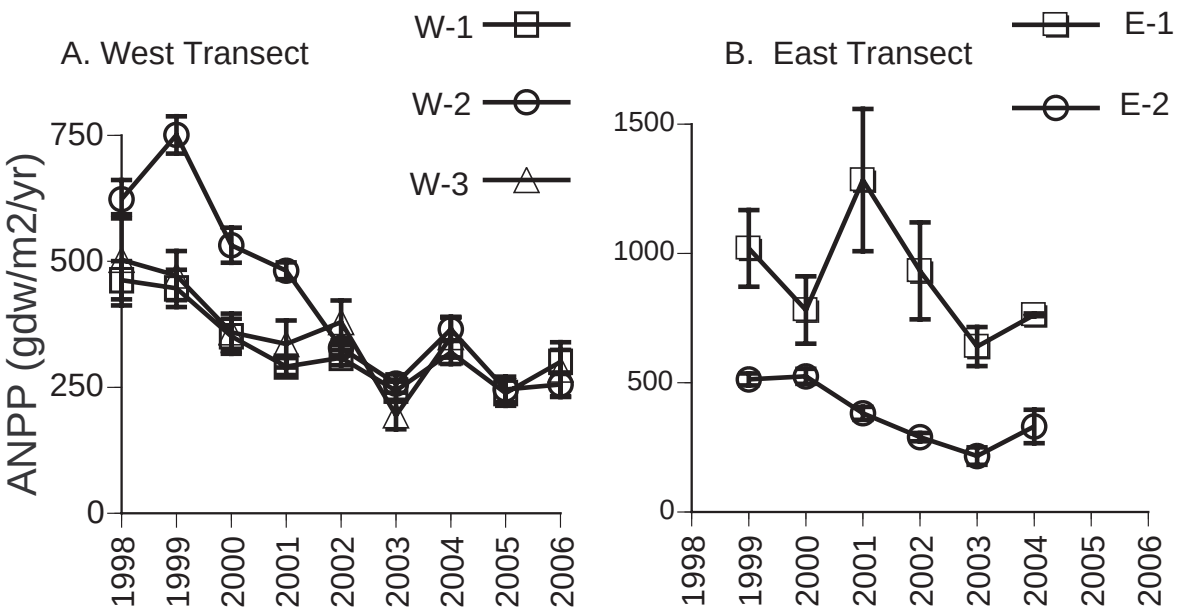

Figure 23. Sawgrass aboveground net primary productivity (ANPP) at the C-111 west (a) and east (b) transect macrophyte monitoring plots. Sampling was terminated at E-1 and E-2 at the end of 2004 due to SFWMD re-prioritization of funding.

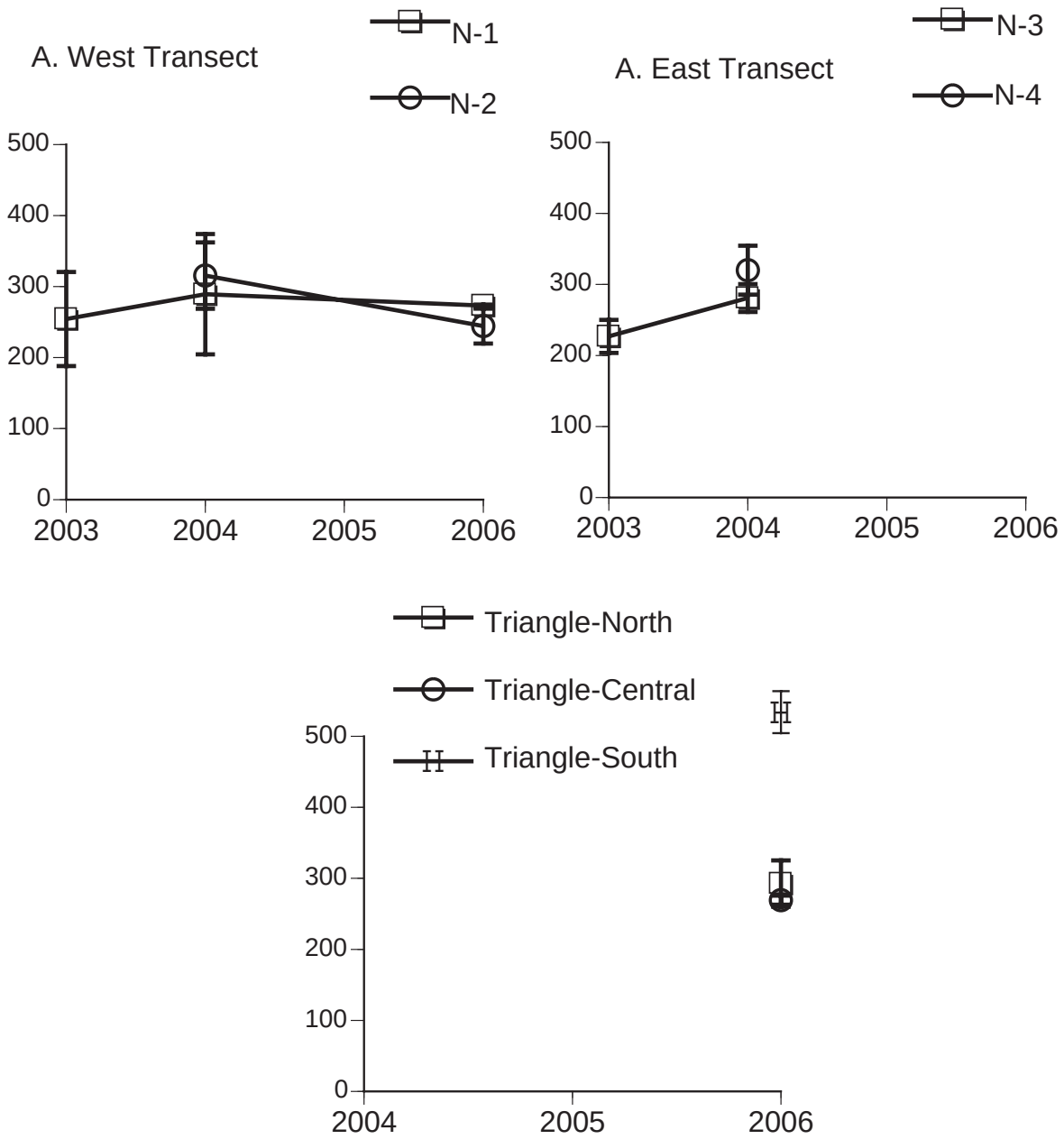

Figure 24. Sawgrass aboveground net primary productivity (ANPP) at the C-11-North west and east transects and the US 1-Card Sound Road Triangle transect macrophyte monitoring plots. Note that the 2005 data gap at N-1 and N-2, and discontinuation of sampling at N-3 and N-4 after 2004 were due to funding shortfalls.

We have also sampled *Eleocharis* stem density bi-monthly at monitoring plots near the W-3 site since 2002 (Fig. 25). These plots were located in an area near scrub red mangrove trees, in areas with little sawgrass. *Eleocharis* stem densities tended to be highest in the wet season (Fig. 25). Stem densities were also lowest in 2002. Childers et al. (2006b) have shown that nearly 40% of the spatial and temporal variability in sawgrass productivity was explained by depth-days and *Eleocharis* density. If increased water depths or longer hydroperiods cause sawgrass production

to decline, spikerush densities will increase almost simultaneously. A longer data record is be needed to verify this trend of higher *Eleocharis* densities though. While salinity may limit *Eleocharis* productivity during the dry season at the AH site in Taylor Slough, we have never observed measurable surface water salinities at our W-4 site in the C-111 Basin—in fact, in most years the W-4 site was dry for much of the dry season.

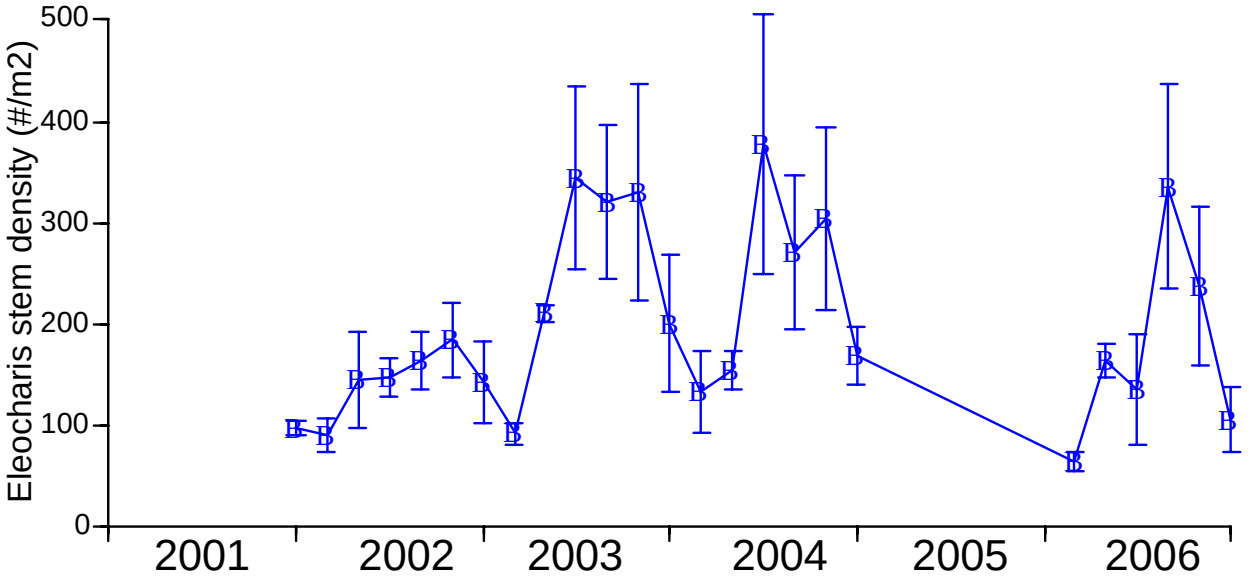

Figure 25. Eleocharis stem density at the W-4 site in the C-111 Basin estuarine ecotone (near the W-3 macrophyte plots). Data gap in 2005 was due to a SFWMD funding shortage.

SIGNIFICANT FINDINGS: C-111 BASIN MACROPHYTE DYNAMICS

Everglades plant communities are vulnerable to changes in either water quality or hydrologic regime. Our data suggest that water quality was not a dominant control on sawgrass productivity in the C-111 Basin for our period of record. However, we found that sawgrass production was significantly negatively related to both mean annual water depth and to depth-days (a hybrid variable, similar to "degree-days" used by meteorologists, calculated as the product of mean water depth and hydroperiod). This finding suggested that, as water depths and hydroperiods increase in the southern Everglades, sawgrass may decline. The former is a primary goal of Everglades Restoration, though, so we investigated how the plant community responded to this hydrologically-controlled reduction in productivity. The next most prominent component of this community at our sites was spikerush (*Eleocharis* sp.). We found that nearly 40% of the spatial and temporal variability in sawgrass productivity was explained by depth-days and *Eleocharis* density. If increased water depths or longer hydroperiods cause sawgrass production—and possibly sawgrass cover—to decline, spikerush densities will increase almost simultaneously. This has important implications for hydrologic restoration: A decline in the "charismatic macrophyte" of the Everglades—sawgrass—in some areas is not necessarily detrimental, and the nearly simultaneous replacement of sawgrass with deeper water species—such as spikerush—suggests that a decline in sawgrass will not be ecologically disruptive. Our results demonstrate that C-111 Basin wetlands are particularly sensitive to environmental change and thus are excellent systems for studying ecological responses to exogenous drivers.