Flux of Organic Carbon in a Riverine Mangrove Wetland in the Florida Coastal Everglades

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ABSTRACT

Short term (daily) and seasonal variations in concentration and flux of dissolved organic carbon (DOC) were examined over 15 tidal cycles in a riverine mangrove wetland along Shark River, Florida in 2003. Due to the influence of seasonal rainfall and wind patterns on Shark River's hydrology, samplings were made to include wet, dry and transitional (Norte) seasons. We used a flume extending from a tidal creek to a basin forest to measure vertical (vegetated soil/water column) and horizontal (mangrove forest/tidal creek) flux of DOC. We found significant ($p<0.05$) variations in surface water temperature, salinity, conductivity, pH and mean concentration of DOC with season. Water temperature and salinity followed seasonal patterns of air temperature and rainfall, while mean DOC concentration was highest during the dry season (May), followed by the wet (October) and 'Norte' (December) seasons. This pattern of DOC concentration may be due to a combination of litter production and inundation pattern of the wetland. In contrast to daily (between tides) variation in DOC flux between the mangrove forest and tidal creek, daily variations of mean water quality were not significant. However, within-tide variation of DOC flux, dissolved oxygen content and salinity was observed. This indicated that the length of inundation and water source (freshwater vs. saltwater) variation across tidal cycles influenced water quality and DOC flux in the water column. Net DOC export was measured in October and December, suggesting the mangrove forest was a source of DOC to the adjacent tidal creek during these periods. Net annual export of DOC from the fringe mangrove to both the tidal creek and basin mangrove forest was 56 g C m^{-2} y^{-1}. The seasonal pattern in our flux results indicates that DOC flux from this mangrove forest may be governed by both freshwater discharge and tidal range.

INTRODUCTION

Coastal mangrove wetlands are valued because they provide food, shelter and nursery habitat for a wide assortment of aquatic and terrestrial species (Robertson & Blaber, 1992; Hogarth, 1999). Mangroves are also valued for their contributions to detritus-based food webs in adjacent estuarine and coastal waters via the export of organic carbon (OC; Odum & Heald, 1975; Twilley, 1988). Litter, mainly leaves and twigs, produced in the mangrove canopy represents a significant source of the organic carbon and nutrients available for export to adjacent coastal waters (Robertson et al., 1992). Leaching of this litter is a rapid component of the decomposition process and provides an important source of dissolved organic material to the soil and water column (Davis et al., 2003; Romero et al., 2005). Given that this organic material is highly labile, a sizable fraction of mangrove detritus is rapidly utilized by heterotrophic microorganisms and made available to higher consumers in the detritus food web (Benner et al., 1986).

Most mangrove wetlands show a net export of organic carbon, and DOC can account for more than 80% of the organic carbon exported (Twilley, 1985; Lee, 1995; Furukawa et al., 1997; Machiwa & Hallberg, 2002). For specific mangrove forest types, it has been shown that much of the variation in export can be attributed to tidal amplitude, inundation frequency, and fauna among other factors (Twilley, 1985; Robertson, 1986; Lee, 1995; Dittmar & Lara, 2001b; Feller, 2002). And these factors can vary seasonally, causing distinct patterns of organic carbon dynamics in estuarine mangrove wetlands (Boto & Wellington, 1988; Dittmar & Lara, 2001a; Dittmar et al., 2001; Davis et al., 2001a; Sutula et al., 2003). However, we still lack an understanding of how small scale forces such as diurnal tides and seasonal variations in upland runoff—as indicated by freshwater inflows—control organic carbon dynamics in these ecosystems.

Few studies have quantified mangrove-water column interactions in situ, and there have been even fewer such studies conducted in mangrove forests of Everglades National Park (ENP; Davis et al., 2001a; Davis et al., 2001b; Sutula et al., 2003). This coastal region is of particular interest where landscape-scale hydrologic restoration efforts are underway. The focus of our study was on the short term (daily) and seasonal variability in organic carbon dynamics (concentration and fluxes) between a riverine mangrove wetland and the Shark River estuary (FL, USA). We hypothesized that seasonal variations in freshwater flow originating from the Everglades and local diurnal tides were important in regulating organic carbon exchange in this wetland. We further hypothesized that the high productivity common to riverine mangrove forests and the high tidal range in Shark River (relative to other estuaries in the Gulf of Mexico) would result in a net export of organic carbon for the year.

METHODS

Site Description

Everglades National Park is located in southern Florida and comprises 610,483 ha, of which 144,447 ha are mangrove forest (Lewis et al., 1985; Welch et al., 1999). Average annual rainfall in the region is 138 cm, with distinct wet (approximately 60% average annual rainfall from June to September) and dry (approximately 25% average annual rainfall from November to April) seasons (Figure 1). Shark River is a mangrove-dominated tidal river along the southwest coast of ENP and is one of the largest estuaries in South Florida. Discharge of freshwater from Shark River Slough to the estuary follows patterns of intra-annual (i.e., seasonal) and interannual rainfall (Chen & Twilley, 1999; Childers et al., 2005). Tides in Shark River are predominantly semi-diurnal with mean amplitude of 0.5–1.0 m.

Our site was located approximately 4 km upstream from the mouth of the estuary at SRS-6 (25°21.852 N, 81°04.667 W), a site routinely sampled as part of the Florida Coastal Everglades (FCE) LTER program. Specifically, our sampling site was located along a small tidal creek that connects the mangrove wetland at SRS-6 to Shark River (Figure 2). The width of the tidal creek is approximately 2 m and the distance from the sampling sites to Shark River was approximately 30 m. The riverine mangrove forest at this location is tidally inundated twice per day (Figure 3) and is dominated by three species of mangroves (*Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa*).

Field Sampling

Samplings were made in 2003 in three seasons: dry (May), wet (October) and the transitional 'Norte' season (December) to understand the importance of season in driving organic carbon dynamics. Also, we sampled across multiple, consecutive tidal cycles (4-6 tides per season) to capture the range of variability in concentration and fluxes within each season.

We used a flow-through flume to measure organic carbon fluxes between the wetland surface and the water column (vertical) and exchanges between the wetland and Shark River (horizontal). The experimental flume was open to surface water flow at both ends and measured approximately 2 m wide and 12.5 m in length, extending from the tidal creek into the mangrove forest. The flume walls were positioned perpendicular to the tidal creek and parallel to the direction of flow of the flooding tidal water, so as to mimic natural flooding patterns in the enclosed area of wetland. Panels on the flumes, consisting of clear, corrugated fiberglass, were removed after each sampling to prevent long-term panel effects such as shading, edge scouring, and detritus accumulation (Childers & Day, 1988).

During each sampling period, an ISCO auto-sampler was placed at each end of the flume and programmed to collect a 1-liter water sample every 30 minutes from a single point inside the flume. Samples were collected simultaneously from each end of the flume during flood and ebb half tides. Samples were retrieved every 12 hours, packed in ice and transported to the laboratory for processing. In addition, we continuously monitored temperature, salinity, pH, conductivity and dissolved oxygen (DO) concentration of tidal creek surface water with a pre-calibrated mini-sonde. We also utilized data on water level and salinity collected continuously at SRS-6 as part of the FCE-LTER program. Lastly, the microtopography of the wetland within the flume was surveyed in August 2003 to build a detailed map of elevation. These elevation data were used in conjunction with water level data to estimate the volume of water in the flume during each sampling and the change in volume (volume flux) between samplings.

Laboratory Analyses

Water samples were filtered through pre-rinsed (triplicate 5 ml rinses with de-ionized water), pre-combusted (4 hr at 500°C) and pre-weighed 47 mm Whatman GF/F papers. Filtration was performed within 24 hr of collection and both filtered and unfiltered samples were refrigerated at 4 ºC in 125 ml bottles. Particulate matter trapped on the filter was dried at 70 ºC for 24 hr and weighed for calculation of total suspended sediment (TSS) concentration, then combusted (500 ºC for 4 hr) to determine losses on ignition.

DOC and TOC concentrations in filtered and unfiltered samples were quantified using high temperature catalytic oxidation (HTCO) and infrared detection with a Shimadzu TOC-5000.

Organic carbon concentrations were determined against potassium hydrogen phthalate standards. Samples were measured in triplicate with a fixed coefficient of variation of 2%. Duplicate samples were analyzed periodically to check for reproducibility of results and to evaluate the precision of measurements.

Statistical Analyses and Flux Calculations

Tidal (flood, ebb) and seasonal (dry, wet, 'Norte') differences in temperature, salinity, conductivity, pH, dissolved oxygen, [TSS] and [DOC] were analyzed using a two-way ANOVA to test for interaction effects of the two factors. In the case of unequal variances during the two-way ANOVA analysis, separate one-way ANOVA and LSD or Dunnett's T3 post-hoc tests ($p<0.05$) were used to analyze differences between seasons and simple one-way ANOVA tests ($p<0.05$) were used to analyze differences between flood and ebb tides.

We used formulas for 'instantaneous flux' and 'net flux' described in Childers & Day (1988) for this study. Net fluxes were obtained by adding flood and ebb instantaneous fluxes for each tidal cycle. We also employed an equation developed by Rivera-Monroy et al. (1995) for calculating net areal fluxes in a tidally flooded mangrove forest in Mexico (Equation 1).

$$\text{Net areal flux } (\text{g m}^{-2}\text{ h}^{-1}) = \frac{\text{total flux}_{\text{upstream}} - \text{total flux}_{\text{downstream}}}{\text{Flume area x total time}} \qquad (1)$$

Using a hypsometric approach, we inferred fluxes of water from changes in water level collected at 30-minute intervals during several whole-tides. Direct measurements of water level within the flume over the course of one complete tidal inundation were regressed with the continuous water level recorder data supplied by the FCE-LTER station along Shark River (SRS-6). The relationship generated was used to predict water level within the flume for all additional sampling periods. To best relate water level in a system with asymmetrical tides, we developed separate correlation curves for flood and ebb tides (adjusted R^2 values of 0.999 and 0.997 for ebb- and flood-tide correlations, respectively).

Paired t-tests between mean upstream and downstream organic carbon concentrations over each half tide were used to determine if fluxes of organic carbon within the flume were significant ($p<0.05$). We used instantaneous flux measurements from individually paired organic carbon concentrations to calculate total flux values independently for each half-tide. No difference in concentration between upstream and downstream pairs was interpreted as no net flux over a given half-tide (net area flux = 0 mg C $m^{-2}h^{-1}$). For example, higher concentrations during flood tide at the streamside end (upstream) indicated a net uptake of organic carbon by the wetland, while lower concentrations at the streamside end indicated a net release (Rivera-Monroy et al., 1995). We calculated net areal fluxes only when water was present at both ends of the flume and a significant difference in mean [DOC] was observed between paired upstream and downstream sample pairs.

RESULTS

The two-way ANOVA tests for half tide or seasonal differences in temperature, salinity, conductivity, pH, dissolved oxygen and [DOC] showed an interaction effect of half-tide and season, though all data exhibited unequal variance. One-way ANOVA tests indicated none of the variables, except pH, varied significantly between flood and ebb tides. The water column pH had a small range; however, and was circum-neutral (7.3–7.6) throughout the study period (Romigh, 2005).

We observed a trend of increasing salinity during flood tide and decreased salinity during ebb tide for all tides sampled, reflecting the estuarine nature of this site. The concentration and % saturation of DO in the water column was highest in May and lowest during October. DO saturation (%) also decreased with increasing duration of inundation, indicating oxygen depletion of the water column due to respiration.

Water temperature in the flume ranged from 17.9 to 30.6 °C and varied seasonally, typical of the regional climate (Figure 4a). Salinity in the flume ranged overall from 6.4 to 29.8 ‰. Lowest salinities were observed in the wet season when freshwater input from the Everglades was greatest (October), and highest salinities were recorded in the dry season (May; Figure 4b). Concentrations of both TSS and DOC were significantly different across samplings (Figures 4c,d). Overall, TSS concentrations varied between 1–192 mg l^{-1}. Significantly higher TSS concentrations occurred in May (mean = 112 mg l^{-1}), while concentrations were low in both October (mean = 22 mg l^{-1}) and December (mean = 24 mg l^{-1}; Figure 4d). DOC concentrations were significantly different between all seasons and ranged from 1.7 to 17.9 mg l^{-1}. Overall, [DOC] was highest in May and lowest in October (Figure 4c).

Significant changes in DOC concentration within the flume were observed for 50% of the tides sampled. More than 95% of the total organic carbon in the samples we collected was in the dissolved fraction. Given that the particulate fraction was so small and our sampling approach did not account for the macro-particulate fraction (leaves, seedlings, etc.), we only considered the dissolved organic fraction in the calculation of fluxes.

Fluxes

We were able to calculate net areal fluxes of DOC for 12 of the 15 tidal cycles measured in this study. Of those, export from the mangrove wetland was the majority of significant fluxes (Figure 5). Half-tide vertical DOC fluxes ranged from -5.52 to 8.9901 g C m^{-2} h^{-1} in May, -14.4591 to 1.3664 g C m^{-2} h^{-1} in October and -2.4017 to 3.7240 g C m^{-2} h^{-1} in December. Overall, total exchanges of DOC were greater at the creek-side end of the flume compared with the forest side.

Most fluxes calculated in the dry season indicated a net import of DOC to the mangrove wetland, with much of that occurring at the tidal creek end of the flume (Figure 5). The highest significant import of DOC to our mangrove site occurred during May sampling at 0.3227 g C m^{-2} h^{-1}. The tidal creek was the source of this material (Figure 5). We also measured a single instance of significant DOC export from the forest in May (Figure 5). Overall, the average import rate of DOC to the mangrove wetland during this dry season sampling was 0.0908 g C m^{-2} h^{-1}, and 86% of this import took place during flood tide.

There was a net export of DOC from our mangrove site at SRS-6 during the wet season. The highest export rate of DOC to the water column (-0.5784 g C m^{-2} h^{-1}) occurred in October, and the average of significant fluxes for this sampling was -0.0606 g C m^{-2} h^{-1} (Figure 5). Approximately, 65% of the DOC exported from the mangrove occurred during ebb tide, with the remainder being exported from the wetland within the flume and transported to interior forest during flood tide. Difficulties in sampling attributed to low tidal range during the December sampling resulted in the calculation of net areal flux for two of the four tidal cycles measured. These fluxes indicated both import and export of DOC with an average DOC import of 0.0265 g C m^{-2} h^{-1} during the ‘Norte’ season.

Relationships between DOC flux and half tide, season, and length of inundation were determined with one-way ANOVA, LSD post hoc analysis and correlation analysis ($p<0.05$). No significant relationship between DOC flux and half tide was determined. Net areal DOC flux (g m^{-2} h^{-1}) in the dry season was significantly different than in the wet and 'Norte' seasons, with net import occurring during the dry season. DOC import was positively correlated with [DOC] and DOC export was negatively correlated with [DOC] (Pearson's correlation, $p<0.05$). Instantaneous flux (g DOC s^{-1}) was negatively correlated with length of inundation. Within seasons, no significant relationship between [DOC] and length of inundation was determined.

To calculate an average yearly DOC flux, we took an average of the significant net areal fluxes measured in this study (-0.0403 g C m^{-2} h^{-1}), multiplied by the product of the average inundation period per tide (2 hr) and the approximate number of tides at the site during 2003 (696). Due to higher than average precipitation during the wet and dry seasons in 2003 and lower precipitation during the 'Norte' season (Figure 1), this estimate equally weights the length of each season in the calculation of an average annual net areal flux. The average inundation period per tide is the mean period of each high tide where we would be able to sample the flume using the approach we describe earlier. This is the point of the tide where approximately 10 cm of water covered each end of the flume. Note, this does not reflect the full duration of inundation that occurs at SRS-6. As a result our estimate is only applicable to the period of time around high tide and to the fringe forest around the area of the flume location. The result of this estimation was a net annual export of DOC from the fringe mangrove to both the tidal creek and basin mangrove forest (56 g C m^{-2} yr^{-1}).

DISCUSSION

The magnitude and direction of material fluxes in estuarine systems involve processes occurring at different spatial and temporal scales. Small-scale processes occurring directly at wetland interfaces (i.e. water-soil, water-atmosphere or soil-atmosphere) are influenced by short-term variability in environmental conditions (i.e., material concentration, wind and rain events, duration of inundation, flushing time). Intermediate-scale processes occurring across areas of similar or adjacent habitats (i.e. tidal creek-fringing wetland, fringing wetland-inland wetland) are influenced by longer temporal scale processes such as seasonal and annual variability in environmental conditions. At larger spatial scales, such as the interface between the mangrove forest and river, we see an incorporation of more general processes related to estuarine mixing and long-term climate patterns controlling carbon and nutrient dynamics.

Water flux estimates and paired upstream/downstream measurements of [DOC] in our study were used to quantify fluxes between the mangrove surface (soil, prop root, epibiont communities, etc.) and inundating water column of a riverine mangrove wetland. Sampling over multiple consecutive tides within a season allowed for the examination of short-term variability in flux that occurs in the natural environment. We measured vertical flux and found daily variability in DOC exchange between the mangrove soil and inundating water column. The differences in vertical fluxes between tides were attributed to the length of inundation and flushing rate of the mangrove soil and the DOC concentration in the water column. We also found seasonal variation in flux and found net import of DOC to the mangrove wetland during the dry season (May), net export to the inundating water column during the wet season (October), and import to the mangrove soil during the ‘Norte’ season (December) in 2003. We used vertical flux and directional flow measurements to calculate horizontal flux and found during the dry season, the net DOC import was mainly from the tidal creek during flood tide and during the wet season, the net export of DOC was mainly to the tidal creek from the wetland during ebb tide.

Particulate organic carbon (POC) can represent a significant amount of the organic matter export from mangrove systems, though it most often varies with season. Export of POC measured in an Australian riverine mangrove forest was 420 g C m^{-2} yr^{-1} (Boto & Bunt, 1981) whereas studies in Florida have measured 64 g C m^{-2} yr^{-1} (Twilley, 1985) and 186 g C m^{-2} yr^{-1} (Heald, 1971). For all sampling periods in our study, DOC accounted for >95% of the TOC in the water column. However, nets were not used in this study to capture leaf-size particulate matter, which may make up a significant portion of export from mangrove forests (Boto & Bunt, 1981; Twilley, 1985). Several other mangrove studies have also measured a high DOC fraction of TOC in the water column. Twilley (1985) estimated that up to 75% of all carbon exchanged in a basin mangrove forest in Florida was DOC, Davis et al. (2001b) estimated >90% of the TOC in mangrove island enclosures was DOC and Sutula et al. (2003) found that in Taylor River, Florida approximately 98% of TOC was dissolved.

Due to the sampling technique and asymmetrical tidal patterns, water samples could only be collected in the mangrove flume during high tide, and only during those high tides when the mangrove forest was inundated. Samples at the beginning and end of a high tide may have been influenced by the re-suspension of particulates produced by stronger currents flowing across the soil surface. However, no significant difference in organic carbon content was detected between filtered and unfiltered samples, indicating very low POC in the water column and little influence of particulate re-suspension on the water samples.

Concentrations of DOC in this riverine mangrove system were slightly higher than reported values for other mangrove systems (Table 1). At SRS-6, DOC concentrations were highest in May 2003, possibly due to relatively high litter fall production (4 gdw m^{-2} d^{-1}) that month (Twilley & Rivera-Monroy, unpublished data). Coincidentally, freshwater inflow was lowest—as indicated by salinity—and tidal amplitude was also quite low (0.7 m) during this sampling period.

Tidal amplitude and freshwater inflow play a factor in regulating DOC flux from estuarine wetland soils by influencing the amount of time the soil interacts with the inundating water column and by regulating the amount of water discharged across the surface. Increased freshwater input has been shown to increase DOC flux from estuaries to adjacent coastal waters, sometimes by as much as 300% (Miller, 1999). Vertical flux data in this study indicate that the highest export of DOC from the wetland soil to the inundating water column occurred during the wet season, when tidal amplitude was greatest (0.9 m) and freshwater inflow from the Everglades was highest. These flux results indicate DOC export from the wetland is controlled to a greater extent by freshwater discharge and tidal range, and is not necessarily positively correlated with DOC concentrations.

Flux estimates for our riverine fringe mangrove site were similar in magnitude to findings of previous mangrove carbon flux studies (Table 2). Seasonal fluxes indicated net import of DOC to the wetland soil during the dry season and export of DOC to the inundating water column during the wet season, with an overall net DOC export of 56 g DOC m^{-2} yr^{-1} from the mangrove wetland to the adjacent tidal creek. Based on leaching rates of mangrove litter (leaves and wood) from this site, leaching losses under conditions of inundation can account for about 43% of the DOC exported from the forest (Romigh, 2005). Previous estimates of total carbon export from mangroves range from 2 to 400 g C m^{-2} yr^{-1} with an average of about 200 g C m^{-2} yr^{-1}, while salt marshes typically export about half this amount (Twilley, 1998). In a 'eulerian', creek flux study in Australia, Boto & Wellington (1988) were unable to detect a net flux of dissolved materials (including DOC) from a fringe mangrove forest. However, the site they sampled received little or no freshwater inflows from adjacent uplands (Boto & Wellington, 1988).

Generally, terrestrially derived DOM undergoes conservative mixing down the estuarine gradient, forming an inverse linear relationship between salinity and concentration. A previous study conducted in Shark River, FL (Jaffe et al., 2004) found that fluxes of DOC are controlled to a great extent by discharge rather than concentration, indicating lower DOC concentration with increasing freshwater input. The wet and 'Norte' season data from our study show a similar inverse linear relationship of salinity vs. DOC, supporting these findings by Jaffe et al. (2004; Figure 6). Consistent high salinities (25–30 ‰)—due to low freshwater input to Shark River during May—coupled with high variation in DOC concentration indicate both import and export processes occurring at the wetland soil-water column interface even during the dry season. However, the non-linear relationship between salinity and DOC concentration during May might be an indication that these processes are not occurring at the same rate as those during other seasons. The energy signature of riverine mangrove forests is higher than in fringe, basin and scrub forests (Twilley, 1995), which may help explain why fluxes from the forest at SRS-6 were higher than those reported in other mangrove systems.

Conclusions

Results from our study support the hypothesis that highly productive, riverine mangrove forests are sources of organic carbon to adjacent coastal waters. The flux of DOC at the mangrove soil-water column interface is seasonal, perhaps in response to regional freshwater inflow, as inferred from Shark River salinity patterns. There was variation in the direction and magnitude of organic carbon flux between consecutive tides. However, when sampling over multiple tidal cycles, trends in DOC flux emerged—with import of DOC to the mangrove soil during the dry season and export to the water column during the wet season. Overall, this mangrove forest showed a net annual export of 56 g DOC m^{-2} yr^{-1}.

Import of DOC to the mangrove during the dry season and export during the wet season suggests that freshwater discharge may indeed have a strong influence on the direction of organic carbon flux to this system. It is unclear, however, whether carbon exchange between the forest canopy and atmosphere mimic these patterns. It is also unclear whether an increase in freshwater flow to the Everglades would significantly affect DOC flux.

This study only addressed a one-year period and cannot identify long-term trends in organic carbon flux for this system. Continued research would help determine the effect of long-term hydrologic influences (drought or regulated increases in freshwater flow) on carbon cycling in mangroves. Combining the quantitative flux data from the mangrove soil-water column interface with atmospheric flux data would certainly help to estimate the carbon budget in these wetlands.

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Table 1. Comparison of surface water DOC and TOC concentrations (in mg l^{-1}) from various mangrove studies.

Location	Wetland Type	Source	TOC	DOC
Florida	riverine mangrove	This study		1.7-17.9
Florida	dwarf & fringe mangrove	Sutula et al. (2003)		8.4-19.2
Zanzibar	fringe mangrove	Machiwa & Hallberg (2002)		0.78-1.28
Florida	fringe mangrove	Davis et al. (2001a)		8.4-21.6
Florida	dwarf mangrove	Davis et al. (2001b)	10.8-18	8.4-18
Brazil	riverine mangrove	Dittmar & Lara (2001)	7.20	4.32
Australia	fringe mangrove	Furukawa et al. (1997)	2.67	2.21
Bahamas	fringe mangrove	Moran et al. (1991)		2.3
Australia	fringe mangrove	Boto & Wellington (1988)		1-2
Florida	basin mangrove	Twilley (1985)	9.4-21	

Table 2. Estimates of net annual flux of TOC and DOC (g C m^{-2} yr^{-1}) from various mangrove wetlands.

Location	TOC	DOC	Method	Source
Florida		-56	flume	This Study
Florida	-7.1		creek flux	Sutula et al. (2003)
Florida		3.04	in-channel flume	Davis et al. (2001a)
Florida		- 381	mangrove enclosures	Davis et al. (2001b)
Florida	-64		flume	Twilley (1985)
Australia		7.3	creek flux	Boto & Wellington (1988)
World Average	-210		review of literature	Twilley (1998)

List of Figures

Figure 1. Seasonal pattern of mean (± sd) temperature (open squares) and precipitation (open circles) in south Florida from 1994–2003 (from USGS). Data from 2003 (closed circles) mirrored the seasonal pattern exhibited across this 10-year record.

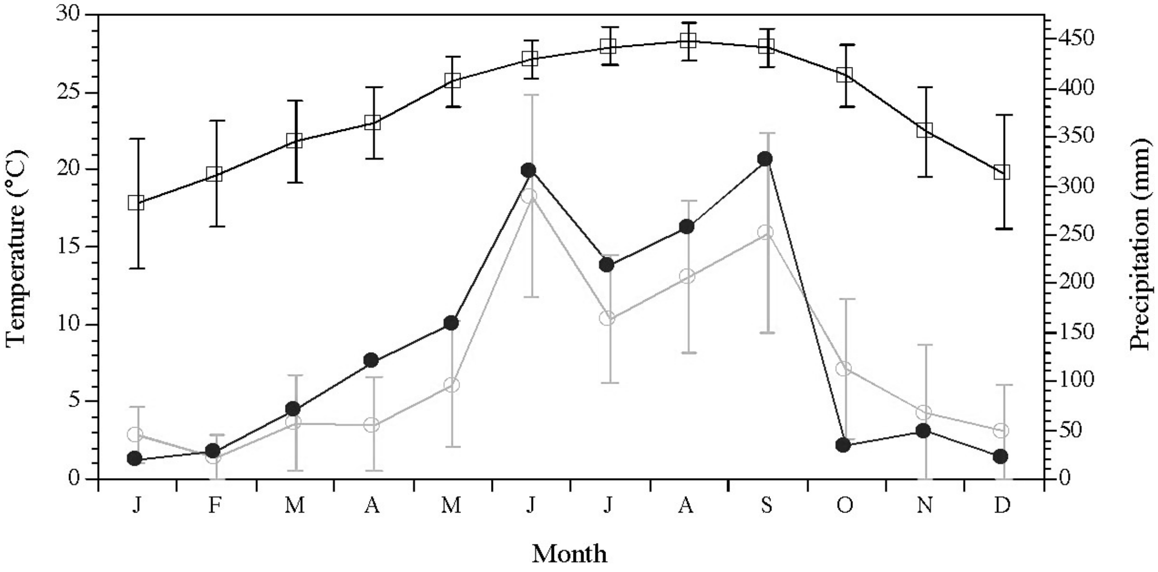
Figure 2. Map of South Florida with the location of the experimental flume study site (SRS-6) along Shark River (Everglades National Park).

Figure 3. Plots of predicted water level in the flume during each 2003 sampling event. Flume water levels calculated from a regression relationship between periodic flume water level measurements and a permanent gauge along Shark River (SRS-6).

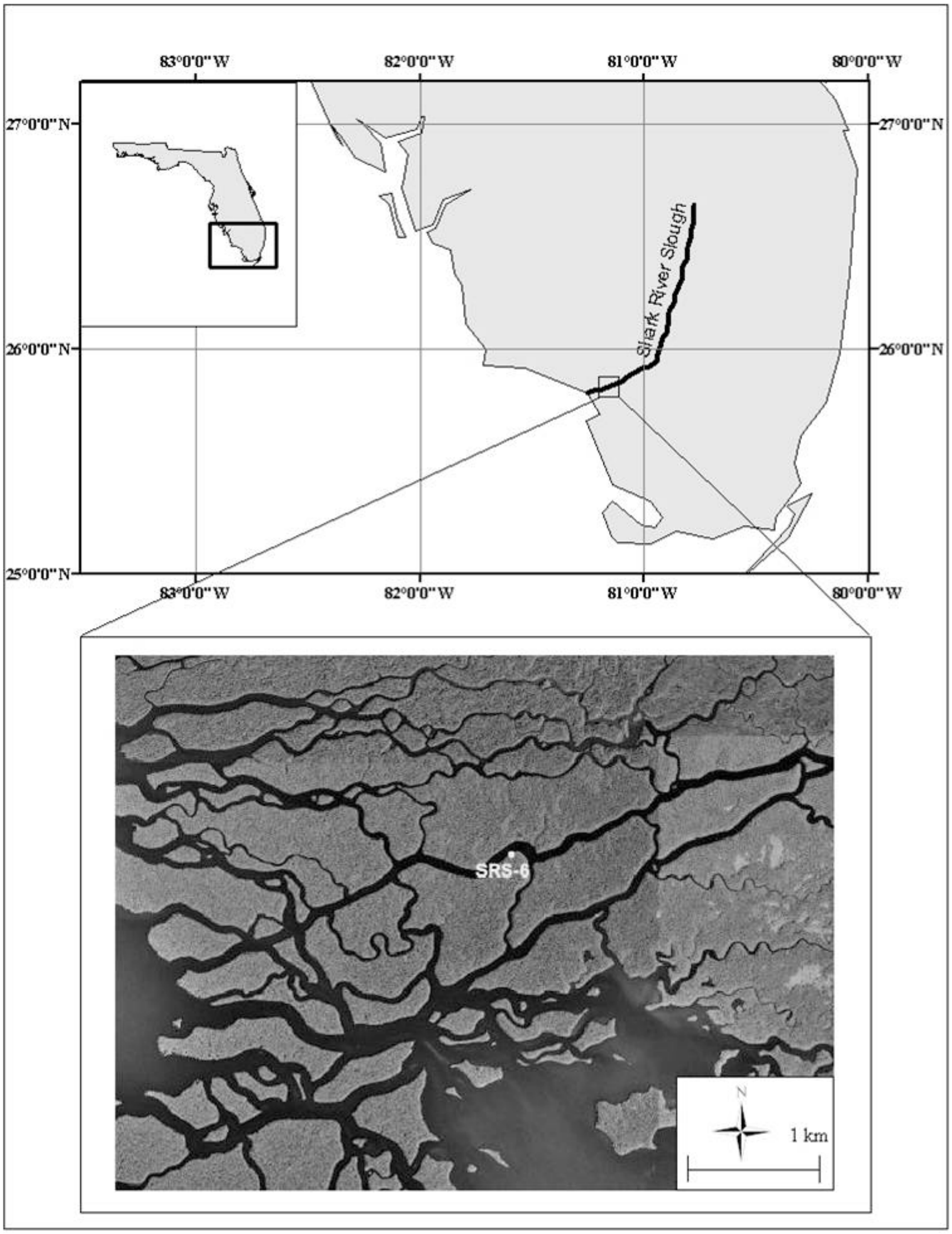
Figure 4. Box-and-whisker plots of (a) temperature, (b) salinity, (c) DOC concentration and (d) TSS concentration at the study site for each 2003 sampling. Different letters indicate significant differences among sampling periods (ANOVA, $p<0.05$).

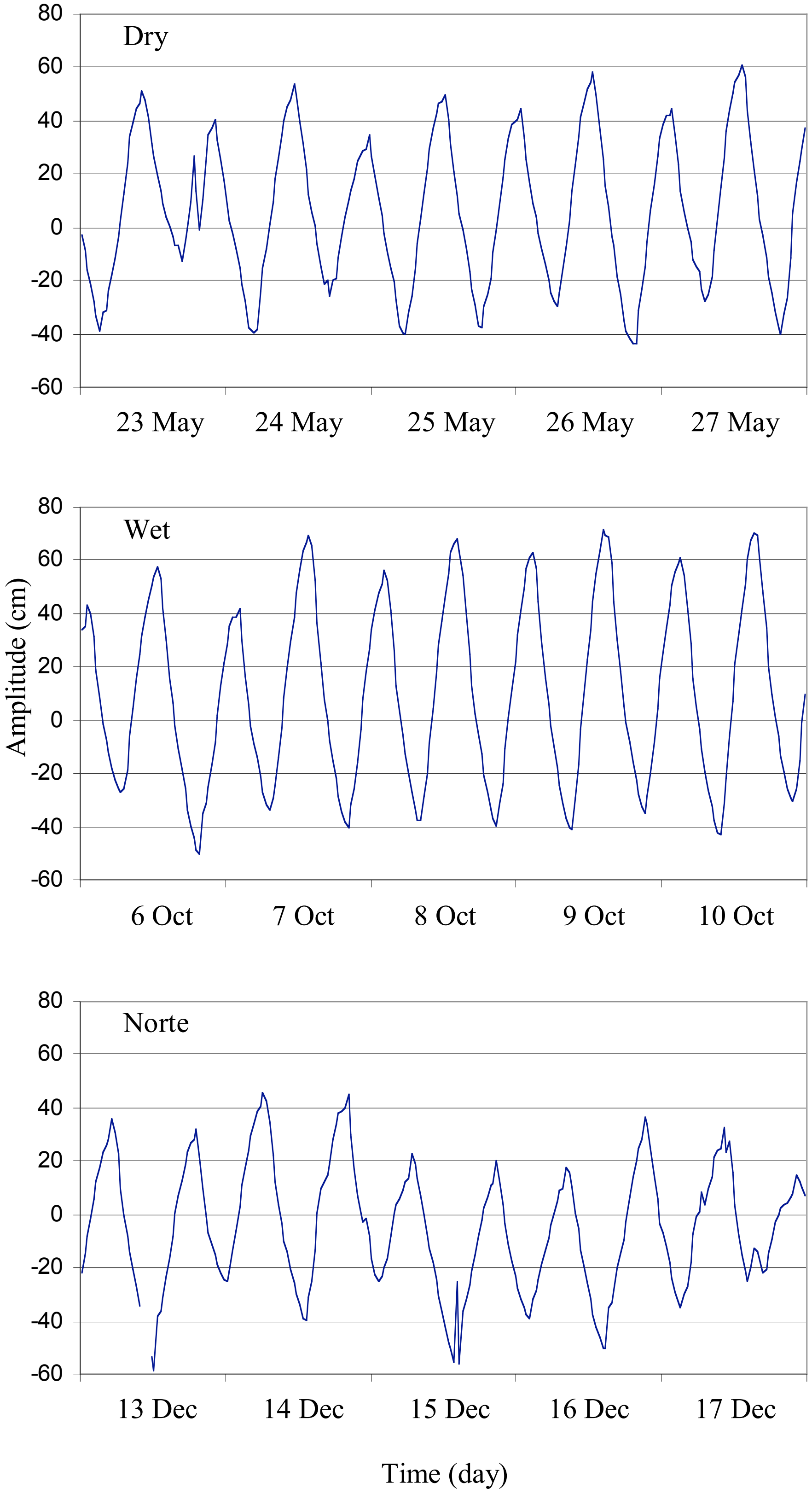
Figure 5. Net areal fluxes of DOC measured in each tidal cycle of the 2003 sampling periods (M = May, O = October, and D = December). Positive values indicate uptake by the wetland; negative values indicate release to the inundating water column. Asterisks indicate fluxes that were not significantly different from zero. 'nd' = No flux data.

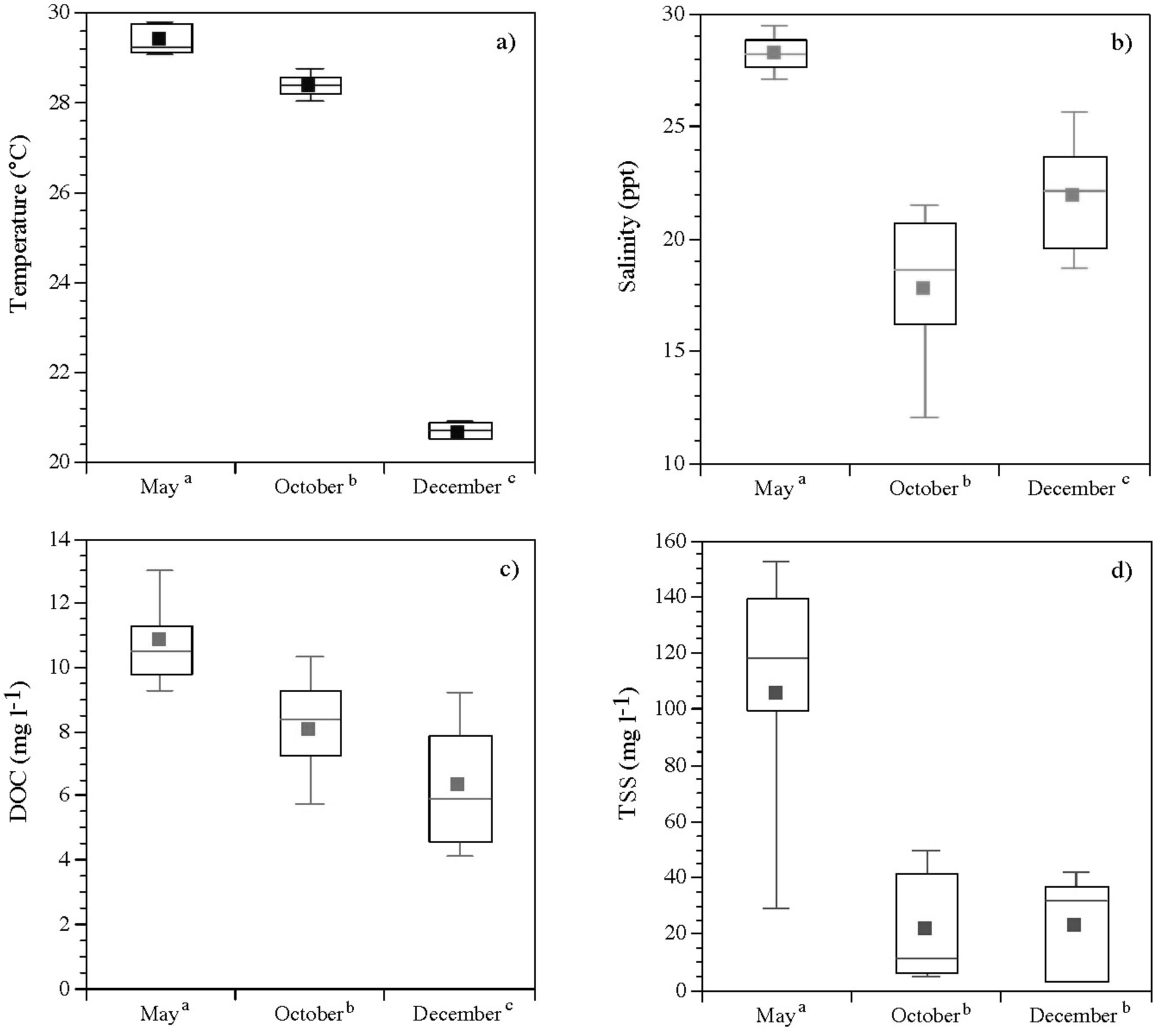
Figure 6. Scatter plot of salinity vs. DOC concentration at SRS-6 for all three sampling periods in 2003.



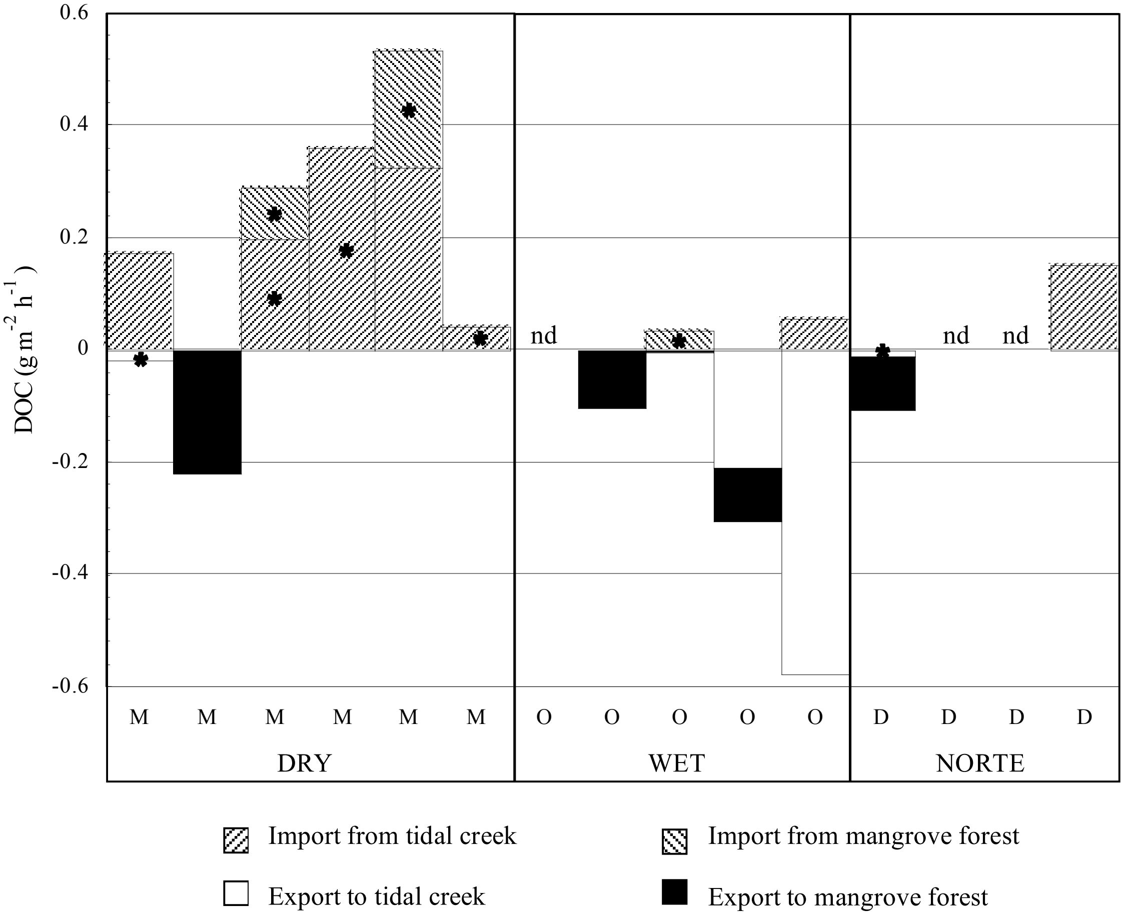
Temperature (°C)
Precipitation (mm)
Month
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
400
450
J
F
M
A
M
J
J
A
S
O
N
D


83°0'0" W
82°0'0" W
81°0'0" W
80°0'0" W
27°0'0" N
26°0'0" N
25°0'0" N
Shark River Slough
SRS-6
N
1 km

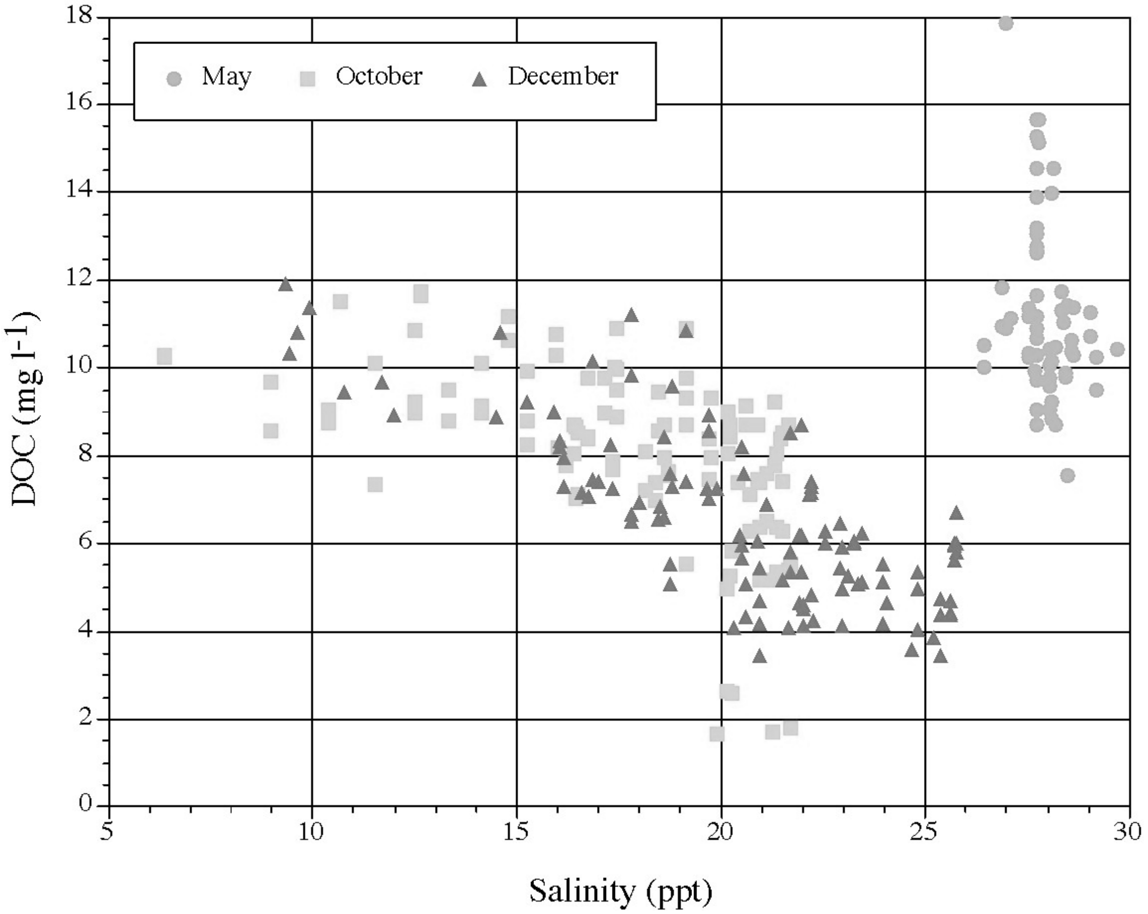

Dry
Wet
Norte
Amplitude (cm)
80
60
40
20
0
-20
-40
-60
23 May
24 May
25 May
26 May
27 May
6 Oct
7 Oct
8 Oct
9 Oct
10 Oct
13 Dec
14 Dec
15 Dec
16 Dec
17 Dec
Time (day)


a)
Temperature (°C)
20
22
24
26
28
30
May a
October b
December c
b)
Salinity (ppt)
10
15
20
25
30
May a
October b
December c
c)
DOC (mg l-1)
0
2
4
6
8
10
12
14
May a
October b
December c
d)
TSS (mg l-1)
0
20
40
60
80
100
120
140
160
May a
October b
December b

2



0.6
0.4
0.2
0
-0.2
-0.4
-0.6
DOC (g m^{-2} h^{-1})
nd
nd
nd
M M M M M M
O O O O O
D D D D
DRY
WET
NORTE
▨ Import from tidal creek
▨ Import from mangrove forest
☐ Export to tidal creek
■ Export to mangrove forest


May
October
December
DOC (mg l-1)
Salinity (ppt)
0
2
4
6
8
10
12
14
16
18
5
10
15
20
25
30