Dial organic carbon fluctuations in a mangrove tidal creek in Sepetiba bay, Southeast Brazil

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Abstract

The carbon (C) concentration and flux, as dissolved organic carbon (DOC), particulate organic carbon (POC) and macrodetritus (MD), were quantified through 4 tidal cycles in a mangrove tidal creek in Southeastern Brazil. DOC was the major fraction of the total C concentration, accounting for 68 and 61% of the total C concentration during ebb and flood periods respectively. Concentrations of DOC (Ebb = 3,41 ± 0,57 mgC.L^{-1} and Flood = 3,55 ± 0,76 mgC.L^{-1}) and POC (Ebb = 1,73 ± 0,99 mgC.L^{-1} and Flood = 1,28 ± 0,45 mgC.L^{-1}) were relatively similar during the four tidal cycles. Macrodetritus presented a wide variation with concentration peaks probably related to external forces, such as winds, which enrich the ebb flow with leaf litter. DOC and POC fluxes depended primarily on tidal and net water fluxes, whereas MD fluxes were not. The magnitude of the DOC and POC fluxes varied with the area flooded at high tide, but not the MD fluxes. DOC was the major form of carbon export to Sepetiba Bay. During the four tidal cycles, the forest exported a total of 1,2 kg of organic carbon per ha, mostly as DOC (60%), followed by POC (22%) and MD (18%).

Keywords: dissolved organic carbon, macrodetritus, mangrove tidal creek, particulate organic carbon.

Flutuações diurnas do carbono orgânico em um canal de maré na Baía de Sepetiba, SE Brasil

Resumo

As concentrações e fluxos de carbono orgânico sob forma de carbono orgânico dissolvido (COD), carbono orgânico particulado (COP) e macrodetritos (MD) foram quantificadas durante 4 ciclos de maré em canal de maré na Floresta Experimental de Itacuruçá, Baía de Sepetiba, RJ, litoral sudeste do Brasil. COD foi a fração mais importante para a concentração total de carbono orgânico, contribuindo com 68 e 61% da concentração total de C nos períodos de maré vazante e enchente, respectivamente. As concentrações de COD (vazante = 3.41 ± 0.57 mgC.L^{-1} e enchente = 3.55 ± 0.76 mgC.L^{-1}) e COP (vazante = 1.73 ± 0.99 mgC.L^{-1} e enchente = 1.28 ± 0.45 mgC.L^{-1}) foram similares durante os 4 ciclos de maré. A fração macrodetritos apresentou uma ampla variabilidade com máximos de concentração relacionados a fatores externos como ventos, que enriqueceram as águas de vazante com macrodetritos. A magnitude dos fluxos de COD e COP, mas não os de macrodetritos, relacionaram-se com os fluxos de água e a conseqüente área inundada pela maré. A fração COD foi a mais importante forma de exportação de carbono orgânico pelo manguezal. Durante os 4 ciclos monitorados, a floresta exportou um total de 1.2 kg de carbono orgânico, 60% sob forma de COD, seguido pelo COP (22%) e pela fração macrodetritos (18%).

Palavras-chave: carbono orgânico dissolvido, macrodetritos, carbono orgânico particulado, manguezais.

1. Introduction

Mangrove ecosystems dominate most tropical coasts. They grow along the depositional environments in protected coastal areas, in estuaries and lagoons, where, once established, they accelerate sediment accretion, by trapping suspended matter and decreasing erosion. Mangroves are exposed to tidal fluctuations and corresponding variability in salinity and water sources. Therefore, the dynamics of water and inorganic and organic compounds depend on interactions controlled by tides, runoff, seasonal fluctuations, and meteorological events (Ovalle et al., 1990; Woodroffe, 1985a,b).

Many studies have focused on the fate of particulate organic carbon (POC) and dissolved organic carbon (DOC) in temperate estuaries and salt marshes (Taylor and Allanson, 1995). However, the fate of organic carbon in mangrove ecosystems has been mostly studied based on a single component analysis with most studies dealing with macrodetritus (MD) balances only. Few studies monitored the transport of the 3 carbon forms simultaneously. Therefore no generalisations regarding export/import of carbon can be made, although the productivity of mangrove ecosys-

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square frame (0.25 m^2); with nylon net of 1.0 mm mesh size fixed on a pole, but allowed to rotate according to water flow direction, adapted from Bach et al. (1986).

Macrodetritus included different plant parts (leaves, branches and reproductive parts) and were cleaned using local seawater and at the laboratory with distilled water.

POC in suspended matter samples, were separated using a pre-weighted GF/C filter. Total organic carbon concentration in POC and MD, were determined by dichromate oxidation following Stricland and Parsons (1972). For all POC determinations a blank of clean filters were analysed simultaneously. Reproducibility of POC and MD analysis were estimated using 4 replicates, giving coefficients of variation smaller than 5%. DOC was determined directly in the filtered samples preserved in phosphoric acid (10% H$_3$PO$_4$; 50 μL.mL^{-1}). Filtrate was stored refrigerated in amber bottles. DOC analyses were performed after further sample acidification (2 N HCl) and sparing with ultra pure air, by high temperature catalytic oxidation with a Dohrman DOC-190. The reproducibility of DOC analysis was estimated using 3 replicates, giving coefficients of variations smaller than 2%.

Flux rates were continuously monitored using a General Oceanics® current meter installed at the center of the creek and 0.3 m above the bottom. Similar to the organic carbon sampling strategy current velocity and water level were measured every 30 minutes. A microtopographic mapping of the forest floor (Ovalle, 1992), allowed the estimation of flooded forest area relative to creek depth at each sampling interval.

4. Results and Discussion

A summary of the study results are shown in Table 1. During flood periods, the maximum flooded mangrove area ranged from 6.6 to 9.0 ha, with maximum creek depth reaching 1.8 m. The maximum flooded area (9.0 ha) included a low *L. racemosa* mangrove forest and salt pans located behind the *R. mangle* forest. Highest current velocities occurred during flood periods. Maximum water fluxes ranged from 108 to 380 dm^3/s during flood periods, whereas during ebb periods maximum fluxes were smaller, ranging from 80 to 350 dm^3/s, depending on the tide (Figure 2).

Water flux fluctuations during the four tidal cycles showed that 82% of the total amount of water flowing during each cycle was moved during only 42% of the tidal cycle time. This agrees with hydrochemical results obtained by Ovalle et al. (1990) for the same forest. Discharge pulses occur at the end of flood periods and at the beginning of ebb periods. The tidal flow will always occur in a matter of minutes, when the pressure gradient changes direction and a turbulent mixing occurs affecting the nepheloid layer at the sediment-water interface. This may eventually affect POC concentrations due to ressuspension of bottom sediments and DOC through migration of C-enriched porewaters (Lee, 1995). The water dynamics during the four tidal cycles were similar

Table 1. Major variables measured at the mangrove tidal creek at the Itacuruçá Experimental forest, SE Brazil. Mean (X), standard deviation (SD) and ranges, relative to 4 tidal cycles.

Tidal Period	Flooded area (ha)	Creek depth (m)	Flux (dm^3.s^{-1})	DOC (mgC.L^{-1})	POC (mgC.L^{-1})	MD (mgC.L^{-1})
Ebb						
X±SD	3.30 ± 2.54	1.36 ± 0.25	−72 ± 117	3.41 ± 0.57	1.73 ± 0.99	0.75 ± 0.94
range	0 to 8.67	0.81 to 1.82	−1 to −346	2.30 to 4.60	1.20 to 3.29	0 to 3.24
Flood						
X±SD	4.34 ± 2.65	1.45 ± 0.27	+78 ± 125	3.55 ± 0.76	1.28 ± 0.45	0.93 ± 1.20
range	0 to 9.04	0.81 to 1.85	+1 to +380	2.30 to 5.30	0.80 to 2.60	0 to 4.34
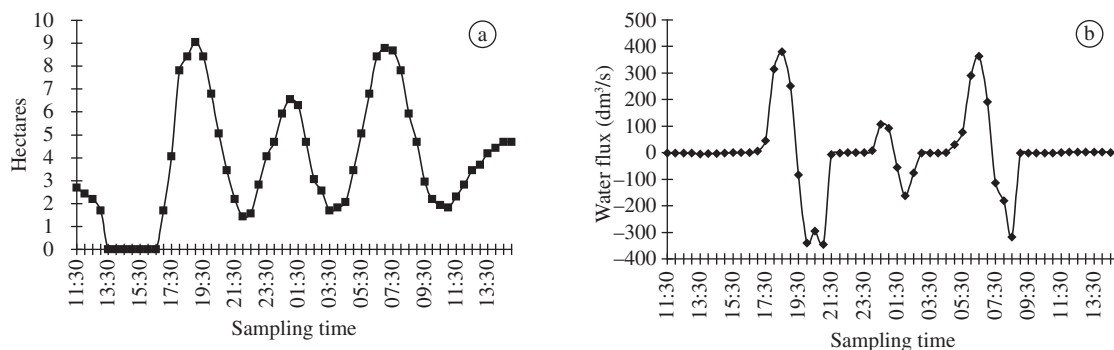
Figure 2. Flooded area (a) and water flux (b) during the tidal cycles at the Itacuruçá Experimental Forest.

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to the dynamics observed during three years of monitoring at this site (Rezende, 1988; Lacerda et al., 1988; Ovalle et al., 1990; Ovalle, 1992; Silva, 1992).

The variation of carbon concentrations in the three different fractions are presented in Figure 3. The larger proportion of the total organic carbon concentration was in the DOC fraction. DOC concentrations were rather constant throughout the cycles, with average concentrations of 3.4 and 3.6 mgC.L^{-1} during ebb and flood periods respectively. Variation of DOC concentrations showed no relationship with tidal period. These concentrations averaged 68 and 61% of the total carbon concentration during ebb and flood periods respectively.

Average POC concentrations were higher during ebb periods, ranging from 1.2 to 3.3 mgC.L^{-1}, whereas during flood periods, average of POC concentrations ranged from 0.8 to 2.6 mgC.L^{-1}. Average POC concentrations were 1.4-times higher and maximum concentrations 2.3-times higher, during ebb periods (Table 1) and accounted for 17 and 23% of the total carbon concentration. Since ebb-period POC in this creek is over 80% of mangrove origin (Rezende et al., 1990), these
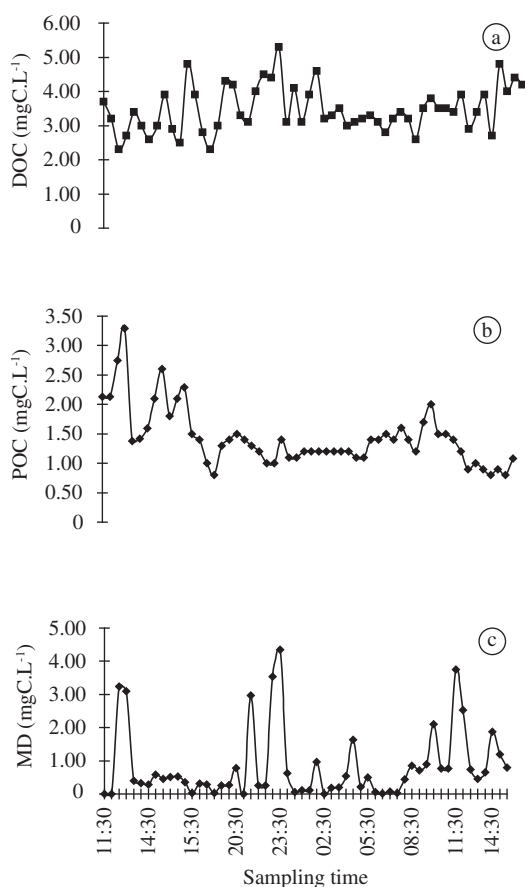
higher concentrations during ebb periods imply a net export of mangrove POC to adjacent coastal waters. A peak concentration of 6.1 mgC.L^{-1}, occurred with very low creek depth, suggesting remobilization of bottom sediments, when water flux changes direction, as suggested by Lee (1995).

The DOC/POC ratio in the mangrove creek was relatively constant (2.2 and 2.5 for ebb and flood period respectively), showing that DOC is an important component in organic carbon balance studies in this ecosystem. This ratio was found to be the around 1.4 in main rivers discharging into Sepetiba Bay, but with a larger variation (0.5 to 2.0) (Rezende, 1993). Although the DOC concentration in the four major rivers of Sepetiba Bay are lower than in the mangrove areas, these rivers can affect the DOC and POC ratios in the Bay. These rivers together contribute 96% of fresh water and particulate matter entering the Bay and can represent a significant source of organic material derived from continental soils and terrestrial vegetation (Rezende, 1993). It is clear however, that the mangrove forest can produce a localised enrichment of DOC in bay waters adjacent to IEF.

Carbon concentrations as MD showed larger variation when compared with POC and DOC. Average MD concentration for the 4 tidal cycles varied from 0.8 and 0.9 mgC.L^{-1}, during ebb and flood periods respectively. However, isolated peaks as high as 4.5 mgC.L^{-1}, occurred but were not related to tidal fluctuation. This resulted in large variability (125%) suggesting that significant amounts of MD can be mobilised instantaneously and may be transported during ebb periods to adjacent areas, where it can be degraded and later becomes a source of POC and/or DOC to the mangrove itself. On the other hand, MD is more likely a significant source of carbon to coastal marine sediments. Boto and Bunt (1981) proposed MD to be the most important carbon fraction transported in an Australia mangrove system and carbon isotopic studies at the IEF, also showed that over 99% of the C buried in mangrove sediments is derived from mangrove MD (Lacerda and Rezende, 1987; Lacerda, 1998). The MD transport is limited by litter fall production, mangrove structure, deposited leaves on the mangrove soil surface, activity of crabs, and tidal energy (Kjerfve, 1990; Silva, 1988; Robertson, 1986).

Variations of the DOC, POC and MD fluxes through the tidal creek during the four tidal cycles are showed in Figure 4. Fluxes of DOC and POC presented peaks simultaneous with water discharge pulses. However, MD fluxes exhibited peaks simultaneous with discharge pulses only during the ebb tide, except during the first cycle when a small peak occurred during flood tide, probably as a result of washing out the mud flats. Silva et al. (1993) showed that litter transport in this same creek is largely influenced by the occurrence of mangrove MD deposited on mud flats located in front of the mangrove forest fringe, which frequently returns to the creek with the incoming tide.

Figure 3. Variations of organic carbon concentrations as dissolved organic carbon (a), particulate organic carbon (b) and macrodetritus (c) during four tidal cycles at the Itacuruçá Experimental Forest.

Carbon fluxes correlate with the inundated forest area (Figures 5a and 5b). During flood periods (Figure 5a) the fluxes of the three different C fractions show a significant positive exponential correlation (P < 0.01) with the inundated area, in particular DOC and POC that are extremely dependent on water fluxes. During the ebb period (Figure 5b) however, the dynamic of inundation pulses is more important than the total surface area flooded. At the early stage of the flood period when about 3 ha of the IEF are inundated, the magnitude of C fluxes varied very little, since this area includes mostly the creek itself and marginal sediments. When the flooded area extends from 3 to 8 ha and therefore including the dense mangrove forest, the C transported through the creek showed
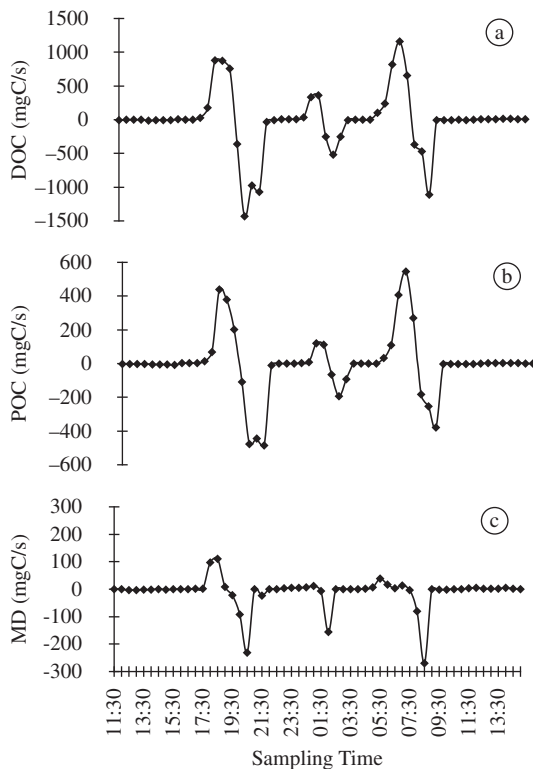
a strong increase. This threshold-like behavior has been shown as an important nutrient transfer mechanism from mangroves to tidal creeks (Cohen et al., 2004). When flooded areas are larger than 8 ha, however, no increase in C fluxes is verified, since the new flooded areas include salt pans and some of the marginal sands that due to its low C content promoted a marked dilution in carbon fluxes.

The MD fluxes show a weaker correlation with the extension of the flooded area when salt pans data are included. However, if only creek and dense mangrove zones are included (flooded area < 8 ha), the correlation turns more significant, since litter fall is directly related to high tree density and productivity of these areas (Silva et al., 1991). Moreover, strong winds and crab activity may significantly affect MD transfer to the creek, independent of the flooded area (Silva et al, 1993; Silva, 1994).

The amount of organic carbon transported during the four cycles studied and the total of the entire sampling period are showed in the Table 2. The pattern observed during ebb and flood periods was similar for DOC and POC alternating net flux of export (–) and import (+), depending on tidal flow direction. MD however, was exported from the forest even during one cycle with net water import, probably in response to winds. DOC presented the highest flux values per cycle, being 2 to 6 times and 2 to 18 times higher than the amount of POC and MD respectively, for each cycle. However, the total amount of carbon exported from the mangroves for the four tidal cycles period was dominated by MD (0.99 kg), followed by DOC (0.76 kg). There was nearly no net export of POC from this forest during the four tidal cycles.

When the amount of carbon transported is normalised for area (kg.ha^{-1}; Table 2), however, DOC clearly dominates the carbon export, followed by POC and MD. This is due to the relationship between DOC and POC with flooded area. Of interesting notice is the net import of water during the four cycles, strengthening the role of the forest as a net exporter of organic carbon. Earlier studies showed little agreement in considering mangroves as net exporters or importers of organic carbon. However, the high productivity of mangroves has often been related to the exportation of organic material to coastal waters (Alongi et al., 2004). The applicability of this generalisation is hampered by the existence of only a few studies that simultaneously analysed the transport

Figure 4. Variations of organic carbon fluxes as dissolved organic carbon (a), particulate organic carbon (b) and macrodetritus (c) during four tidal cycles at the Itacuruçá Experimental Forest.

Table 2. Mass balance of organic carbon as dissolved organic carbon (DOC), particulate organic carbon (POC) and macrodetritus (MD), after four tidal cycles.

Cycle	DOC (kg)	POC (kg)	MD (kg)	DOC (kg.ha^{-1})	POC (kg.ha^{-1})	MD (kg.ha^{-1})	Water (m^3)
1st	+4.81	+1.93	+0.38	+0.64	+0.26	+0.04	+1,771
2nd	−5.64	−2.31	−0.61	−1.17	−0.50	−0.12	−1,553
3rd	+3.49	+1.81	−0.15	+0.31	+0.19	−0.04	+1,184
4th	−3.42	−1.46	−0.61	−0.51	−0.21	−0.09	−1,083
Σ	−0.76	−0.03	−0.99	−0.73	−0.26	−0.21	+319

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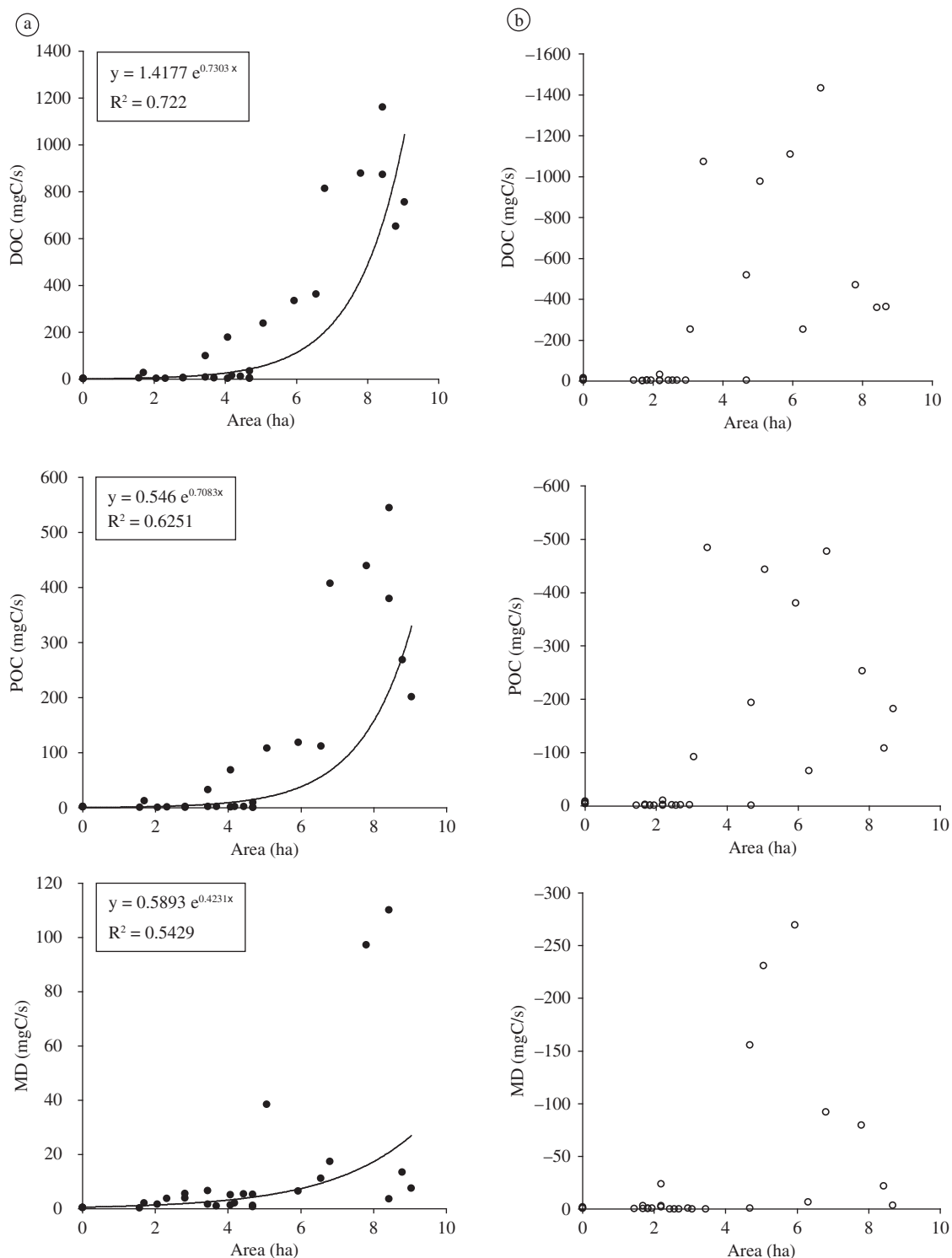
Figure 5. Trends of organic carbon fluxes and inundated area during flood a) closed circles and ebb b) open circles periods of the Itacuruçá Experimental Forest.

of all fractions of organic carbon. In this study, notwithstanding its short duration, we have shown that different fractions of the total organic carbon behave differently and, most important, are controlled by different envi-

ronmental variables (e.g. flooded area extension, mostly DOC; vs external forces, such as wind, mostly MD). On the other hand, our results agree with salt marsh studies (Taylor and Allanson, 1995; Williams et al., 1992; Dame

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et al., 1991) and a few mangrove studies (Twilley, 1985; 1988; Alongi et al., 2004), highlighting the importance of DOC as the major organic carbon fraction exported from mangroves.

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