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Influence of water management and natural variability on dissolved inorganic carbon dynamics in a mangrove-dominated estuary

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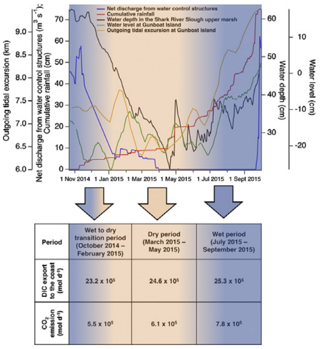
HIGHLIGHTS

- Describes the effect of water management on inorganic carbon fluxes in the Shark River estuary
- First ever estimate of mangrove estuary inorganic carbon fluxes during a year
- Estimates the social cost associated with carbon fluxes
- Relevant application to develop sustainable water management strategies

GRAPHICAL ABSTRACT



Period	Wet to dry transition period (October 2014 – February 2015)	Dry period (March 2015 – May 2015)	Wet period (July 2015 – September 2015)
DIC export to the coast (mol d^{-1})	23.2×10^5	24.6×10^5	25.3×10^5
CO_2 emission (mol d^{-1})	5.5×10^5	6.1×10^5	7.8×10^5

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ABSTRACT

High-resolution time series measurements of temperature, salinity, pH and pCO_2 were made during the period October 2014–September 2015 at the midpoint of Shark River, a 15 km tidal river that originates in the freshwater Everglades of south Florida (USA) and discharges into the Gulf of Mexico. Dissolved inorganic carbon dynamics in this system vary over time, and during this study could be classified into three distinct regimes corresponding to October 2014–February 2015 (a wet to dry season transition period), March–May 2015 (dry period) and July–September 2015 (wet period). Average net longitudinal dissolved inorganic carbon (DIC) fluxes and air-water CO_2 fluxes from the Shark River estuary were determined for the three periods. Net DIC fluxes to the coast were estimated to vary between 23.2 and 25.4 × 10^5 mol d^{-1} with an average daily DIC flux of 24.3 × 10^5 mol d^{-1} during the year of study. CO_2 emissions ranged between 5.5 and 7.8 × 10^5 mol d^{-1} with an average daily value of 6.4 × 10^5 mol d^{-1} during the year. The differences in estuarine carbon fluxes during the study period are attributed to differences in the relative importance of hydro-climatological drivers. Results suggest that, during months characterized by reduced rainfall, carbon fluxes are affected by water management via control structures in the upstream Everglades marshes. During months with high rainfall, when culverts are closed and rainfall events are more frequent, carbon fluxes depend more on other forcings, such as rainfall and groundwater discharge.

1. Introduction

Mangrove ecosystems, situated along tropical and subtropical coastlines, are important transition zones between the land and the ocean

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(Alongi, 2012). They provide valuable ecosystem services, such as protection of the coastal zone, nursery ground for juvenile fish, and areas for subsistence and recreational fishing (e.g., Bouillon et al., 2008; Fedler, 2009). Moreover, they act as important modulators of carbon fluxes from the land to the ocean, due to their high productivity and carbon sequestration rates, as well as rapid cycling of organic and inorganic carbon (Twilley et al., 1992; Jennerjahn and Ittekkot, 2002; Dittmar et al., 2006; Alongi, 2012). Therefore, mangrove ecosystems may play an important role in the global carbon budget and the climate system and, ultimately, in mitigating climate change (Nellemann et al., 2009). Although it is difficult to assess the value of non-market ecosystem services provided by mangroves, such as their role in the global carbon budget, Stern (2006) suggested a carbon sequestration value of about $17,500 per hectare. This estimate highlights the importance of good management practices to prevent the further loss and degradation of these ecosystems and to catalyze their recovery.

The largest contiguous mangrove forest in North America extends along the southwest coast of Florida (USA). The forest receives significant surface and groundwater discharge from the inland freshwater marshes of Everglades National Park (ENP; Smith et al., 2016). Surface water flows into these marshes across the upstream boundary of ENP are highly regulated. Since the late 1990s, ENP has been a primary focus of the Comprehensive Everglades Restoration Plan (CERP), a multi-billion dollar effort to improve the quality, quantity, timing, and distribution of surface water flows (called sheet flow) in the freshwater marshes of the Everglades. Altered sheet flow patterns in this system are the result of many, often competing, regional water distribution and allocation targets for drinking water supply, flood control, and ecological requirements. Water depths, hydroperiods and salinity conditions in the mangrove ecotone, located at the downstream terminus of the Everglades, are affected by upstream water management decisions, which alter the natural freshwater flow volume, duration and distribution. As a consequence, these hydrological conditions will likely change significantly as a result of large-scale efforts such as CERP. This coastal system will also be impacted by sea level rise, adding uncertainty to predictions of future hydrologic conditions. An improved understanding of mangrove responses to changing freshwater discharge, including potential changes in carbon dynamics, is needed. Furthermore, carbon accounting could help to inform future CERP cost-benefit analysis, given the high social cost of adding CO_2 to the atmosphere, as well as the ecosystem service benefits derived from carbon burial in the organic soil of the mangrove forest.

Jerath et al. (2016) estimated the total organic carbon storage of the Everglades mangrove forest at a median value of 335.6 MgC ha^{-1} (33,560 gC m^{-2}). Barr et al. (2010), using eddy covariance-based estimates of net ecosystem CO_2 exchange and information on forest-soil carbon accumulation rates, calculated very high levels of annual net ecosystem production, with values up to 1,100 gC m^{-2} y^{-1} (11 MgC ha^{-1} y^{-1}) in a part of the mangrove forest in western ENP. Additionally, they indicated that the carbon budget in this forest could be strongly affected by environmental drivers, such as the inundation frequency, due to its control on the lateral carbon flux from the forest to the adjacent estuarine waters. They concluded that a significant portion of ecosystem respiratory CO_2 fluxes were exported as dissolved inorganic carbon (DIC) from the forest as a result of tidal inundation, and suggested that eddy covariance-based estimates of carbon accumulation potential of this ecosystem could be lower if accounting for these fluxes. Since 80% of the total, and 90% of the mangrove-derived dissolved carbon in the Shark River Estuary is in the form of DIC, and between 13 and 21% of the total DIC in the Shark River estuary returns to the atmosphere as CO_2 (Ho et al., 2017), the focus here is on DIC dynamics and fluxes.

Currently, little information is available to constrain long term longitudinal DIC fluxes (i.e., export from the estuary to coastal waters), and further investigations of the relationships between variability and magnitude of carbon fluxes and freshwater discharge over seasonal and annual periods are needed to better understand the carbon budget in this and other mangrove ecosystems. Here, the relationships between carbon fluxes from the Shark River estuary and hydrodynamic drivers, including freshwater management at the upstream boundary of ENP, are investigated. A better understanding of these linkages may help to predict the impacts of freshwater restoration plans on estuarine carbon dynamics. In particular, increasing freshwater discharge from the upstream water control structures into ENP, as currently planned by CERP, would increase the overall freshwater input into the Shark River Slough (SRS) and, potentially, the inorganic carbon flux from the Shark River estuary to the Gulf of Mexico (GOM) and the atmosphere. Moreover, since hydrodynamic regimes in Shark River estuary differ during different times of the year as a result of different tidal forcings and freshwater inputs, the effects of restoration on inorganic carbon fluxes in the Shark River estuary may vary seasonally.

The goals of this study are to determine air-water CO_2 flux and longitudinal DIC flux to the GOM from a mangrove-dominated estuary, the Shark River in ENP, and to investigate the role of hydro-climatic conditions in governing the inorganic carbon dynamics over seasonal and annual timescales. Freshwater inflow from upstream marshes, current velocities, and wind are recognized as the main drivers in controlling the Shark River discharge to the GOM (Levesque, 2004). As a consequence, the analysis here explicitly accounts for these forcings and is extended to include additional hydrodynamic drivers, such as marsh water levels and managed discharges from water control structures in the uppermost region of ENP.

Longitudinal DIC and air-water CO_2 fluxes are computed from automated high-resolution measurements of pH and CO_2 partial pressure (pCO_2) at a fixed station located in the middle of the estuary (i.e., Eulerian framework). Here, fluxes integrate hydrodynamic and biogeochemical processes operating upstream and downstream of the mid-estuary station (e.g., Bergamaschi et al., 2012). Correlations between inorganic carbon fluxes and environmental controls are then analyzed, and results are discussed in the context of future management strategies. Finally, the economic significance of longitudinal DIC and air-water CO_2 fluxes is examined.

2. Materials and methods

2.1. Study site

Measurements were made at a midpoint station (Gunboat Island, GI) in the Shark River (Fig. 1), a tidal estuary located at the downstream terminus of Shark River Slough, the primary drainage feature of ENP (Saha et al., 2012). The Shark River begins at Tarpon Bay and flows for approximately 15 km into the GOM. The system experiences semidiurnal tides, with a mean amplitude of ca. 1 m (Ho et al., 2014). The surrounding area is generally dominated by red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves (Chen and Twilley, 1999), which are flooded at least partially during most high tides (Ho et al., 2014). The mean depths in Tarpon Bay and Shark River at mid-tide are 1.4 ± 0.3 and 2.8 ± 0.4 m, respectively, and their surface areas are 1.48 and 2.54×10^6 m^2, respectively. This subtropical region is characterized by distinct dry (November to April) and wet (May to October) seasons. Discharge calculated at a gaging station near the midpoint of Shark River (USGS Shark River in Fig. 1; U.S. Geological Survey, 2017), indicates that, over a 4-year period from 2010 to 2014, hourly residual mean discharges (i.e., filtered for tides) ranged from −37.7 to 58.6 m^3 s^{-1} during the dry season and from −53.8 to 67.1 m^3 s^{-1} during the wet season (positive values indicate flow toward the coast), while water temperatures ranged from 11 to 30 °C and from 20 to 33 °C during the dry and wet seasons, respectively.