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Seasonal and habitat-wise variations of creek water particulate and dissolved organic carbon in arid mangrove (the Persian Gulf)

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ABSTRACT

The present study examines the effect of mangrove vegetation and different seasons on organic carbon pools, distributions, and source compositions under the stressed hydro-climatological settings of the Iranian coast (Persian Gulf). Significant seasonal and spatial differences were detected only for the δ^{13}POC (particulate organic carbon) owing to the fluctuation of its sources. Five end-member particulate organic carbon sources (POC) (mangrove leaf, planktonic particles, zooplankton, microphytobenthos (MPB), and sediment) contributed to the POC pool at different levels depending on their seasonal and site-specific abundance. Variations in topographic features such as, the elevations of mangrove and non-mangrove creeks, appeared to play an important role in regulating POC concentrations but not DOC concentrations. Planktonic particles contributed to the POC pool (maximum 10–65%) at the mangrove sites mostly in the summer whereas the contributions of sediment and MPB (5–35%) increased in winter. Iranian mangroves are weak exporters of carbon to the Persian Gulf where mangrove plant materials (leaf, litter) had little contributions to the POC and DOC pool (5–25% and 8–15%, respectively). It is most likely that OC export in these arid regions are limited by low rainfall and river input. Finally, seasonality and site-specific activity largely control OC dynamics in these relatively understudied arid mangroves.

1. Introduction

Recent global estimates recognize mangroves as the most carbon (C) rich type of forest ecosystem in the tropics. Globally mangroves store 4–20 billion tons of C in their sediment (Donato et al., 2011), which is five times more than typically observed in temperate, boreal and tropical terrestrial forests on a per-unit-area basis (Bouillon, 2011). Mangrove forests cover 137,760 km^2 worldwide, having largest extent found in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%) (Giri et al., 2011). Mangrove-fringed coastlines are known for actively exchanging materials and organic matter (OM) between terrestrial and marine environments, as regulated by tidal dynamics and geomorphological settings (Adame and Lovelock, 2011). Previous global estimates have shown that mangroves cover only 0.1% of the earth's continental surface, but account for 11% of the total input of terrestrial particulate organic carbon (POC) into the ocean (Jennerjahn and Ittekkot, 2002) and 10% of the terrestrial dissolved organic carbon (DOC) exported to the ocean (Dittmar et al., 2006). Mangroves are complex habitats where trees have developed unique pneumatophores to survive in the relatively anoxic sediment and forest are dissected by numerous channels and creeks that drains water to the adjacent estuary or ocean. These intertidal creeks play an important role in exporting carbon and nutrients through flushing of litter, coarse wood debris, and benthic algae (such as microphytobenthos) or importing them as marine algae within a tidal cycle, thus maintain the productivity of the system (Kristensen and Suraswadi, 2002; Bouillon et al., 2007). Although there are several significant reports about sources and transport of DOC and POC in mangrove dominated coastal systems (Bouillon et al., 2007; Maher et al., 2013; Ho et al., 2017; Ray et al., 2015, 2018a,b), there is a gap in understanding their distribution among different habitats and intertidal creeks. The biogeochemistry of organic carbon (OC) as a function of the presence or absence of mangrove vegetation alongside tidal creeks is particularly important to understand in the context of estuarine and ocean carbon cycles.

The present study complements our previous works on the OC

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sources to food webs at the northern edges of mangrove distributions in the Indian Ocean where mangroves thrive under extreme temperatures (> 35 °C in summer), very low rainfall and high salinities (> 35 psu, Al-Khayat and Jones, 1999). Our previous works at Qeshm Island (Persian Gulf) reported that fish population dynamics and their food sources were related to habitats and seasons (Shahraki and Fry, 2015; Shahraki et al., 2016), and showed the dominance of phytoplankton as sources of DOC and POC in the Iranian mangroves (Ray and Shahraki, 2016). Mangroves in the Persian Gulf have been neglected with respect to OC dynamics. In this context, Qeshm Island is particularly important as a reference site due to the presence of vegetated and non-vegetated areas that can be used to understand the influence of mangrove processes on the distribution of DOC and POC concentrations and their stable isotopes. Furthermore, we consider seasonality as one of the vital factors regulating DOC and POC variations in these mangroves because previous studies in other tropical estuaries and mangroves have shown considerable seasonality in the concentrations and sources of OC and nutrients (Cawley et al., 2013; Leopold et al., 2016; Maher et al., 2013).

Present study is aimed at better understanding the role of habitats and seasons in OC fluctuations in an arid mangrove region. Our main question is: how the distributions and source compositions of DOC and POC vary depending on the presence or absence of mangrove vegetation (i.e., mangrove vs non-mangrove sites) and contrasting seasons? To address this, stable isotopes ($\delta^{13}C$, $\delta^{15}N$) of various end-members such as mangrove leaf, sediment, MPB, planktonic particles and zooplankton were used for mass-based calculations. Multivariate statistical analyses were performed to assess whether DOC and POC differed in concentrations and isotopes between habitats and seasons.

2. Materials and methods

2.1. Study Sites

The study was carried out at the mangrove and non-mangrove sites of Qeshm Island (Iranian coast of Persian Gulf, 26.8°N, 55.75°E), which has the largest mangrove area in Iran, composed exclusively of *Avicennia marina* (Fig. 1). Four mangrove-dominated creeks (C1, C2, C3, C4) and two non-mangrove creeks (C5, C6) are studied. Water from both types of creeks ultimately flows into a main channel. C2 and C3 are situated at a lower topographic elevation and were larger in size (low-lying creeks) than C1 and C4 (high-lying creeks) (Fig. 1). The distance between mangrove and non-mangrove creeks is approximately 4 km. C1, C2, C3, and C4 are situated in a pristine environment. Although C5 and C6 are located at the border of a small fishing harbor, the creeks were chosen carefully so that the distance from the harbor would minimize anthropogenic effects on ecosystem carbon dynamics. There are no reefs, seagrass or macroalgae beds in the vicinity of the two sites.

The mangrove forest at Qeshm Island is generally dry implying no tidal water above the sediment interface except on spring tide. Average tidal range is ~ 2.5 m in the study area. The mangroves extend 5–50 m inland as a fringe along the creek banks, and are 3–6 m tall. Sediment texture is dominated by silt and sand (sand: 40.7%, silt: 43.2%, clay: 16.1%, Ali et al., 2017). Further details of the study area can be found in companion papers (Shahraki et al., 2014; Shahraki, 2015; Ray and Shahraki, 2016).

2.2. Sampling and analytical techniques

Field campaigns were conducted at the Qeshm Island during winter (2011–2012) and summer (2012). We used a mechanized boat to reach the mouth of all 6 creeks and collected water samples at both high and low tide. Mangrove and non-mangrove sites were similar with respect to many of the measured parameters. Salinity averaged 38.3 ± 0.5 psu in the mangrove site and 40.3 ± 2.3 psu in the non-mangrove site, suggesting a stable non-estuarine mangrove environment. Water temperatures in winter averaged 19.6 ± 1.5 °C and 19.6 ± 2 °C for mangrove and non-mangrove, respectively and 33.7 ± 1 °C and 34 ± 2 °C, in summer, respectively. Table 1 gives the details about the sampling and results of water parameters. Samples of fresh (green) and senescent (yellow) *A. marina* leaves were hand-picked. Leaf components are potential POC sources in the mangrove surrounding aquatic system due to tidal flushing of leaf/litter debris from the sediment to the adjacent water (Rezende et al., 2007; Ray et al., 2018b). Due to high water residence time at Qeshm Island (Ray and Shahraki, 2016), we expect POC derived from leaf/litter during spring tide would persist still in the water column and contribute to the POC pool.

Decomposing mangrove leaves were also collected from the bottoms of the creeks and combined for analysis of C, N and their stable isotopes. During low tide, the top 2 cm surface sediment was sampled in duplicate with a spoon while MPB were collected by gently scraping off the visible mats. Plankton was sampled at high water after sunset by filtering 10 L of water through plankton nets (10 μm mesh size). Because it was not possible to obtain phytoplankton samples free of zooplankton, they were considered as mixture of phyto- and zooplankton, whereas zooplankton samples that were caught with a bigger mesh size (200 μm) net were only zooplankton. Hence, all plankton samples contained the particles of given sizes. Details of these end-members collections were described by Shahraki et al. (2014). Water samples were collected in triplicate from the surface using a 2 L Niskin bottle. Samples were stored in a cool box before filtration of a known volume of tidal water (250 mL) on pre-weighed and pre-combusted (overnight at 450 °C) 47 mm Whatman GF/F filters (0.45 μm mesh size), and subsequently dried for analysis of total suspended matter (TSM), plankton and particulate organic carbon (POC) and particulate nitrogen (PN) along with their isotope ($\delta^{13}C$, $\delta^{15}N$). Nutrient samples were collected in 15 mL plastic tubes for analysis of dissolved nitrogen (NO_3/NO_2/NH_4) and phosphate. Nutrient samples were freeze-dried and silicate samples were kept in a cooler on ice until analyses could be performed.

For DOC and δ^{13}DOC analyses, water samples were filtered through syringe filters (cellulose-acetate membrane), stored each in 25 mL amber glass bottles, acidified with 0.2 M H_3PO_4 until the pH level fell to 2 and kept in a refrigerator. Syringe filters were soaked in deionized distilled water for 24 h. to discard organic leaching before use. DOC samples are available only for the summer collection. All samples (solid, filter and water) were transported to the laboratory on ice for further processing and analysis.

Total organic carbon (TOC) and total nitrogen (TN) content (%) of the solid powdered samples and filter residues were determined with an Euro EA3000 Elemental Analyzer. Samples for $\delta^{13}C$ and $\delta^{15}N$ were analyzed with a Delta Plus isotope ratio mass spectrometer connected to the Carlo Erba Flash EA elemental analyzer via a Finnigan ConFloII interface. The carbon and nitrogen analysis are expressed in conventional delta (δ) notation as parts per mil (‰). The analytical precision (average of measured data subtracted by the arithmetic mean) of the measurement was < 0.12‰ for both $\delta^{13}C$ and $\delta^{15}N$. The DOC concentration was determined using a Shimadzu TOC-V_{CSH} Analyzer and NDIR detector (non-dispersive infrared detector) calibrated against potassium hydrogen phthalate. DOC stable isotope analysis was carried out at MPI-Jena isotope laboratory (Germany) using a HPLC system coupled to a DELTA^{plus} XP IRMS through an LC IsoLink interface (Thermo Fisher Scientific, Germany). The δ^{13}DOC values were reported as per mil relative to the PDB standard with an overall uncertainty of ± 0.10‰ (see Ray and Shahraki, 2016 and Scheibe et al., 2012). The study only examines the effect of different seasons on the particulate organic carbon (POC) pools due to the scarcity of dissolved organic carbon (DOC) data in the winter.

Bathymetric surveys of the creeks were carried out at the end of the sampling period in February 2012 to assess the local topography with respect to tidal inundation and drainage patterns. The survey included measuring water levels across different horizontal transects for each