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Multiple sources driving the organic matter dynamics in two contrasting tropical mangroves

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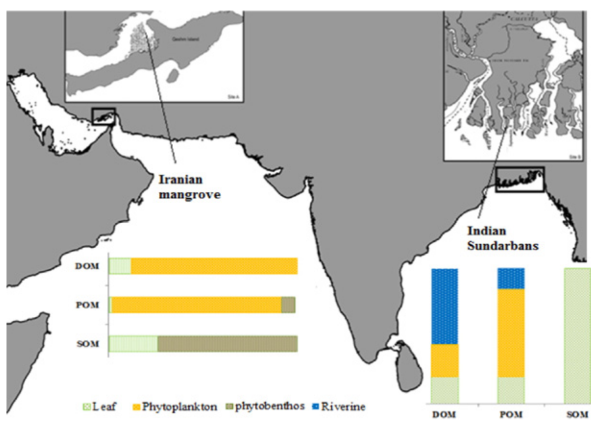
HIGHLIGHTS

- Sources of OC have been identified and compared between two contrasting mangroves.
- Phytoplankton dominated the DOC and POC pool in the Iranian mangroves.
- River input contributed half of the total DOC and part of POC in the Indian Sundarbans.
- Microphytobenthos dominated the SedOC over the tidal flat of Iranian mangroves.
- Leaf-litter was the main contributor of SedOC in the Indian Sundarbans.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, we have selected two different mangroves based on their geological, hydrological and climatological variations to investigate the origin (terrestrial, phytobenthos derived, and phytoplankton derived) of dissolved organic carbon (DOC), particulate organic carbon (POC) in the water column and the sedimentary OC using elemental ratios and stable isotopes. Qeshm Island, representing the Iranian mangroves received no attention before this study in terms of DOC, POC biogeochemistry and their sources unlike the Sundarbans (Indian side), the world's largest mangrove system. Slightly higher DOC concentrations in the Iranian mangroves were recorded in our field campaigns between 2011 and 2014, compared to the Sundarbans (315 ± 25 μM vs. 278 ± 42 μM), owing to the longer water residence times, while 9–10 times greater POC concentration (303 ± 37 μM, $n =$ 82) was linked to both suspended load (345 ± 104 mg L^{-1}) and high algal production. Yearlong phytoplankton bloom in the mangrove-lined Persian Gulf was reported to be the perennial source of both POC and DOC contributing 80–86% to the DOC and 90–98% to the POC pool. Whereas in the Sundarbans, riverine input contributed 50–58% to the DOC pool and POC composition was regulated by the seasonal litter fall, river discharge and phytoplankton production. Algal derived organic matter (microphytobenthos) represented the maximum contribution (70–76%) to the sedimentary OC at Qeshm Island, while mangrove leaf litters dominated the OC pool in the

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Indian Sundarbans. Finally, hydrographical settings (i.e. riverine transport) appeared to be the determinant factor in differentiating OM sources in the water column between the dry and wet mangroves.

1. Introduction

The global extent of mangrove sediment surface area is <2% of the area of marine environments, yet they account for 10 to 15% of the total organic carbon (OC) burial in the oceans (Duarte et al., 2005; Jennerjahn and Ittekkot, 2002) and are best known for active transport and processing of dissolved and particulate organic matter (as DOM and POM) through estuaries to the coastal ocean (Alongi, 2014, Bouillon et al., 2008; Dittmar et al., 2006). Mangroves are generally confined to the tropical and subtropical regions of the world (between approximately 30° N and 30° S latitude) and accounts for about 2.4% of tropical forest (Spalding et al., 1997). The largest mangrove systems are found in Asia (42%, Giri et al., 2011), with the Sundarbans representing the largest tract of mangrove forest in the world and an UNESCO world Heritage site. Although there are few significant reports available in the literature on the carbon dynamics in different Asian mangroves (e.g. in Indian Sundarbans: Ray et al., 2011, Godavari mangrove: Bouillon et al., 2003; Malaysian and Indonesian mangrove: Alongi et al., 2004; Murdiyarso et al., 2009), the data for the Middle-East region is quite sparse. Particularly, to this date there is no comprehensive report on the sources and biogeochemistry of the organic carbon on the Persian Gulf's mangroves of Iran, despite Iran having the largest acreage of natural mangrove forests, with an area ranking 43rd in the world and 10th in Asia (FAO, 2007). This is the first baseline study on the Persian Gulf's mangroves where different organic carbon sources were identified and their contribution level to the total organic matter (dissolved and particulate) was estimated. These mangroves located at the southern coast of Iran, are known to receive little rainfall (<200 mm yr^{-1}, Reynolds, 2002) and no permanent freshwater input throughout the year. Drainage areas of the various creeks in the Qeshm mangroves were reported in the range between 2774 and 11,460 m^2 (Shahraki et al., 2016). The Sundarbans (Indian part) is a region of positive water balance with large inputs from major rivers like the Ganges and also known for high rainfall (>1500 mm yr^{-1}, Ray et al., 2011, 2013) and river discharge (3000 ± 1000 m^3 s^{-1}, Mukhopadhyay et al., 2006). Hydrographical settings, such as rainfall and river discharge contribute to the allochthonous sources of the organic matter, while in situ production (phytoplankton) favored by sufficient sunlight, dissolved oxygen and nutrient conditions act as autochthonous source. Our previous study on the Indian Sundarbans revealed the riverine input to be one of the major sources of organic matter (Ray et al., 2015). Moreover river discharge is one of the major sources of nutrients such as nitrite, nitrate, ammonium, phosphate and silicate (Dyer, 1973; McClanahan, 1988; Singh and Ramesh, 2011), which are essential for the phytoplankton growth that builds up organic matter during photosynthesis. Hence it is expected that the functioning of mangroves in the Persian Gulf in terms of organic matter sources, productivity and nutrient concentrations in arid conditions might be different than that of wet mangroves in the Indian Sundarbans.

Therefore the main objectives of this study is to (1) apply stable isotopes of dissolved organic carbon (δ^{13}DOC), particulate organic carbon and nitrogen (δ^{13}POC, δ^{15}PN) and dissolved inorganic carbon (δ^{13}DIC) to understand the end member source-signatures of the mangrove organic matter in the Persian Gulf (here end members are leaf, phytoplankton and benthic algae) and (2) compare the results with Indian Sundarbans to identify the regulating factors (physical or biological) responsible for differentiating organic matter sources between the two contrasting mangroves, i.e. dry and wet.

2. Study area

The study was carried out at Qeshm Island, Iranian coast of the Persian Gulf, a protected biosphere reserve at the northern edge of mangrove distribution in the Indian Ocean (26.80 N, 55.75°E) (Fig. 1). Mangroves in Iran were reported to have an area of 107 km^2. Qeshm Island, representing 62% of the total (Danehkar, 1998, 2001) was selected as an ideal site for this study (Site A). Qeshm Island will be referred as "Iranian mangroves" in this text. The mangrove system in the northwest of Qeshm Island is composed exclusively of *Avicennia marina*, growing in the high intertidal area, with tree heights of 3–6 m and the mangrove floor is flooded only during spring tides (Shahraki et al., 2016). The tide is semidiurnal, with tidal ranges from 1 to 3 m at neap tides and 3–4 m at spring tides. The region is arid with an annual precipitation below 200 mm (Reynolds, 2002). High temperatures in summer and dry winds in winter can cause 1–2 m of evaporation per year, creating salinities >39, typical for most Gulf waters (Sheppard et al., 2010).

Our second study area, Lothian Island (Site B) is located in the Indian Sundarbans (21°32′–21°42′ N and 88°05′-89° E, Fig. 1). The Sundarbans is the largest natural mangrove system with an area of 10,200 km^2, with a region of 4200 km^2 of reserved forest located in India. In 1985, the Indian Sundarbans was included in UNESCO's list of world heritage sites. The Indian part of the Sundarbans is crisscrossed by the estuarine phases of several distributaries of the River Ganges: Hooghly, Mooriganga, Saptamukhi, Thakuran, Matla, Bidya, Gosaba and Haribhanga, forming a sprawling archipelago of 102 islands. 54 of these have been reclaimed for human settlement with the rest remaining in a natural state. Lothian Island situated at the buffer zone of the Sundarbans Biosphere Reserve and with an area of 38 km^2, is completely intertidal and covered by the thick dominant mangrove species, *Avicennia alba*, *Avicennia marina* and *Avicennia officinalis*. Therefore, Lothian Island was taken as being representative of the Sundarbans mangrove ecosystem. In Table 1 we present a comparative overview of the hydrological, geological and climatological conditions of the Persian Gulf (Qeshm Island) and Sundarbans mangroves (Lothian Island).

3. Materials and methods

3.1. Sample collection and preservation

We conducted research campaigns to the Qeshm Island in December 2011 and February 2012 (cool, dry period) and in August/September 2012 (hot, dry period). Sampling at the Lothian Island was performed during May (pre-monsoon) and December (post-monsoon), 2014. For both campaigns we hired mechanized boat to collect samples and sediment from the mangrove creeks. Additionally, from the Hooghly estuary which is the main artery of the Sundarbans mangrove ecosystem, we collected nearly freshwater water (salinity ≤1.5) samples and sampling point was located about 100 km from the Site B (not shown in the map). This was done in order to understand the effect of river input on the organic matter sources between the two sites in which Site A was completely devoid of fresh water input. During the field campaign, meteorological data were received as personal communication from the Qeshm Meteorological Station, whereas for Sundarbans, they were obtained from a local meteorological office (Alipore, Kolkata).

Sampling procedure as well as the analytical approach was very similar while campaigning in both the mangroves. In case of Qeshm Island, samples were collected at different locations across the mangrove-lined creeks during both high tide and low tide but in all cases salinity