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Research Article

Variability of organic carbon matter and nitrogen deposits in a carbonate platform of mangroves

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Abstract

Mangroves are usually characterized by their high potential for long-term sequestration of organic carbon. Sediment accretion by these valuable habitats increased their capability of organic carbon sequestration. In this study, we aimed to examine the organic carbon sequestration of mangrove expansion *(Avicennia germinans)* in southern Iran. Different variables have been investigated in the sampled sediments, including $\delta^{13}C$, $\delta^{15}N$, TOC, TN, and C/N ratio. Our findings indicated the significant variation of measured variables in several top intervals, reflecting the existence of autochthonous and allochthonous organic substances. Our data showed that the minority of $\delta^{13}C$ values are lower than -23% in the S3 site, suggesting that mangrove litter is a critical input OC ($\delta^{13}C$, -28 to -30%). On the other hand, the significantly higher value of $\delta^{13}C$ (-14 to -23%) indicates that phytoplankton and possibly local microphytobenthos are the primary sources of organic materials inputs. Moreover, site S4 presents the highest mean value of C/N, TN, and $\delta^{15}N$, which can be justified because of its proximity to the estuary and supply of organic matters imported from algal sources. The substantial role of mangrove forests depositing organic carbon should be investigated in the global carbon cycle.

Keywords: Climate change, $\delta^{13}C$, $\delta^{15}N$, mangrove forest sediment, organic carbon

Introduction

Mangroves are located in the transitional zone between land and marine ecosystems (Gilman *et al.* 2008). These forests are highly susceptible to both changes induced from terrestrial and marine sides as they grow at these transitional boundaries. Land use and climate change are reported to have a significant impact on mangrove forests (Duarte *et al*. 2013). Mangroves trap the organic matters in their deposited sediments which can be penetrated to the several meters in the bottom layers (Schile et al., 2016) which makes them one the richest ecosystem and the most abundant organic C reserves in the tropics and subtropics, with an average of 1,023 MgC/ha (Donato *et al.* 2011). It is believed that coastal wetland mangroves are the most organic-rich forests and it is expected that global warming increases the expansion of C3 -riched mangroves in the coastal wetlands (Williamson *et al*. 2011).

Mangroves' responses to global changes are expected to be noticeable because of the fast sea-level risen, which has occurred in many locations globally, which helps discern differences in carbon sequestration in such transitional zones (Hopkinson *et al.* 2012). Empirical data on soil's carbon can improve critical uncertainties in measuring the mangrove's carbon storage. Many of the world's ecosystems have an unclear annual flux of carbon (Malhi and Grace 2000). There is no specific data on the global mass of organic carbon balance in the coastal ecosystems, like mangroves and coral reefs (Smith and Hollibaugh 1993).

Mangroves may receive their deposited organic carbon from two allochthonous (freshwater, marine phytoplankton, coastal vegetation, and riverine transport of eroded soils) and autochthonous (litters, mangrove detritus, benthos, and benthic vegetation) sources (Ranjan *et al*. 2010). Plant tissue' C3 content can be regarded as a terrestrial organic matter which has OC/TN and OC/OP ratios with higher negative δ13C values in comparison with marine sources like benthic algae, macroalgae, and plankton (Briggs *et al*. 2013). But, organic carbon's storage in mangrove sediments has been stated to be varying as expressed between <2.00 and <40.00 %, with a medium organic carbon of 2.20 % (Kristensen *et al*. 2008).

In the northern shorelines of the Persian Gulf and Oman Sea, mangroves constitute one of southern Iran's critical coastal habitats. Drastically change in seawater level and human activities, primarily aquaculture-related impacts, can be regarded as some of the most threatening factors that threaten such valuable ecosystems (Toosi *et al.* 2019).

The present study was conducted to explore the organic carbon (OC) sequestration in mangrove forests based on C/N ratio, isotopic $\delta^{13}C$, and $\delta^{15}N$ criteria.

Material and methods

The study was conducted in mangrove-protected areas on Qeshm Island (Fig.1), Hormaozgan province, Iran (26°45' and 26°56'N and longitudes of 55°37' and 55°47'E) (The study area covered by around 9200 ha of mangrove forests, dominated by *Avicennia marina*. Qeshm has a subtropical climate with a long summer (mid-April to October) and short winter (December-February) with hot desert-like weather during the summers. Based on the Domarten drought index Hormozgan is regarded as an arid region (Iran Meteorological Organization). Based on the mean monthly temperature, the temperature ranges from 26.71 to 28.65ºC (with an average of 27.5ºC) along the Hormozgan coastline. The absolute minimum temperature recorded in the area is about 2.8ºC. Mangroves can tolerate mean minimum temperature, ranging from about 12 to 14ºC during the winters (Ellison 2004). The mean annual rainfall is 160 m; salinity varies from 38 to 48 mg/liter, and there is no permanent river on the island, except for some seasonal streams which flow to the coastal area. The sediment of the coastal zone originates from both continental sources and rapid and considerable benthos growth. The studies of tide height in tidal stations show that the highest annual mean tide occurs in the central parts. Tidal amplitude in Hormozgan coasts varies between 0.5 and 2 m. The presence of some endangered, vulnerable, and rare species like *Pelecanus crispus*, *Platalea leucorodia*, and *Phoenicopterus ruber* in the study area multiply the study's critical role area as an important biodiversity hotspot (Petrosian *et al.* 2016).

Sampling and analysis

Four sediment cores were collected at the study site by inserting a 5 (diameter)× 50 (length) cm plastic tube into the sediment during low tide (Fig. 1) The sediment samples were pressed out of the container and divided at 1 cm intervals from the core top to depth of 30 cm, and at 2 cm intervals until the bottom of the core (50 cm). Dry Bulk Density (DBD) was estimated through the dry sediment weight over the initial volume (g/cm^3). A homogenized portion was acidified to remove carbonates, then dried, and ground to the fine powder for organic carbon, Total N, $\delta^{13}C$, and $\delta^{15}N$. Samples were processed using a PDZ Europa ANCA-GL (Automated Nitrogen, Carbon Analyzer-Gas/Solids/Liquids) elemental analyzer connected to a PDZ Europa 20-20 isotope ratio mass spectrometer. Based on the duplicate samples from the two cores, the average relative standard deviation was 0.28% for C and 0.02% for N. Concerning the analytical precision of stable isotopes, the instrumentation error is expected to be less than 0.2‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$ based on long-term standard deviations of the samples compared to standard.

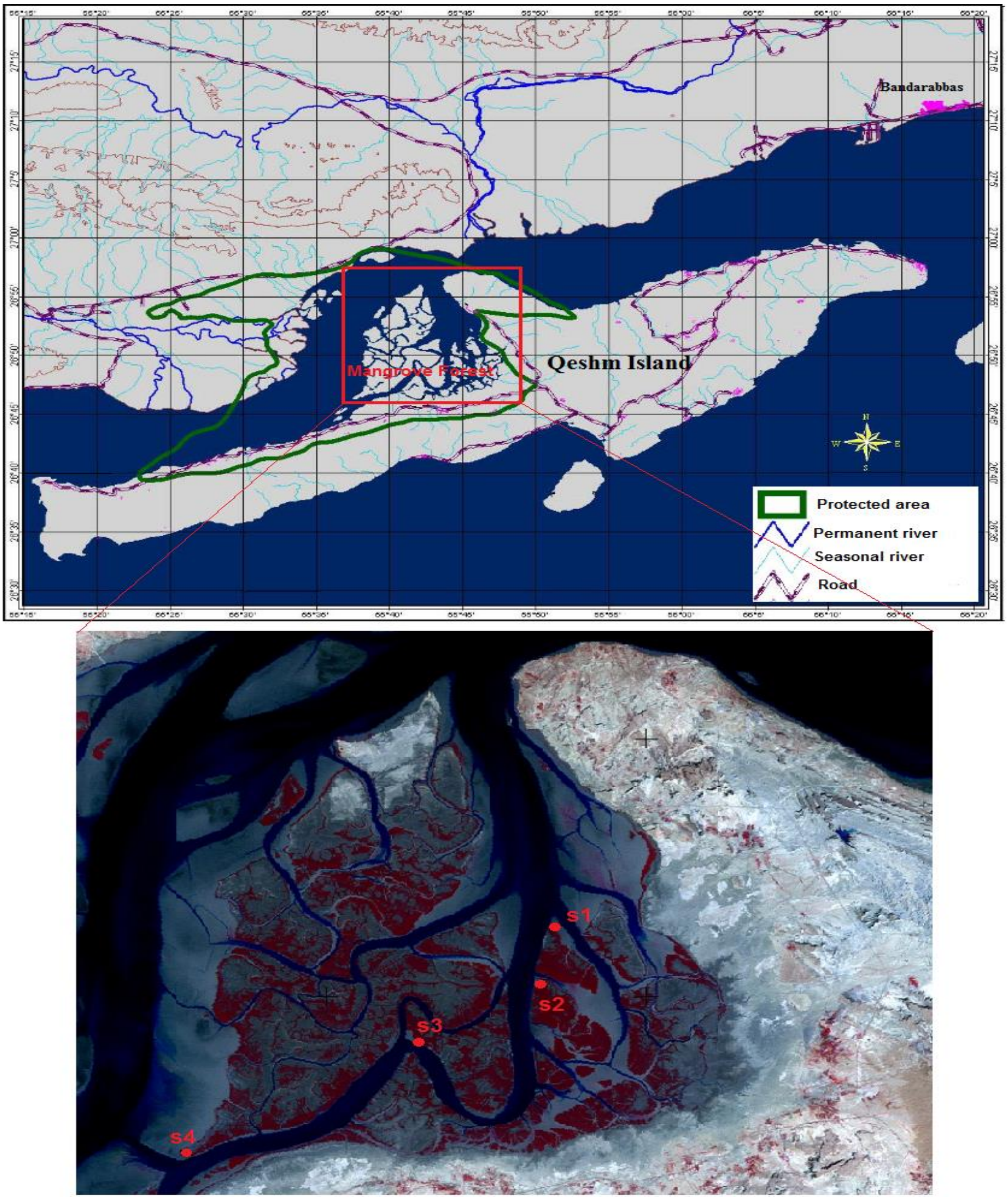


Figure 1. Location of Qeshm mangrove forest in Hormozgan province, south of Iran and Core Sediment Samples

The mean values of $\delta^{13}C$, $\delta^{15}N$, % OC, TN variables were compared by one-way analysis of variance (ANOVA) using SPSS 19.0. The significance of the difference between means data was evaluated at the 95% confidence level using the Duncan method. Coefficients of correlation between them were used to determine the sensitivity of OC response to the change of other factors.

Results

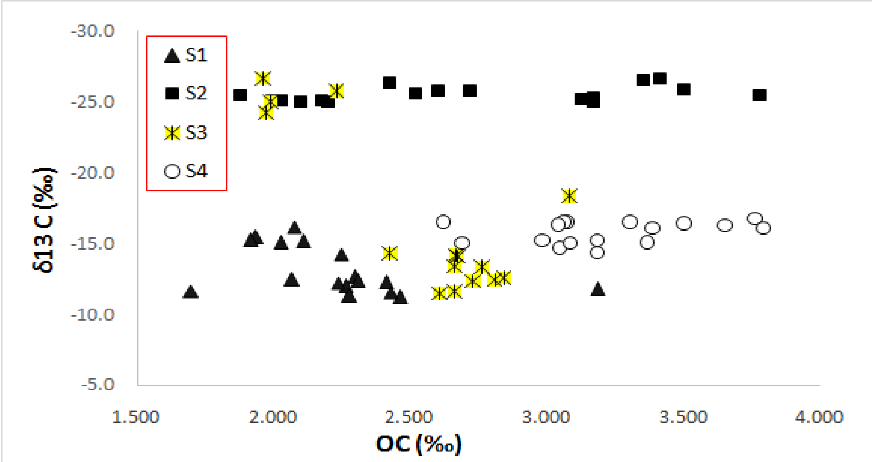
Table 1 shows the mean and standard deviation of each core sample's sediment profile in the study area. The highest mean values of $\delta^{13}C$, $\delta^{15}N$, % OC, TN, and C/N are observed in S1, S4, S4, S1, and S4 sites, respectively. Also, the highest mean value of Dry Bulk Density (DBD) was 1.96 (g cm^{-3}) in S1. The mean value of $\delta^{13}C$ for all intervals was -17.77 ‰. Overall, the organic carbon content of mangrove sediments was found to vary between 1.7 and 3.76%. The results show that the mean value of organic carbon percent amount was 2.68%, $\delta^{13}C$ values ranged from -11.2 to -26.6%, and C/N ratios varied between 12.2 and 36.2.

Table 1. Mean and Standard Deviation (SD) of sediment profile characteristics of four study mangrove

	Bulk Density (g cm^{-3})		**Organic C (%)**		**N (%)**		**Organic C (mg cm^{-3})**		**Total N (mg cm^{-3})**		**C:N**		**$\delta^{13}C$ (‰)**		**$\delta^{15}N$ (‰)**	
Core	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S4	1.35	0.30	3.22	0.33	0.14	0.01	42.85	7.73	1.86	0.45	27.53	4.41	-15.77	0.78	9.58	2.34
S3	1.13	0.23	2.54	0.35	0.12	0.01	29.26	8.50	1.36	0.23	24.83	4.84	-16.61	5.72	4.48	0.54
S2	1.32	0.24	2.71	0.61	0.13	0.00	36.82	13.84	1.76	0.31	24.35	5.17	-25.50	0.55	4.00	0.23
S1	1.42	0.22	2.23	0.32	0.15	0.00	31.31	4.88	2.09	0.33	17.72	2.96	-13.09	1.69	7.75	0.77
Mean	1.31	0.25	2.68	0.40	0.13	0.01	35.06	8.74	1.77	0.33	23.61	4.35	-17.74	2.18	6.45	0.97

Figure 2 shows the carbon stable isotopic composition ($\delta^{13}C$), nitrogen stable isotopic composition ($\delta^{15}N$), and organic carbon percent content (% OC) in the sampled sediments (Fig. 2, (δ15N) (‰) vs. (δ13C). Also, there was no significant change in δ13C ‰ values associated with the increasing % OC at any part of the study sites. The same range of δ13C ‰ showed a different value of organic carbon percent amount (Fig. 2), (δ15N ‰) in comparing with organic carbon percent content. There was also no positive correlation between δ13C ‰ and δ15N, δ15N ‰compared to δ13C ‰) (Fig. 2)
The variation in $\delta^{13}C$ has made the % OC trend representation unclear (Fig. 3). Our findings showed a negative relationship between %OC and $\delta^{13}C$‰ in S3 estuary. As can be inferred from fig.2 (right), there is no relationship between $\delta^{13}C$% and $\delta^{15}N$%. The same range of $\delta^{13}C$% has been found for S4 (with high $\delta^{15}N$% values) and S2 stations (with low $\delta^{15}N$% values). Furthermore, we found a wide range of $\delta^{13}C$% variation in S3 station while the amount of $\delta^{15}N$% was recorded to be similar.
Figure 3 shows $\delta^{15}N$%, $\delta^{13}C$%, OC, TN, and C/N of each sediment core in S2, S3, S1, and S4 sites. $\delta^{15}N$% and $\delta^{13}C$% slightly changed around 1% and 1.5% in depth, respectively, in S2 station. Although the $\delta^{13}C$ values were relatively stable from 0 to 10 cm in the S3 sediment of mangrove sites, they increased from 10 to 30 cm. The $\delta^{13}C$ values changed only slightly from -11 to -16% in S1 core. The $\delta^{13}C$ values decreased from -17% to -14 % to 9 cm depth in S4 sediment; however, they increased to -17% at the end of S4 core. Organic carbon and TN increased in depth in all stations except S3, with some disorders in surface intervals. There was an increasing trend in organic carbon and TN (mg/cm^{-3}) in-the lowest profile of sediment samples taken from S3 station. Although C/N ratio showed a decreasing trend in S4 and S3 sites, it had an increasing trend in S2 and S1 in-depth. S4 site,

which was found in the coastal mangroves had higher TOC, TN, TN, and $\delta^{15}N$.



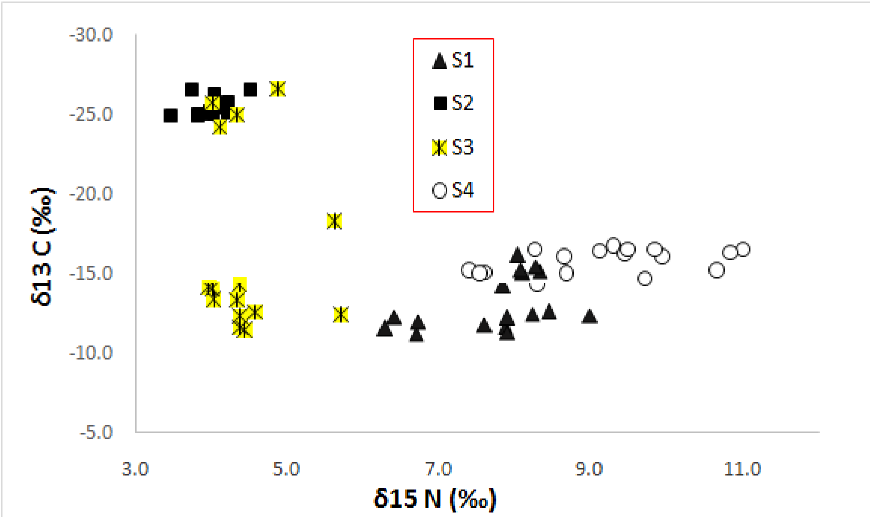


Figure 2. (Above δ13C (in ‰) of organic carbon versus organic carbon content (% dry weight) of surface sediments from mangrove ecosystems, and (below) δ13C (in ‰) of sediment organic carbon versus δ15N (in ‰) ratios of sediments from Qeshm mangrove ecosystems

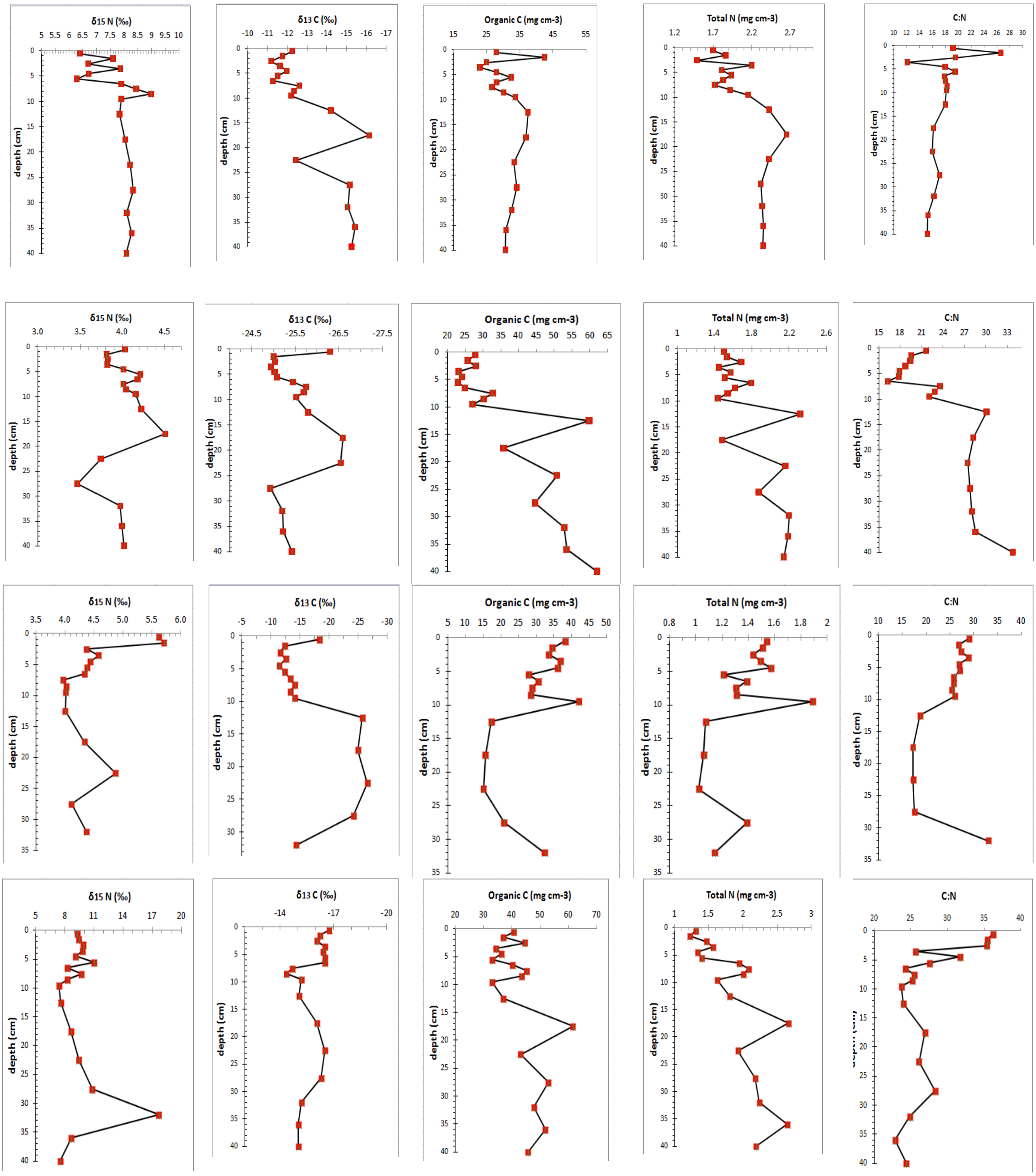


Figure 3. Depth profiles of soil characteristics for dated intervals of the four sediment cores from above to below S1, S2, S3 and S4 respectively

Discussion

The range of variations of organic carbon percent content in all intervals was meager compared to other data from similar researches (Marchand *et al*. 2003, Yang *et al*. 2013).

Our findings indicated that the percent amount of organic carbon is different among the S2, S1, and S4 stations, while it was not observed in $\delta^{13}C$% values. Moreover, S3 station lower concentrations of organic carbon were recorded, which can be coincided with less negative $\delta^{13}C$ values. The higher nitrogen stable isotopic values indicate less negative δ13C because of planktonic and benthic microalgal organic matter sources (Meyers 1994).

The maximum and minimum mean values of $\delta^{13}C$ were -4‰ and -16‰ in S4 and S3 sites, respectively. It is known that C4 plants ($\delta^{13}C$ = -15 to -9 ‰) are generally heavier than C3 plants ($\delta^{13}C$ = -35 to -20 ‰) than for mangroves (as C3 plants) with $\delta^{13}C$ values of -28‰, isotopic signatures close to many terrestrial plants can be expected (Jennerjahn and Ittekkot 2002, Kennedy *et al*. 2004). Kennedy *et al*. (2004) found significant differences for isotopic signatures of plants like seagrasses ($\delta^{13}C$ = -5.8 to -13.3 ‰) and sestons ($\delta^{13}C$ = -9.6 to -22.9 ‰) among 15 different sites in Southern China's sea. The $\delta^{13}C$ signatures indicate a nominal ranking of organic matters: seagrass > epiphyte > seston > mangrove. Furthermore, according to the literature, $\delta^{13}C$ commonly ranges from -29.4‰ to -20.6‰ in mangrove's sediments (Bouillon *et al.* 2003, Thimdee *et al*. 2003, Gonneea *et al*. 2004); however, it ranges from -10.3‰ to -26.6‰ for seagrass sediments (Kennedy *et al.* 2004, Papadimitriou *et al*. 2005). Soto-Jimenez *et al*. (2003) used isotope δ13C to determine the organic carbon source in a Mexican marsh, which was detected as-20.4 ‰ on average. Planktonic and macrophytic sources constituted the primary originating source of organic carbon.

The benthic microalgae and mangrove litter were the most significant autochthonous carbon origins in the study area. Based on different local conditions, seagrass detritus and phytoplanktonic materials might play a crucial role in mangrove's carbon input (Breithaupt *et al*. 2012). High variability of the organic compounds in the top layers can be related to the role of both allochthonous and autochthonous resources (Breithaupt *et al*. 2012). The highest mean value of C/N, TN, and $\delta^{15}N$ in core S4 samples presents the proximity to the estuary and supply of marine organic materials from algal sources (Smoak *et al.* 2013).

It also appeared that seagrass and epiphyte could not be the sources of deposited organic carbon in S2, S4, and S1stations, even if the present results have the same range since they have not been observed in the sampling sites. Higher values indicate a non-mangrove origin of organic carbon as the measurement of global mangrove proposed amounts of -28 to -30‰ (Kristensen *et al.* 2008). Since there are no main rivers in this area except some seasonal creeks, there are no river-transported terrestrial materials to the Qeshm mangrove forests. This evidence suggests that the most important source of marine organic carbon is mainly derived from dead phytoplankton cells. Marine and algal organic sources are the supply of allochthonous (Sanders *et al*. 2014). The concentrations of total organic carbon and total nitrogen increased in depth in all study sites except in S3.

Much of the variation in these proxies can be defined by a transparent two-source mixing model whereby suspended matter (variable but generally higher δ13C values) and mangrove litter (low $\delta^{13}C$ values) are as end members (Bouillon *et al.* 2003). The research data show that a minority of $\delta^{13}C$ values are less than -23% in S3 site, thus suggesting a vital input of mangrove litter ($\delta^{13}C$, -28 to -30%). The comparable high δ13C values (-14 to -23%) indicate significant inputs of the imported and possibly local C-enriched ($\delta^{13}C$,-16 to -24%) carbon sources.

Bouillon *et al.* (2003) demonstrated that organic carbon in mangrove sediment had low $\delta^{13}C$ and C/N in small carbon stocks mangroves, thus indicating that the sediment organic carbon primary source was suspended solids at the sea-coast. Whereas the organic carbon in sediment had high C/N and $\delta^{13}C$ in mangroves with high carbon stocks, hence suggesting that the primary source of sediment organic carbon was the mangrove plant. Also, most of the organic carbon in the mangroves aggregated in the belowground roots, which could change sediment's organic matter content through some physiological processes. For instance, the underground roots can discharge oxygen into the mangrove sediments, resulting in the decomposition of dead roots and the exudate of living ones. This function consequently can increase the storage of sedimentary organic carbon in mangroves' sediment (Bouillon *et al.* 2003).

Local conditions concerning soil and bedrock composition, the proximity of river discharges, climate, local fauna, and flora, exposure to the extreme water flow can affect carbon transformation and transportation conditions in mangroves (Kristensen *et al.* 2002).

Conclusion

In this study, we examined the organic carbon sequestration of mangroves expansion *(Avicennia germinans)* in southern Iran. The significantly high value of $\delta^{13}C$ indicated phytoplanktons and possibly local microphytobenthos were the main sources of organic materials inputs in the study area. Whereas, the organic carbon in sediments associated with high C/N and $\delta^{13}C$ in mangroves and high carbon stocks, indicated the primary role of mangroves in forming organic carbon deposits. Moreover, site S4 showed the highest mean value of C/N, TN, and $\delta^{15}N$, which can be interpreted by its proximity to the inlet and receiving a supply of marine organic materials from algal sources. The substantial amounts of organic carbon in mangrove forests should be considered in the global carbon budget estimation for providing a better perspective of spatial and temporal changes in carbon deposition. Further research is required in mangroves to identify factors responsible for different organic carbon deposition in other geographic regions.

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