Estimation of carbon pools in the biomass and soil of mangrove forests in Sirik Azini creek, Hormozgan province (Iran)

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Abstract

Despite the increasing interest in mangroves as one of the most carbon rich ecosystem, arid mangroves are still poorly investigated. We aimed to improve the knowledge of biomass and soil carbon sequestration for an arid mangrove forest located at the Azini creek, Sirik, Hormozgan Province (Iran). We investigated the biomass and organic carbon stored in the above and belowground biomass for three different regions selected based on the composition of the principal species: 1) *Avicennia marina*, 2) mixed forest of *A. marina* and *Rhizophora mucronata*, and 3) *R. mucronata*. Topsoil organic carbon storage was also estimated for each analysed area, considering 0-30 cm of soil depth. Biomass carbon storage, considering both aboveground (AGB) and belowground biomass (BGB), was significantly different between the cover areas. Overall, the mean forest biomass (MFB) was 283.1 ± 89 Mg C ha^{-1} with a mean C stored in the biomass of 128.9 ± 59 Mg C ha^{-1}. Although pure *Rhizophora* stand showed the lowest value of above and below tree carbon (AGC+BGC); 17.6±1.9 Mg C ha^{-1}), soil organic carbon stock in sites under *Rhizophora spp.* was significantly higher than in the site with pure stand of *Avicennia spp.*. Overall, forest soil stored the highest proportion of Sirik mangrove ecosystem organic carbon (59 %), with a mean value of 188.3 ±27 Mg C ha^{-1}. These results will contribute to broaden the knowledge and the dataset available, reducing the uncertainties related to estimates and modelling of carbon pools in arid mangrove ecosystem, which also represent an important climatic threshold of mangrove worldwide distribution.

Keywords: Azini creek; *Avicennia marina*; *Rhizophora mucronata*; Soil carbon storage; Biomass carbon storage; Arid mangrove

1. Introduction

Mangroves are typically distributed within the tropics, but they are also extended into the subtropical and warm temperate regions in the tidal zones, coastal rivers, estuaries and bays of the world (Hamilton &Casey 2016, Naidoo 2009, Zeinali et al. 2017). Although a relatively small part of the world's forests are mangrove, they are among the most productive and biologically important ecosystems, providing a wide range of services to human society (Giri et al. 2011). Mangrove trees reduce coastal erosion caused by natural phenomena and increase the aesthetic value of the coast (Hashim et al. 2010, Zeinali et al. 2018). They also offer a physical habitat for a wide range of marine animals (Nagelkerken et al. 2008) and convey ecosystem services that span their natural range limits (Ewel et al. 1998).

Mangroves play an important role in absorbing atmospheric $CO_{2,}$ being able to stabilize significant levels of atmospheric carbon dioxide in their biomass and soils (Donato et al. 2011, Wang et al. 2014). Their high primary productivity and the high amount of carbon stored in their soil (Castaneda 2010), leads mangroves to be among the most carbon-rich forests in the tropics, containing on average 1,023 Mg carbon per hectare (Komiyama et al. 2005b; Donato et al. 2011). The potential of coastal ecosystems as carbon sinks is also due to their autochthonous and allochthonous sources of organic carbon (OC) input (Andreetta et al. 2016, Bouillon et al. 2003).

Mangroves are now threatened by human activities: projects that divert river water from coastal regions can increase salinity and cause mangrove degradation (Parida &Jha 2010). Furthermore, deforestation can transform mangrove ecosystem from an important sink to a source of carbon, with negative repercussions on climate (Hamilton &Friess 2018, Hashim et al. 2010). The need to reduce deforestation in countries that are expanding carbon consumption was considered by the United Nations Framework Convention on Climate Change (UNFCCC) with a focus on tropical forests (Motel et al. 2009).

In the Middle East mangrove forests are found in Iran, along the shores of the Persian Gulf and the Gulf of Oman, as well as around Bahrain, Qatar, Saudi Arabia and the United Arab Emirates (Danehkar 1996). In the southern coasts of Iran, the Hara forest, which is the local name for mangrove forests, is dominated by *Avicennia marina* species, while *Rhizophora mucronata* growth is limited to Sirik Azini Creek (Giri et al. 2011). This ecosystem offers a series of services to the local communities: mangrove branches and leaves are important fodder for camels and cattle; *A. marina* wood is used in the construction of buildings and in the production of charcoal. Medicinal substances are obtained from *A. marina* leaves and branches (Zahed et al. 2010). Recently, global changes, combined with local constraints, threaten the Hara forest ecosystem (Zahed et al. 2010). Mangrove stands have deteriorated, among the others, by camel grazing, oil pollution due to fuel smuggling, the introduction of invasive species such as the black rat, and unregulated fishing (Mashayekhi et al. 2016). For these reasons, national programs are quantifying the economic opportunity costs of conservation for local stakeholders in order to reduce tree harvesting and deforestation activities in the Hara forest (Mashayekhi et al. 2016).

In this context a thorough understanding of the Iranian mangrove ecosystem in relation to one of the key ecosystem services, such as the capacity to store organic carbon, is assuming a particular importance.

The Hara forest is an arid mangrove ecosystem, characterized by severe temperatures, sparse and sporadic rainfall, and high salinity. Despite the increasing research on mangroves worldwide, mangroves from arid regions are still poorly investigated and only in the last years, the estimates of organic carbon pools for mangrove in arid regions have experienced increasing interest. New data are available especially for Saudi Arabia (Almahasheer et al. 2017, Eid et al. 2019, Shaltout et al. 2020), Qatar (Chatting et al. 2020), Mexico (Ochoa-Gómez et al. 2019), United Arab Emirates (Schile et al. 2017), Iran (Etemadi et al. 2018) and Egypt (Eid &Shaltout 2016). Mangroves in arid regions may represent different dynamics as compared to wetter climates, since they could be more susceptible to climate change than other areas (Etemadi et al. 2018). Etemadi et al. (2016) observed a 3.14°C increase in minimum temperatures for the 1968-2011 period in the south of Iran, and reported the associated potential negative effects on salinity and sea level rise. Despite *Avicennia* being recognized as having high salinity tolerance and being adapted to survive in extreme climatic conditions (Schile et al. 2017), a climate and environmental change might inhibit plant growth. Iranian mangroves are among the most northerly distributed mangroves in the north hemisphere in severe climatic condition and they should then be placed as a climatic threshold. Due to the scarcity of data concerning carbon sequestration considering both biomass and soils in arid mangrove in a vulnerable area, further investigation is thus needed. Most of the above-mentioned studies in the region have been carried out in mono specific *A. marina* stands. The purpose of this study was to investigate biomass and soil carbon storage in mangrove forests of Sirik Azini Creek considering mixed stands as well as *Rhizophora sp*. stands, aiming to answer the following question: How might different forest stands affect carbon stocks in an arid mangrove ecosystem?

The obtained results will contribute to the improvement of global modeling, offering new empirical data on an understudied and fragile ecosystem, which represent an important threshold of mangrove worldwide distribution. The estimate of Hara forest carbon storage will also support the local policy to promote management activities acting to protect this small and fragile forest immerged in an arid environment.

2. Materials and methods

2.1 Study area

This study was conducted in the Azini creek of the Sirik mangrove forest, which covers an area of 773 ha in southern Iran in the Oman Sea (26°19′ N, 057° 05′ E; Fig. 1). The Sirik mangrove forest is an arid environment with low mean annual rainfall, ranging between 100 and 300 mm, and high annual mean temperature (25.8 °C), with extremely high summer temperatures that exceed 40°C (Parvaresh et al. 2011, Taghizadeh 2007). The coasts of Sirik are exposed to diurnal tides one high and one low tide evry lunar day). Lithological facies upstream of the area are gypsiferous shale, sandstone conglomerate, polymictic piedmont conglomerate and sandstone, and sedimentary melange. The soil texture of the study area is sand 22%, silt 58% and clay 20% (Parvaresh et al. 2011, Taghizadeh 2007). Annual sediment yield is high: approximately 5,350 t km^{-2} y^{-1} of this sediment is transported by the Gaz River and discharged into the Sirik mangrove forest and trapped by *Avicennia marina* trees (Parvaresh et al. 2011, Taghizadeh 2007). There are farm lands and traditional ranching upstream. Mangrove forests in Sirik spread in several creeks and Azini creek is a major breeding and wintering ground for many waterbirds.

2.2. Sampling scheme

Nine plots with dimensions of 10 m x10 m were randomly defined within Sirik Azini creek during the month of July, and distributed from the shore to the sea (Fig. 1). The study area was divided in three regions based on vegetation cover: 1) three plots were selected in the monospecific *A. marina* forest, 2) three plots in the mixed *A. marina* and *R. mucronata* forest, 3) three plots in the monospecific *R. mucronata* forest.

2.3 Forest structure and carbon stocks in the aboveground biomass

In each plot, mangroves were counted, and their trunk diameters were measured using a caliper. For *A. marina* species, trunk diameter at breast height (DBH) should be measured at a height of 130 cm above the ground, but since the trunks of the trees in this region were often branched into two or more branches before this height, the diameter of tree trunk was measured at ground level D_0 (Komiyama et al. 2005a). In *R. mucronata* species, 30 cm above the highest prop root, the trunk diameter $D_{R0.3}$ was measure (Wang et al. 2014).

Tree wood was sampled in the plots to estimate the wood density of the two species. Three trees were selected in each plot and a sample was taken from each of them. For this purpose, a piece of each tree was separated from one of the sub-branches with a length of approximately 25-30 cm and to prevent the samples from drying out, they were wrapped in straw paper, placed in separate plastic bags, and transferred to the laboratory.

Wood density was determined following the methods of (Osazuwa-Peters &Zanne 2011a). First the wood samples were placed in the oven at 105°C for 72 hours, then the mass of the pieces was measured using a digital scale and the wood density (P) of the two species was calculated using the following equation (Osazuwa-Peters &Zanne 2011b):

$P = m/v \ (\mathrm{g/cm^3})$

Where m is the mass and v is the volume of the piece of wood.

The above ground biomass (AGB), below ground biomass (BGB) and the total forest biomass were calculated using the following allometric equations (Komiyama et al. 2005b, Wang et al. 2014).

$\mathrm{AGB}_{=}0.251pD^{2.46}$

$\mathrm{BGB}_{=}\ 0.199p^{0.899}D^{2.22}$

where D is the trunk diameter and p is wood density.

$TFB=AGB+BGB$

where TFB is the total forest biomass., Based on the number of plots and the area of the study area, the amount of biomass in Mg ha^{-1} in vegetative regions was calculated. Above (AGC) and belowground tree carbon (BGC), were converted from the biomass (AGB and BGB) by using conversion factors of 0.48 and 0.39, respectively (Kauffman and Donato, 2012).

2.4 Soil sampling and analysis

At each plot, five soil cores were collected using a cylindric corer with a diameter of 5 cm and a length of 30 cm. The samples were packed in plastic bags and transferred to the laboratory in order to determine dry weight, bulk density (BD), organic matter (OM) and soil organic carbon (SOC). In order to obtain the dry weight, the soil samples were placed in aluminum containers in an oven at 105°C for 72 hours. In order to determine bulk density (BD), the mass of the samples was measured. The volume of the samples is equal to the volume of the corer cylinder.

Loss-on-ignition method was applied to measure soil organic carbon. (Castaneda 2010, Davies 1974). To make the results comparable and to get homogeneous soil samples, a mineral soil fraction smaller than 2 mm was used for soil analysis, thus all living macroscopic roots, plant and animal residues with a diameter larger than 2 mm were removed from the soil samples by dry sieving (ISO, 2006). The soil samples of each vegetative region were pounded separately into a porcelain mortar, sieved and homogenized. 5 g of soil samples were placed in a furnace for 2 hours at 550 °C. They were weighed and the reduction of soil weight indicates the amount of organic matter. The percentage of organic carbon (OC %) was calculated by dividing the percentage of organic matter (OM %) by the *van Bemmelen* factor (1.724).

To estimate the amount of soil organic carbon (SOC) for the first 30 cm of soil depth, the following equation (Batjes 1996) was applied:

$$SOC_i = BD_i \times \ OC_i \times D_i$$

SOCi is the content of soil organic C per surface unit, BD is bulk density, OC is the amount of organic carbon in the layer i and Di is the thickness of the soil layer. For each sampling point, a unique layer (Di) from 0 to 30 cm depth was sampled, so the value of OC was representative of the whole thickness of the topsoil, which is the most carbon-rich part of a soil profile. Coarse fragments were not present in the studied soils.

2.7 Statistical analysis

The analysis of variance (one way-ANOVA) was applied to identify the influence of vegetation stands on each variable: diameter, wood density, forest biomass and forest carbon. These data were previously tested for normality by using One-Sample Kolmogorov-Smirnov Test. Statistical analyzes were performed using IBM SPSS Statistics 19 software. Further, for each considered soil parameter (bulk density, organic carbon and soil organic carbon stock) the non-parametric

Kruskal-Wallis test was used, within the R-environment (R Core Team, 2021), to test the influence of vegetation cover (as independent variable) on soil variables: bulk density, organic carbon content and soil organic carbon stock. The aim was to identify significant differences in these parameters between *A. marina* and mixed *A. marina* and *R. mucronata forest*, between *A. marina* and *R. mucronata* forest, and between the monospecific *R. mucronata* forest and mixed forest.

3. Results and discussion

3.1 Carbon stock in the biomass

The value of *A. marina* wood density (0.75 ± 0.05 g cm^{-3}) was higher than the wood density that was estimated for other countries, such as South America, Australia and Southeast Asia, while the value of *R. mucronata* wood density (0.83 ± 0.06 g cm^{-3}) was intermediate (Table 1; Zanne et al. 2009). Wood density also differed significantly ($p < 0.001$; Fig 2) between the two species. The diameters of *R. mucronata* were significantly lower than those for the other two forest covers (Fig 2). In the mixed stands the wide range of the values shown by the boxplot (Fig 2A) is due to large diameters of *A. marina* trees with a mean value of 27.9 cm, higher than mean diameter of pure *A. marina* stands.

The above ground (AGB), below ground (BGB) and the total biomass of mangroves (TFB) in the three regions are reported in Table 2. The TFB was significantly different between *A. marina*, *A. marina* and *R. mucronata*, and *R. mucronata*, being 253.9, 556.1 and 39.2Mg ha^{-1}, respectively. The mean AGB of mangrove forest at Siriki Azini creek was 205.9±79 Mg ha^{-1}, the mean BGB was 77.9±45 Mg ha^{-1}, and the mean TFB of the site was 283.1 Mg ha^{-1}. Although the mean biomass of mangrove forest of Sirik is lower than many studied mangrove forests (Table 3), it is sizable. Inconsistent with previous studies that have stated that *A. marina* biomass is lower than other mangrove species (Zhila et al. 2014), in this study *A. marina* biomass was higher than *R. mucronata*. We compared our results with ABG and BGB values reported a by Komiyama et al. (2008) for different worldwide distributed mangrove forests (Table 3). The highest TFB was estimated for a *Rhizophora* forest located in Panama (585.4 Mg ha^{-1}), about twice the value found for Sirik forest in this study, while the lowest TFB was found in a mixed mangrove forest located in southern Pang Nga region of Thailand (90.2 Mg ha^{-1}). The biomass of mangrove forest in Sirik (283.1 Mg ha^{-1}; this study) is comparable with the biomass of *R. apiculata* forest in Halmahra Indonesia and the biomass of *Rhizophora spp*. forest Thailand (Ranong Southern).

3.2 Soil organic carbon storage

Bulk densities for *A. marina*, *A. marina* and *R. mucronata*, and *R. mucronata* regions were 1.43±0.09, 1.22±0.09 and 0.92±0.12 g cm^{-3}, respectively, with significant differences between different areas (Fig. 3). However, OC (%) for *R. mucronata* plot was significantly higher than OC content in the other two regions (Fig. 3 and Table 4). The SOC storage showed significant differences between the *Avicennia* site and the other two areas (Fig. 3).

In *A. marina* region BD was significantly the highest and the OC was the lowest (2.7 ± 0.5 %; Fig. 3), while *R. mucronata* region showed the opposite behavior with the lowest BD value and the highest OC content (8.1±0.8 %) for the first 30 cm of the soil depth. Values of OC concentration (%) were lower than those reported by Donato et al. (2011) while soil bulk densities are significantly higher. The mean soil organic carbon storage in the whole Hara Forest was 188.3 ± 27 Mg ha^{-1} (Table 4), which is about 59 % of the forest stored carbon.

Soil carbon storage was higher than values reported for other countries, as southeastern Australia (57.3-94.2 Mg ha^{-1}; (Howe et al. 2009), Okinawa, Japan (57.3 Mg ha^{-1}; (Khan et al. 2007)), North Vietnam (68.5 Mg ha^{-1}; (Cuc et al. 2009) and Palawan, Philippines (173.7 Mg ha^{-1}; (Abino et al.

2014) and lower than SOC storage in northern Sulawesi, Indonesia (822.1 Mg ha^{-1}; (Murdiyarso et al. 2009) and Yanglu Bay in southern China (275 Mg ha^{-1}; (Wang et al. 2014).

Focusing on the comparison with other studies on carbon pools in arid regions (Table 5), we observed high SOC stock values. This was due to higher OC content, compared to other studies, rather than BD values. The high soil carbon storage can be due to high annual sediment yield: approximately 5,350 t km^{-2} y^{-1} of sediments are transported by the Gaz River and discharged into the Sirik mangrove forest (Taghizadeh 2007); this is a likely transport mechanism of organic matter in this river-dominated coastline (Twilley et al. 2018), where SOC stocks are partly composed of allochthonous material (Andreetta et al. 2016). Considerable SOC stocks can also originate from in situ BGB production (Krauss et al. 2014) that in our sites is the highest for the mixed site *(Avicennia* and *Rhizophora)*. This is likely due to the large diameters of the *A. marina* trees, that in the mixed stands are higher than those for pure stands. This kind of detritus contains lignocellulose that is resistant to enzymatic breakdown and especially the lignin component is less depolymerized. Detritus therefore becomes lignin enriched (Cragg et al. 2020) and particularly in costal environment where anoxic conditions can be maintained by prolonged floods, decomposition of OM is slow down and accumulation of OC forms a major carbon sink in blue carbon ecosystems (Cerón-Bretón et al. 2011, Cragg et al. 2020). Furthermore, most of the studies on mangrove soils in the Middle East coasts have been carried out on *Avicennia* sites, while in the present study two of the three investigated areas were influenced by *Rhizophora spp* forests with values of SOC stocks comparable with those reported for the *Rhizophora* site in the Gulf of California (Mexico; Ochoa-Gómez et al., 2019; Table 5). Our results showed that differences in vegetation cover play a key role in soil carbon storage. However, further investigation is needed to better understand the processes, the source and fate of organic carbon in arid mangrove considering a wide range of environmental variables such us for example the impact of bioturbation on SOC storage (Andreetta et al. 2014).

3.3. Total forest and soil carbon storage

Considering both forest and soil carbon storage, significant differences were found between different vegetation regions (Fig 4), with the highest values observed for the mixed forests and the lowest for *R. mucronata*. The mean Hara Forest carbon stored in the above and below ground (roots) biomass was 98.5 Mg ha^{-1} and 30.4 Mg ha^{-1}, respectively with a total carbon in mangrove biomass of 128.9 ±59 Mg ha^{-1}, equivalent to about 41% of the total carbon storage of the forest ecosystem (317.2 ±86 Mg ha^{-1}). Indeed, we found that a large amount of organic carbon of the Sirik mangrove ecosystem is stored in the soil (188.3 ±27 Mg ha^{-1}). Carbon storage of mangrove ecosystem in Sirik region was estimated 317.2 ±86 Mg ha^{-1}, which is significant and can play an important role in reducing global climate changes by carbon capture and storage. Our results are in agreement with Eid et al. (2019), that highlighted how the capacity to stored OC in arid areas is not as low as previously presented, therefore increasing the available data will be of interest in drawing a more reliable picture of this peculiar ecosystem.

Conclusion

This study represents a first step for deepening the understanding of the Iranian mangrove forests as representative of arid ecosystem and their role in capturing organic carbon considering both the biomass and the soil component. The importance of soil as a carbon sink is particularly significant, being about 59% of the total mangrove ecosystem estimate, while 31% is allocated in the above ground biomass. Soil carbon storage was significantly higher in the *Rhizophora* and in the mixed area, maintaining a high capacity of the entire forest system to stored carbon even when the carbon stored in the biomass is low, as for the *R. mucronata* in this study. However, the Hara Forest is not a really extensive and it is directly delimited by a very arid region, thus climate change and anthropogenic impact can easily perturbate the fragile balance of this ecosystem. Our results will likely support research programs that aim to work in the framework of climate change and policy that act to better manage mangrove from a local to a global point of view.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data were included in the manuscript.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Ahmad Homaei and Ehsan Kamrani conceived and designed research. Mahmood Askari conducted experiments. Mahmood Askari, Ahmad Homaei, Farrokhzad Zeinali and Anna Andreetta analyzed data. Mahmood Askari, Farrokhzad Zeinali, and Ahmad Homaei wrote and Ahmad Homaei, Ehsan Kamrani and Anna Andreetta edited the manuscript.

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Table 1. Comparison of the study results and the density of wood of *A. marina* and *R. mucronata* species studied in different parts of the world as reported by (Zane 2009)

Species	Wood density (g cm^{-3})	Region
A. marina	0.520	South America (tropical)
A. marina	0.689	Australia/PNG (tropical)
A. marina	0.650	South-East Asia (tropical)
A. marina	0.732	Australia/PNG (tropical)
A. marina	**0.751**	**Iran/Sirik (this study)**
R. mucronata	0.740	South-East Asia (tropical)
R. mucronata	0.771	Australia/PNG (tropical)
R. mucronata	0.820	South-East Asia (tropical)
R. mucronata	**0.825**	**Iran/Sirik (this study)**
R. mucronata	0.835	Australia/PNG (tropical)
R. mucronata	0.904	South-East Asia (tropical)

Table 2. Estimation of above (AGB) and below ground biomass (BGB), and total biomass (TFB) in the 3 vegetation regions.

Species	**AGB (kg)**	**BGB (kg)**	**TFB (kg)**
A. marina	2810.89	1152.28	3963.17
A. marina & R. mucronata	12285.36	4398.47	16683.83
R. mucronata	464.78	248.39	713.17
Total	15561.03	5799.14	21360.17

Table 3. Comparison of biomass estimation results of mangrove forests in Sirik Azini creek region in this study and mangrove forests biomass in other part of the world as reported by Komiyama et al (Komiyama et al. 2008).

	Species	**TFB (t ha^{-1})**	**BGB (t ha^{-1})**	**AGB(t ha^{-1})**	**Region**
2	Rhizophora forest	585.4	306.2	279.2	Panama
3	Rhizophora SPP. forest	571.4	272.9	298.5	Thailand (Ranong Southern)
4	R.apiculata forest	552.9	196.1	356.8	Indonesia (Halmahera)
6	R.apiculata forest	476.3	177.2	299.1	Indonesia (Halmahera)
7	A.marina forest	462	121.0	341.0	Australia
10	R.apiculata forest	315.6	98.8	216.8	Indonesia (Halmahera)
11	**A.marina & R.mucronata**	**283.1**	**77.9**	**205.9**	**Iran (Sirik; this study)**
12	Rhizophora SPP. forest	292..9	11.7	281.2	Thailand (Ranong Southern)
13	A.marina forest	291.8	147.3	144.5	Australia
14	A.marina forest	272.6	160.3	112.3	Australia
15	R.stylosa forest	272.2	94.0	178.2	Indonesia (Halmahera)
16	Mixed forest	192.5	50.3	142.2	Thailand (Trat Eastern)
18	R.mangle	127.3	64.4	62.9	Puerto-rico
19	Mixed forest	90.2	28.0	62.2	Thailand (Southern pang-nga)

Table 4. Mean ±SD: bulk density (BD), organic carbon (C), soil organic carbon storage (SOC), aboveground biomass (AGB), belowground biomass (BGB), total forest biomass (TFB=AGB+BGB), total forest carbon (TFC=AGC+BGC), Mangrove ecosystem carbon storage in Sirik Azini creek region.

Species	BD (g/cm^3)	C (%)	SOC (Mg C ha^{-1})	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TFB (Mg ha^{-1})	TFC (Mg C ha^{-1})	Ecosystem C-stocks (Mg C ha^{-1})
A. marina	1.43(±0.09)	2.7(±0.5)	115.9 (±22)	180.5(±56)	73.5(±28)	253.9(±78.9)	115.3 (±37.9)	282.1
A. marina &R. mucronata	1.27(±0.09)	6.2(±1.0)	226.2 (±37)	409.5(±298)	146.6(±107)	556	253.7 (±175)	466.5
R. mucronata	0.92(±0.12)	8.1 (±0.8)	222.7 (±21)	25.6(±3.4)	13.6(±1.7)	39.2(±5.1)	17.6(±1.9)	238.1
Mean	1.19 (±0.1)	5.6 (±0.8)	188.3 (±27)	205.9(±79)	77.9(±45)	283.1	128.9 (±59.3)	317.2

Table 5 Comparison of OC (%), bulk densities (BD) and soil organic carbon stock (SOC) of mangrove forests in Sirik Azini creek region in this study and those for other arid mangrove regions.

Site	Vegetation	OC (%)	BD (g cm^{-3})	Depth (cm)	SOC (Mg OC ha^{-1})	Reference
Red Sea coast of Saudi Arabia	*Avicennia marina*	1.4-1.8	1.5-1.9	50	67-105	Shaltout et al., 2020
Qatar	*Avicennia marina*	0.3-6.9	0.2-2	50	20-64	Chatting et al., 2020
La Paz Bay - Gulf of California (Mexico)	*Rhizophora mangle*			45	208.9 ± 144.6	Ochoa-Gómez et al., 2019
	Avicennia germinans			45	155.5 ± 72.1	
Sirik, Iran	*Avicennia marina*	2.7±0.45	1.43	30	115.9±21.5	This study
	Avicennia&Rhizophora	6.2±1.04	1.27	30	226.2±37.2	This study
	R. mucronata	8.1±0.81	0.92	30	222.7±21.0	This study
United Arab Emirates	*Avicennia marina*			100	36.7–367.0	Schile et al., 2017
Jask area in southern, Iran	*Avicennia marina*	0.1-1.1	1.1-1.9			Etamadi et al., 2018
Kingdom of Saudi Arabia	*Avicennia marina*	0.2-1.5		100	43±5	Almahasheer et al., 2017
Farasan Islands, Saudi Arabia	*Avicennia marina*	1.63±0.03	1.55±0.02			Eid et al., 2020
	R.mucronata	1.49±0.02	1.48±0.02			
Southern Red Sea coast, Saudi Arabia	*Avicennia marina*	2.3-3.3	1.25-1.45	30	110	Eid et al., 2019
Red Sea coast, Egypt	*Avicennia marina*	1.55±0.06	1.40±0.02	40	85	Eid and Shaltout, 2016

Figure Captions

Figure 1. Location of the study site: Azini creek in Sirik (Iran).

Figure 2. Boxplots of A) the diameter (cm) and B) the woody density (g cm^{-3}) among the vegetation areas. Different lowercase-letters indicate significant differences between different regions (p <0.05).

Figure 2. Boxplots of A) the soil bulk densities (BD), B) OC content and C) soil organic carbon storage (SOC) for the three different vegetation areas of mangrove forest in Sirik Azini creek region. Different lowercase-letters indicate significant differences between the vegetation regions (p <0.05).

Figure 4. Mangrove forest carbon allocation in the biomass (ABC and BGC) and soil organic carbon storage (SOC) for the three vegetation regions.

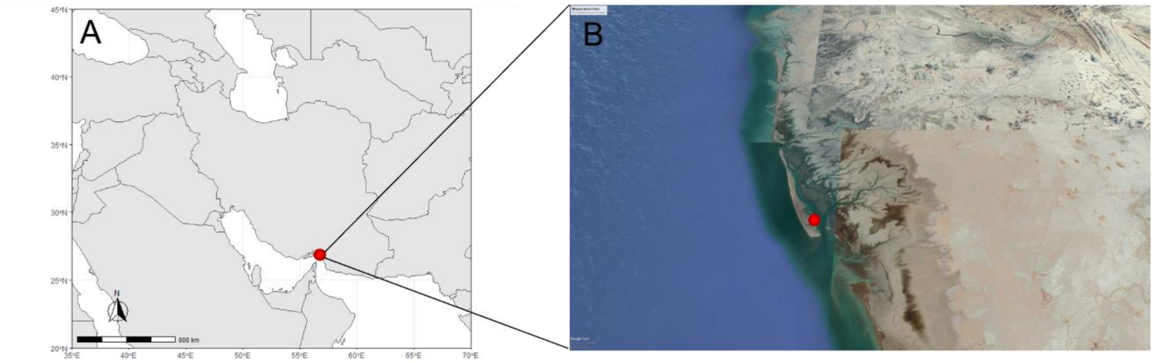
A
B
45°N
40°N
35°N
30°N
25°N
20°N
35°E
40°E
45°E
50°E
55°E
60°E
65°E
70°E
N
600 km

Figure 1

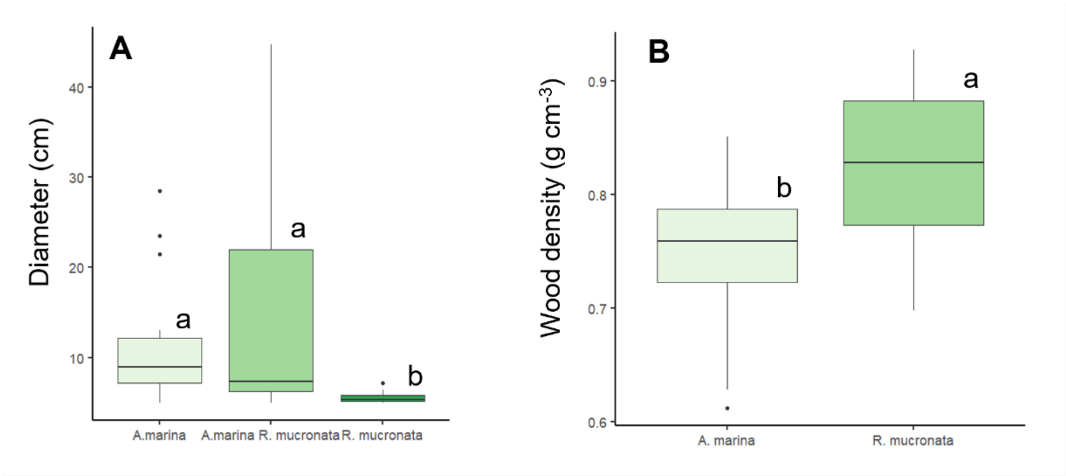
A
Diameter (cm)
40
30
20
10
a
a
b
A.marina
A.marina R. mucronata
R. mucronata
B
Wood density (g cm-3)
0.9
0.8
0.7
0.6
a
b
A. marina
R. mucronata

Figure 2

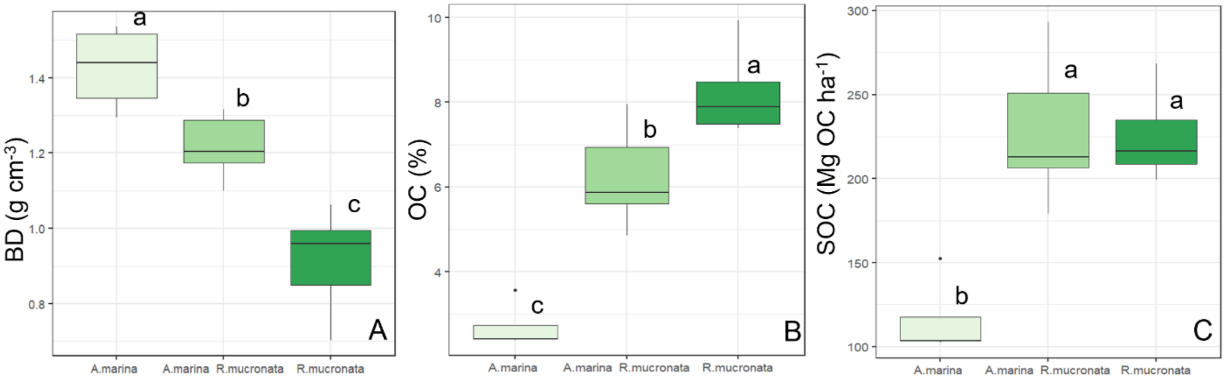
a
b
c
BD (g cm^{-3})
1.4
1.2
1.0
0.8
A
A.marina
A.marina R.mucronata
R.mucronata
10
8
6
4
OC (%)
a
b
c
B
A.marina
A.marina R.mucronata
R.mucronata
300
250
200
150
100
SOC (Mg OC ha^{-1})
a
a
b
C
A.marina
A.marina R.mucronata
R.mucronata

Figure 3

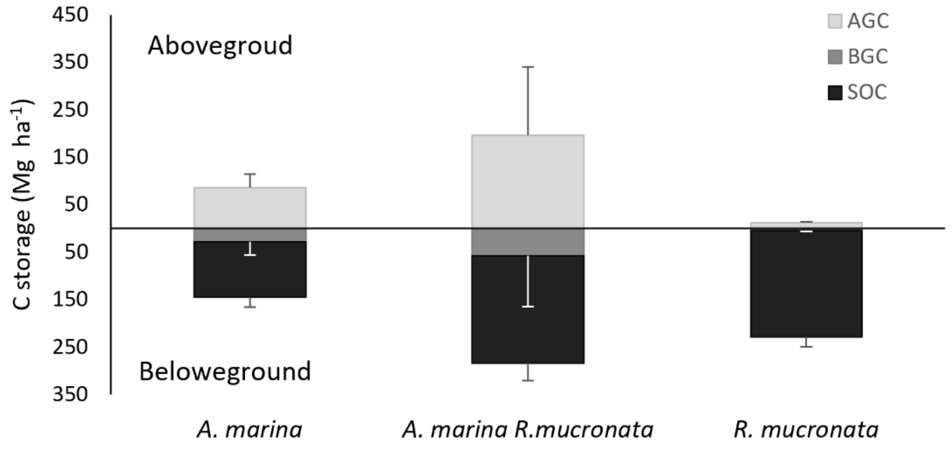
450
350
250
150
50
50
150
250
350
C storage (Mg ha-1)
Abovegroud
Beloweground
AGC
BGC
SOC
A. marina
A. marina R.mucronata
R. mucronata

Figure 4