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 on mangroves due to their recognition as one of the most carbon rich ecosystem, arid mangroves are still poorly investigated. We aimed to improve the knowledge on biomass and soil carbon sequestration for an arid mangrove forest located at the Azini creek, Sirik, Hormozgan Province (Iran). Three different regions were considered based on the composition of the principal species growing in the study area: 1) *Avicennia marina*, 2) mixed forest of *A. marina* and *Rhizophora mucronata*, and 3) *R. mucronata*. Biomass carbon storage, considering both aboveground (AGB) and belowground biomass (BGB), was significantly different between the cover areas. Significantly higher values of soil organic carbon stock were found in the sites under *Rhizophora spp.* than in the site with pure stand of *Avicennia spp.* . Overall, the mean forest biomass (TFB) was 305 Mg ha^{-1} and the highest proportion of organic carbon (62 %) was found to be stored in the soil, while the lowest was located in the root biomass (BGB; 10%). The AGB accounted for about 28% of the C stored in the studied site, with significant differences between the three vegetation areas. Our results on carbon storage can be used by local policy to promote conservation actions in arid mangrove forests, which also represent an important climatic threshold of mangrove worldwide distribution.

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 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, storing more than twice the global CO_2 emissions. Their high primary productivity and the high amount of carbon stored in their soil (Castañeda-Moya et al. 2010), leads to higher amount of mean carbon storage than that in high tropical, temperate and northern forests (Komiyama et al. 2005). 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) and the role of mangrove forests in stabilizing significant levels of atmospheric carbon dioxide in their biomass and in the soils has been emphasized in recent years (Osazuwa-Peters &Zanne 2011).

Notwithstanding, mangroves are now threatened by human activities and their exploitation often goes beyond the natural replacement level. The projects such as diverting river water from coastal and mangrove regions can increase salinity and thus may destroy mangroves (Parida &Jha 2010). The rapid disappearance and destruction of mangroves can convert this 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 (Davies 1974).

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, 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 communities living in areas adjacent to the forests: mangrove branches and leaves are important fodder for camels and cattle; *A. marina* wood is used in the construction of buildings, as firewood in the production of charcoal and in the manufacture of local wooden doors. Honey production also depends on *A. marina* flowers, and medicinal substances such as saponins, flavonoids and tannins, are obtained from its leaves and branches (Giri et al. 2011).

Recently, global changes combined with local constrains threaten the Hara forest ecosystem (Zahed et al. 2010). Mangrove stands have been 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 users 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. 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 being 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). Evidence of increasing temperature (about 3.14°C for the minimum temperature) in the south of Iran has been reported by Etemadi et al. (Etemadi et al. 2016), with potential negative effects on salinity and sea level rise. Despite the *Avicennia* recognized high salinity tolerance and adaptation to survive at extreme climate conditions (Schile et al., 2017), the progressive climate and environmental change might inhibit plant growth. Iranian mangroves, being the most northerly distributed in the north hemisphere with severe climatic condition, should be thus placed as a climatic threshold. The scarcity of data concerning carbon sequestration considering both biomass and soils in arid mangrove, a vulnerably area, needs thus further investigation. The purpose of this study was to investigate biomass and soil carbon storage in mangrove forests of Sirik Azini Creek to examine the relationship between forest cover and carbon sequestration in an arid mangrove ecosystem. The obtained results will contribute to the improvement of global model, 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 the southern Iran in the Oman Sea (26°19' N, 057° 05' E, Fig. 1). Sirik mangrove forest is a hot and arid environment with low mean annual rainfall, ranging between 100 and 300 mm, and high annual mean temperature (26.8 °C), with extremely high summer temperatures that exceed 40°C. In this area, monthly mean evaporation is 292 mm, and soil salinity gradually increases towards the sea. The coasts of Sirik are exposed to diurnal tides (high and low tides) once a day. Geological 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). 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

Seven plots with dimensions of 10 m x10 m were randomly determined within Sirik Azini creek from the shore to the sea in July (Fig. 1). The study site was divided in three regions based on vegetation cover: 1) two plots were selected in the monospecific *A. marina* forest, 2) three plots were studied in the mixed *A. marina* and *R. mucronata* forest, 3) two 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. 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 and Zanne (Osazuwa-Peters &Zanne 2011). The volume of all pieces was measured by this method. Then, they were placed in the oven at 105°C for 72 hours, 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:

P=m/v (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. 2005, Wang et al. 2014).

AGB = $0.251pD^{2.46}$

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, AGB is the above ground biomass and BGB is the below ground biomass. Total Forest Carbon (TFC) was then obtained by multiplying TFB by carbon concentration (43.21%, (Wang et al. 2014).

2.4 Soil sampling and analysis

At each plot, two 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). 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). Plant and animal residues such as roots, branches, leaves and shells were removed from the soil samples. 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, 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, Di is the thickness of the soil layer. Coarse fragments were not present in the studied soils.

2.7 Statistical analysis

Data collected were tested for normal distribution by using Shapiro–Wilk test and then the analysis of variance (ANOVA) was applied to identify significant differences, for all the considered variables, between different vegetation areas. Statistical analyzes were performed using IBM SPSS Statistics 19 software.

3. Results And Discussion

3.1 Carbon stock in the biomass

In order to estimate the biomass according to Komiyama equations (Komiyama et al. 2005), two factors of wood density and tree trunk diameter were required. 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 differed significantly ($p < 0.001$, Fig 2) between the two species.

The above ground (AGB), below ground (BGB) and the total biomass of mangroves (TFB) in the three regions are reported in Table 2. According to the number of plots and the area of the study sites, the amount of biomass in Mg ha^{-1} in vegetative regions was calculated. The TFB was significantly different between *A. marina*, *A. marina* and *R. mucronata*, and *R. mucronata*, being 198.15, 556.13 and 35.66 Mg ha^{-1}, respectively. The mean AGB of mangrove forest at Siriki Azini creek was 222.30 Mg ha^{-1}, the mean BGB was 82.85 Mg ha^{-1}, and the mean TFB of the site was 305.15 Mg ha^{-1}. Although the mean biomass of mangrove forest of Sirik is lower than many studied mangrove forests (Table 3), it is significant. 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. (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 (305.15 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).

In the Sirik mangrove forest, the ratio between AGB / BGB was 2.68 which is in the range of values typically founded in mangrove forests (between 2 and 3), while AGB/BGB is significantly lower than the values reported for the terrestrial highland forests. These differences in biomass allocation (AGB vs. BGB) reflect distinct environmental factors and the peculiar mangrove forest environment leads to an allocation of more biomass to belowground in order to enhance nutrient uptake (Castañeda-Moya et al. 2013) or may be seen as an adaptation for life in soft and muddy sediments (Komiyama et al. 2008). However, mechanisms that control TFB and biomass allocation should be tested in future in order to clarify feedbacks that drive carbon storage in mangrove forests of arid region.

3.2 Soil organic carbon storage

Bulk densities for *A. marina*, *A. marina* and *R. mucronata*, and *R. mucronata* regions were 1.43, 1.22 and 0.92 g cm^{-3}, respectively with significant differences between different areas (Fig. 3), while 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%, Fig. 3), while *R. mucronata* region showed an opposite behavior with the lowest BD value and the highest OC content (8.1%). Values of OC concentration (%) were lower than those reported by Donato et al. (Donato et al. 2011) while soil bulk densities are significantly higher. The mean soil organic carbon storage in the whole Hara forest was 188 Mg ha^{-1} (Table 4), which is about 62 % 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 (173.75 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 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 value of Sirik mangrove soil carbon storage should be ascribed 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 likely a mechanism of organic matter transport to this river-dominated coastline (Twilley et al. 2018), where SOC stocks is composed by a component 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 highest for the mixed site *(Avicennia* and *Rhizophora)*. 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 are 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 costs have been carried out on *Avicennia* sites, while in the present study two of the three investigated areas were influenced by *Rhizophoraspp* forests with values of SOC stocks comparable with those reported for *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 as a driver 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 biomass and soil carbon storage

Considering both biomass 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 ground biomass was 96. Mg ha^{-1}, 36 Mg ha^{-1}in the below ground biomass (root) and 188 Mg ha^{-1}in in the forest soil. The total biomass of mangrove forests in Sirik was 132 Mg ha^{-1}, equivalent to about 38% of the total carbon storage of the forest. Mangrove ecosystem carbon storage includes total soil and forest carbon storage. Therefore, carbon storage of mangrove ecosystem in Sirik region was estimated 302 (Mg ha^{-1}), which is significant and can play an important role in reducing global climate changes by carbon capture and storage. Our results point to a consideration 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, thus enriching present available data will be of interest to draw a more reliable picture of this peculiar ecosystem.

4. Conclusion

This study represents a first step for a deepest 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 62% of the total forest estimate, while 28% 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 wide and borders directly 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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References

1. Abino AC, Castillo JAA, Lee YJ (2014): Species diversity, biomass, and carbon stock assessments of a natural mangrove forest in Palawan, Philippines. Pak. J. Bot 46, 1955-1962

2. Almahasheer H, Serrano O, Duarte CM, Arias-Ortiz A, Masque P, Irigoien X (2017): Low carbon sink capacity of Red Sea mangroves. Scientific reports 7, 1-10
3. Andreetta A, Fusi M, Cameldi I, Cimò F, Carnicelli S, Cannicci S (2014): Mangrove carbon sink. Do burrowing crabs contribute to sediment carbon storage? Evidence from a Kenyan mangrove system. Journal of Sea Research 85, 524-533
4. Andreetta A, Huertas AD, Lotti M, Cerise S (2016): Land use changes affecting soil organic carbon storage along a mangrove swamp rice chronosequence in the Cacheu and Oio regions (northern Guinea-Bissau). Agriculture, Ecosystems & Environment 216, 314-321
5. Batjes NH (1996): Total carbon and nitrogen in the soils of the world. European journal of soil science 47, 151-163
6. Bouillon S, Dahdouh-Guebas F, Rao A, Koedam N, Dehairs F (2003): Sources of organic carbon in mangrove sediments: variability and possible ecological implications. Hydrobiologia 495, 33-39
7. Castañeda-Moya E, Twilley RR, Rivera-Monroy VH, Zhang K, Davis SE, Ross M (2010): Sediment and nutrient deposition associated with Hurricane Wilma in mangroves of the Florida Coastal Everglades. Estuaries and Coasts 33, 45-58
8. Castañeda-Moya E, Twilley RR, Rivera-Monroy VH (2013): Allocation of biomass and net primary productivity of mangrove forests along environmental gradients in the Florida Coastal Everglades, USA. Forest Ecology and Management 307, 226-241
9. Castaneda E (2010): Landscape patterns of community structure, biomass and net primary productivity of mangrove forests in the Florida Coastal Everglades as a function of resource, regulators, hydroperiod, and hurricane distrubance.
10. Cerón-Bretón J, Cerón-Bretón R, Rangel-Marrón M, Murielgarcia M, Cordova-Quiroz A, Estrella-Cahuich A (2011): Determination of carbon sequestration rate in soil of a mangrove forest in Campeche, Mexico. WSEAS Transactions on Environment and Development 7, 55-64
11. Chatting M, LeVay L, Walton M, Skov MW, Kennedy H, Wilson S, Al-Maslamani I (2020): Mangrove carbon stocks and biomass partitioning in an extreme environment. Estuarine, Coastal and Shelf Science 244, 106940
12. Cragg SM, Friess DA, Gillis LG, Trevathan-Tackett SM, Terrett OM, Watts JE, Distel DL, Dupree P (2020): Vascular plants are globally significant contributors to marine carbon fluxes and sinks.
13. Cuc NTK, Ninomiya I, Long NT, Tri NH, Tuan MS, Hong PN (2009): Belowground carbon accumulation in young Kandelia candel (L.) Blanco plantations in Thai Binh River Mouth, Northern Vietnam. International Journal of Ecology & Development 12, 107-117
14. Davies BE (1974): Loss-on-ignition as an estimate of soil organic matter. Soil Science Society of America Journal 38, 150-151
15. Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M, Kanninen M (2011): Mangroves among the most carbon-rich forests in the tropics. Nature geoscience 4, 293-297
16. Eid EM, Shaltout KH (2016): Distribution of soil organic carbon in the mangrove Avicennia marina (Forssk.) Vierh. along the Egyptian Red Sea Coast. Regional Studies in Marine Science 3, 76-82
17. Eid EM, Arshad M, Shaltout KH, El-Sheikh MA, Alfarhan AH, Picó Y, Barcelo D (2019): Effect of the conversion of mangroves into shrimp farms on carbon stock in the sediment along the southern Red Sea

coast, Saudi Arabia. Environmental research 176, 108536

18. Etemadi H, Samadi SZ, Sharifikia M, Smoak JM (2016): Assessment of climate change downscaling and non-stationarity on the spatial pattern of a mangrove ecosystem in an arid coastal region of southern Iran. Theoretical and Applied Climatology 126, 35-49
19. Etemadi H, Smoak JM, Sanders CJ (2018): Forest migration and carbon sources to Iranian mangrove soils. Journal of Arid Environments 157, 57-65
20. Ewel K, TWILLEY R, Ong J (1998): Different kinds of mangrove forests provide different goods and services. Global Ecology & Biogeography Letters 7, 83-94
21. Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N (2011): Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20, 154-159
22. Hamilton SE, Casey D (2016): Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Global Ecology and Biogeography 25, 729-738
23. Hamilton SE, Friess DA (2018): Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. Nature Climate Change 8, 240-244
24. Hashim R, Kamali B, Tamin NM, Zakaria R (2010): An integrated approach to coastal rehabilitation: mangrove restoration in Sungai Haji Dorani, Malaysia. Estuarine, Coastal and Shelf Science 86, 118-124
25. Howe A, Rodríguez J, Saco P (2009): Surface evolution and carbon sequestration in disturbed and undisturbed wetland soils of the Hunter estuary, southeast Australia. Estuarine, coastal and shelf science 84, 75-83
26. Khan MNI, Suwa R, Hagihara A (2007): Carbon and nitrogen pools in a mangrove stand of Kandelia obovata (S., L.) Yong: vertical distribution in the soil–vegetation system. Wetlands Ecology and Management 15, 141-153
27. Komiyama A, Poungparn S, Kato S (2005): Common allometric equations for estimating the tree weight of mangroves. Journal of tropical ecology, 471-477
28. Komiyama A, Ong JE, Poungparn S (2008): Allometry, biomass, and productivity of mangrove forests: A review. Aquatic botany 89, 128-137
29. Krauss KW, McKee KL, Lovelock CE, Cahoon DR, Saintilan N, Reef R, Chen L (2014): How mangrove forests adjust to rising sea level. New Phytologist 202, 19-34
30. Mashayekhi Z, Danehkar A, Sharzehi G, Majed V (2016): Coastal Communities WTA Compensation for conservation of mangrove forests: a choice experiment approach. Knowledge and Management of Aquatic Ecosystems, 20
31. Murdiyarso D, Donato D, Kauffman JB, Kurnianto S, Stidham M, Kanninen M (2009): Carbon storage in mangrove and peatland ecosystems: A preliminary account from plots in Indonesia. Working paper 48. Bogor Banat, Indonesia: Center for International Forestry Research. 35 p., 1-35
32. Nagelkerken I, Blaber S, Bouillon S, Green P, Haywood M, Kirton L, Meynecke J-O, Pawlik J, Penrose H, Sasekumar A (2008): The habitat function of mangroves for terrestrial and marine fauna: a review. Aquat. Bot. 89, 155-185
33. Naidoo G (2009): Differential effects of nitrogen and phosphorus enrichment on growth of dwarf Avicennia marina mangroves. Aquatic Botany 90, 184-190

34. Ochoa-Gómez JG, Lluch-Cota SE, Rivera-Monroy VH, Lluch-Cota DB, Troyo-Diéguez E, Oechel W, Serviere-Zaragoza E (2019): Mangrove wetland productivity and carbon stocks in an arid zone of the Gulf of California (La Paz Bay, Mexico). Forest ecology and management 442, 135-147
35. Osazuwa-Peters O, Zanne A (2011): Wood density protocol. URL http://www.publish.csiro.au/prometheuswiki/tiki-pagehistory. php
36. Parida AK, Jha B (2010): Salt tolerance mechanisms in mangroves: a review. Trees 24, 199-217
37. Parvaresh H, Abedi Z, Farshchi P, Karami M, Khorasani N, Karbassi A (2011): Bioavailability and concentration of heavy metals in the sediments and leaves of grey mangrove, Avicennia marina (Forsk.) Vierh, in Sirik Azini Creek, Iran. Biological trace element research 143, 1121-1130
38. Schile LM, Kauffman JB, Crooks S, Fourqurean JW, Glavan J, Megonigal JP (2017): Limits on carbon sequestration in arid blue carbon ecosystems. Ecological Applications 27, 859-874
39. Shaltout KH, Ahmed MT, Alrumman SA, Ahmed DA, Eid EM (2020): Evaluation of the carbon sequestration capacity of arid mangroves along nutrient availability and salinity gradients along the Red Sea coastline of Saudi Arabia. Oceanologia 62, 56-69
40. Taghizadeh A (2007): Environmental management of Sirik mangrove forest. Islamic Azad University, Iran
41. Twilley RR, Rovai AS, Riul P (2018): Coastal morphology explains global blue carbon distributions. Frontiers in Ecology and the Environment 16, 503-508
42. Wang G, Guan D, Zhang Q, Peart M, Chen Y, Peng Y, Ling X (2014): Spatial patterns of biomass and soil attributes in an estuarine mangrove forest (Yingluo Bay, South China). European journal of forest research 133, 993-1005
43. Zahed MA, Rouhani F, Mohajeri S, Bateni F, Mohajeri L (2010): An overview of Iranian mangrove ecosystems, northern part of the Persian Gulf and Oman Sea. Acta Ecologica Sinica 30, 240-244
44. Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J (2009): Global wood density database.
45. Zeinali F, Homaei A, Kamrani E (2017): Identification and kinetic characterization of a novel superoxide dismutase from Avicennia marina: An antioxidant enzyme with unique features. International journal of biological macromolecules 105, 1556-1562
46. Zeinali F, Homaei A, Kamrani E, Patel S (2018): Use of Cu/Zn-superoxide dismutase tool for biomonitoring marine environment pollution in the Persian Gulf and the Gulf of Oman. Ecotoxicology and environmental safety 151, 236-241
47. Zhila H, Mahmood H, Rozainah M (2014): Biodiversity and biomass of a natural and degraded mangrove forest of Peninsular Malaysia. Environmental Earth Sciences 71, 4629-4635

Tables

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. (2008)

Region	**AGB (t ha⁻¹)**	**BGB (t ha⁻¹)**	**TFB (t ha⁻¹)**	**Species**	
Panama	279.2	306.2	585.4	Rhizophora forest	2
Thailand (Ranong Southern)	298.5	272.9	571.4	Rhizophora SPP. forest	3
Indonesia (Halmahera)	356.8	196.1	552.9	R.apiculata forest	4
Indonesia (Halmahera)	299.1	177.2	476.3	R.apiculata forest	6
Australia	341.0	121.0	462	A.marina forest	7
Indonesia (Halmahera)	216.8	98.8	315.6	R.apiculata forest	10
Iran (Sirik, this study)	**222.3**	**82.9**	**3052**	**A.marina & R.mucronata**	11
Thailand (Ranong Southern)	281.2	11.7	292..9	Rhizophora SPP. forest	12
Australia	144.5	147.3	291.8	A.marina forest	13
Australia	112.3	160.3	272.6	A.marina forest	14
Indonesia (Halmahera)	178.2	94.0	272.2	R.stylosa forest	15
Thailand (Trat Eastern)	142.2	50.3	192.5	Mixed forest	16
Puerto-rico	62.9	64.4	127.3	R.mangle	18
Thailand (Southern pang-nga)	62.2	28.0	90.2	Mixed forest	19

Table 4. Carbon storage of vegetative regions and the entire mangrove forests in Sirik Azini creek region. D is the diameter of the trunk $D_{R0.3}$ for *Rhizophora* specie.

Species	BD g/cm^3	C %	SOC Mg ha^{-1}	D cm	AGB Mg ha^{-1}	BGB Mg ha^{-1}	TFB Mg ha^{-1}	AGB/BGB	TFC Mg ha^{-1}	C - stocks Mg ha^{-1}
A. marina	1.43	2.7	115.9	10.89	140.54	57.61	198.15	2.43	85.6	201.5
A. marina & R. mucronata	1.27	6.2	226.2	14.60	409.51	146.62	556.13	2.79	240.3	466.5
R. mucronata	0.92	8.1	222.7	5.53	23.24	12.42	35.66	1.87	15.4	238.1
Total	1.187	5.6	188.3	10.52	222.30	82.85	305.15	2.68	131.9	302

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

Figures

Figure 1

Location of the study site: Azini creek in Sirik (Iran). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

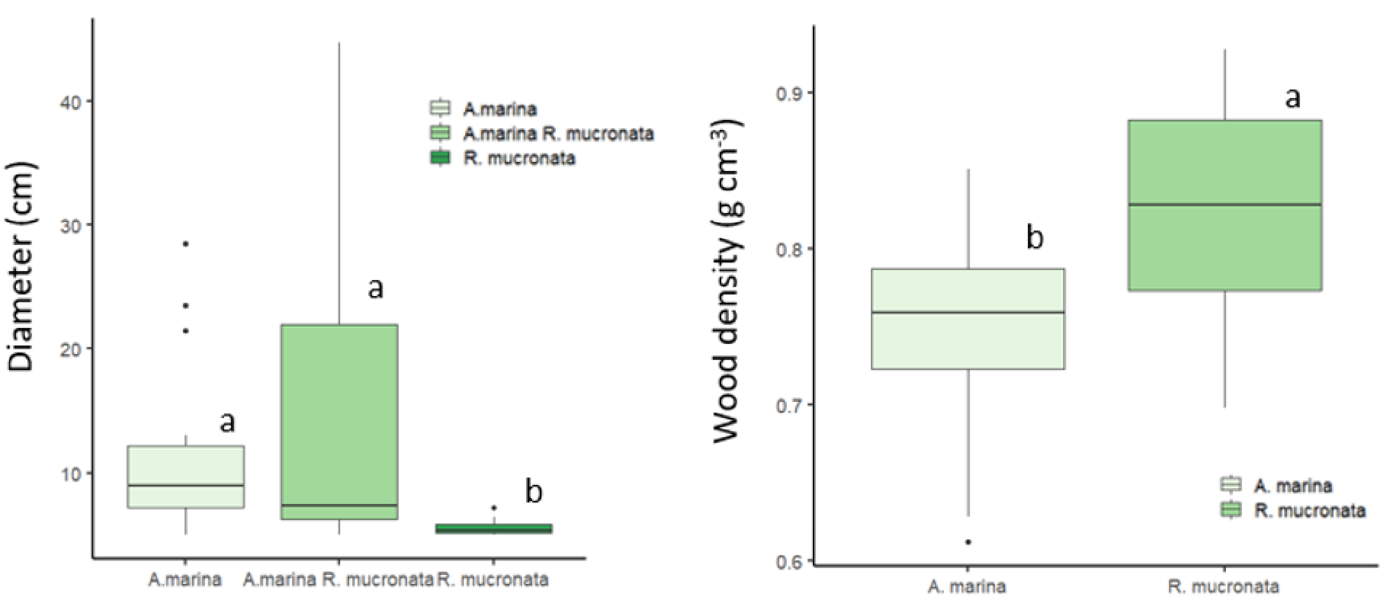

Figure 2

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

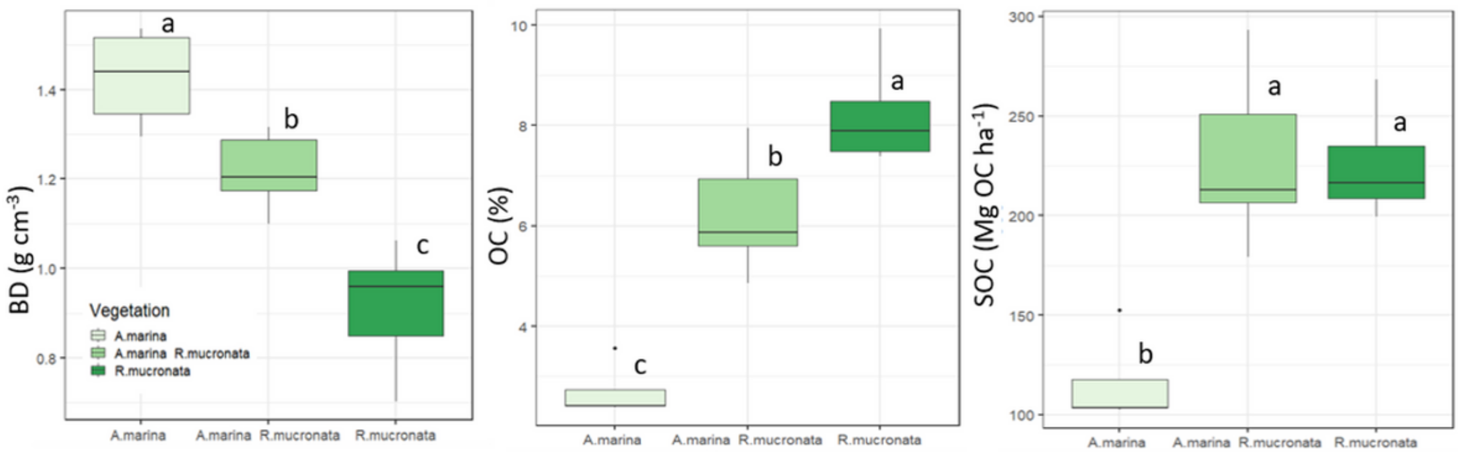

Figure 3

Boxplots of the soil bulk densities (BD), OC content and 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).

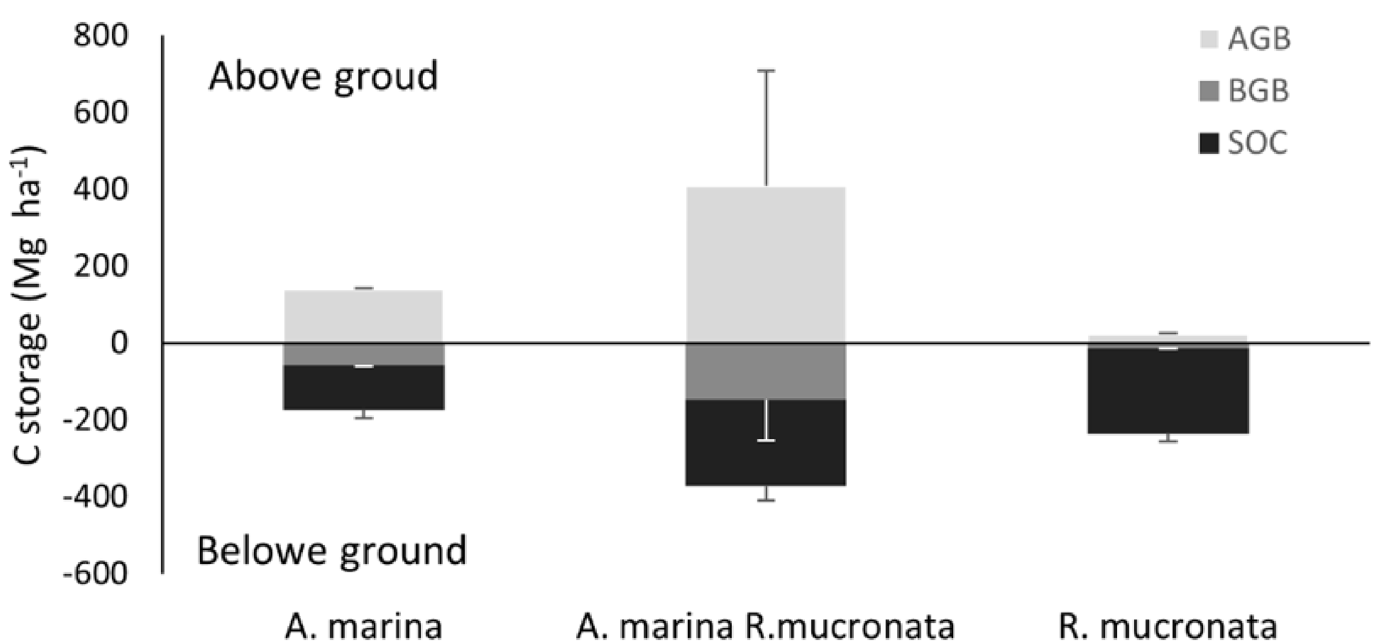

Figure 4

Mangrove forest carbon allocation in the biomass (ABG and BGB) and soil organic carbon storage (SOC) for the three vegetation regions.