Journal of Arid Environments xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Forest migration and carbon sources to Iranian mangrove soils

Hana Etemadi[a,*], Joseph M. Smoak[b], Christian J. Sanders[c]

[a] Environmental Science, Persian Gulf Research Institute, Persian Gulf University, P.O. Box: 7516913817, Bushehr, Iran
[b] Environmental Science, University of South Florida, Florida, 33701, USA
[c] National Marine Science Centre, School of Environment, Science and Engineering, Southern Cross University, Coffs Harbour, New South Wales, Australia

ARTICLE INFO

Keywords:
Organic carbon
Sea level rise
Climate change
Arid mangrove wetland expansion
Jask mangroves

ABSTRACT

Mangrove forests rank as one of the world's most productive biomes and their soils are highly efficient in accumulating organic carbon (OC). Most research on OC in mangrove forests has focused on moist tropical and sub-tropical regions. Here we examine an arid mangrove forest (composed of the species *Avicennia marina*) from the Jask area in southern Iran. The organic carbon content, TOC:TN ratios and $\delta^{13}C$ signatures indicate that marine algae and microalgae are a greater source of organic material than the terrestrial inputs at three out of the four study sites in this work. Furthermore, sea-level rise as well as geomorphic and topographic differences are contributing to the mangrove landward migration and expansion of 112 ha (or 33%) of these arid forests between 1956 and 2012. This is substantial as up to 0.60 g OC cm^{-2} were found in the upper 42 cm of the soils. However, these values should be taken with caution as the large inorganic carbon deposition in the soils here and in other regions may offset the CO_2 sequestration of the global arid mangroves in terms of climate mitigation.

1. Introduction

Mangroves provide numerous ecological services such as nursery and breeding grounds for fish and invertebrates, coastal protection (e.g., typhoon, flood, and tsunami), and store large amounts carbon (Breithaupt et al., 2012). Coastal ecosystems can have autochthonous and allochthonous sources of organic carbon (OC) input including material from planktonic and terrestrial origin (Bouillon et al., 2003). Studies show that OC storage by mangrove forests is generally two to three times greater than most terrestrial forests (Tue et al., 2012), storing between 547 ± 66 t ha^{-1} in subtropics and temperate regions and 895 ± 90 t ha^{-1} in the tropics (Sanders et al., 2016).

Mangrove forests often contain organic soils up to several meters deep and are ten times more efficient at sequestering carbon dioxide on a per area basis per year than boreal, temperate, or tropical forests (Smoak et al., 2013; Sanders et al., 2014). Therefore preserving and restoring these coastal wetlands have been proposed as a way to sequester CO_2 as a means of mitigating anthropogenic climate change (Schile et al., 2016). However, ongoing natural and human-induced alterations that effects the composition of wetland plant species, the quantity of above ground biomass as well as soil biogeochemistry are not yet fully understood. Uncertainties on estimates of mangrove C storage can be improved by empirical data on soil C, which are currently lacking in many regions around the globe. Increasing the spatial data will help refine estimates of global C storage. The synergy of land use and climate change, including the impacts of sea level rise, presents additional uncertainties in the fate and management of coastal C storage (Donato et al., 2011).

Arid environments cover one third of the Earth's surface, where annual rainfall is less than 250 mm a year and the high evapotranspiration potential as well as intense solar radiation is prevalent (Jafari et al., 2018). Arid mangroves ecosystems are characterized by sever temperatures, sparse and sporadic rainfall, high salinity and low nutrient inputs. They are adapted to survive near the limit of their tolerance at extremes in temperature, rainfall and salinity (Schile et al., 2016). Compared to the moist tropics stands, mangrove forests in the arid-zones have lower biomass and productivity, consist of more dense but smaller trees, and tend to inhabit areas with coarser sediment deposits (Alongi, 2015). While mangrove research has grown steadily in the last 50 years, there are a lack of investigation on mangroves from arid reigns. Mangroves in arid regions, including those located in the south of Iran which are the most northerly distributed in the north hemisphere, may represent very different dynamics as compared to other areas. Studies in these regions are important as they are the least studied marine coastal ecosystems of which the paucity of data concerning carbon research as well as climate change impacts on arid mangroves may create a bias toward moist regions in global investigations on wetland carbon sequestration.

Mangroves in an arid setting in the United Arab Emirate along the arid mangroves in the south coast of the Persian Gulf have lower

* Corresponding author.
E-mail addresses: etemadihana@gmail.com, h.etemadi@pgu.ac.ir (H. Etemadi), smoak@mail.usf.edu (J.M. Smoak), Christian.Sanders@scu.edu.au (C.J. Sanders).

https://doi.org/10.1016/j.jaridenv.2018.06.005
Received 2 March 2018; Received in revised form 2 June 2018; Accepted 9 June 2018
0140-1963/

Please cite this article as: Etemadi, H., Journal of Arid Environments (2018), https://doi.org/10.1016/j.jaridenv.2018.06.005

biomass (Schile et al., 2016) and the organic production and carbon turnover rates are lower than most other regions as they compensate carbon deficit by fast litter decomposition to sustain their metabolism (Sánchez-Andrés et al., 2010). There are only a few reliable reports on the climate change impact and the sources of OC in Iranian mangroves. However, Iran ranks 43rd in the world and 10th in Asia in terms of mangrove area (FAO, 2007). Unlike most mangrove systems that have been examined in wetter climates, these arid forests could be more susceptible to climate change. For instance, Etemadi et al. (2015) reported that the minimum temperatures in the south of Iran increased by +3.14 °C over the past 42 years and predicted a further increase to above 38 °C during warm seasons by 2080–2099. Moreover, indirect effects of a rising temperature are increases in salinity and humidity, which may further exacerbate mangrove survival conditions. Accelerating local SLR in this region and the severe climatic conditions in the south of Iran place these mangrove ecosystem at a climatic threshold.

Increasing sea-level rise (SLR) has been cited as the greatest threat to mangroves, which have responded to past sea-level changes by migrating landward or upward (Krauss et al., 2011). In the 20th century, sea-level has risen approximately 20 cm mainly due to thermal expansion of the oceans and melting of glacial ice caused by global warming. Global average sea levels are projected to rise at a rate of 8 and 16 mm yr^{-1} between 2081 and 2100 (IPCC, 2013). Sea level rise may vary from one location to another due to local factors (e.g. tectonic processes, ocean circulation, elevation changes of the wetland sediment surface, coastal subsidence, and sediment budgets) (McLeod and Slam, 2006). Through landward migration and/or soil-surface elevation changes via accretion of autochthonous and allocthonous material, mangrove ecosystems have been remarkably persistent and resilient during rapid sea-level rise (5–15 mm yr^{-1}) during the late Quaternary Period (Alongi, 2008).

The aim of this study is to: (1) Determine the resilience of the mangrove forests to an accelerating sea level rise (ASLR) and to reconstruct their historical expansion in the south of Iran; (2) Quantify the soil carbon stocks and delineate the origin of organic matter through use of elemental organic C and N ratios as well as their isotopic signals ($\delta^{13}C$ and $\delta^{15}N$); and, (3) Compare inorganic and organic carbon stocks to determine offsets in terms of CO_2 sequestration. Based on the lower primary production in these arid regions with harsh climatic conditions and potentially high inorganic carbon deposition, we hypothesize that these systems are much lower in OC sequestration efficiency than forests in wetter conditions. These differences in OC sequestration efficiencies may intern skew the global average carbon sequestration estimates.

2. Site description

The study area includes three protected areas within Hormaozgan province (East Jask, West Jask and Gabrik Mangrove forests), located between 25°33′ to 25°42′ N latitude and 57°46′ to 58° 35′ E longitude. Yekboni estuary (YEK) is located in the West Jask protected area. Shahreno estuary (SH) and Khalasi estuary (KH) are in the East Jask protected area and Gabrik estuary (GET) is situated in Gabrik mangrove forest (Fig. 1). Jask is characterized by arid region with a dry climate condition consisting of hot and dry summers with mild and rainy winters resulting in an excess of evaporation over precipitation. Mean annual rainfall and temperature is 135.56 mm and 26.83 °C respectively (Etemadi , 2014). Water salinity ranges from 36.5 to 41.8 ppt. The grain size of sediment in the study area is 49.15% silt, 32.41% clay, 18.44% sand and 7.84% organic (Azizpour et al., 2014). Tides in Jask coastline are semi-diurnal with approximately 1–4 m tidal range (See Etemadi et al., 2018, for details).

The mangrove forests in this region are dominated by species *Avicennia marina*. *Avicennia* are known to be tolerate to salinity variations and can persist in hypersaline environments. However, the adaptation to the threshold environment in the Persian Gulf might inhibit water uptake and reduce growth. The mangrove forests in the study region are not directly influenced by anthropogenic activities.

3. Methods

3.1. Sediment processing

A sediment core was collected at each study site (Fig. 2) by inserting a 5 cm diameter acrylic tube into the substrate during low tide. The sediment was extruded from the tube and sectioned at 1 cm intervals from the core top down to 30 cm, and at 2 cm intervals from 30 cm depth until the bottom of the core (50 cm). Dry bulk density was determined as the dry sediment weight over the initial wet volume (g cm^{-3}). Two subsamples from each depth interval were dried and ground to powder for carbon analysis. One subsample was acidified to remove carbonates to determine organic carbon and the other subsample was not acidified to determine total carbon. These analyses were performed using a Flash Elemental Analyser coupled to a Delta V IRMS (isotope ratio mass spectrometer), Thermo Fisher. Inorganic carbon was calculated by deducting the organic carbon content from the total organic carbon. The average relative standard deviation based on duplicate samples from the two cores was 0.28% for the OC and TC and 0.02% for N. For analytical precision of stable isotopes, the instrumentation error was less than 0.2‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$ based on long-term standard deviations of samples compared to standard.

3.2. Remote sensing analysis

Normalized Difference Vegetation Index (NDVI) was applied to three Landsat satellites images from four different years (1972, 1987, 2000, and 2009) to determine land cover changes over four decades. In the secondary analysis stage, a Maximum Likelihood Classification (MLC) program was used to define the mangrove and non-mangrove areas from the extracted vegetation areas using ENVI model (version 4.8). The training areas for mangroves and other vegetation types were selected from the digital aerial imagery due to the high-resolution, and the mangrove boundary was also delineated on this imagery for reference. The displayed image with the above classes was spectrally enhanced by histogram equalization.

Medium scale (1:25,000) black and white panchromatic aerial photographs procured by the www.ngo-iran.ir%2Fngo.htm&ei=Xq7u-UMGEBMzJsgbe4oHgBQ&usg=AFQjCNEKsgfQbd01j8YtaJcEifjPTcWSQg&sig2=PjTSVar9y9PyjXOdL3ApQA&bvm=bv.1357700187,d.Yms" > National Geographical Organization of Iran in 1956 were scanned and imported into ArcGIS (ESRI Inc. version 9.2). These were imported as digital images at a resolution 1000 dots per inch. We used tonality (contrast), crown texture, structure, tree height, and relative position on the ground attributes to distinguish mangroves (Kairo, 2001). Field data collected for this study included Ground Control Points (GCPs) for image geo-rectification and spectral signature. The geo-referenced images had RMSE of less than 0.5 pixel which was considered satisfactory. Visual inspection showed that the overlaid images matched each other well.

3.3. Tide gauge data analyses

A trend in the rate of relative sea-level change for Jask Mangrove forest was calculated using mean monthly relative sea-levels obtained from analysis of data from the Jask (25.63ºN, 57.77ºE) and Chabahr (25.2958ºN, 60.630ºE) tide gauge stations. Data sources obtain from Coastal Area Hydrogarphy Management in National Cartographic Center (http://www.ncc.org.ir). Linear and second order polynomial regression models were fit to the mean monthly relative sea-level data at Jask station from January 1997 to February 2011 and in Chabahar station from January 1991 through February 2009, an elapsed period of 19 years.