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MODELLING THE NET GHG EMISSION (TCO2E) AND CARBON SEQUESTRATION FOR THE POTENTIAL SILVICULTURE AND RESTORATION OF MANGROVE ALONG THE EGYPTIAN RED SEA AND GULF OF AQABA COAST

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Abstract: The mangroves in Egypt are halophytic trees growing in the upper part of the intertidal zone on the Red Sea shores, lagoons, and on coasts sheltered. The current study was able to determine that suitable environmental conditions that necessary to support mangrove silviculture and restoration. In the current study, we used the Verified Carbon Standard (VCS) as a greenhouse gas (GHG) crediting program to calculate the long-term expected average of carbon stock for potential mangrove (*Avicennia marina*) silviculture and restoration for (10, 30, 40, and 50 years to harvest cycle of carbon stock) and we estimated the expected average of soil organic carbon (SOC), and carbon sequestration (tCo2/ha) for 10 years of *A. marina* mangrove silviculture. The results showed that the expected average of total carbon sequestration (tCo2) per hectare recorded 1261.11, 23497.66, and 59214.21 tCo2/ha for 10, 30, and 50 years respectively. Moreover, the estimate of net GHG emission reductions or removals (tCO2e) for the potential mangrove silviculture and restoration activities recorded 3407.42 and 316583.63 tCO2e for 10 and 50 years respectively. Additionally, the expected average total of soil organic carbon (SOC) was recorded at 121.7 t/ha after 10 years of mangrove silviculture. In the current study, since the results of restoration activities may vary within the environmental condition and management regime, an assessment of the efficiency of restoration activities in different scenarios is necessary. Thus, our focus should be extended from developing the regulatory framework of carbon accounting to improving management and policy in mangrove restoration as forest carbon stock enhancement. This holistic effort would increase the benefit of mangrove ecosystem services for communities.

Keywords: Red Sea, mangrove, blue carbon, climate change, GHG emission, mangrove restoration.

INTRODUCTION

Mangroves have long been recognized for the broad range of ecosystem services they provide (Spalding *et al*., 2010; Shepard *et al.,* 2011). More recently, mangroves received attention for their capacity to store large volumes of carbon (Pendleton *et al.,* 2012). On average, mangroves contain three to four times the mass of carbon typically found in boreal, temperate, or upland tropical forests (Donato *et al.,* 2011).

Conservation of mangroves is considered a potentially low-cost option for reducing CO2 emissions (Pendleton *et al.*, 2012). A large area of mangroves in the world, protecting mangroves achieves emissions reductions at a lower cost than reducing emissions elsewhere in the economy (Siikamäki *et al*., 2012).

Designing and evaluating market mechanisms for mangrove conservation requires several spatially explicit scientific inputs, including information on the mangrove area susceptible to deforestation, carbon in mangrove biomass and soils, annual carbon sequestration, the emissions profiles of mangroves converted to other uses, and the opportunity cost of protecting mangroves (Siikamäki *et al.*, 2013). A growing number of researchers have recognized the need for more and better science and are calling for continued research on the potential to include mangrove conservation in climate change policy (Pendleton *et al.,* 2012). Donato *et al.*, (2011) estimate that soil carbon comprises 49–98% of carbon in mangrove forests.

The mangroves in Egypt occupy about 525 hectares (Zahran and Willis, 2009). Mangrove formations along the Egyptian shoreline are formed mainly of *A. marina*, a salt-excreting species (Afefe *et al.*, 2019); except for a few locations near the Egyptian-Sudanese border area, where *R. mucronata* coexists along with *A. marina* (PERSGA, 2004).

The aim of the work is to estimate the net GHG emission reductions or removals (tCO_2e) in Egypt for future mangrove silviculture and to give the opportunity to transfer this knowledge to other countries in the Red Sea region. In the current study, we reviewed different literature to describe the suitable locations and environmental factors for mangroves along the Egyptian Red Sea Coast based on the geological setting of the area such as soil, topography, and digital elevation models.

METHODS

The Study Area

The mangroves in Egypt occupy about 525 hectares (ha) distributed in 28 different locations along the Egyptian Red Sea coast, and the Gulf of Aqaba (Zahran and Willis, 2009). The mangroves of Egypt consist of

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Avicennia marina, except for a few stands in the southern Egyptian-Sudanese border area where *Rhizophora mucronata* coexists along with *A. marina* (PERSGA, 2004). (Figure 1).

Data Analysis and Reporting

The primary data underpinning this paper was collected depending on articles, reports, books, and reviews of different literature to describe the suitable locations and environmental factors for mangroves along the Egyptian Red Sea Coast based on the geological setting of the area such as soil, topography, and digital elevation models.

Climate Analysis

DIVA-GIS is software for geographic data analysis of geographic information systems (GIS), and BIOCLIM is a bioclimatic prediction system using surrogate terms (bioclimatic parameters) to approximate energy and water balances at a given location and can produce up to 19 bioclimatic parameters based on the climate variables maximum temperature, minimum temperature, rainfall, solar radiation, and pan evaporation (Nelson *et al*., 1997).

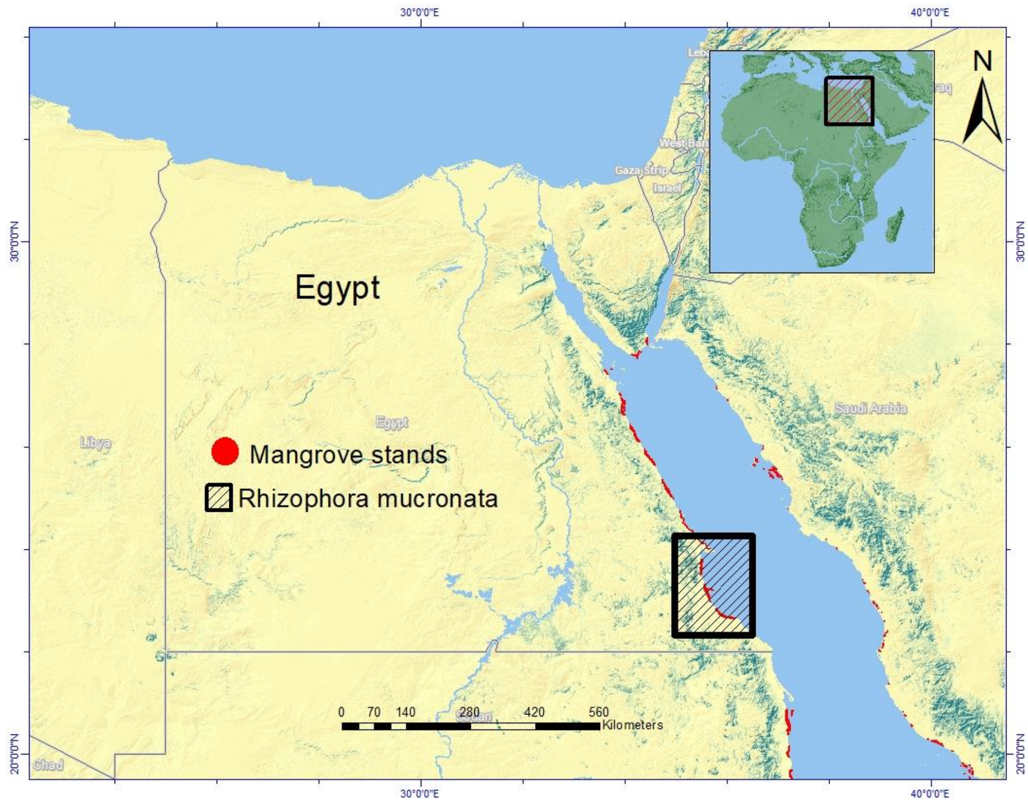

Fig. 1. Map locations of the two mangrove species stands along the Red Sea and Gulf of Aqaba in Egypt.

The Verified Carbon Standard (VCS)

The Verified Carbon Standard (VCS) is the world's most widely used greenhouse gas (GHG) crediting program (VCS, 2011). It drives finance toward activities that reduce and remove emissions, improve livelihoods, and protect nature. VCS projects have reduced or removed nearly one billion tons of carbon and other GHG emissions from the atmosphere. Use the following equation to calculate the long-term average GHG benefit (VCS, 2022):

$$LA = \frac{\sum_{T=0}^{N} PE_t - BE_t}{n}$$

Where: **LA** = The long-term average GHG benefit; **PEt** = The total to-date GHG emission reductions and removals generated in the project scenario (tCO2e). Project scenario emission reductions and removals shall also consider project emissions of CO2, N2O, CH4, and leakage.

BEt = The total to-date GHG emission reductions and removals projected for the baseline scenario (tCO2e); **t** = Year; **n** = Total number of years in the established time period.

Use the following equation to calculate the long-term average change in carbon stock.

$$LC = \frac{\sum_{T=0}^{N} PC_t - BC_t}{n}$$

LC = The long-term average change in carbon stock

PCt = The total to-date carbon stock in the project scenario (tCO2e)

BCt = The total to-date carbon stock projected for the baseline scenario (tCO2e)

t = Year; **n** = Total number of years in the established time period

RESULTS AND DISCUSSION

There have been a number of studies on site suitability for establishing mangrove silviculture and restoration (Macintosh *et al.*, 2002; Ren *et al.*, 2008; Walters, 2000; and Bhat and Suleiman, 2004). In each of these studies, the same basic criteria necessary for the successful establishment of mangrove silviculture were the same as those identified in this paper, namely, Air temperature, water salinity and temperature, tidal and wave energy, soil type and factors, and stability and flood risk. Monsef and Smith (2008) found that a number of barren sites had an excellent potential for establishing mangrove silviculture. There many studies including Ramsey and Jensen (1996); Coleman *et al.* (2008); and Azlan and Othman (2009) have used remote sensing, satellite imagery, and using heads-up hand digitizing off a computer monitor for mapping mangroves and locations of suitable sites for mangrove silviculture and restoration.

Moreover, Afefe *et al*., (2019) divided the environmental aspects of mangrove growth in Egypt into four groups: (1) Geomorphological aspects of Red Sea lagoons, bays, and islands; (2) Water characteristics; (3) Climatic conditions and (4) Man-made modifications.

The current study is in accordance with those of Walters (2000); Bhat and Suleiman (2004); and Ren *et al. (*2008) who identified six environmental factors that are necessary to determine if a coastline is capable of starting and maintaining mangrove silviculture are: (1) water salinity, (2) flash flood potential, (3) water temperature, (4) air temperature, (5) tidal and wave energy, and (6) soil type and stability, and these environmental boundaries in mind, our approach was to determine where, if anywhere, on the Red Sea Coast of Egypt these environmental requirements were met.

Suitable Climate, Topography, and Boundaries

Through a review of the previous literature, we found that, from a geographical point of view, the Egyptian mangroves are divided into the Sinai mangroves, and mangroves growing on the Egyptian-African Red Sea coast (PERSGA, 2004).

Suitable Climatic conditions:

Mangrove plants do not adequately develop when annual average temperatures are below 19°C, which corresponds with the seawater isotherm of 20°C during the coldest period of the year (Alongi, 2002). While mangrove plants are intolerant to freezing temperatures both air and water temperatures may never decrease below 0°C. Optimal temperatures for mangroves are not only limited by cold temperatures but also by high temperatures because they hinder tree settling. Photosynthesis of most mangrove species sharply declines when the air temperature exceeds 35°C (Moore *et al*., 1973).

However, for the domestic case: Mangrove is a tropical formation and its best growth occurs in high temperatures. It seems that individual trees and shrubs, especially of the salt-excreting species like *A. marina,* withstand to some extent dry and hot climates. Mangrove formations along this shoreline are formed mainly of *A. marina,* a salt-excreting species. The mean maximum temperature is 32.2 ° C yearly and 37.5 °C in summer months (Paramaraj, 2004). Similar observations were reported by Scholander *et al.* (1962) along the Red Sea coast.

Table 1.

The average values of "19" bioclimatic variables for the study areas

Bioclimatic Variable	Safaga	Qusier	Wadi El-Gemal	Elba
Annual Mean Temperature	23.8	24.9	25.6	26.2
Mean Monthly Temperature Range	10.3	9.4	11.1	12
Isothermality (2/7) (* 100)	44.3	43.9	48.7	51.5
Temperature Seasonality (STD * 100)	481.9	452.7	444.7	435.7
Max Temperature of Warmest Month	34.4	34.6	36.2	37.5
Min Temperature of Coldest Month	11.2	13.3	13.4	14.2
Temperature Annual Range (5-6)	23.2	21.3	22.8	23.3
Mean Temperature of Wettest Quarter	25.1	26.5	24.2	24.8
Mean Temperature of Driest Quarter	18.2	19.4	29.6	20.8
Mean Temperature of Warmest Quarter	29.3	30	30.5	31
Mean Temperature of Coldest Quarter	17.4	19.1	19.9	20.6
Annual Precipitation	2	2	9	15
Precipitation of Wettest Month	1	1	5	10
Precipitation of Driest Month	0	0	0	0
Precipitation Seasonality (CV)	233.5	233.5	189.6	229.1
Precipitation of Wettest Quarter	2	2	7	14
Precipitation of Driest Quarter	0	0	0	0
Precipitation of Warmest Quarter	0	0	0	0
Precipitation of Coldest Quarter	0	0	1	2

The study of climate was important to see the changes in temperature and precipitation during the last years in the study area. Climate data was obtained from the Worldclim bioclimatic database, which houses 19 summary variables of precipitation and temperature for the 1950–2000 time periods (Hijmans *et al*., 2005). The average values of the "19" bioclimatic variable for the most important mangrove areas at the Egyptian Red Sea are recorded as shown in Table 1.

Suitable Geomorphological forms:

Mangrove vegetation is absent from the Mediterranean and the northern parts of the Gulfs of Suez and Aqaba, being present only along the Red Sea coast of Egypt from Hurghada southwards as well as at Ras Muhammed at the southern extremity of the Sinai Peninsula (Figure 2). *Avicennia marina* is the dominant mangrove but *Rhizophora mucronata* occurs in a few stands in the most southerly part of the coast (Zahran and Willis, 2009). According to Saenger (2003) and Anonymous (2006), the total area occupied by the mangrove vegetation in Egypt is about 525 ha (1250 feddans) in sites with different areas distributed along the shoreline of the Red Sea and its islands and the Sinai Peninsula.

Through reviewing different literature (Fouda and Gerges, 1994; and Afefe, 2021a) on features and topography of the Red Sea coastal area in the Egyptian mangrove stands, we found that the mangroves in Egypt growing in three main geomorphological forms in different stands of mangroves at Egyptian Red Sea and South Sinai coastline (Figure 2). Moreover, Zahran and Willis (2009) reported that the usual habitat of the mangrove of the Egyptian Red Sea coast is the shallow water along the shore, especially in protected areas: lagoons, bays, coral, or sand bars parallel to the shore.

Fig. 2. The three main geomorphological forms of mangroves in Egypt (Afefe, 2021a; Google Earth, 2024).
Legend: (A): A mangrove community growing on an extensive inter-tidal flat (Marsa Shaab, South Shalatine - Gebel Elba); **(B):** An example of a mangrove community growing in an enclosed bay, protected by a coralline ridge (23km South of Safaga**); (C):** A mangrove community growing in a channel (Ras Mohammed, South Sinai)

In a few localities, *A. marina* grows on the terrestrial side of the shoreline, and in one locality (delta of Wadi Gemal) the bushes are partly covered by sand hillocks. This situation is apparently due to the silting of the shoreline zone originally occupied by the mangrove (Figure 3), and the structure of the mangrove vegetation on the Red Sea coast of Egypt is simple – usually a single layer of *A. marina*. In localities where *R. mucronata* is included, this forms a stratum towering over that of *A. marina* (Zahran and Willis, 2009). According to EEAA (1998); Zahran and Willis (2009); and Afefe (2021a) we designed a diagram of coastal morphological features: sharm, marsa, bay, islands, and submerged reefs in mangroves ecosystem (Figure 4).

Fresh Water Resources:

Moreover, freshwater seems to be a controlling factor in mangrove growth, since a previous study in Qatar (Batanouny, 1986) concluded that mangrove growth sites must receive fresh water from inland, either as overland flow or as underground seepage and the rainwater plays another role in mangrove growth: it washes salts secreted on the leaves. The source of surface water all over the Eastern Desert (where the mangroves) is the rainfall on the chains of the Red Sea Mountains, where the mountain rains may feed the wadis of the Eastern Desert with considerable torrential flows (Hassib, 1951) (Figure 5).

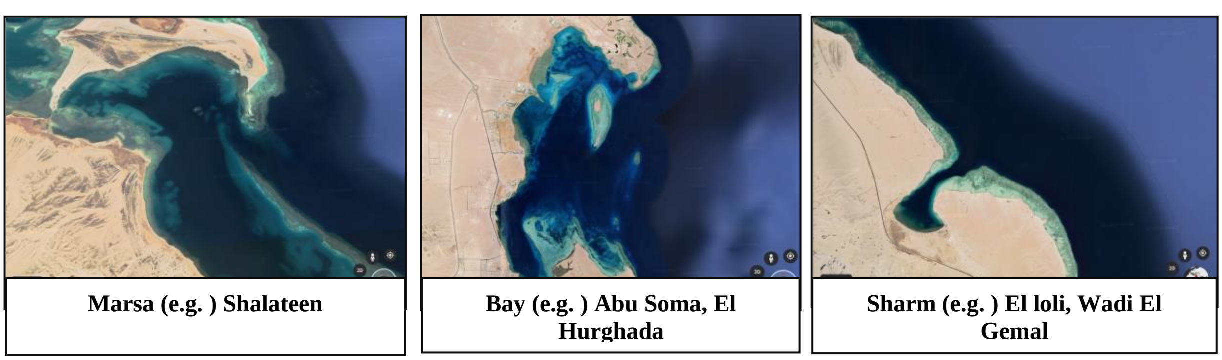

Fig. 3. Diagram of coastal morphological features: charms, marsas, and bays (Afefe, 2021a) using Google Earth (2024).

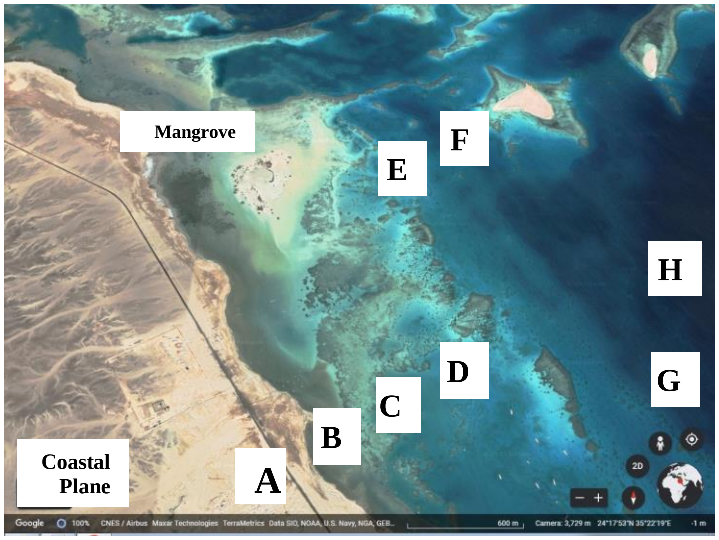

Fig. 4. Cross-sectional diagram of marine and terrestrial survey and transect zones (**Afefe, 2021a)** using Google Earth (2024).
Legend: A = supra tidal zone; **B** = intertidal zone; **C** = reef flat; **D** = reef edge;
E = reef wall; **F** = coral patches; **G** = submerged reefs and **H** = islands

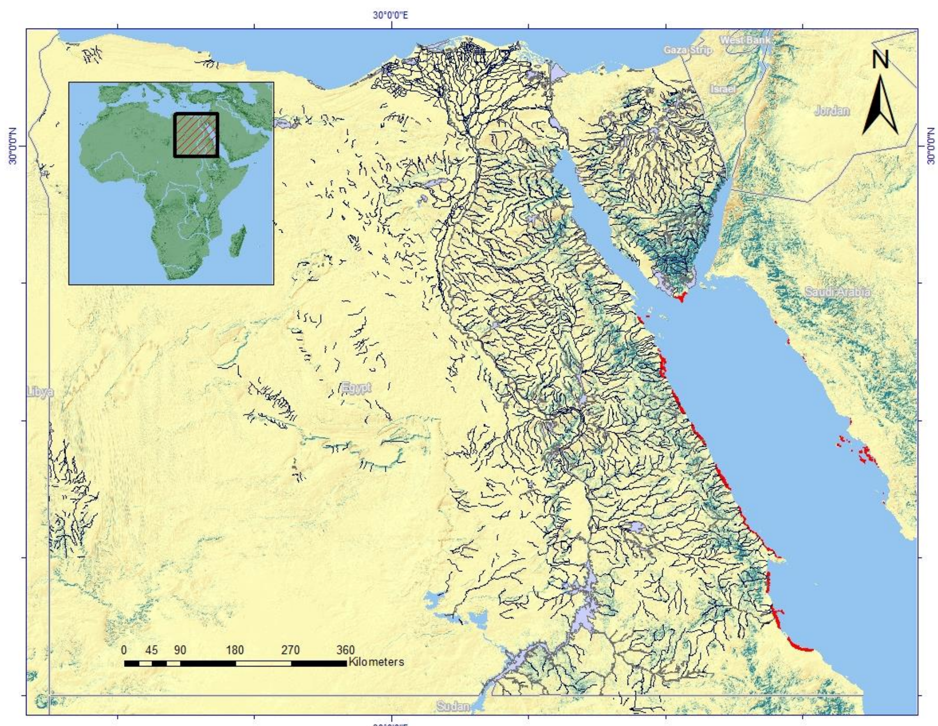

Figure 5. Map of water streams and flows wadies and locations of mangroves (Red plots) at the Egyptian Red Sea Coast

Water Temperature, Speed and Salinity Measurements

Water Salinity

Many studies were examined to understand the adaptations, ecophysiological processes, and morphological characteristics of *A. marina* trees growing in a per-arid area on the Red Sea coast of Egypt (Teraminami *et al.*, 2013; Matsuo *et al.*, 2016; Afefe *et al.*, 2019; and Afefe *et al*., 2021). The study of Afefe *et al*. (2020) suggested that *Rhizophora mucronata* is a highly salt-tolerant species, which maintains its salt balance like a true halophyte though its growth is retarded at very high salinity. Moreover, they reported that *A. marina* is relatively more tolerant and adapted to salinity, low rainfall, and extreme temperature conditions than *R. mucronata* and this explains the larger local distribution (in Egypt) of *A. marina* than *R. mucronata*.

Mangroves grow under extreme environmental and climatic conditions such as high salinity, temperature, and radiation (Moorthy and Kathiresan, 1999). The Avicenniaceae appear to be more tolerant to salinity stress than the Rhizophoraceae (Hutchings and Saenger, 1987). For instance, *Avicennia marina* trees seem to grow well up to 75% seawater, with a hypothesized growth inhibition at higher salinities due to high sodium chloride (NaCl) concentrations in the tissues (Clough, 1984). However, seedlings of *A. marina* exhibited various growth responses under different salinity regimes, with the highest growth recorded at 50% seawater (17 ppt). The lowest overall growth was found in seedlings of *A. marina* raised under 0 ppt salinity, which was even lower than the growth of seedlings raised in 100% seawater (35 ppt) (Downtown, 1982; and Ghowail *et al.*, 1993). These studies suggest that even within a species, salt tolerance changes depending on life stage, with seedlings being potentially more sensitive to salt stress than mature trees. In comparison, Water stress may be the main effect of high salinity on the growth of the Rhizophoraceae (Clough, 1984). However, the seawater salinity ranging from 41.04 to 43.95 ppt in the south of the Red Sea mangrove (Gebel Elba) as an area considered hyper-arid (EEAA, 2018), and the mean water salinity of all measurements was 40.01 ppt in Gulf of Aqaba (EEAA, 2009), with total mean of EC for *A. marina* 38.74 ds/m and 40.62 ds/m for *R. mucronata* (Afefe *et al*., 2020).

Water temperature

The continuous fluctuations in the temperature of sea water in mangrove areas at the Gulf of Aqaba reached 12.75 ºC during the same day while the minimum water temperature recorded reached as low as 17.07 ºC and the maximum recorded 30.69 ºC, with the average water temperature reached 22.63 ºC (EEAA, 2009).

Water current speed and direction

Temporal variations in the speed of the water flow at the mangrove area, and the flow of seawater to and back from the mangrove area are significantly related to tidal cycles and inundation regimes. The maximum water current speed recorded was 24 cm/s during spring tide, while there was absolutely no water movement in some instances, and the mean water current speed was 6 cm/s during the study of the mangrove environment at the Gulf of Aqaba (EEAA, 2009).

The daily sea tidal needs for mangrove

The daily tidal range averages 0.6m in the northern part of the Red Sea. This is augmented by a seasonal evaporation effect of an estimated 0.5m between summer and winter (Edwards, 1987). For future mangrove silviculture and restoration, the tidal data can be derived using the free tidal prediction program WXTide32 to select the potential silviculture stations along the Egyptian Red Sea. The tide data for a potential location can be extrapolated based on a weighted inverse distance method, and the depths measured during the field survey were then corrected to datum, i.e. lowest astronomical tide, based on these tidal values (Vanderstraete *et al*., 2002).

Suitable Soil Factors

The mangroves grow in soil with high sand content, low silt and clay fractions, and low calcium carbonate content (Bhat *et al*., 2004). In Australia, mangroves grow in soils with a wide range of soil textures, from coarse sand to fine alluvial soils, heavy clays, and peats, but most soils have soil salinity near that of the tidal water (Clough, 1984).

The mangroves are not restricted to specific soil conditions although each community tends to show a niche relation to certain soil variables. Hence, several soil properties could serve as indicators for community-type differentiation (Ukpong, 1995). For example, higher acidity (pH-values) prevails in soils associated with *Rhizophora* communities than in *Avicennia* communities. *Rhizophora* has an extensive fibrous root system that forms thick peat-like mud, which lowers the pH after decomposition (Hart, 1962).

Through a review of the literature on the Egypt mangrove, we found that the soil of *A. marina* mangrove contains 4.5–19.5% calcium carbonate whereas that of *R. mucronata* is highly calcareous, containing up to 80% of its weight of calcium carbonate. The tidal mud of the mangrove vegetation of the Red Sea coast is usually grey or black, and often foul-smelling (Kassas and Zahran, 1967).

Afefe *et al. (*2019) reported that the soil mineral composition for *A. marina* mangrove recorded a higher value for Na+ (8.22%) and Cl- (7.9%), and the K+ a higher value recorded (1.4 %) and recorded 0.81% and 0.33% for Ca++ and Mg++ respectively. While the soil mineral composition for *R. mucronata* recorded a higher value for Na+ (6.7%) and (7.23%) for Cl-. While, the mean values for K+, Ca++, and Mg++ ions were noted as 0.64%, 2.13%, and 0.31 % respectively.

Additionally, EEAA (2009) reported that *R. mucronata* stands to have the lowest salinity, silt, pH, and Na, but the highest of sand and CaCo3. Where, *A. marina* had the highest values of silt, clay, pH, K, and Na. Additionally, *R. mucrorata* contained higher ash content (28.2%) than *A. marina* (18.8%). The higher values were associated with Cl, Mg, Ca, and Na. The organic carbon content of mangroves ranges from 0.3% to 2.2% and pH ranges from 8.5 to 9.0. A notable difference between the tidal mud colonized by *A. marina* and that by *R. mucronata* is the low content of calcium carbonate in the former (4.5–19.5%) as compared with the calcareous mud (80%) in the latter (Zahran and Willis, 2009).

Moreover, According to Afefe *et al. (*2019), the mean soil bulk density (SBD) was recorded 1.16 g cm^{-3} for both mangrove species, and the soil organic carbon (SOC) content recorded 34.95 g C kg^{-1} for the both mangrove species, and the total mean SOC content was statistically higher in *A. marina* stands (39.66 g C kg^{-1}) than *R. mucronata* stands (33.15g C kg^{-1}). On the other hand, El-Khouly and Khedr (2007) stated that the habitat of *R. mucronata* is characterized by low soil salinity, silt, and pH values, compared with that of *A. marina* that grows in more saline habitats and had the highest value of silt. Plots of the association growth of *R. mucronata* and *A. marina* showed intermediate values for most of the studied soil variables. The results suggest that while abiotic environmental conditions may account for the absence of *R. mucronata* in high saline mud soils along the Red Sea coast of Egypt, but also the tolerance of each species to each particular is also more important in the formation of mixed growth of both species.

However, According to Afefe *et al. (*2019), the mangroves showed variations between the mangrove species in mineral composition at different locations, wherein all the locations of mangrove, Na+ and Cl+ ions were dominant than K+, Ca++, and Mg++ ions, and both ordination techniques indicated that electric conductivity, CaCO3, K^+, Ca^{++}, Cl^-, Na^+ and Mg^+, were the most important parameters determining the distribution of the two of mangrove species (*A. marina* and *R. mucronata*) pattern at the Egyptian Red Sea coast.

Estimated the expected net GHG emission reductions or removals (tCO_2e) for potential silviculture and restoration of mangroves in Egypt

There are many opportunities to introduce science into policy in addressing climate change adaptation and mitigation related to the mangrove ecosystem. The emissions from mangrove forest degradation and mangrove conversion are ongoing but currently not well accounted for in the national GHG (greenhouse gas) inventory (Afefe, 2021a). The current study highlights the importance of strengthening GHG inventory by further involvement of mangrove carbon of potential mangrove silviculture and restoration into carbon forest accounting. GHG emission from mangroves can be estimated from carbon stock changes in carbon pools that comprise several compartments (ie. above and below-ground biomass, and soils) (Kauffman and Donato, 2012). The removal or conversion of mangroves to other land use could have significant consequences for marine ecosystem primary production and contribute to substantial CO2 emission, ie greenhouse gas (GHG), to the atmosphere (Pendleton *et. al*., 2012).

Afefe *et al.,* (2020) reported that the average biomass per hectare of Egypt mangroves recorded 74997.1 and 22536.8 kg for *A. marina* and *R. mucronata,* respectively, and the total organic carbon content for mangroves of Egypt (525 ha), recorded 17.73 Gg C for biomass and 5.97 Gg C $year^{-1}$ for soil, with a total of 23.7 Gg C of organic carbon content storage in mangroves ecosystem in Egypt.

In the current study, since the results of restoration activities may vary within the environmental condition and management regime, an assessment of the efficiency of restoration activities in different scenarios is necessary. Thus, our focus should be extended from developing the regulatory framework of carbon accounting to improving management and policy in mangrove restoration as forest carbon stock enhancement. This holistic effort would increase the benefit of mangrove ecosystem services for communities.

In the current study, the primary mangrove vegetation data of Egyptian mangroves was collected depending on the results of Afefe *et al.* (2019).

In the current study, we used the Verified Carbon Standard (VCS) Programme as a greenhouse gas (GHG) crediting program (VCS, 2022) to calculate the long-term average carbon stock for potential mangrove silviculture and restoration in Egypt for planting *A. marina* mangrove, with an average of 786 tree/ha (for 10, 30, 40, and 50 years to harvest cycle of carbon stock) (Tables 2, 3).

In year one, the project begins with clearing the land. In the following years, carbon is sequestered as aboveground biomass from silviculture and restoration activities. The final column shows the to-date GHG emission reductions and removals in the project scenario. The annual change in GHG benefit is the additional GHG emissions reduced or removed each year in the scenario.

A review of the available literature on silviculture and restoration of mangroves shows mixed successes of restoration efforts (Ellison, 2000), even though it has been said that mangrove wetlands are easy to restore and create (FAO, 1994). Whereas the lost mangrove plant species can be returned (Kairo, 1995), a restored forest may or may not function as the original pre-disturbed system (McKee and Faulkner, 2000). This is especially true where there is no natural model, simple or complex, on which to base the recreated mangrove stand (Field, 1998). In East Africa, information on earlier mangrove plantation practices is scanty. Reference is made to mangrove planting in Lamu, Kenya, after the trees were clear-felled during the First World War (1914–1918) by the Smith and McKenzie Company (Roberts and Ruara, 1967). In Tanzania, attempts to replant mangroves in the abandoned saltpans of the Tanga district failed probably because of environmental factors (e.g. soil salinity and acidification) as well as poor species selection (Semesi and Howell, 1992). Moreover, Abd-El Monsef *et. al*. (2013) identified the suitability value ranges for the environmental parameters of mangroves on the southern Saudi Arabian Red Sea Coast these environmental requirements were met, and the results included: Air temperature: ranged from 8 to 47 ºC; Water temperature ranged from: 22 to 34 ºC; Water salinity ranged from: 36 to 3.8%; Wave and tide energy: low; Flash flood potential: low; Soil type: sandy to sandy loam.

Table 2.
The expected average of carbon sequestration and net GHG emission reductions or removals for mangrove silviculture of *A. marina* mangrove after 10, 30, 40, and 50 years

Year	Carbon Sequestration (tCo2/ha)	Total Net Carbon (tCo2/year) / ha	Estimated net GHG emission reductions or removals (tCO2e) / ha
1	22.61	22.61	0.00
2	42.10	42.10	22.61
3	66.97	66.97	64.71
4	90.50	90.50	131.67
5	107.11	107.11	222.18
6	125.89	125.89	329.29
7	152.05	152.05	455.18
8	182.57	159.95	584.62
9	213.94	171.85	725.09
10	257.37	190.40	872.07
Total - 10 Years	**1261.11**	1129.43	3407.42
11	294.07	203.57	1038.93
12	337.75	230.63	1225.88
13	429.65	303.76	1437.74
14	529.31	377.25	1715.34
15	580.69	398.12	2062.08
16	682.42	468.48	2428.82
17	761.67	504.30	2853.87
18	935.29	641.22	3321.47
19	1220.31	882.56	3919.02
20	1307.13	877.48	4709.68
21	1364.49	835.18	5487.50
22	1406.76	826.08	6271.30
23	1425.77	743.35	6995.64
24	1435.76	674.09	7659.75
25	1471.00	535.71	8160.22
26	1528.05	307.74	8410.91
27	1580.05	272.92	8631.84
28	1644.61	280.12	8847.40
29	1658.84	252.08	9085.24
30	1642.95	217.18	9318.32
Total-30Year	**23497.66**	**10961.27**	**106988.37**
Total-40Year	**40715.67**	**12283.43**	**206577.39**
Total-50Year	**59214.21**	**12943.97**	**316583.63**

Table 3.
The expected average of soil organic carbon (SOC), aboveground biomass (AGB), and belowground biomass (BGB) for potential silviculture of *A. marina* mangrove for 10 years [with an estimated average of 786 tree/ha and 6.08 cm of diameter at breast height (DBH) for 10 years consistent growth]

Year	AGB (kg/ tree)	BGB (kg/tree)		SOC (t/ha)
1	2.88	3.85		12.17
2	6.21	6.06		24.34
3	11.59	9.84		36.51
4	16.14	14.50		48.68
5	18.61	15.99		60.85
6	22.98	17.38		73.02
7	28.72	22.67		85.19
8	37.42	29.31		97.36
9	46.03	36.41		109.53
10	62.74	45.24		121.70
30	878.12	482.43		365.10
50	1077.66	579.73		608.5

Fortunately, through a cooperative project between the Ministry of Agriculture and Land Reclamation, the Egyptian Environmental Affairs Agency, and the International Tropical Timber Organization (ITTO) silviculturing and rehabilitation of mangrove plants (*A. marina* and *R. mucronata*) in representative sites of the shoreline of the Red Sea of Egypt have been successfully conducted (Anonymous, 2006). About 50 feddans have been cultivated with these two mangrove species, and rehabilitation of about 5 feddans has been also conducted from 2003 to 2007 through the project of ITTO (EEAA, 2009). However, mangrove forestation is proceeding at a large scale in Bangladesh, India, and Vietnam principally to provide protection in typhoon-prone areas as well as to generate economic benefits for the poor coastal communities (Saenger and Siddique, 1993). For the conservation of mangroves, the sustainable management of the mangrove and floral biodiversity in the Red Sea coastal area requires stopping the severe human impacts that lead to eliminating certain plant populations and modifying the complex plant communities into simple fragile ones (Afefe, 2020; Abbas *et al*., 2016; Afefe *et al*., 2016; and Afefe, 2021b). Where, the major threats to mangroves in Egypt are the exploitation for coastal development (as removal for constructing hotels, roads, and other infrastructures), firewood, camel feed, and timber by human beings, this leads to a great loss of mangroves (Afefe, 2021a).

CONCLUSION

The current study is in accordance with those of Macintosh *et al.* (2002); Ren *et al. (*2008); Walters (2000); and Bhat and Suleiman (2004) they identified six critical environmental factors that are necessary to determine if a coastline is capable of starting and maintaining mangrove silviculture are: (1) air temperature, (2) water temperature (3) water salinity, (4) tidal and wave energy, (5) flash flood potential and (6) soil type and stability. The present study field observation with the literature review found that the mangroves in Egypt growing in three main geomorphological forms included a mangrove community growing on an extensive inter-tidal flat; in an enclosed bay, protected by a coralline ridge; and growing in a channel. Moreover, Afefe (2021a) reported that there are four groups for environmental aspects of mangroves in Egypt including Climatic conditions; Geomorphological aspects of Red Sea lagoons, bays, and islands; Water characteristics, and Man-made modifications.

On the other hand, Siikamäki *et al.*, (2012) developed the first spatial estimates of global mangrove soil carbon, using country and regional-level mean estimates of soil carbon concentrations derived from the literature. While this provides an important first step, the estimates do not capture the fine-scale variation in mangrove soil carbon concentrations and, therefore, the fine-scale variation in potential benefits from mangrove conservation in different locations. The current study agrees with Jardine and Siikamäki (2014) that a key challenge in assessing the carbon benefits of mangrove conservation is the lack of rigorous spatial estimates of mangrove soil carbon stocks. Unlike other tropical forests, for which the bulk of carbon storage is in biomass, mangrove carbon is primarily stored in the soil.

In the current study, since the results of restoration activities may vary within the environmental condition and management regime, an assessment of the efficiency of restoration activities in different scenarios is necessary. Thus, our focus should be extended from developing the regulatory framework of carbon accounting to improving management and policy in mangrove restoration as forest carbon stock enhancement. This holistic effort would increase the benefit of mangrove ecosystem services for communities. Knowledge of mangrove species zonation is essential in determining suitable areas for different species. Where, it is difficult to generalize planting sites for successful mangrove restoration, as this will depend on local environmental conditions and the species to be planted. Therefore, urgent need to evaluate the success of rehabilitation trials of mangroves that are implemented along the Red Sea coast to contribute to the success of current and future conservation activities for mangroves. The study calls for devising effective management strategies for monitoring and conserving the degraded mangrove cover. Monitoring and effective management strategies can help in maintaining and conserving the degraded mangrove cover and assessing site suitability for restoring mangroves.

AUTHORS CONTRIBUTIONS

Conceptualization, Abdelwahab A. Afefe; methodology, Abdelwahab A. Afefe; data collection Abdelwahab A. Afefe; data validation, Abdelwahab A. Afefe and Reda A. Abu-moustafa; data processing Abdelwahab A. Afefe; writing—original draft preparation Abdelwahab A. Afefe; writing—review and editing, Abdelwahab A. Afefe and Reda A. Abu-Moustaf.

CONFLICT OF INTEREST

The authors do not have any competing financial, professional, or personal interests from other parties.

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REFERENCES

Abbas M., Afefe A., Hatab E., Gaber E., Vegetation-Soil Relationships in Wadi El-Rayan Protected Area, Western Desert, Egypt. Jordan Journal of Biological Sciences. Volume 9, Number 2, June .2016- ISSN 1995-6673, 2016.

Abd-El Monsef H., Aguib S., Ayman S., Locating suitable mangrove plantation sites along the Saudi Arabia Red Sea Coast. Journal of African Earth Sciences 83, 2013.

Afefe A., Composition and changes in the spontaneous flora of the Wadi El Rayan Ramsar site, Fayoum, Egypt, in the last 20 years. Limnological Review, Sciendo. Volume 20: Issue 3, 2020.

Afefe A., Linking Territorial and Coastal Planning: Conservation Status and Management of Mangrove Ecosystem at the Egyptian - African Red Sea Coast. Aswan University Journal of Environmental Studies (AUJES). Vol. 2, No. 2, pp. 91-114, (June 2021). DOI: 10.21608/AUJES.2021.65951.1013, 2021a.

Afefe A., Inventory and Conservation of Wild Flora in Gebel Shayeb El-Banat as a Potential Protected Area, the Red Sea Region, Egypt. Aswan University Journal of Environmental Studies (AUJES). Article 2, Volume 2, Issue 1, Winter 2021, Page 11-25, 2021b.

Afefe A., Abbas M., Soliman A., Khedr A., Hatab E., Physical and chemical characteristics of mangrove soil under marine influence. A case study on the Mangrove Forests at Egyptian-African Red Sea Coast. Egyptian Journal of Aquatic Biology & Fisheries. Vol. 23(3): 385 –399, 2019.

Afefe A., Abbas M., Soliman A., Khedr A., Hatab E., Tree biomass and soil carbon stocks of a mangrove ecosystem on the Egyptian-African Red Sea coast. Fundamental and Applied Limnology/ E. Schweizerbart'sche Verlagsbuchhandlung. FAL 193, issue 3, 2020.

Afefe A., Hatab E., Abbas M., Gaber E., Assessment of Threats to Vegetation Cover in Wadi El Rayan Protected Area, Western Desert, Egypt. International Journal of Conservation Science, Volume 7, Issue 3, 2016: 691-708, 2016.

Afefe A., Khedr A., Abbas M., Soliman A., Responses and Tolerance Mechanisms of Mangrove Trees to the Ambient Salinity along the Egyptian Red Sea Coast. Limnological Review, Sciendo. Limnol. Rev. (2021) 21, 1: 3-13, 2021.

Alongi D.M., Present state and future of the world's mangrove forests." Environmental conservation, 29 (03): 331-349, 2002.

Anonymous, Assessment, and Management of Mangrove Forests in Egypt for Sustainable Utilization Development. ITTO, Japan in association with MALR, MSEA, EEAA, Cairo, Egypt. Progress Report No. 6, 176pp., 2006.

Azlan N., Othman R., Monitoring of mangrove areas using remote sensing toward shoreline protection. In: Proceedings of GIS OSRAVA, Malaysia, pp. 236– 341, 2009.

Batanouny K., Ecology and plant life in the state of Qatar, 1st edition, Qatar University, Ad-Doha, in Arabic, 414pp., 1986

Bhat, Suleiman, Classification of Soils Sup- porting Mangrove Plantation in Kuwait," *Archives of Agronomy and Soil Science*, Vol. 50, No. 6, pp. 535- 551, 2004.

Bhat N., Shahid S., Suleiman M., Mangrove (*Avicennia marina*) establishment and growth under the arid climate of Kuwait. Arid Land Research and Management 18: 127-139, 2004.

Clough B.F., Growth and salt balance of the mangroves *Avicennia marina* and *Rhizophora stylosa* in relation to salinity. Aust. J. Plant Physiol., 11: 419-430, 1984.

Coleman T.L., Manu A., Twumasi Y.A., Application of Landsat to study of mangrove ecology along the coast of Ghana. Journal of the ISPRS 49, 362–379, 2008.

Donato D.C., Kauffman J.B., Murdiyarso D., Kurnianto S., Stidham M., Kanninen M., Mangroves among the most carbon-rich forests in the tropics Nat. Geosci. 4 293–7, 2011.

Downtown W.J.S., Growth and osmotic relations of the mangrove *Avicennia marina*, as influenced by salinity. Aust. J. Plant Physiol., 9: 519-528, 1982.

Edwards F.J., Climate and Oceanography, in EDWARDS A.J. & HEAD S.M. (eds.), Key Environments: Red Sea, Oxford, Pergamon Press, pp. 45-69., 1987.

Egyptian Environmental Affairs Agency (EEAA), Environmental data of coastal waters of the Red Sea for 2017, Coastal Water Programme, Egyptian Environmental Affairs Agency (first, second, third, and fourth) reports. 6 pp., 2018.

Egyptian Environmental Affairs Agency (EEAA), Red Sea Coastal Marine Protected Area Strategy, Egyptian Red Sea Coastal and Marine Resource Management Project, EEAA, Egypt, 84 pp., 1998.

Egyptian Environmental Affairs Agency (EEAA), Assessment and Management of Mangrove Forest in Egypt for Sustainable Utilization and Development. Final report project, funded by The International Tropical Timber Organization, 65pp, 2009.

El-Khouly A.A., Khedr, A.A., Zonation Pattern of *Avicennia marina* and *Rhizophora mucronata* along the Red Sea Coast, Egypt. World Applied Sciences Journal, 2(4): 283-288, 2007.

Ellison A., Mangrove restoration: Do we know enough?. Restoration Ecology, 8: 219–229, 2000.

FAO, Mangrove forest management guidelines. FAO Forestry Paper 117. Rome, pp 320, 1994.

Field C., Rationales and practices of mangrove afforestation. Marine and Freshwater Research, 49: 353–358, 1998.

Fouda M. M., Gerges A. M., Implication of climate change in the Red Sea and Gulf of Aden Region: An Overview. UNEP Regional Seas Reports and Studies No. 156. in cooperation with PERSGA. 99 pp., 1994.

Ghowail S.I., Abdel-Monem A.M., El-Ghamry W.M., Saber N.E., Preliminary studies on the effects of different salinity levels on germination, growth, and anatomy of the mangrove (*Avicennia marina*). In: Leith H and Al Massom A (Eds) Towards the

Rational use of High Salinity Tolerant Plants, Kluwer Academic Publishers, The Netherlands, pp 237-244, 1993.

Hart M.G.R., Observation on the source of acid in the empoldered mangrove soils. Formation of elemental sulfur. Plant and Soil, 17: 87-98, 1962.

Hassib M., Distribution of plant communities in Egypt. Bull. Fac. Sci. Univ. Fouad I, Cairo, Egypt, 29: 59–261, 1951.

Hijmans R.J., Cameron S.E., Parra J.L., Jones P.G., Jarvis A., Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978, 2005.

Hutchings P., Saenger P., Ecology of Mangroves. University of Queensland Press, St Lucia, Australia., 388p, 1987.

Jardine L.S., Siikamäki J.V., A global predictive model of carbon in mangrove soils. Environ. Res. Lett. 9 (2014) 104013 (9pp), 2014.

Kairo, J.G., Artificial regeneration and sustainable yield management of mangrove forests in Gazi Bay, Kenya. MSc Thesis, University of Nairobi, Nairobi, Kenya, pp 116, 1995.

Kassas M., Zahran M.A., On the ecology of the Red Sea littoral salt marsh, Egypt. Ecol. Monogr., 37(4). 297–315, 1967.

Kauffman J.B., Donato D.C., Protocols for the Measurement, Monitoring and Reporting of Structure, Biomass and Carbon Stocks in Mangrove Forests. Working Paper 86; CIFOR: Bogor, Indonesia. 50 pp., 2012.

Macintosh D., Ashton E., Havanon S., Mangrove Rehabilitation and Intertidal Biodiversity, Estuarine, Coastal and Shelf Science. Elsevier Publications, 323pp., 2002.

Matsuo N., Banjo R., Teraminami T., Afefe A., El-Shaffai A., Nakashima A., Nawata H., Yoshikawa K., Branch Morphology of a Mangrove (Avicennia marina (Forsk.) Vierh) Growing in a Per-Arid Area on the Egyptian Red Sea Coast Regulates Water Use of Its Leaves. Journal of Arid Land Studies. 26-3, 91-94, 2016.

McKee K., Faulkner P., Restoration of biogeochemical function in mangrove forests. Restoration Ecology 8: 274–259, 2000.

Monsef E., Smith S., Site selection for mangrove plantations along the Egyptian Red Sea Coast. World Applied Sciences Journal 3 (7), 740–747, 2008.

Moore RT., Miller PC., Ehlering J., Lawrence W, Seasonal trends in gas-exchange characteristics of 3 mangrove species.Photosynthetica7:387-394, 1973.

Moorthy P., Kathiresan K., Photosynthetic efficiency in rhizophoracean mangroves with reference to compartmentalization of photosynthetic pigments. Revista de Biologia Tropical, 47: 21–25, 1999.

Nelson A., LeClerc G., Grum M., The development of an integrated Tcl/Tk and C interface to determine, visualize and interrogate infraspecific biodiversity. Internal CIAT document. GIS Laboratory, CIAT, Cali, Colombia. pp. 102, 1997.

Paramaraj M., Eco-Physiological Studies of Mangroves in Tuticorin District, Tamilnadu. PhD Thesis, Manonmaniam Sundaranar University, India. pp. 189, 2004.

Pendleton L., Donato D.C., Murray B. C., Crooks S., Jenkins W.A., Sifleet S., Craft C., Fourqurean J. W., Kauffman J. B., Marbà N., Estimating global ‘blue carbon’ emissions from conversion and degradation of vegetated coastal ecosystems PloS one 7 e43542, 2012.

Pendleton L., Donato D.C., Murray B.C., Crooks S., JenkinsW.A., Sifleet S., Craft C., Fourqurean J.W., Kauffman J.B., Marbà N., Megonigal P., Pidgeon E., Herr D., Gordon D., Baldera A., Estimating global blue carbon emissions from conversion and degradation of vegetated coastal ecosystems, PLoS One,7: 1-7, 2012.

PERSGA, Status of Mangroves in the Red Sea and Gulf of Aden. Technical Series Number 11, PERSGA, Jeddah, 67 pp., 2004.

Ramsey E., Jensen J., Remote sensing of mangrove wetlands. Photogrammetric Engineering and Remote Sensing 62 (8), 939–948, 1996.

Ren H., Jian S., Lu H., Zhang Q., Shen W., Han W., Restoration of mangrove plantations and colonization by native species. Springer Publishers, Ecological Research 38 (3), 394– 410, 2008.

Roberts R.W., Ruara W., Lamu mangroves inventory. Part 1 and 2. Spartan Air Services (Canada) and Forest Department, Nairobi. Ministry of Environment and Natural Resource, Kenya. 155 pp., 1967.

Saenger P., Rehabilitation, Conservation and Sustainable Utilization of Mangroves in Egypt. EEAA, Cairo, 33pp, 2003.

Saenger P., Siddique N.A., Land from the sea: the afforestation program of Bangladesh. Ocean and Coastal Management, 20: 23–39, 1993.

Scholander P.F., Hammel H.T., Hemmimgsen E.A., Garey W., Salt balance in the mangrove. Plant Physiol., 37:722- 729, 1962.

Semesi, A.K., Howell, K., The mangroves of the East African region. UNEP, Nairobi. 34 pp, 1992.

Shepard C., Crain C., Beck M., The protective role of coastal marshes: a systematic review and meta-analysis PloS one 6 e27374, 2011.

Siikamäki J., Sanchirico J.N., Jardine S.L., Global economic potential for reducing carbon dioxide emissions from mangrove loss Proc. Natl. Acad. Sci. 109 14369–74, 2012.

Siikamäki J., Sanchirico J. N., Jardine S., McLaughlin D., Morris D., Blue carbon: coastal ecosystems, their carbon storage, and potential for reducing emissions Environ.: Sci. Policy Sustainable Dev. 55 14–29, 2013.

Spalding M., Kainuma M., Collins L., World Atlas of Mangroves (London: Earthscan), 2010.

Tomohiro T., Atsushi N., Mao O., Naoko M., Ryo N., Hiroshi N., Abdelwahab A., Amgad E., Ken Y., Effects of shoot position on shoot and leaf morphology of Avicennia marina in the hyperarid Red Sea coastal region of Egypt. Landscape and Ecological Engineering,1-9, 2013.

Ukpong I.E., An ordination study of mangrove swamp communities in West Africa Vegetation, 116: 147-159, 1995.

Vanderstraete T., Goossens R., Ghabour T., Bathymetric mapping of coral reefs in the Red Sea (Hurghada-Egypt) using Landsat7 ETM+ Data, Proceedings of the Seventh International Conference on Remote Sensing for Marine and Coastal Environments, Ann Arbor (USA), Veridian, CD-ROM, 2002.

VCS, VCS GUIDANCE. AFOLU Guidance: Example for Calculating the Long-Term Average Carbon Stock for ARR Projects with Harvesting. Verified Carbon Standard – Verra, 2011.

VCS, VCS Standard v4.2. Verified Carbon Standard – Verra, 2022.

Walters B., Local mangrove planting in the Philippines are Fisherfolk and fishpond effective. Restoration Ecology 5 (12), 34–40, 2000.

Zahran M., Willis A., The vegetation of Egypt. Springer, 2nd edition, 437, 2009.