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Habitat-Based Estimate of Carbon Content in Mangrove *Avicennia marina* (Forssk.) Vierh. of South Sinai, Egypt

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Abstract: *Climate change is a global challenging issue, elevated levels of atmospheric carbon dioxide as a result of increased anthropogenic activities and the resulted consequences are exceeding the predominant change in climate conditions to result in several deteriorations as habitat loss, species population and diversity loss, sea level rise threatening coastal habitats including mangrove ecosystem, hurricanes, floods and desertification. The world began since Kyoto protocol in 1997 to work mainly in two dimensions, first is minimizing practices results in more emissions of greenhouse gasses, the second is trying to encourage activities that increase uptake of atmospheric carbon dioxide. Present study tried to provide a more accurate estimate using non-destructive method for the carbon content in biomass of Avicennia marina as one of pioneer ecosystems in carbon storage in both biomass and sediments. Using a species and climatic specific allometric equations above- and below-ground biomass was estimated for mangrove in two marine protected areas in South Sinai then further estimate of total carbon content, the total mangrove carbon in biomass was 109.33, 41.92, 70.3, 29.2 Mg C ha^{-1}in intertidal, shoreline, salt plain and planted mangrove respectively while about 95% of the mangrove cover is in intertidal habitat. The total carbon content of mangrove biomass in Sinai and Egypt is 5409.93 and 55954.11 Mg C.*

Keywords: *Carbon storage, Climate change, Coastal ecosystems, Mangrove biomass, Mangrove plantation*

I. Introduction

Climate change' is the persistent change in the state of the climate properties, which remains for decades [1]. The basic physics of climate change have been known for more than a century, ancient Greeks, Americans in the 19th-century and Swedish scientist Svante Arrhenius, they all linked cutting of forests trees and burning more coal with the resulted changes in rainfall pattern in a region and add more carbon dioxide gas to the Earth's atmosphere, what would results raising of the Earth average temperature [2]. Then more accurate measurements of atmospheric CO_2 concentration, initiated by Charles David Keeling in 1958, constitute the master time series documenting the changing composition of the atmospheric CO_2 concentration creating " Keeling Curve " showing changes in atmospheric CO_2 concentrations since 1960 and still continued [3].

A remarkable change in various terrestrial (including freshwater), coastal and marine ecosystems including changes in species distribution, population size and community composition are clearly associated with global climate change [4]. Mangrove ecosystem is highly threatened, based on available evidence of all the climate change outcomes. Rising of mean-sea-level presenting the greatest impact on the mangrove ecosystem, which directly results in net lowering of sediments elevation, which is highly risky especially if there is limited area for mangrove landward transgression [5]. It is estimated that about 35% of the global area of mangroves has been lost during the last 20 years, a rate of reduction that exceeds that of other tropical ecosystems such as coral reefs and rainforests [6, 7].

Mangroves, which occupy only about 0.4% of the global forests area are very important sinks for atmospheric CO_2 [8, 9] they are also considered among the most productive ecosystems of the globe as they are account for providing about 11% of the total terrestrial carbon input into the world oceans [10]. It is estimated that the above-ground biomass growth of mangrove equals 9.9, 3.3 and 18.1 tons of dry matter/ha^{-1} yr^{-1} in tropical wet, tropical dry and subtropical regions, respectively [11, 12, 13]. While, the below-ground estimated biomass were 43, 8-25 and 53–76 t ha^{-1} for *Avicennia marina*, *Rhizophora mucronata* and *Sonneratia alba* respectively in Gazy bay, Kenya [14], whereas greater values of below-ground biomass were recorded for *Avicennia marina* in Australia, 109–126 t ha^{-1} [15]. In the Arabian region few studies were conducted on the mangrove biomass generally and almost no studies were conducted on estimation of mangrove carbon content in the total biomass, estimated above and below-ground biomass production in two *Avicennia marina* mangrove stands in Marsa Shuaiba and Yanbu regions on the Red sea coast of Saudi Arabia showed that the total above-ground biomass in Shuaiba, was 18.58 t ha^{-1} which is remarkably higher than that of Yanbu site (10.77 t ha^{-1}), overall, below-ground fine roots biomass of both sites was 67.8 t ha^{-1}, while above ground biomass was 14.77 t ha^{-1} and a root to shoot ratio of 0.78 [16]. The above ground biomass of *Avicennia marina* trees in Sirik arid area in Iran is low in comparison with other studies; the total above ground biomass is 17.16 t ha^{-1} [17]. Estimated above-ground biomass of *Avicennia. marina* of Mangawhai Harbour, New Zealand was between 2.69 - 8.88 kg m^{-2}, which is less than the above-ground biomass of *Avicennia marina* stands in other temperate regions in both New Zealand and Australia. Below-ground biomass was ranged between 11.62 - 14.7 kg/m^2, which is concordant with that of larger trees sites below-ground biomass [18].

1.1 Objectives

1- Provide detailed and habitat based estimate of total mangrove carbon content in biomass.
2- Compare distribution of above- and below ground carbon in mangrove.
3- Evaluate total carbon in biomass of ten years old planted mangrove.

1.2 Justification of the Study

Aware tourism development near valuable coastal ecosystems and encouraging conservation and rehabilitation of these ecosystems are important. Mangrove ecosystem in the studied region in both Ras Mohammed National Park and Nabq Marine Protected Area in South Sinai are bordering one of the world's fast-growing tourism development regions, Sharm El Sheikh Resort, current study is trying to emphasize one of the several known values of mangrove ecosystem as good carbon sink (in biomass) and almost single source of nutrients to one of the world's poor seas in productivity, the Red Sea and bordering an arid region, also trying evaluate the significance of ten years old mangrove plantation as a carbon sink.

II. Methodology

2.1 Study Area

Study sites are located South Sinai, first at Nabq marine protected area while the second at the most southern tip of Sinai Peninsula in Ras Mohammed National Park (Fig. 1).

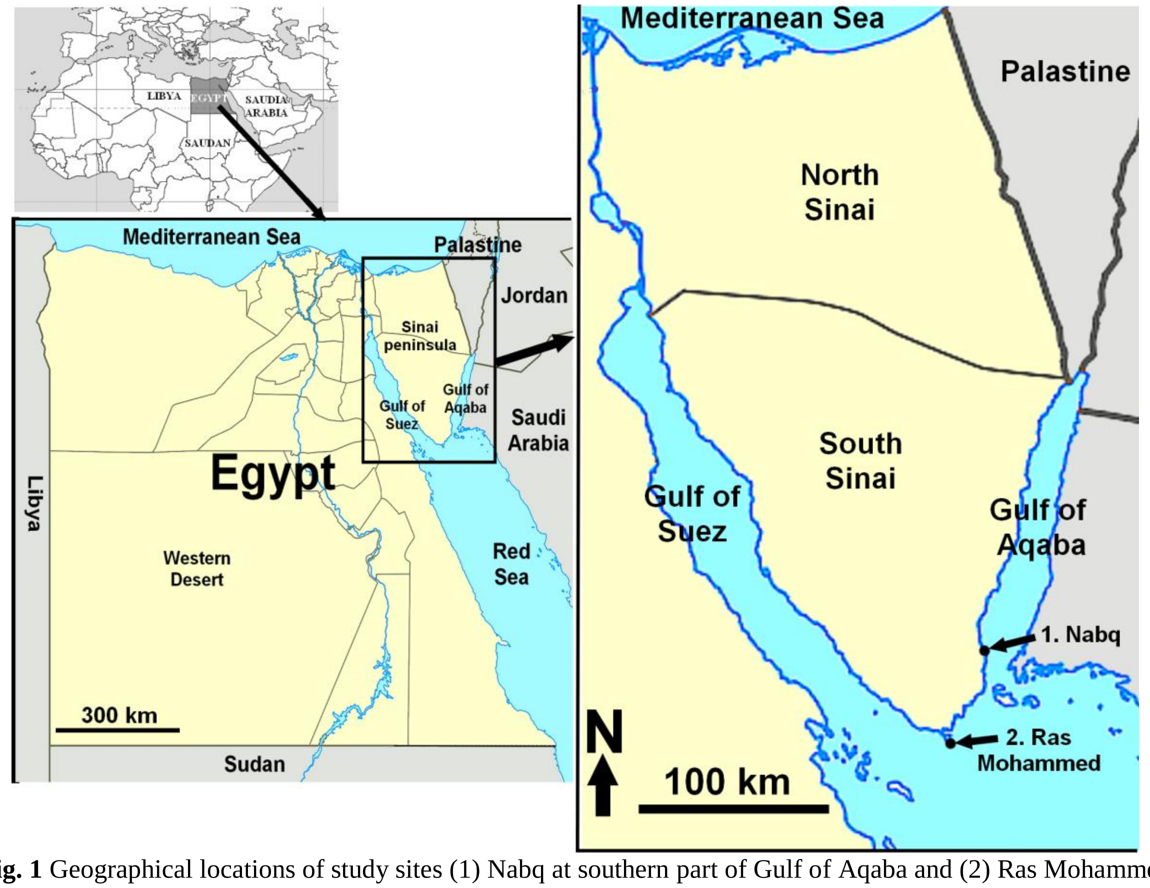

Fig. 1 Geographical locations of study sites (1) Nabq at southern part of Gulf of Aqaba and (2) Ras Mohammed at the most southern tip of Sinai Peninsula.

2.2 Climate

Average monthly temperature (^oC), precipitation (mm) and solar radiation (Mj/m^2) in both study sites are presented in (Fig. 2), minor differences in the shown climatic parameters mostly in average monthly precipitation. Wind direction of Nabq is between north of northeast (52.2 %) and northeast (23.4 %) having average annual direction of 28^o from the north and average annual speed of 22 km/h while in Ras Mohammed the average annual wind direction is 314^o and average annual wind speed of 6.0 km/h. Solar radiation in both Nabq and Ras Mohammed has average of 20.8 Mj/m^2, while the maximum radiation occurs in Jun (28.4 Mj/m^2) and the lower in Dec. (12.6 Mj/m^2) [19].

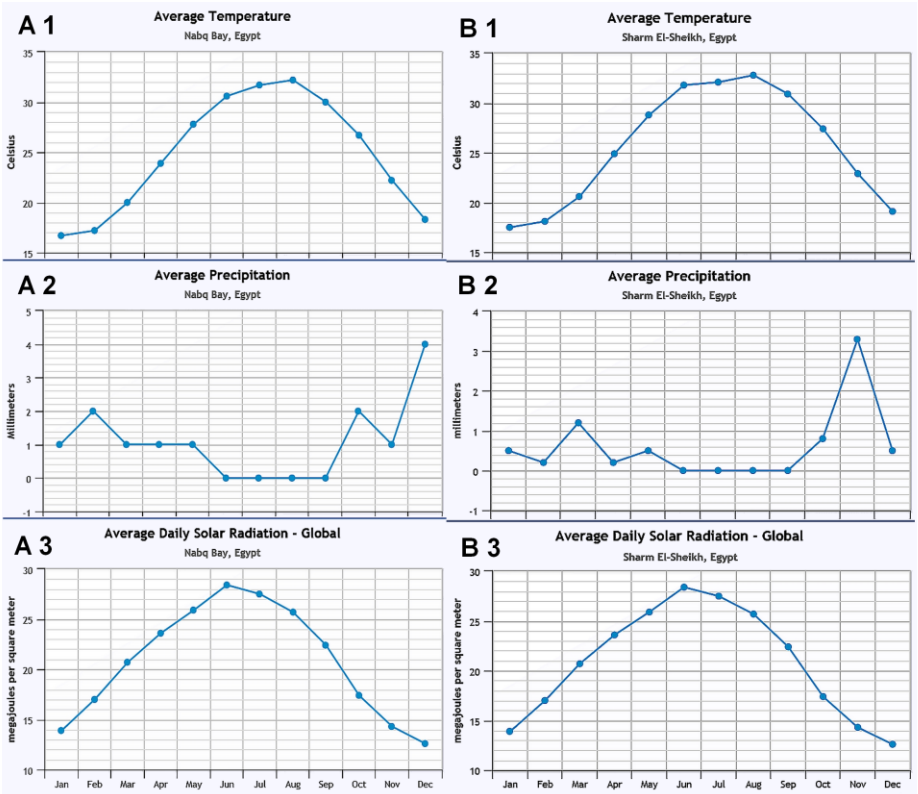

Fig. 2 Average daily recording of 30 years for temperature (^oC), precipitation (mm) and solar radiation (mj m^{-2}) in Nabq study site (A1,A2 and A3) and Ras Mohammed (B1, B2 and B3), source modified after [19].

2.3 Selection of Study Sites

Work conducted to cover all mangrove stands (*Avicennia marina*) in South Sinai either naturally occurring or transplanted mangrove sites. Nabq protected area mangrove of four main stands (50.09 ha) and Ras Mohammed National Park (only 0.9 ha) were the main targets of this study (Fig. 1). Naturally occurring mangrove in the target stands are developed in four different habitats, include: intertidal, shoreline, salt plains and sand mounds [20]. Plots were selected to cover these habitats evenly to enable further comparing and more accurate evaluation of mangrove biomass and carbon content, mangrove developed on sand mounds was not covered by present study due to the absence of clearly defined trunk for diameter at breast height measurement (DBH) and further calculations of trees carbon in biomass using allometric equations. Eight length different belt transects of 10 meters width were allocated perpendicular to shoreline starting from first inland individuals in salt plain habitat passing through shoreline mangrove habitat and ended at almost last individuals in the intertidal habitat mangrove. In Ras Mohammed mangrove is trapped in a shallow channel in the intertidal habitat only, so that study quadrats of 10 X 10m were allocated randomly in the small study sites, three plantation sites were tested also to compare with naturally occurring mangrove using direct quadrate allocation in the plantation sites.

2.4 Sampling Method

Sampling followed modified method from nested plot method [21], quadrates allocation was conducted according to change in habitat type and environmental gradients and plot was a 10 X 10 m quadrate and measuring of all individuals DBH inside the quadrate along the belt transect of different lengths according to forest width, finally total resulted biomass and estimated carbon will be in kg $0.01ha^{-1}$.

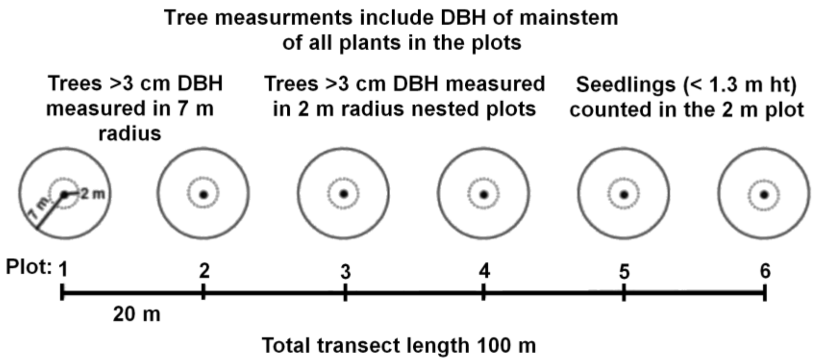

Fig. 3 Sampling for trees DBH measures was slightly modified from nested plot method [21].

2.5 Assessment of Mangrove Biomass

Since all mangrove stands in Egypt are almost in protected areas under the law 102/1983 for protected areas any destructive based method would not possible [22], so the method followed non-destructive technique based on pre-established species and climatic specific allometric equations to calculate above and below-ground biomass of *Avicennia marina* using trees measures. The trunk diameter measured with a tree caliper (A.M. LEONARD) at 130 cm height with little shifting up or downward to avoid trunk abnormalities due to branching or presence of swellings of previously decayed branches. In the case of eccentric branches, the 'true' diameter is calculated by having the average of longest and shortest axes, smaller bushy individuals' circumference is measured just above the ground level following the same bases of trees.

Table 1 Allometric equations were used to calculate trees biomass for *Avicennia marina trees*, B = biomass (kg), D = diameter at breast height (cm).

Avicennia marina size class	Estimate	Equation	R^2	Source
Individuals DBH > 4 cm	Above-ground biomass	$B=0.4721D^{2.299}$		[23]
	Below-ground biomass	$B=1.28D^{1.17}$	00.99	[24]
Individuals DBH < 4 cm	Above-ground biomass	$B=200.4D^{2.1}*.001$		[25]
	Below-ground biomass	B=0.923*above-ground biomass	00.99	[24]

In order to calculate tree carbon content, global default factors (based on tissue nutrient analysis) of 0.48 and 0.39 of above- and below-ground biomass, respectively, were used [21]. Values expressed in units of mega gram of carbon per hectare (Mg C ha^{-1}).

III. Results and Discussion

3.1 Comparing Mangrove Biomass and Carbon Content in Studied Habitats

The average of single tree biomass in different habitats was notably highly variable in studied mangrove habitats and planted mangrove sites, average tree biomass were 92.27 ±9.03, 16.55 ±2.39, 40.47 ±3.46 and 21.18 ±3.38 Kg and the average total tree carbon content were 43.26 ±4.28, 7.58 ±1.11, 18.62 ±1.62 and 10.47 ±1.56 Kg for intertidal mangrove, shoreline mangrove, salt plain mangrove and planted mangrove respectively (Fig. 4). Mangroves of Sinai especially mangrove stands with considerable density are found along a stretch of coast of the alluvial fan of Wadi Kid in Nabq protected area showed remarkable variations in trees measures (mainly heights and DBH) [20], so significant differences in the average tree carbon content in different habitats.

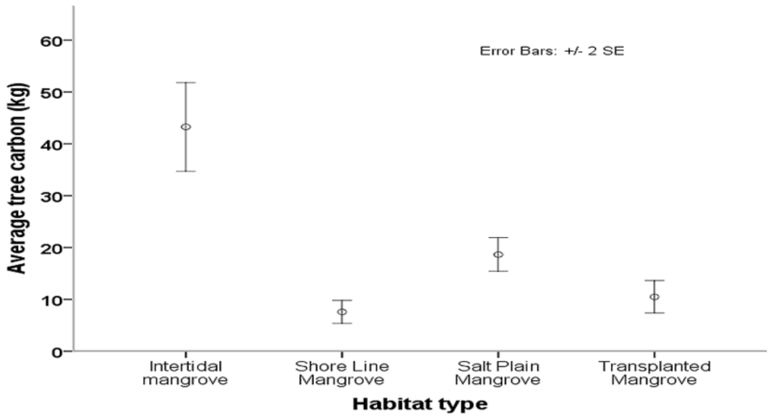

Fig. 4 Mean tree carbon content (kg) in all mangrove studied habitats, bars represent standard error of mean.

3.2 Distribution of Above- and Below-ground Carbon in Studied Habitats

Trees carbon content distribution between above and below-ground showed great variation between habitats, it was near equal distribution of carbon content of ten years old transplanted mangroves in both Nabq and Ras Mohammed protected areas. In shoreline and salt plain habitats near one-quarter of the trees carbon content was below-ground and three-quarters were above-ground, moving to intertidal mangrove where a larger trees are present with about 88.26% of trees biomass was above-ground and only 14.08% was below-ground (Fig. 5)

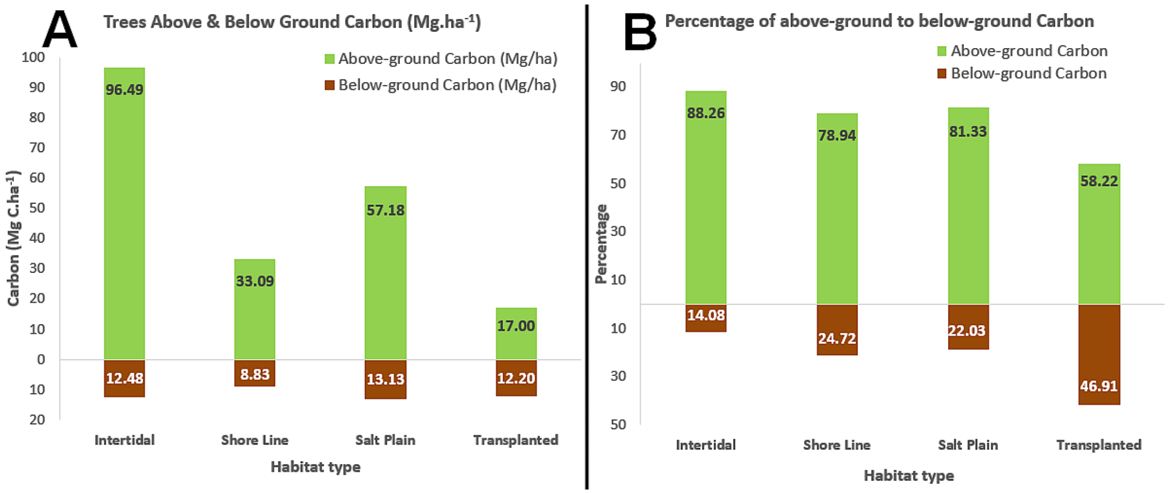

Fig. 5 Distribution percentage of above-ground to below-ground mangrove carbon in all studied habitats and for transplanted mangrove (A) and the average above and below-ground mangrove carbon content (Mg C.ha^{-1}) (B).

Mangrove below-ground biomass (BGB) values were almost similar in intertidal, salt plain and planted mangrove habitats, while it was lower in shoreline mangrove habitat, current study results of below-ground carbon (BGC) were higher for all habitats than that values determined for *Avicennia marina* in Abu Dhabi in the Arab Emirates [26] but were similar to present study results for shoreline habitat mangrove of Abu Dhabi using the same allometric equations. Higher mean values of BGC reported for Australian *Avicennia marina* [7], also higher estimate was reported than current study for *Avicennia marina* on the Red Sea coast in Saudi Arabia [16]. This could be explained with those mangroves in Red Sea coast of Egypt are under a severe environmental regime of both high salinity and temperature, which exhibited possibly, limits biomass and primary productivity as compared with this of Kenya growing under favorable conditions of salinity, humidity and temperature [27]. Comparing the ratio of below-ground carbon (BGC) to above-ground carbon (AGC) in all studied habitats it was observed that *Avicennia marina* showed a gradual shift in tree biomass to the above-ground part either with age development or with the increase in trees total biomass, this may attribute to that at early development stages *Avicennia marina* give a higher priority of to establish a proper root system in the loose anaerobic sediments conditions of highly dynamic coastal habitat.

Reported BGC of natural and planted *Avicennia marina* in Gazy Bay Kenya was higher than obtained by present study, similar to present study results both planted *Avicennia marina* and *Sonneratia alba* showed greater below-ground biomass per unit area as compared to their corresponding naturally growing mature trees, but the converse situation was observed in the case of *Rhizophora mucronata*. This is possibly due to that *Avicennia marina* and *Sonneratia alba* are seaward most species, hence they are continuously subjected to more wave action, therefore a higher root biomass is urgent for anchorage purposes and for support in the unstable loose substrate [14]. According to the total mangrove cover in South Sinai, 50.99 ha [20] and its distribution on the defined habitat [28], it possible to precisely estimate the total carbon stored in biomass in Sinai mangrove. The total mangrove cover area of Egypt is about 525 ha [29] and considering that all mangroves distributed in Egypt along the Red Sea coast and the Red Sea islands and according to their distribution percentages on the well-defined mangrove habitats in South Sinai attained values of 94.76%, 3.04%, 1.43% and 0.77% on intertidal, shoreline, salt plain and sand mound habitats, respectively [20]. The total planted mangrove in Egypt is about 12.55 ha [30], so the total organic carbon content in mangrove biomass of Sinai and Egypt is 5409.93 and 55954.11 Mg C respectively (Table 2).

Table 2 Total carbon content in *Avicennia marina* biomass in both Sinai and Egypt.

Habitat	**Average carbon content in biomass (Mg C. ha^{-1}) according to present study**	**Mangrove distribution percentages on different habitats**	**Sinai Mangrove cover (ha) in defined habitats [20]**	**Elucidated mangroves cover (ha) in the defined habitats Egypt, [29]**	**The total carbon content of Sinai mangrove (Mg C)**	**The total carbon content of Egypt mangrove (Mg C)**
Intertidal mangrove	109.33	94.76	48.32	497.49	5282.8256	54390.5817
Shoreline Mangrove	41.92	3.04	1.55	15.96	64.976	669.0432
Salt Plain Mangrove	70.31	1.43	0.73	7.51	51.3263	528.0281
Transplanted Mangrove	29.20	----	0.37	12.55*	10.804	366.46
Total		**99.23****	**50.97*****	**533.51**	**5409.93**	**55954.11**
*** Total transplanted mangrove cover (ha) in Egypt [30].**						
**** Missing 0.77% is the percentage of mangrove cover on sand mounds habitat, not evaluated by present study.**						
***** Area not including mangrove developed inland forming sand aggregates.**						

IV. Conclusion

Mangrove ecosystem in South Sinai coast is occupying four different habitats starting from intertidal, shoreline, salt plain ending inland on sand mounds sharing community with up to four different species and forming up to 5 meters high coastal sand mounds in some locations. It is recommended that any further study on mangrove as a vegetation or as an ecosystem should conduct on the base of defined habitats since great differences either in vegetation population demography, productivity and biomass are remarkably observed, these differences in vegetation are accompanied with differences in associated biota and edaphic factors. Intertidal mangrove carbon content is three-folds of shoreline mangrove and double-folds these of salt plain mangrove. A ten years old restored *Avicennia marina* areas in South Sinai maintained in two protected areas showed a total biomass more than double-folds of these planted in Saudi Arabia under almost similar arid conditions.

Avicennia marina is showing a gradual shift in tree biomass to the above-ground portion either with age development or with the increase of the total tree biomass, this may be explained by the higher priority of *Avicennia marina* to establish a proper root system in loose anaerobic sediments conditions to support the above-ground biomass. Total trees carbon content was linked to trees biomass and followed the same distribution pattern in habitats or above- and below-ground, higher biomass, higher carbon content, total trees carbon content of *Avicennia marina* in Indonesia and Australia were four and six times, respectively as total trees carbon obtained in this study. Planted *Avicennia marina* in previously depleted mangrove areas developed faster and yielded higher biomass as compared to the plantation in non-mangrove areas even under similar plantation procedures and environmental conditions, so restoration is better than transplantation.

Mangrove ecosystem have a high value as a good source of organic matter for the marine ecosystems, more likely where it exists along the coast of a poor sea in arid region like the Red Sea, high capacity of mangrove ecosystem to store more carbon *via* photosynthesis in the biomass beside other several ecological values what requires a proper management of land uses near these ecosystems (coastal systems generally and mangrove specifically) to ensure conservation of these coastal systems otherwise missing one the world efficient natural mitigation tools of elevated levels of atmospheric CO_2 and their consequences. Resources managers in marine protected areas and related conservation authorities in similar areas as in the Red Sea are invited to start similar evaluation for their mangrove ecosystem using the same nondestructive method.

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