الإمارات العربية المتحدة
وزارة البيئة والمياه

بمشاركة

AGEDI
مبادرة أبوظبي العالمية للبيانات البيئية
Abu Dhabi Global Environmental Data Initiative

Blue Carbon at the National Level Extension – Technical Report

Final

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بدعم من

هيئة البيئة أبوظبي
Environment Agency ABU DHABI

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1. Executive Summary

Blue Carbon in the Northern and Eastern Emirates is a second phase extension to the Abu Dhabi Blue Carbon Demonstration Project, commissioned by the Abu Dhabi Global Environmental Data Initiative (AGEDI) with the support of the Environment Agency – Abu Dhabi (EAD). These projects improve understanding of carbon storage and the other services that coastal and marine Blue Carbon ecosystems provide across the United Arab Emirates (UAE).

The Abu Dhabi Blue Carbon Demonstration Project comprised five components: 1) A **carbon baseline assessment** (to which study is an extension) quantifying carbon stocks in coastal ecosystems and rates of carbon sequestration associated with mangrove afforestation; 2) A **geographic assessment** mapping Abu Dhabi's Blue Carbon ecosystems and providing a carbon analysis tool to support informed decision making; 3) An **ecosystem services assessment** investigating the goods and services beyond carbon sequestration that Blue Carbon Ecosystems provide; 4) A **policy component** identifying options for incorporating Blue Carbon and Ecosystem Services in Abu Dhabi's policy and governance frameworks; and 5) A **Blue Carbon and ecosystem services finance feasibility assessment** drawing together findings of each component to recommend feasible policy and market options for implementing Blue Carbon projects in Abu Dhabi.

For this national study, two members of the International Blue Carbon Scientific Working Group – a network of scientists with specialist knowledge of carbon cycling in coastal ecosystems – were engaged to quantify carbon stocks in Blue Carbon ecosystems within Khor (lagoons) along the coast of Dubai, Sharjah, Ajman, Umm al-Quwain and Ras al Khaimah. The team worked closely with AGEDI, EAD and the Ministry of Environment and Water (MoEW) and local government staff to select, access, and sample field locations.

Standard field and analytical approaches were used to enable comparison with a growing global dataset on carbon stocks within coastal ecosystems. The investigation provided a baseline assessment of carbon stocks at 10 mangroves and one algal flat of the Northern and Eastern Emirates – perhaps the largest carbon stocks of the UAE. This extends to a total of 57 sites sampled in the UAE, representing natural mangroves, planted mangroves, salt marshes, seagrass meadows, and algal mats. These new data points in the Northern and Eastern Emirates will form an important part of the overall national Blue Carbon account for the UAE.

Carbon stocks of existing natural intertidal ecosystems mangroves were sampled from sites that were representative of the Northern and Eastern Emirates. This included sites both in the Sea of Oman and the Arabian Gulf. Sites were selected to represent a range of environmental settings (e.g. islands, mainland coast line, and sheltered estuaries. The sites that were selected for survey were in consultation with local environmental agencies using the following criteria: (i) sample across as much of the study area as logistically possible, and (ii) sample areas where the mangrove ecosystem has a large spatial extent.

As of 2015, the carbon stocks of 18 mangroves of the UAE have been quantified. This includes four in the Sea of Oman (Kalba), six in the Arabian Gulf of the Northern and Eastern Emirates, and eight in the Abu Dhabi Emirate. The data suggest that mangroves of the Northern and Eastern Emirates are generally larger than those of the Abu Dhabi Emirate, but this does vary. The mean ecosystem carbon stock of the mangroves of the three areas are 389, 229, and 140 Mg C/ha, respectively. The mean ecosystem carbon stock of all Northern Emirate sites combined was 296 Mg C/ha. The carbon stocks of the Northern and Eastern Emirates were significantly different ($p<0.10$) from those of the mangroves sampled in Abu Dhabi.

The greatest differences among sites are in the plant carbon pools and in deeper soil layers. There were few differences in the carbon pools of soils 0-30 cm in depth. However, the plant carbon stocks of the Northern and Eastern Emirates greatly exceeded that of the Abu Dhabi mangroves (i.e. >80 Mg C/ha for the Northern and Eastern Emirates but <21 Mg C/ha for the sampled Abu Dhabi mangroves). Additional differences were found at greater soil depths. For example, the mean carbon pools of soils >50 cm in depth was 57 Mg C/ha for the Abu Dhabi mangroves, but 185 Mg C/ha at the Sharjah sites.

Globally, mangrove carbon stocks have been reported to be about 1000 Mg C/ha. The carbon stocks of hyperarid and hypersaline mangroves of the UAE are at the lower end of carbon stocks. Interestingly, they are similar in size to the carbon stocks of mangroves of sandy substrates such as has been reported for Madagascar. The very high carbon stocks measured for Kalba South (518 Mg/ha) are similar to productive mangroves in many parts of the world.

It is also important to remember that these Blue Carbon ecosystems hold the largest carbon stocks found across the Arabian Peninsula. Because of ecosystem services related to carbon cycling, such as fisheries and associated cultural heritage, the conservation and protection of these ecosystems is warranted.

It is apparent that all sites have been degraded to varying degrees and that mangrove loss of these natural stands is ongoing. Apparent degrading activities include construction, urban encroachment, land fill, pollution, trash, and hydrological disruptions.

Conservation measures to protect these high value ecosystems and restoration measures to recover degraded sites will bring benefits for the environment and for the people of the Emirates.

1.1 Recommendations / Observations Arising from Study

1.1.1 General Observations

- All sites sampled offer a unique biodiversity providing the people of the UAE with a number of important ecosystem services. These are among the most magnificent natural ecosystems of the UAE. Conservation of these globally unique, important and valuable ecosystems is warranted.
- It is very apparent that all sites have been degraded to varying degrees and that mangrove loss of these natural stands is ongoing. Apparent degrading activities include construction. Urban encroachment, land fill, pollution, trash, and hydrological disruptions.
- Environmental analyses (field and remote sensing) are needed to determine ongoing losses and predict future mangrove distribution to develop conservation/preservation plans.
- In terms of the conservation, restoration and preservation of the mangroves of the UAE, land managers and planners should consider the watershed level effects of ground and surface water disruption, influences on tidal patterns and pollution effects.
- Because of the unique values and ecosystem services provided by mangroves, a moratorium on any further loss is recommended.

1.1.2 Opportunities for Conservation and Restoration

- **Khor Kalba** is a unique mangrove ecosystem with many large stands of ancient and very large mangroves. The soils were the deepest and most carbon-rich of any site sampled in the UAE. The level of biodiversity was reflected in the high crab and bird densities of the area, in addition to turtles and the schools of fish in the channels. Current and ongoing conservation efforts have resulted in an ongoing recovery of both mangroves and the shellfish and fish resources of the ecosystem. Conservation and public education opportunities are recommended to ensure protection in balance with development in the surrounding area.

- **Khor Kalba (restoration)** The health of sections of Khor Kalba has been negatively impacted by disruption to hydrology with construction of a wall at the border with Oman. An investigation into restoration opportunities is warranted.

- **Ras Al Khor** – These are among the largest/tallest mangrove in the UAE and close to the center of Dubai, yet they are threatened by pollution, land fill and tidal disruption. We observed an area of significant die-off; it did not appear to have been a natural phenomenon but the effects of some pollution event. There is a need for further investigation of its cause to prevent future die-offs. Given this site's potential to serve as a really valuable education/recreation site for Dubai, protection and conservation are recommended. The volunteers for the project who live in the Dubai area suggested that greater access via education programs and boardwalks could greatly increase public awareness of the importance and value of mangroves.

- **Umm Al Quwain** – offers a very rich and diverse ecology, and is perhaps unique among the emirates as a location where all blue carbon ecosystems are found directly connected with coastal dune landscape. Though development is encroaching around the margin, much of the Khor at Umm Al Quwain remains intact. This Khor might be considered for high level conservation designation to protect uniqueness and integrity of this important site.

2 Introduction

2.1 Project Context

"Blue Carbon" refers to the functional attributes of coastal and marine ecosystems to sequester and store carbon. Blue Carbon ecosystems of the UAE include mangrove forests, salt marshes and seagrass beds. Another potential Blue Carbon ecosystem identified as a result of this project is cyanobacterial "blue-green algal" mats (hereafter referred to as algal flats). When these ecosystems are destroyed, buried carbon can be released into the atmosphere, contributing to global warming. In addition to their climate-related benefits, Blue Carbon ecosystems provide highly valuable *Ecosystem Services* to coastal communities. They protect shorelines, provide nursery grounds for fish and habitats for a wide range of terrestrial and aquatic species, and support coastal tourism. They also have significant cultural and social values.

A prior study, the Abu Dhabi Blue Carbon Demonstration project quantified carbon stocks and the other services provided by coastal and marine Blue Carbon ecosystems along the coast of the Emirate, and also contributed to the improved understanding of this relatively new concept on a regional and international level (Crooks et al., 2013; Crooks et al., 2014; Campbell et al., 2014). The project enhanced local capacity to measure and monitor carbon in coastal ecosystems and to manage associated data. In addition, it identified options for the incorporation of these values into policy and management to support sustainable ecosystem use and the preservation of their services for future generations.

Building on the results of the Abu Dhabi Blue Carbon Demonstration (ADBC) project, the Northern and Eastern Emirates Project extended the baseline assessment of the total carbon stocks of mangroves to the Northern and Eastern Emirates. This effort included field surveys specifically quantify the carbon of mangroves ecosystems, capacity building for those interested in learning Blue Carbon and mangrove ecology sampling approaches, and extensive laboratory and computer analysis to determine carbon stocks in a scientifically defensible manner. These new data points in the Northern and Eastern Emirates will form an important part of the overall national Blue Carbon account for the UAE.

Carbon stocks of existing natural intertidal ecosystems mangroves were sampled from sites that were representative of the Northern and Eastern Emirates, including both from the Sea of Oman and the Arabian Gulf. Sites were selected to represent a range of environmental settings (e.g. islands, mainland coast line, and sheltered estuaries). The sites that were selected for survey were in consultation with local environmental agencies using the following criteria: (i) sample across as much of the study area as logistically possible, (ii) sample areas where the mangrove ecosystem has a large spatial extent.

The investigation provided a baseline assessment of carbon stocks at 10 mangrove areas and one algal flat of the Northern and Eastern Emirates, which is perhaps the largest carbon stocks of the UAE.

2.2 International Context

The Blue Carbon concept has strengthened interest in the management and conservation of coastal marine ecosystems, supporting climate change mitigation efforts. However, there are still gaps in the understanding of Blue Carbon, and incentives and policies are needed to ensure more sustainable environmental management practices.

The experience and knowledge gained from the project will help guide other Blue Carbon projects and international efforts, such as the International Blue Carbon Initiative[1] and the Global Environment Facility's (GEF) Blue Forests Project, of which AGEDI contributed co-financing as well as serving as an intervention site. This project also has helped develop Blue Carbon science and data management through the production of tools and the testing of methodologies that can be utilized and up-scaled to the international arena to enhance international Blue Carbon cooperation and training.

2.3 Project Setting

In just over 40 years, Abu Dhabi has evolved from a small fishing community to the largest of the seven emirates of the UAE. With the vision and direction from His Highness the late Sheikh Zayed Bin Sultan Al Nahyan, the environment has become an intrinsic part of the heritage and traditions of the people of the UAE.

This national affinity to the sea has led to the initiation of the prior Abu Dhabi Blue Carbon Demonstration project and this extension to the Northern and Eastern Emirates in order to explore the values that coastal ecosystems provide to the UAE, and to help preserve environmental and cultural heritage. The project is commissioned by AGEDI with the support of EAD and in partnership with MoEW.

2.4 Science Team

The Principal investigators of this study are members of the International Blue Carbon Scientific Working Group. Hosted by Conservation International, the International Union for Conservation of Nature (IUCN), and the Intergovernmental Oceanographic Commission (IOC), this working

[1] http://thebluecarboninitiative.org/

group of scientists assists in the building of capacity for the understanding of carbon cycling by coastal marine ecosystems. The Science Working Group runs in parallel with the International Blue Carbon Policy Working Group under the Blue Carbon Initiative.

The goals of the Science Working Group are to:

1) Assess the feasibility of coastal Blue Carbon as a conservation and management tool and its potential for climate change mitigation

2) Provide implementable recommendations for coastal marine conservation and management that maximizes sequestration of carbon and avoids emissions in coastal systems

3) Establish a network of demonstration projects to quantify carbon stocks and fluxes, test protocols for monitoring, reporting and verification

4) Promote and support scientific research on carbon cycling by coastal Blue Carbon ecosystems

Dr. Stephen Crooks is an independent consultant, as well as Climate Change Program Manager at Environmental Science Associates, a US-based environmental consultancy. He is a practitioner in wetlands restoration and specializes in planning for climate change adaptation and mitigation. He is a founder of the Blue Carbon Initiative, and member of both the International Blue Carbon Scientific and Policy Working Group, a member of the Intergovernmental Panel on Climate Change (IPCC) Expert Working Group developing supplementary guidance for national greenhouse gas accounting to include wetlands, a Steering Committee Member of the IUCN Species Survival Commission (SSC) Mangrove Specialist Group, and an AFOLU expert for Wetland Restoration and Conservation category under the Verified Carbon Standards (VCS) Registry. He is working with Restore America's Estuaries to establish a global VCS wetlands restoration carbon offset methodology, and the United Nations Environment Programme (UNEP) to develop best practice guidelines for coastal wetlands carbon projects.

Dr. Boone Kauffman is a professor of Ecosystem Studies in the Department of Fisheries and Wildlife at Oregon State University and a Senior Associate with the Centre for International Forestry Research. He is a member of the IPCC, the International Blue Carbon Science and Policy Working groups, and is a science advisor to the

Coalition for Rainforest Nations. Dr. Kauffman's research focus is on the relationships between land use, climate change, and carbon dynamics of tropical wetland ecosystems.

2.5 Capacity Building

During the course of this project, training on field Blue Carbon stock assessment and all necessary equipment has been provided by the Principle Investigators, the competent environment authorities of each emirate, as well as MOEW and AGEDI. Calculation of living biomass carbon stocks can be derived from allometric and other questions provided in this report. Soil carbon stocks were derived by laboratory analysis at home institutes in the United States. Universities in the UAE possess the necessary equipment (carbon/nitrogen analyzer) to quantify soil carbon samples. To aid simple determination of carbon stocks, a regression curve between a simple analysis, "Loss on Ignition," and carbon analysis were derived for all ecosystems. AGEDI or MoEW could elect to purchase the equipment for Loss on Ignition or have samples run through a geotechnical, soils or university laboratory, for which this is standard equipment.

More broadly, awareness has been built within location agencies on existence of Blue Carbon issues. An essential component of the fieldwork was the local and international capacity building that it facilitated. During the surveys, personnel from EAD, MoEW, partners of the Blue Forest Project and volunteers through the EWS-WWF network provided invaluable support in the field and were able to interact directly with the team of world renowned and respected coastal carbon scientists. International partners from Madagascar who are currently undertaking similar projects in their own countries using the methodologies written by these scientists were supported to participate, and as a result were given the opportunity to discuss the theory and practical application of carbon assessments in blue carbon ecosystems.

Photos: Thank-you to our survey teams






2.6 Report Organisation

This report summarizes findings of the field of Blue Carbon ecosystem carbon stocks for the coast of the Northern and Eastern Emirates. Additionally, this report provides a summary of the local and global context of Blue Carbon research, and details methods, laboratory analysis and results of research.

2.7 Acknowledgements

The National blue carbon Project is the outcome of a successful partnership between the UAE Ministry of Environment and Water and AGEDI, implemented in collaboration with Environment Agency– Abu Dhabi)and the competent authorities of each Emirate including Dubai Municipality, Environment and Protected Areas Authority of Sharjah, Municipality and Planning Department Ajman, Environment Protection and Development Authority of Ras Al Khaimah and Umm Al Quwain Municipality. Thank-you also to the two Representatives of Blue Ventures Madagascar – for cross capacity-building and sharing of experience.

A special thank-you to EWS-WWF for their participation and facilitating access to their volunteer network.

3 Study Area

The study areas were the dominant natural mangroves of the Northern and Eastern Emirates of the UAE. Coastal wetland plant communities in the UAE also include planted mangroves, marshes (usually Chenopodaceae-dominated communities), and sabkha (landscapes devoid of vascular vegetation but occasionally with a cover of algae). The coastal wetlands of the area are flooded by a mixture of seawater from tidal fluxes and very infrequent rain showers, ground water, locally freshwater run-off or ground water from mountains (as at Khor Kalba) or anthropogenic sources of freshwater (sewer and storm runoff). Sampling of this project focused on the mangrove ecosystems with the exception of one algal flat. The climate of the UAE is hot and hyperarid. Salinity levels of soils and water can be high relative to marshes and mangroves in other areas of the world (Table 1), which are typically around that of open ocean seawater salinities, and uncommonly more than twice that of ocean salinity.

Table 1: Metadata of the sampled mangroves and algal flats of the Northern and Eastern Emirates, UAE.

Location	Emirate	Longitude	Latitude	Soil depth (cm)*	Soil water Salinity (ppt)*	Soil water pH*	Approx canopy ht (m)
				Mean ± SE	Mean± SE	Mean± SE	
Kalba North	Sharjah	25° 1'2.50"N	56°21'23.38"E	87± 8	35±1	6.8±0.1	3
Kalba South	Sharjah			160±13	41±1	7.0±0.0	5
Kalba East	Sharjah			131±21	nd	6.9±0.1	5
Kalba West	Sharjah	25° 0'34.43"N	56°21'35.92"E	85±10	36±0	7.2±0.0	5
Ras Al Kamiah	Ras Al Kaimah	25°46'22.01"N	55°56'47.55"E	179±6	45±3	7.2±0.0	**3**

Khor Al Rams	Ras Al Kaimah	25°53'53.15"N	56° 2'23.12"E	48±4	40±1	7.1±0.0	3
Al Zorah	Ajman	25°26'7.45"N	55°28'42.38"E	77±2	44±2	6.9±0.0	2-4
Khor Al Jafra	Umm Al Quwain	25°31'59.43"N	55°35'33.98"E	40±6	48±1	7.0±0.0	3
Khor Al Madar	Umm Al Quwain	25°33'43.82"N	55°36'17.24"E	34±3	46±1	7.0±0.1	3-4
Ras Al Khor	Dubai	25°11'26.24"N	55°19'37.10"E	227±19	67±2	6.8±0.0	5-7
UAQ Algal flat	Umm Al Quwain	25°32'33.7"N	55°38'33.20"E	nd	85±5	7.3±0.1	0
*Numbers are means ± one standard error							

Continuation: Unique characteristics of the mangroves sampled in the Northern and Eastern Emirates, November 2014.

Site	Description
Kalba North	Very dense, medium-statured stand (3m ht); fairly large trunk diameters; most trees mature but young; deep carbon rich soils.
Kalba South	Very large mangroves with an open understory; soils >1m depth; much diversity and density of crabs - apparent at all Kalba sites.
Kalba East	A site with large mangroves; carbon-rich soils. Noticeable organic materials at depth to 50-100 cm depth.
Kalba West	On western channel; largest trees sampled; soils shallower that other Kalba sites.
Ras Al Kaimah	Extremely dense stands of mangrove; dense oyster numbers on pneumatophores; soils were gray in color with OM concentrated at the surface.
Khor Al Rams	An open site with the highest seedling density of all sites measured. Sites were on an island typical of the area. Very shallow

	soils (10-15 cm depth); this is in contrast to a freshwater inlet where tall mangroves and a truly unique reed dominated.
Al Zorah	A dense mangrove stand on sandy soils; a dark horizon at 40-70 cm depth potentially indicating a buried soil horizon.
Khor Al Jafra	A low/medium mangrove; a unique mix of low-mature plants ≈2m ht interspersed with taller mangroves (>2 -4 m); very shallow soils (10-15 cm).
Khor Al Madar	Open canopy mix of a few trees 3-4 m in height with mature low (<2m) and many seedlings; soils were very shallow; high diversity in adjacent seagrass/sand flats – with many starfish and anemones, etc.
Ras Al Khor, Dubai	Tall stands of mangrove trees (some of the tallest in the UAE >5m in height); deep sandy soils (>2 m depth with a shallow peat layer at the surface (≈5cm)). The site was adjacent to a large and recent die-off, not likely of natural causes – appeared to be likely death from some pollution plume.

Photo: survey team Al Rams

4 Methods

4.1 Field sampling

Survey work occurred in November, 2014. The goals were to sample composition, structure, and total ecosystem carbon stocks of the mangroves of the Northern and Eastern Emirates of the UAE, including sites adjacent to both the Sea of Oman and the Arabian Gulf.

At each of the 10 selected mangroves whole-ecosystem carbon stocks were quantified following methodologies developed during the 2013 Abu Dhabi Blue Carbon Demonstration Project (Crooks, et al., 2014a,b). Methods also followed closely those described in Kauffman and Donato (2012) but modified for the unique scenarios of the UAE. At each of the 10 native mangrove sites, carbon stocks were measured in six plots established 20 m apart along a 100m transect (Figure 1). As protocols developed during the Abu Dhabi Blue Carbon Demonstration Project were followed, the data are statistically comparable to that collected in 2013. Data was collected necessary to calculate aboveground and belowground C stocks of trees and soils at each plot. In addition to carbon stocks, tree density and basal area of the mangrove stands were measured.

4.2 Metadata

At each site a number of important variables were collected (Table 1). The exact coordinates using a GPS were determined at each plot center. This is extremely important in order to scale the stand level carbon stocks to a regional/landscape level. At each site the soil pH and the soil salinity were also measured. The exact direction of the transect was also recorded. Photos of each sampled site were also taken. The database of photos taken during the survey is available upon request through AGEDI. Other data includes participants of the data collection. A sample of the metadata sample sheet can be found in the appendix.

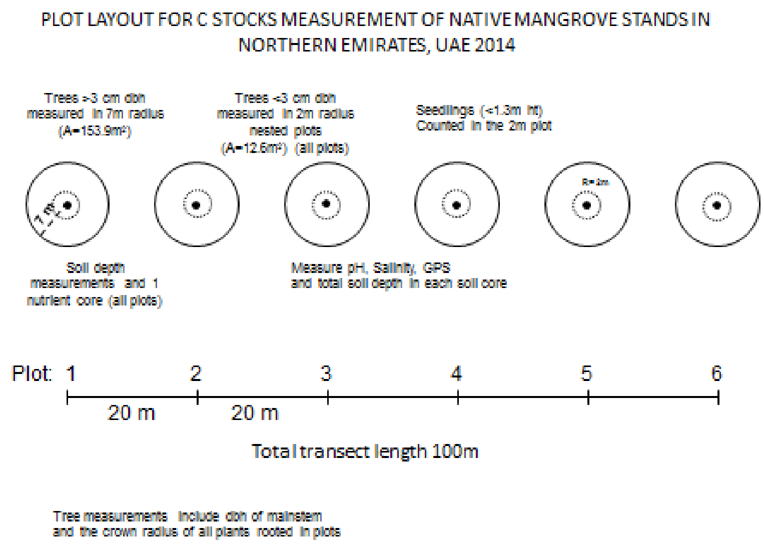


Figure 1: Experimental field design to determine forest structure and carbon stocks in natural mangroves of the UAE.

4.3 Biomass of trees and shrubs

In the native mangroves and older planted stands composition, tree density, and basal area was quantified through measurements of mainstem diameter usually at 1.3 m height (DBH) of all trees rooted within each plot of each transect. In the young mangroves stands where many individuals are <1.3 m in height the height and mainstem diameter at 50 cm were measured. Trees were measured using a nested plot approach. Plot size for trees >3 cm dbh was 154 m^2 (radius of 7 m). Trees <3 cm dbh are measured in a nested plot with a radius of 2 m^2 (12.56 m^2). Seedlings (individuals <1.3 m in height) were counted in the 2 m radius plot to determine their densities.

Allometric equations were used to calculate tree biomass for each site (Table 2). For the ADBC project several allometric equations were examined to determine the biomass of the *A. marina* (Clough et al. (1996), Comely and McGuinns (2005), Dharmawan and Siregar (2008), and Pavaresh et al. (2012). For aboveground biomass determination it was determined that the most suitable equations to use are those the equations developed by Clough et al. (1997) from the arid coast of Northwestern Australia. Similar to this study, the individual mangroves were frequently multi-stemmed. Further, this equation was developed from sites with an annual rainfall of <400mm, high levels of solar radiation, and day time summer temperatures of up to 45-50^{o}C. Belowground root biomass for mangrove trees was calculated using the formula by Comely and McGuiness (2005) which was developed specifically for *A marina*.

Table 2: Allometric equations utilized to calculate plant biomass (aboveground and belowground) for A. marina trees of the Northern and Eastern Emirates United Arab Emirates

Component	Equation	R^2	Source	Location
Aboveground Avicenna marina	$B=0.17758D^{2.2990}$	$r^2=0.97$	Clough et al. 1997	Australia
A germinans (for plants <1.3m ht) at UAQ	$B=0.2004D^{2.1}$	$r^2=0.82$	Fromard et al. (1998)	French Guinea
Belowground	$B=1.28D^{1.17}$	$r^2=0.98$	Comely and McGuiness (2005)	Australia
	B=0923*aboveground biomass		Belowground/ aboveground ratio based upon Comely and McGuiness (2005)	Australia

Note: B = biomass (kg), D = diameter at breast height (cm),

No equation was available for the small *A. marina* plants in the plantations sampled during the ADDCB project. As such, a formula was developed for small A*. germinans* plants (<4cm dbh) from Fromard et al. (1998) which yielded reasonable approximations of the aboveground biomass of the small seedlings. Equations for belowground biomass do not exist for the small plants of plantations. Comely and McGuiness (2005) reported that of the total below ground biomass accounted for 48% of the total plant biomass of A marina. Therefore we calculated belowground biomass of the plants in mangrove plantations as 0.923 of that of the calculated aboveground biomass.

Tree C was determined by multiplying the tree biomass by C concentration of aboveground and belowground tissues. Kauffman and Donato (2012) provided a global default factor of 0.48 for aboveground and 0.39 for belowground biomass.

Standing dead trees are also part of the carbon stock and therefore included in the calculations. For each dead tree, the DBH was measured and assigned to one of three decay class described in Kauffman and Donato (2012): 1- dead trees without leaves, 2- dead trees without secondary branches, and 3- dead trees without primary or secondary branches. The biomass for each tree status will be calculated using allometric equations of plant components. For dead trees of Status 1, biomass was calculated as the total dry biomass minus the biomass of leaves. The biomass of trees of Status 2 was calculated of stems and, branches. Finally, the biomass of trees of Status 3 will be calculated as the biomass of the mainstem.

4.4 Soil carbon and nutrients

The dominant carbon stocks of the UAE mangroves are the soil carbon pools. As such great care and effort was placed in the sampling of this carbon pool. Methods were employed that followed though of the ADDCB project. At each plot, soil samples for bulk density and nutrient concentration were collected using a specialized peat auger consisting of a semi-cylindrical chamber of 5.1 cm-radius attached to a cross handle. This auger is efficient for collecting relatively undisturbed cores from wet soils under mangroves Donato et al. (2011). The core was systematically divided into depth intervals of 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm and >100 cm (if parent materials were not encountered before 100 cm depth). From each core, the depth to parent materials (marine sands or bed rock) was measured. Depth were measured to marine sands (point of refusal) at three locations near the plot center using graduated aluminium rod. Once the cores was extracted from the earth, known volume (5 cm width) of sediment were sampled from the center of each of the depth intervals. Samples were placed in metal cans, dried and then transported to the laboratory for carbon analysis. The area of the soil auger opening is 22.948 cm^2 and the total volume of the sample collected is 114.74 cm^3.

Soil samples were dried to a constant mass at 50°C and then weighed to determine dry bulk density (grams of soil per cubic cm). The dry samples were then homogenized by grinding them to a fine powder using an electric grinder and mortar and pestle. Duplicate ca. 1g aliquots of each soil sample were then transferred to pre-ashed and pre-weighed 20 cm^3 glass scintillation vials. The samples were ashed in a furnace at 500°C for 6 hours until constant weight was reached. For each subsample, Loss on Ignition (LOI) was calculated as:

(**LOI = Initial dry weight – weight remaining after ashing initial dry weight x 100%**

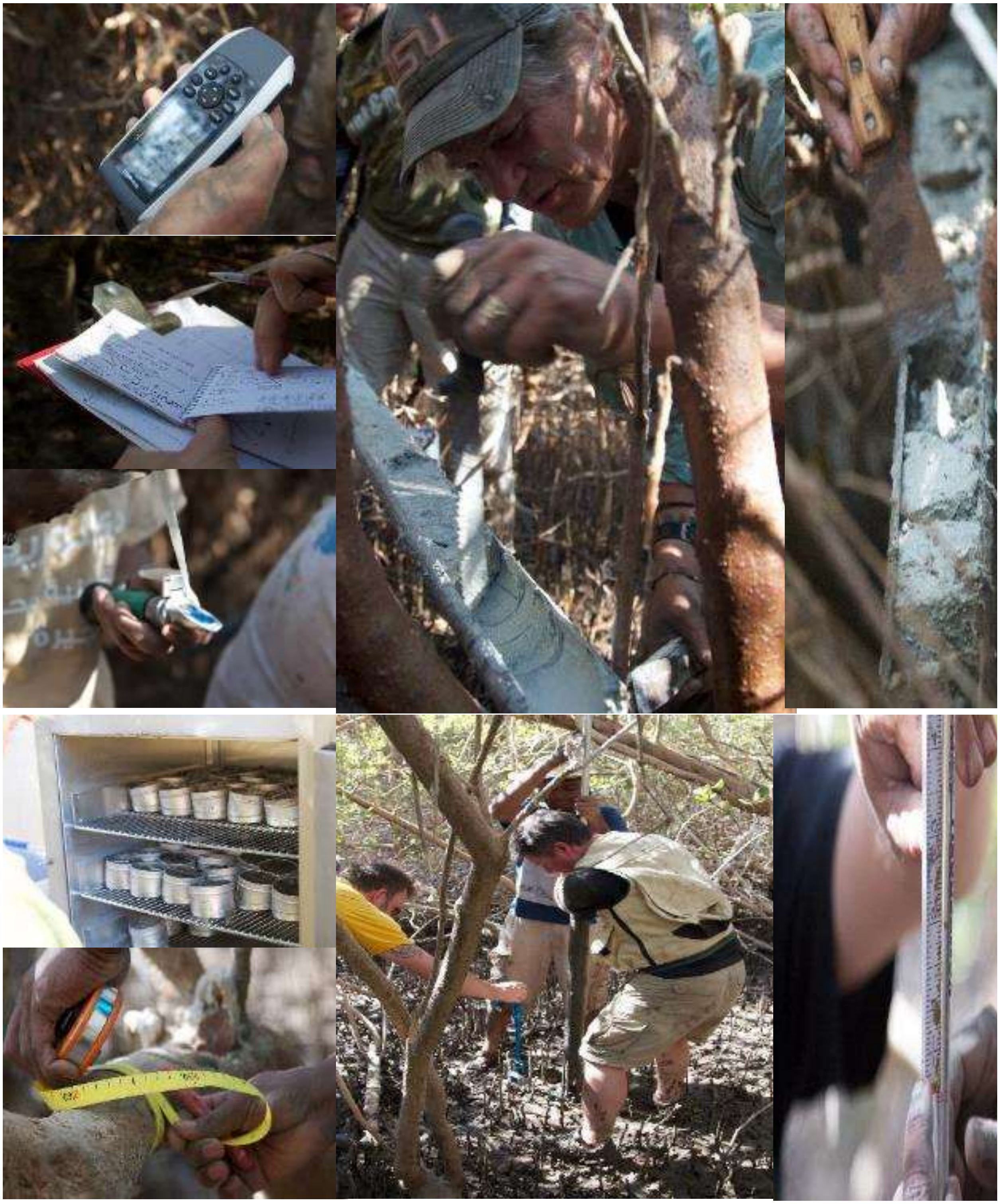
Total Carbon (TC_{soil}) content of the soils was determined using an automated elemental analyzer (Fisons NA1500). In order to determine the Organic Carbon (C_{org}) content of the soil samples, the instrumental analyzer-furnace ashing procedures described by Fourqurean et al. (2012) was used. We assumed any carbon remaining in the LOI sample was inorganic carbon. The Inorganic Carbon content of the ash (IC_{ash}) remaining after the LOI measurements was determined using the elemental analyzer; this IC_{ash} value was scaled back to the original weight of the unashed sample using the LOI to calculate the Inorganic Content of the original soil (IC_{soil}). This was then calculated C_{org} (expressed in units of % of dry weight) as:

$$C_{org} = TC_{soil} - IC_{soil}$$

Carbon density (gC/cm^3) for each depth interval was calculated by multiplying the C_{org} value for each depth increment by the corresponding Dry Bulk Density (DBD). In order to calculate the carbon content of core segment ($CC_{segment}$), the following equation was used:

$$(CC_{segment} = (z_{segment} \times \text{carbon density}_{segment})/100$$

where $z_{segment}$ is the length of the given depth interval. The product is divided by 100 to convert C_{org} units from % of dry weight to gC per g (dry weight). The total C_{org} was calculated by summing $CC_{segment}$ values from the length of each core.



5 Results

5.1 Tree biomass and aboveground carbon pools

5.1.1 Tree Density, Basal Area, and Biomass

While all mangroves in the UAE consist of a single plant species – *Avicennia marina*, there is tremendous variation in stand structure across this region. For example mangrove density ranged 3,613 trees/ha at Kalba West to 41,039/ha Khor Al Madar, UAQ. The stands of Kalba and Ras Al Khor were lowest in density, but were comprised of large statured mature trees. The high densities of stands at Khor Al Madar (UAQ) and Al Zorah (Ajman) are reflective of the low to medium statured stands (<3-5m in height) that were difficult to walk through. Al Rams was an open, low statured stand on an island but had very high seedling densities.

Basal area or the area of land occupied by the mainstems of trees, is a reflection of both tree size and density. The large statured stands of Kalba and Ras Al Khor (Dubai) had basal areas exceeding 30 m^2/h.

In contrast the relatively open and smaller statured stands of Khor Al Jafra (UAQ) and Al Rams had the lowest basal area (<16 m^2/ha).

Closely related to basal area, is the calculation of aboveground plant mass. There was over an eight-fold difference in the aboveground biomass and carbon mass of the trees in the 10 sampled stands of the Northern and Eastern Emirates (Table 4). Aboveground biomass of the mangroves ranged from 31 Mg/ha at the Khor Al Jafra (UAQ) site to 244 Mg/ha at the Kalba South site. Sites sampled with the greatest aboveground biomass included all of the Kalba sites as well as the Ras Al Khor and Ras Al Kamiah sites.

5.1.2 Mangrove tree carbon pools

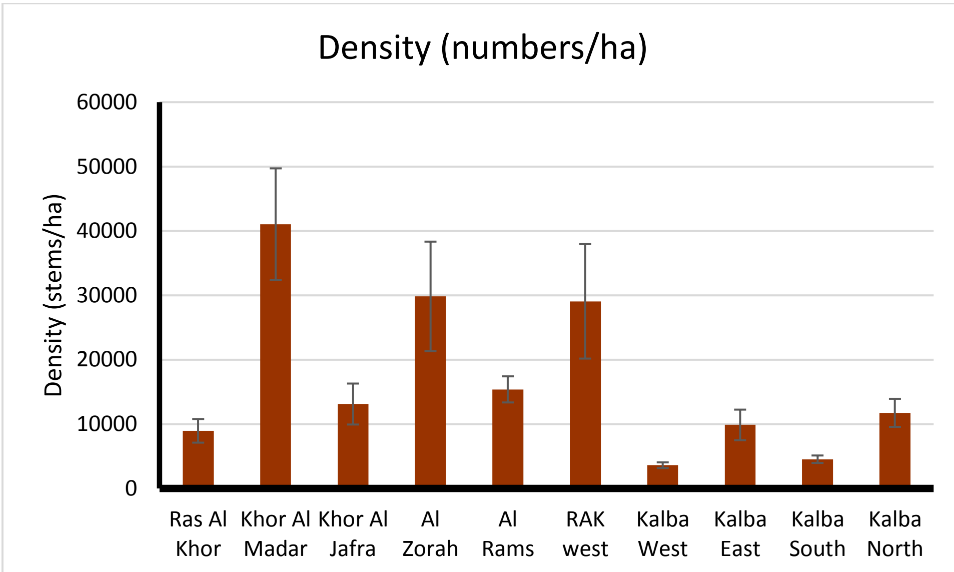
Combining the aboveground with the belowground plant carbon pools we found that plant carbon ranged from 33 Mg C/ha at the Khor Al Jafra (UAQ) site to 148 at the Kalba South Site

The mangrove of Ras Al Khaimah and Ras Al Khor, Dubai were also significantly large in the size of the mangrove carbon pool. The total mangrove plant carbon pool of the sampled mangrove at Ras Al Khaimah was 114 Mg/ha and at Ras Al Khor (Dubai) was 103 Mg/ha.

In comparing the four sampled sites of the Sea of Oman to the Arabian Gulf it is clear that tree density of the Arabian Gulf sites were greater than those of the Sea of Oman (Figure 5). Mean density of the Arabian and Oman Sea sites were 22,898 and 7442 /ha, respectively (figure 5). These are really dense forests compared to upland forests.

The Sea of Oman sites (Kalba) greatly exceeded the plant mass of the Arabian Gulf (Figure 6). Total mass of the Arabian and Oman Sea sites were 83 and 119 Mg/ha, respectively. But comparisons such as this are difficult given the wide range in variation of mangroves of the

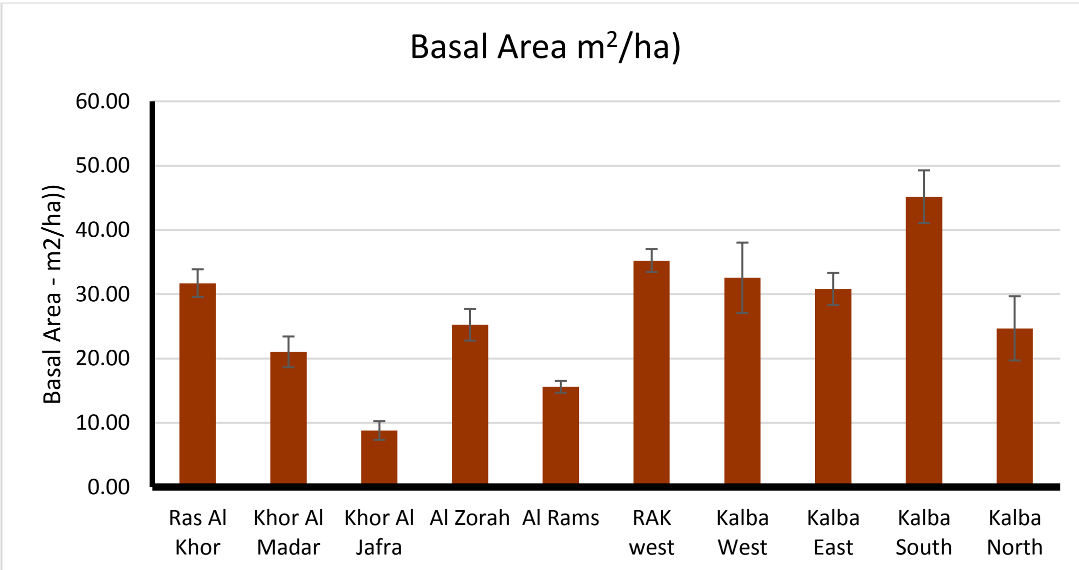
Arabian Gulf. Here total plant carbon among sampled stands varied by over three fold from 33 to 108 Mg/ha (Figure 4).



Note: Vertical bars represent one standard error.

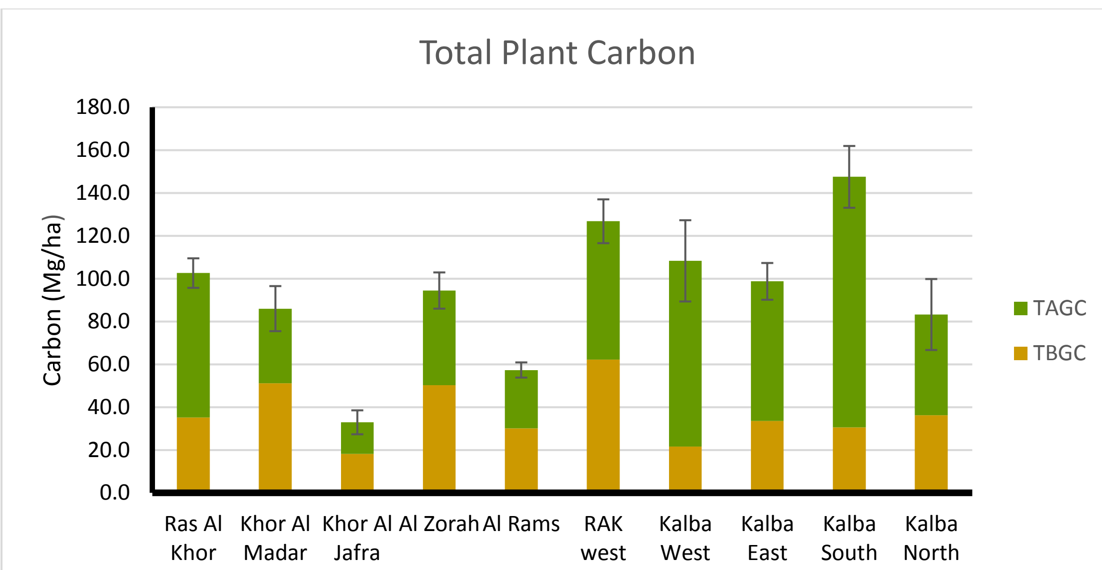
Figure 2: Mangrove tree density (stems/ha) of sampled mangroves of the Northern and Eastern Emirates, UAE. The specific location and Emirate of each site may be found in Table 1.

Photo: Ras Al Khaimah



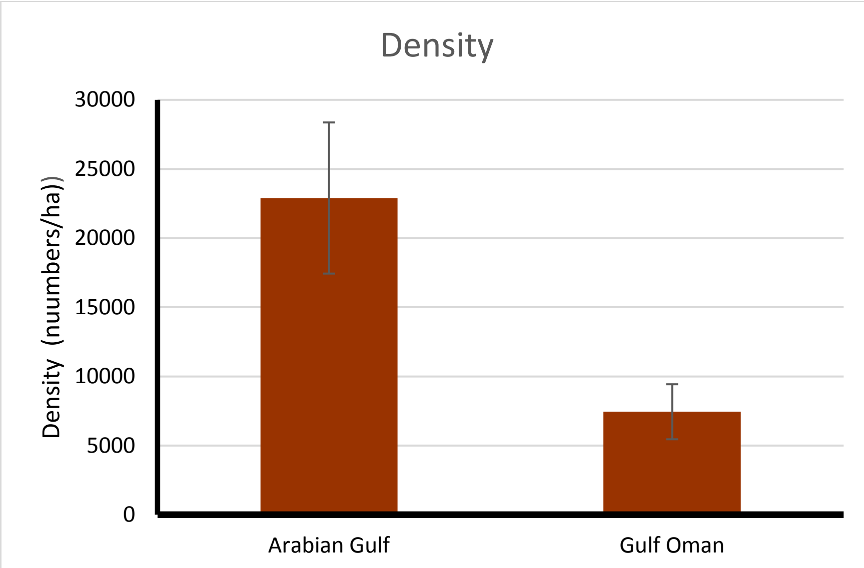
Note: Vertical bars represent one standard error.

Figure 3: Basal areas (m2/ha) of sampled mangroves of the Northern and Eastern Emirates, UAE



Note: Vertical bars represent one standard error

Figure 4: Total carbon pools found in the mangrove trees (aboveground and belowground, Mg/ha) of sampled mangroves of the Northern and Eastern Emirates, UAE. The total carbon pools are broken down by Total aboveground carbon (TAGC) and total belowground carbon (TABC).



Note: Vertical bars represent one standard error.

Figure 5: Density (numbers/ha) of mangroves of the Northern and Eastern Emirates, separated into those of the Arabian Gulf and those of the Sea of Oman.

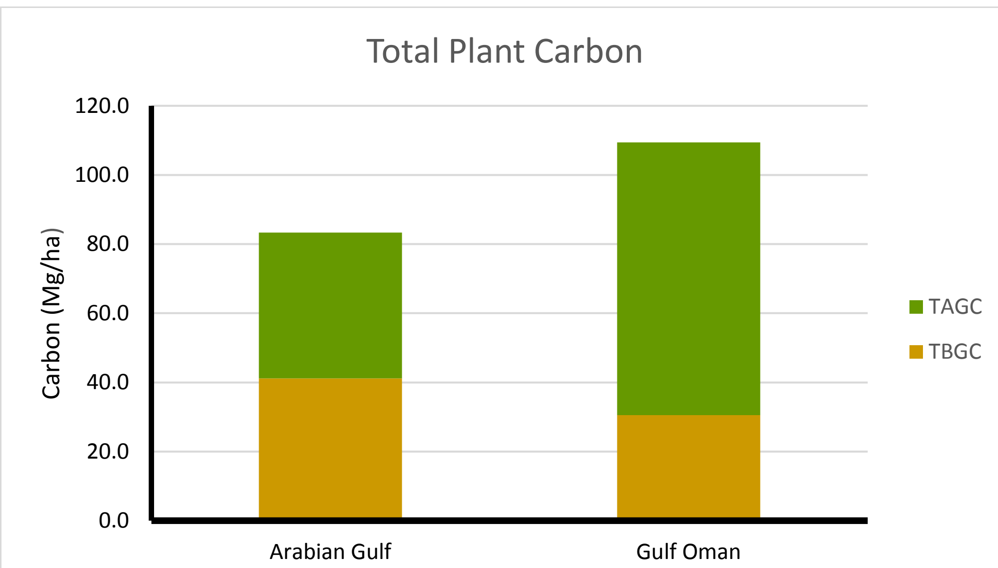


Figure 6: Total carbon pools of mangroves of the Northern and Eastern Emirates, separated into those of the Arabian Gulf and those of the Sea of Oman.

Table 3: Density (numbers/ha) basal area (m^2/ha), biomass (Mg/ha) and carbon pools (Mg/ha) of the vegetation component of 10 mangroves samples in the Northern and Eastern Emirates, UAE.

	Density (no./ha)		Basal Area (m^2/ha)		Aboveground biomass		Belowground biomass		Total plant biomass		Aboveground carbon		Belowground carbon		Total tree carbon	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Ras Al Khor, Dubai	8951	1838	31.70	2.16	140.3	11.2	90.3	8.9	230.6	15.5	67.3	5.4	35.2	3.5	102.6	6.9
Khor al Madar, UAQ	41039	8680	21.02	2.40	72.6	8.5	131.1	18.7	203.7	25.3	34.9	4.1	51.1	7.3	86.0	10.5
Khor Al Jafra, UAQ	13111	3181	8.78	1.45	30.8	5.4	46.5	8.1	77.3	13.1	14.8	2.6	18.1	3.2	32.9	5.6
Al Zorah, Ajman	29841	8500	25.26	2.47	92.1	13.1	128.7	16.7	220.9	19.9	44.2	6.3	50.2	6.5	94.4	8.5
Al Rams, RAK	15385	2028	15.60	0.92	56.8	3.6	77.1	5.3	133.9	8.3	27.3	1.7	30.1	2.1	57.3	3.5
RAK west	29062	8890	35.23	1.77	134.4	6.6	125.8	16.7	260.2	17.6	64.5	3.2	62.2	10.3	113.6	10.2
Kalba West, Sharjah	3613	441	32.55	5.48	180.5	34.8	55.5	6.8	236.0	40.6	86.7	16.7	21.6	2.6	108.3	19.0
Kalba East Sharjah	9871	2373	30.83	2.51	144.8	18.1	86.1	12.2	230.8	19.7	65.2	8.1	33.6	4.8	98.7	8.6
Kalba South Sharjah	4539	581	45.17	4.08	243.6	26.9	78.4	6.4	190.7	30.8	116.9	12.9	30.6	2.5	147.5	14.4
Kalba North Sharjah	11744	2178	24.68	4.99	97.9	20.2	92.9	17.9	353.0	37.8	47.0	9.7	36.2	7.0	83.2	16.6

5.2 Soil carbon pools

Determination of organic carbon in carbonate rich soils such as encountered in the UAE is a difficult process. Adequately partitioning the organic carbon from inorganic carbon is confirmed through examination of the relationships between carbon estimates and organic matter concentration. There should be a relatively high correlation between organic carbon and organic matter, but not such a good relationship between total carbon and organic matter because of the inclusion of inorganic carbon in the total carbon fraction (Figures 7 and 8). In our analysis we found a strong relationship between organic carbon and organic matter (r^2=0.68) and a rather weak relationship between total carbon and organic matter (r^2=.040). This suggests that organic matter determinations alone to arrive at a reasonably accurate prediction of the organic carbon in these soils is appropriate. The relationship between organic carbon and soil bulk density was also examined to determine its efficiency in predicting soil organic carbon (Figure 9). Here, the relationship was significant (r^2=0.50). But this relationship was not so strong for the vast majorities of samples with bulk densities exceeding 0.75.

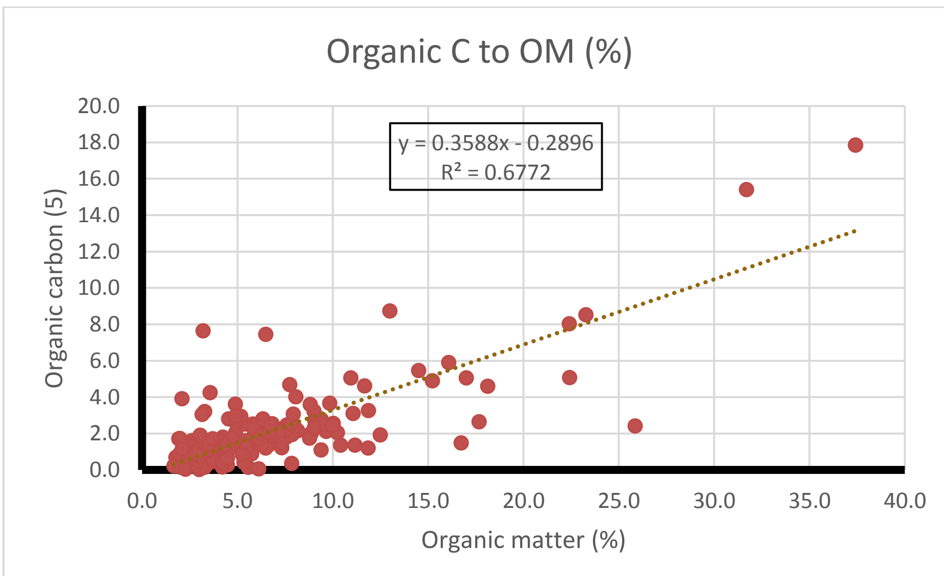


Figure 7: The relationship between soil organic matter concentration (%) and Organic carbon (%) for soils of mangroves of the Northern and Eastern Emirates, UAE.

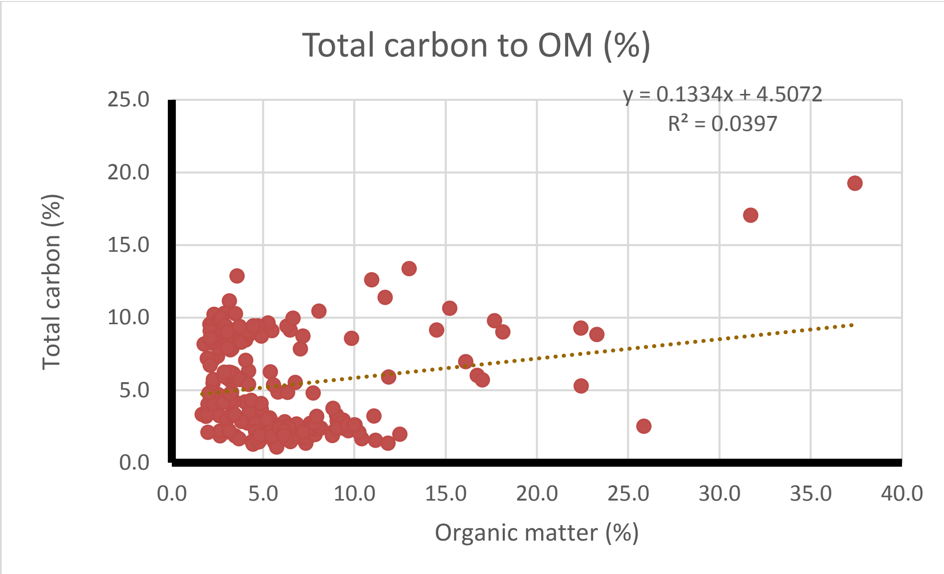


Figure 8: The relationship between total soil carbon (organic+ Inorganic; %) and Organic carbon (%) for soils of mangroves of the Northern and Eastern Emirates, UAE.

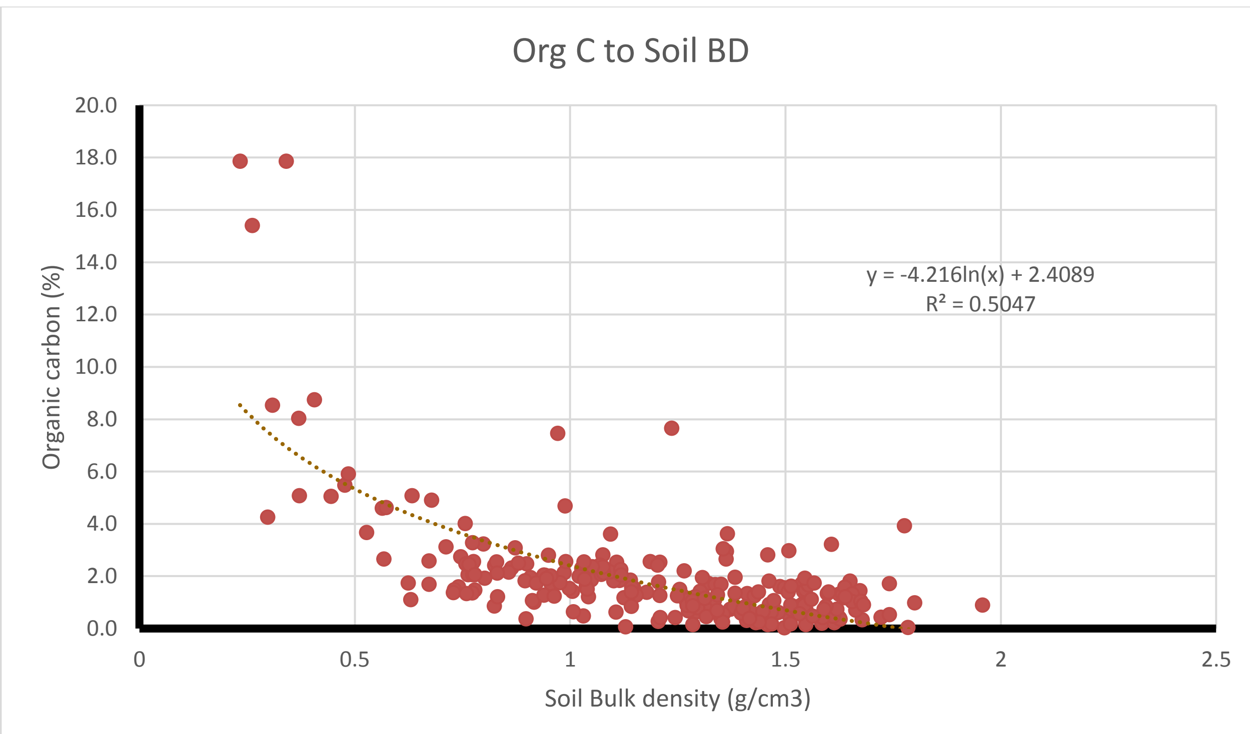


Figure 9: The relationship between soil bulk density (g/cm³) and Organic carbon (%) for soils of mangroves of the Northern and Eastern Emirates, UAE.

Table 4: Organic matter concentration (%), Bulk density (g/cm3), organic carbon concentration (%), carbon density (g/cm3), and the carbon stock (Mg/ha) of mangroves of the Northern and Eastern Emirates, UAE. Numbers in parentheses after the site name is the mean soil depth (± one standard error).

	Depth Intervals (cm)									
	0-15	SE	15-30	SE	30-50	SE	50-100	SE	>100	SE
Al Rams (48±4)										
Organic Matter	10.75	2.07	2.72	0.17	2.08	0.10				
Bulk Density	0.66	0.08	1.39	0.07	1.65	0.04				
Carbon conc	3.60	0.74	1.71	1.19	0.72	0.20				
Carbon density	0.02	0.00	0.02	0.01	0.01	0.00				
mean C mass	31.96	4.97	32.67	21.88	23.35	9.65				
Al Zorah (77±2)										
Organic Matter	4.80	0.53	2.61	0.23	2.34	0.24	3.12	0.29		
Bulk Density	1.19	0.09	1.45	0.06	1.55	0.02	1.44	0.04		
Carbon conc	1.73	0.42	0.76	0.11	0.92	0.25	0.75	0.18		
Carbon density	0.02	0.00	0.01	0.00	0.01	0.00	0.01	0.00		
mean C mass	29.50	7.06	16.32	2.15	28.23	7.63	26.97	5.41		
Kalba East (131±21)										
Organic Matter	6.41	0.55	7.18	0.43	10.18	3.19	5.94	0.34	5.12	0.74
Bulk Density	0.99	0.09	0.97	0.02	1.05	0.05	1.14	0.08	1.10	0.10
Carbon conc	1.86	0.61	1.81	0.11	2.02	0.18	1.62	0.15	1.68	0.29
Carbon density	0.02	0.01	0.02	0.00	0.02	0.00	0.02	0.00	0.01	0.00
mean C mass	26.77	9.23	26.26	1.44	41.85	2.96	88.28	10.39	53.93	33.22
Kalba North (87±8)										
Organic Matter	8.08	1.93	7.16	0.81	5.38	0.31	5.51	0.42	3.66	*
Bulk Density	0.90	0.08	0.98	0.08	1.14	0.06	1.21	0.10	1.54	*
Carbon conc	1.37	0.30	1.84	0.39	1.37	0.09	1.60	0.19	1.42	*
Carbon density	0.01	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	*
mean C mass	18.06	3.70	24.93	3.48	30.68	0.93	66.15	16.64	8.04	8.04

Kalba South (160±13)										
Organic Matter	9.89	0.74	8.35	0.71	8.35	0.91	5.44	0.93	5.14	0.90
Bulk Density	0.79	0.05	0.87	0.07	1.02	0.12	1.39	0.10	1.32	0.08
Carbon conc	1.88	0.23	1.99	0.17	2.14	0.25	1.55	0.35	1.92	0.54
Carbon density	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.01
mean C mass	22.80	3.42	25.49	2.12	41.33	3.17	101.70	18.76	175.79	65.55
Kalba West (85±10)										
Organic Matter	6.95	1.21	6.80	0.31	6.70	0.30	5.69	0.61	6.04	2.77
Bulk Density	0.75	0.03	1.06	0.05	1.13	0.06	1.36	0.08	1.35	0.26
Carbon conc	2.10	0.20	2.79	1.02	2.12	0.13	2.04	0.21	3.41	0.20
Carbon density	0.02	0.00	0.03	0.01	0.02	0.00	0.03	0.00	0.05	0.01
mean C mass	23.86	2.76	42.32	14.47	47.70	2.82	76.46	16.32	20.73	14.56
Ras Al Khor (227±19)										
Organic Matter	10.41	2.15	4.25	0.48	2.68	0.25	2.91	0.25	2.66	0.18
Bulk Density	0.77	0.09	1.33	0.04	1.53	0.04	1.43	0.05	1.43	0.04
Carbon conc	2.72	0.70	1.34	0.40	0.87	0.20	1.07	0.43	0.47	0.11
Carbon density	0.02	0.00	0.02	0.01	0.01	0.00	0.02	0.01	0.01	0.00
mean C mass	27.99	5.78	27.04	8.68	27.11	6.74	76.95	29.70	86.24	26.01
Ras Al Kamiah (187±6)										
Organic Matter	18.84	1.87	3.62	0.15	3.31	0.35	3.23	0.20	4.48	1.12
Bulk Density	0.46	0.07	1.51	0.06	1.60	0.05	1.50	0.02	1.49	0.06
Carbon conc	5.98	0.81	1.01	0.21	0.82	0.44	0.76	0.28	1.46	0.40
Carbon density	0.03	0.00	0.02	0.00	0.01	0.01	0.01	0.00	0.02	0.01
mean C mass	37.79	2.46	23.39	5.18	25.35	13.35	58.06	21.92	160.42	33.18
Khor Al Madar (34±3)										
Organic Matter	16.08	6.08	3.70	0.64	3.59	0.50				

Bulk Density	0.38	0.08	1.28	0.12	1.41	0.10				
Carbon conc	8.55	2.76	1.41	0.32	1.33	0.43				
Carbon density	0.03	0.01	0.02	0.00	0.02	0.01				
mean C mass	41.00	9.61	23.63	5.03	11.39	4.71				
Khor Al Jafra (40±6)										
Organic Matter	4.08	0.24	3.05	0.32	5.90	1.82	2.10	*		
Bulk Density	1.20	0.10	1.69	0.03	1.52	0.23	1.31	*		
Carbon conc	1.09	0.42	1.44	0.52	1.33	0.33	1.15	*		
Carbon density	0.01	0.01	0.02	0.01	0.02	0.00	0.02	*		
mean C mass	20.41	8.36	34.30	14.94	18.61	7.23	3.15	3.15		
Algal Flat UAQ (no data)										
Organic Matter	5.11	0.92	4.31	0.60	3.22	0.15	2.84	0.11	3.84	1.12
Bulk Density	0.80	0.12	1.07	0.06	1.18	0.05	1.32	0.04	1.34	0.03
Carbon conc	1.08	0.28	1.14	0.23	0.90	0.22	1.68	0.24	1.55	0.21
Carbon density	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.02	0.00
mean C mass	4.11	0.87	12.41	2.85	10.85	3.11	43.37	7.70	87.44	22.30

Note: Data are the mean of 6 plots and the Standard Error. Numbers next to the sites is the soil depth (Cm ±SE). Therefore blank boxes denote depths beyond the soil limits for that site.

The components to measure carbon pools are organic matter concentration and soil bulk density. In general when soils are rich in organic matter or organic carbon they have a lower soil bulk density (Figure 9). Further, soils at the surface typically had a lower bulk density and higher organic matter concentration that soils deeper in the profile. The exception to this pattern was the Kalba sites where carbon concentration remained high throughout the soil profile. The lowest bulk densities in soils were found at the Khor Al Madar, UAQ and Ras Al Kaimah sites with mean bulk densities of 0.46 and , 0.38 g/cm^3 respectively. The highest bulk densities were consistently found at the deepest depths of the soil profiles of the mangroves. For example, in those sites with soils >100cm the mean bulk density at this depth was >1.1 to 1.5 g/cm^3.

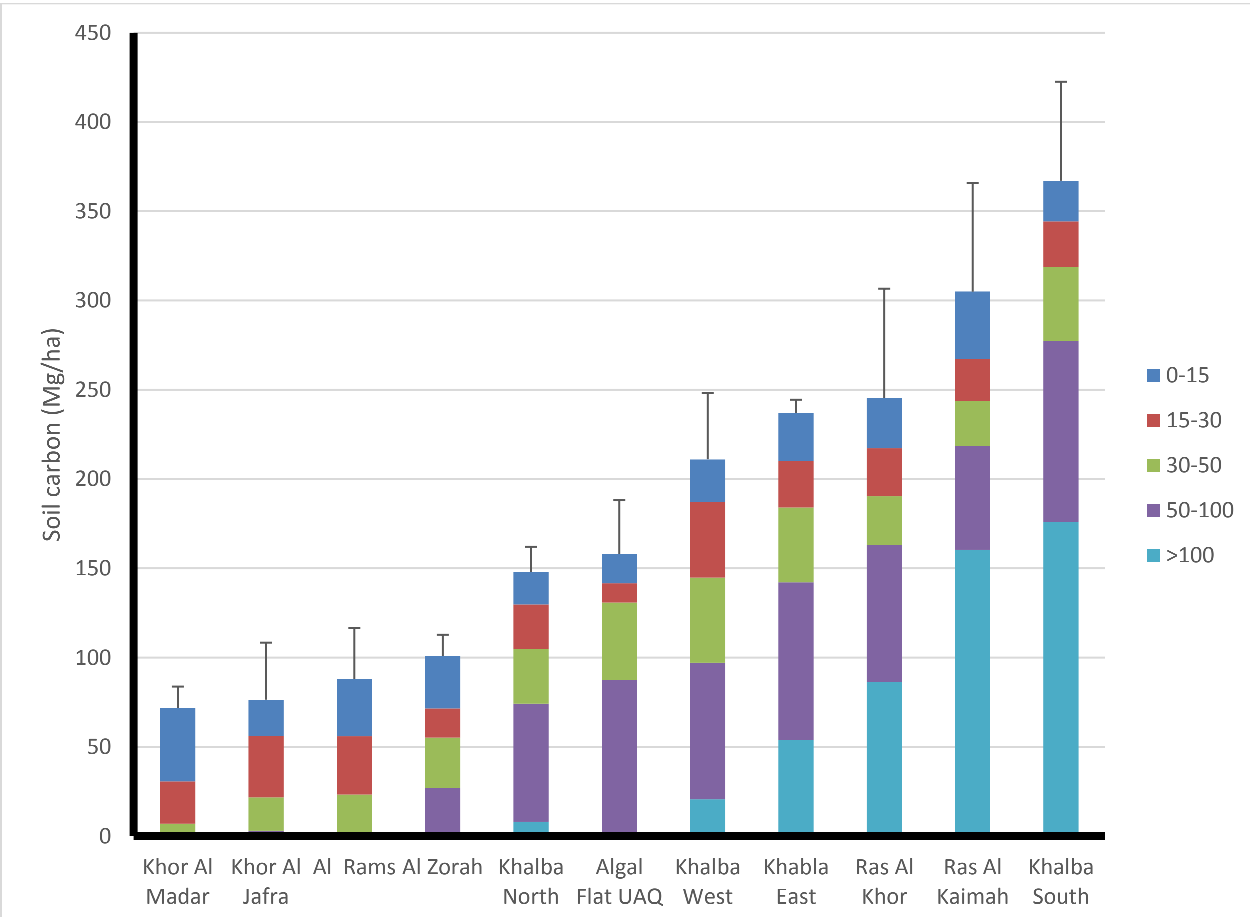
The soil carbon concentration varied greatly among soil samples at the sampled mangrove sites. The highest mean carbon concentration was found in the surface soils of the Khor Al Madar, UAQ site where the mean carbon concentration was 8.6%. similar high surface values were measured at Ras Al Kaimah with a mean surface concentration of 6.0%. The lowest concentrations of carbon were usually found within the deeper layers of the soil profile. For example, the carbon concentration at the lowest sampled depth at Khor Al Jafra, UAQ was 0.33 % and was 0.75% at Al Zora, Ajman. This pattern was not observed at the Kalba sites. For example, the Kalba East site had a consistent and relatively high organic carbon concentration of the entire depth of the soil profile. Here organic carbon concentration was >1.6% throughout the profile depth to 160 cm. Similar results were observed at all of the Kalba sites.

There was a very broad range in soil carbon pools; the mean carbon pools of Khor Al Madar, UAQ, Khor Al Jafra, UAQ and Al Rams, RAK were <90 Mg C/ha while those of Ras Al Kaimah and Kalba South exceeded 300 Mg C/ha (Figure 10). The Kalba South site with relatively carbon-rich, deep soils was quite noteworthy with a mean carbon pool of 367 Mg C/ha. The Ras Al Khor site with deep soils had a soil carbon pool of 245 Mg C/ha. In these sites with large carbon pools the majority occurred in the deeper soil horizons. Among all sites there really is little difference in the carbon pools of the soils at depths of <30 cm. The largest differences in carbon stocks are largely related to soil depth and to a lesser degree soil carbon concentration. For these reasons it is important to measure soil carbon pools for the entire depths of the soil horizon.

5.3 Total Ecosystem carbon stocks

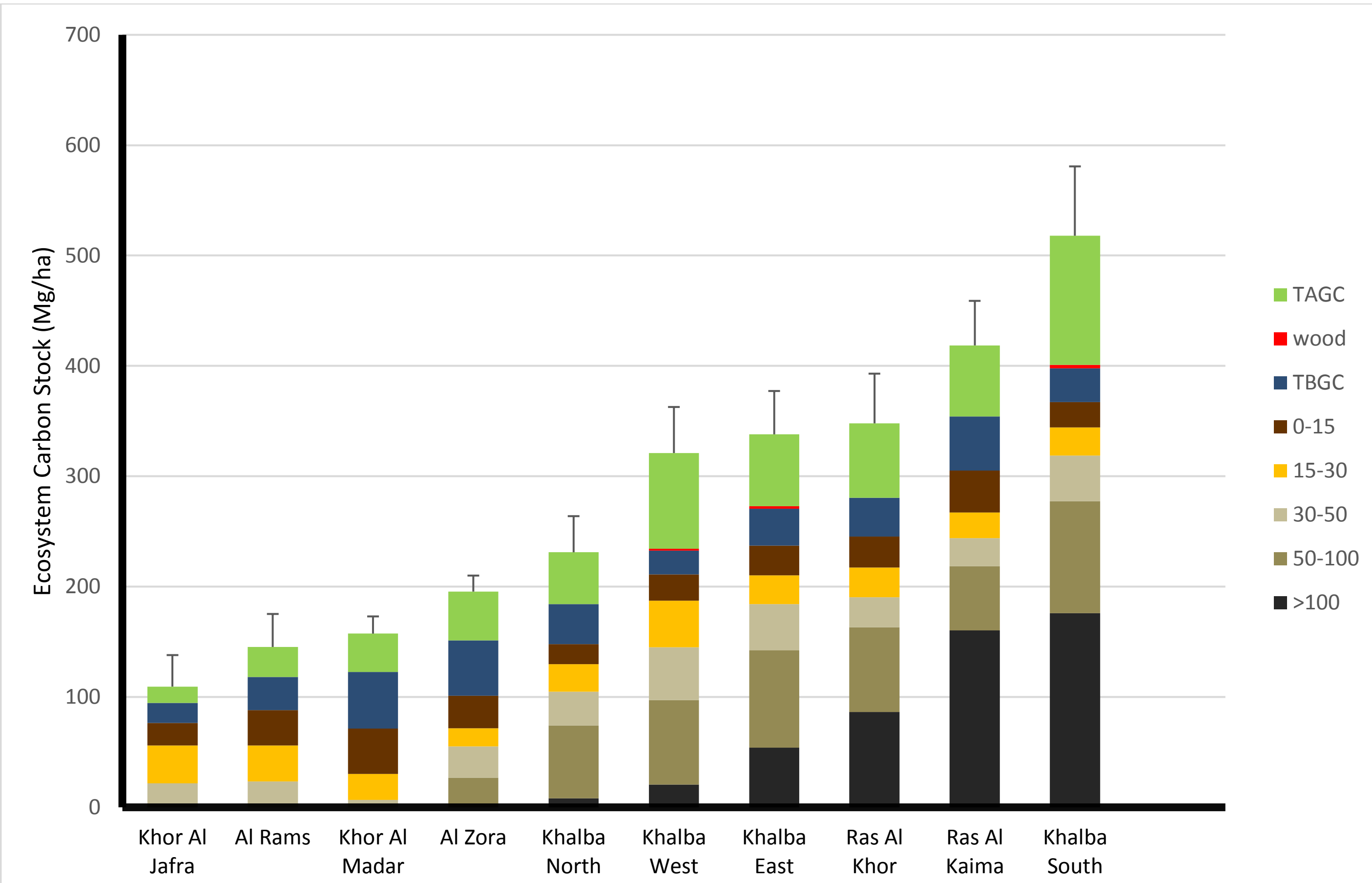
The mean ecosystems carbon stock consisting of vegetation, downed wood, and soils was 293 Mg C/ha for mangroves of the Northern and Eastern Emirates. The wide diversity in soils, geomorphology, hydrology, and vegetation structure resulted in a very broad range of 109 to 667 Mg C/ha. Soils comprised 45 to 78% of the total ecosystem carbon stocks. This is quite interesting as this suggests that the plant carbon pools comprise a greater percentage (22 to 55%) of ecosystem stocks than larger mangroves of areas such as that of the Indo-Pacific (Donato et al 2012, Kauffman et al. 2013). Downed wood in the UAE comprised a very small percentage with measurable amounts only observed at the Kalba sites.

A highly significant relationship was found between aboveground plant carbon and total ecosystem carbon (r^2=0.88; Figure 12). This is not necessarily a common phenomenon among mangroves. For example such highly significant relationships did not exist between aboveground mangrove biomass and total ecosystem carbon stocks in either Mexico o/r the Dominican Republic (Kauffman et al 2014; Kauffman et al In press). For the mangroves of the Northern and Eastern Emirates, measurement of the aboveground biomass could yield good estimates of total ecosystem carbon stocks using the equation presented in Figure 11.



Note: Vertical bars represent one standard error.

Figure 10: Soil Carbon pools (mg C/ha) for the sampled mangrove sites of the Northern and Eastern Emirates, UAE.



Note: Vertical bars represent one standard error.

Figure 11: Total ecosystem carbon stocks (Mg/ha) of sampled mangroves of the Northern and Eastern Emirates, UAE.

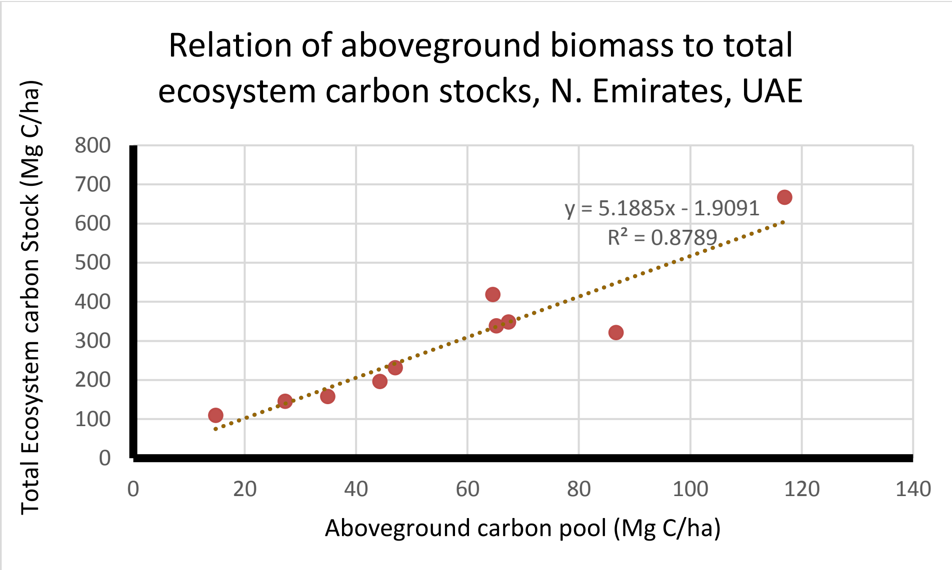


Figure 12: The relationship of aboveground biomass (x axis) to total ecosystem carbon stocks (y axis) for mangroves of the Northern and Eastern Emirates. This relationship suggests that aboveground carbon stocks can be used to accurately estimate total ecosystem carbon stocks.

Table 5: Carbon stocks (Mg/ha) of mangroves of the northern mangroves, United Arab Emirates.

Site		0-15 cm	15-30 cm	30-50 cm	50-100 cm	>100 cm	Total soil	TAGC	TBGC	wood	Eco stock
Khor Al Jafra, UAQ	**mean**	**20.4**	**34.3**	**18.6**	**3.1**	**0.0**	**76.48**	**14.8**	**18.1**	**0.0**	**109.4**
	SE	8.4	14.9	7.2	3.1	0.0	31.96	2.6	3.2	0.0	28.5
Al Rams, RAK	**mean**	**32.0**	**32.7**	**23.3**	**0.0**	**0.0**	**87.98**	**27.3**	**30.1**	**0.0**	**145.3**
	SE	5.0	21.9	9.6	0.0	0.0	28.58	1.7	2.1	0.0	29.9
Khor Al Madar, UAQ	**mean**	**41.0**	**23.6**	**6.8**	**0.0**	**0.0**	**71.70**	**34.9**	**51.1**	**0.0**	**157.4**
	SE	9.6	5.0	3.6	0.0	0.0	12.13	4.1	7.3	0.0	15.5
Al Zora, Ajman	**mean**	**29.5**	**16.3**	**28.2**	**27.0**	**0.0**	**101.03**	**44.2**	**50.2**	**0.0**	**195.5**
	SE	7.1	2.2	7.6	5.4	0.0	11.84	6.3	6.5	0.0	14.5
Kalba North	**mean**	**18.1**	**24.9**	**30.7**	**66.2**	**8.0**	**147.87**	**47.0**	**36.2**	**0.0**	**231.1**
	SE	3.7	3.5	0.9	16.6	8.0	14.27	9.7	7.0	0.0	32.7
Kalba West	**mean**	**23.9**	**42.3**	**47.7**	**76.5**	**20.7**	**211.07**	**86.7**	**21.6**	**1.7**	**321.0**
	SE	2.8	14.5	2.8	16.3	14.6	37.29	16.7	2.6	0.4	41.7
Kalba East	**mean**	**26.8**	**26.3**	**41.8**	**88.3**	**53.9**	**237.09**	**65.2**	**33.6**	**2.2**	**338.0**
	SE	9.2	1.4	3.0	10.4	33.2	7.39	8.1	4.8	0.9	39.3
Ras Al Khor, Dubai	**mean**	**28.0**	**27.0**	**27.1**	**77.0**	**86.2**	**245.33**	**67.3**	**35.2**	**0.0**	**347.9**
	SE	5.8	8.7	6.7	29.7	26.0	61.34	5.4	3.5	0.0	45.1
Ras Al	**mean**	**37.8**	**23.4**	**25.4**	**58.1**	**160.4**	**305.00**	**64.5**	**49.1**	**0.0**	**418.6**
Khaimah	SE	2.5	5.2	13.3	21.9	33.2	60.73	3.2	6.5	0.0	40.4
Kalba South	**mean**	**22.8**	**25.5**	**41.3**	**101.7**	**325.0**	**367.13**	**116.9**	**30.6**	**3.3**	**517.9**
	SE	3.4	2.1	3.2	18.8	153.5	55.45	12.9	2.5	1.2	62.8
UAQ	**mean**	**4.1**	**12.4**	**10.8**	**43.4**	**87.4**	**158.10**	**0.0**	**0.0**	**0.0**	**158.2**
Algal Flat	SE	0.9	2.9	3.1	7.7	22.3	29.97	0.0	0.0	0.0	31.6

Note: Means are in bold the standard errors (SE) are normal.

6 Discussion

As of 2015, the carbon stocks of 18 mangroves of the UAE have been quantified. This includes four in the Sea of Oman (Kalba), six in the Arabian Gulf of the Northern and Eastern Emirates, and eight in the Abu Dhabi Emirate. The data suggest that mangroves of the Northern and Eastern Emirates are generally larger than those of Abu Dhabi Emirate, but this does vary. The mean ecosystem carbon stock of the mangroves of the three areas are 389 (Sea of Oman), 229 (Northern and Eastern Emirates – Arabian Gulf), and 140 Mg C/ha, (Abu Dhabi mangroves). The mean ecosystem carbon stock of all Northern Emirate sites combined was 296 Mg C/ha (Figure 12, Table 12). The carbon stocks of the Northern and Eastern Emirates were significantly different ($p<0.10$) than the mangroves sampled in Abu Dhabi (Figure 12).

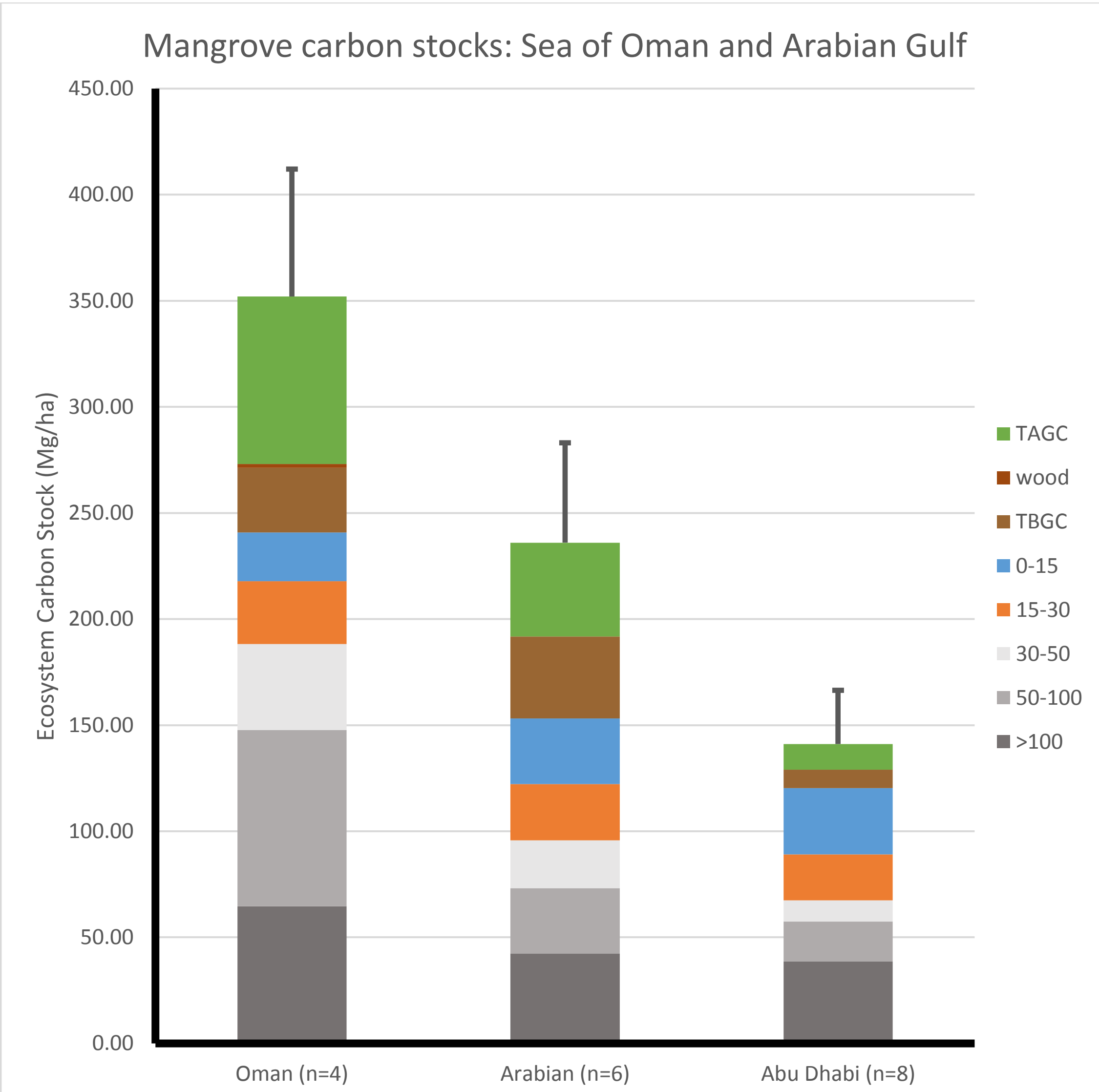
The greatest differences among sites are in the plant carbon pools and in deeper soil layers. There were few differences in the carbon pools of soils 0-30 cm in depth. However the plant carbon stocks of the Northern and Eastern Emirates greatly exceeded that of the Abu Dhabi mangroves (i.e. >80 Mg C/ha for the Northern and Eastern Emirates but <21 Mg C/ha for the sampled Abu Dhabi mangroves). Additional differences were found at greater soil depths. For example, the mean carbon pools of soils >50 cm in depth was 57 Mg C/ha for the Abu Dhabi mangroves but 185 Mg C/ha at the Sea of Oman sites. While there are significant site differences (i.e., some sites in Abu Dhabi do have larger carbon stocks than the Northern and Eastern Emirates and vice versa), in general the sites of the Northern and Eastern Emirates have larger carbon stocks than those of Abu Dhabi.

Globally, mangrove carbon stocks have been reported to be about 1000 Mg C/ha (Donato et al 2012, Alongi 2014, UNEP 2014). The carbon stocks of hyperarid/hypersaline mangroves of the UAE are at the lower end of carbon stocks. Interestingly they are similar in size to the carbon stocks of mangroves of sandy substrates such as has been reported for Madagascar. The very high carbon stocks measured for Kalba South (518 Mg/ha) are similar to productive mangroves in many parts of the world (Adame et al. 2012, Kauffman et al. 2013).

Umm Al Qwain was the only location sampled in the Northern and Eastern Emirates with an extensive algal flat area. Carbon stocks at this high intertidal algal flat were found to be low, but not insignificant. During the Abu Dhabi field campaign, relatively high carbon stocks were found in those algal flats at lower elevations relative to tides and where impaired circulation fostered hypersaline conditions (>150 psu).

It is also important to remember that these Blue Carbon ecosystems hold the largest carbon stocks found across the Arabian Peninsula. As well as storing carbon coastal wetlands, including algal flats, release provide a source of carbon and other nutrients that support bird and nearshore food chains. It has been determined, for example, that the marine fisheries food chain in parts of arid Australian is supported by the capture of carbon by algal flat areas which are subsequently released during storms to the marine environment (e.g. Adame et. al.2012). Such flows of carbon are likely occurring in the

Arabian Gulf and Sea of Oman. Because of ecosystem services related to carbon cycling, the conservation and protection of these ecosystems is warranted.

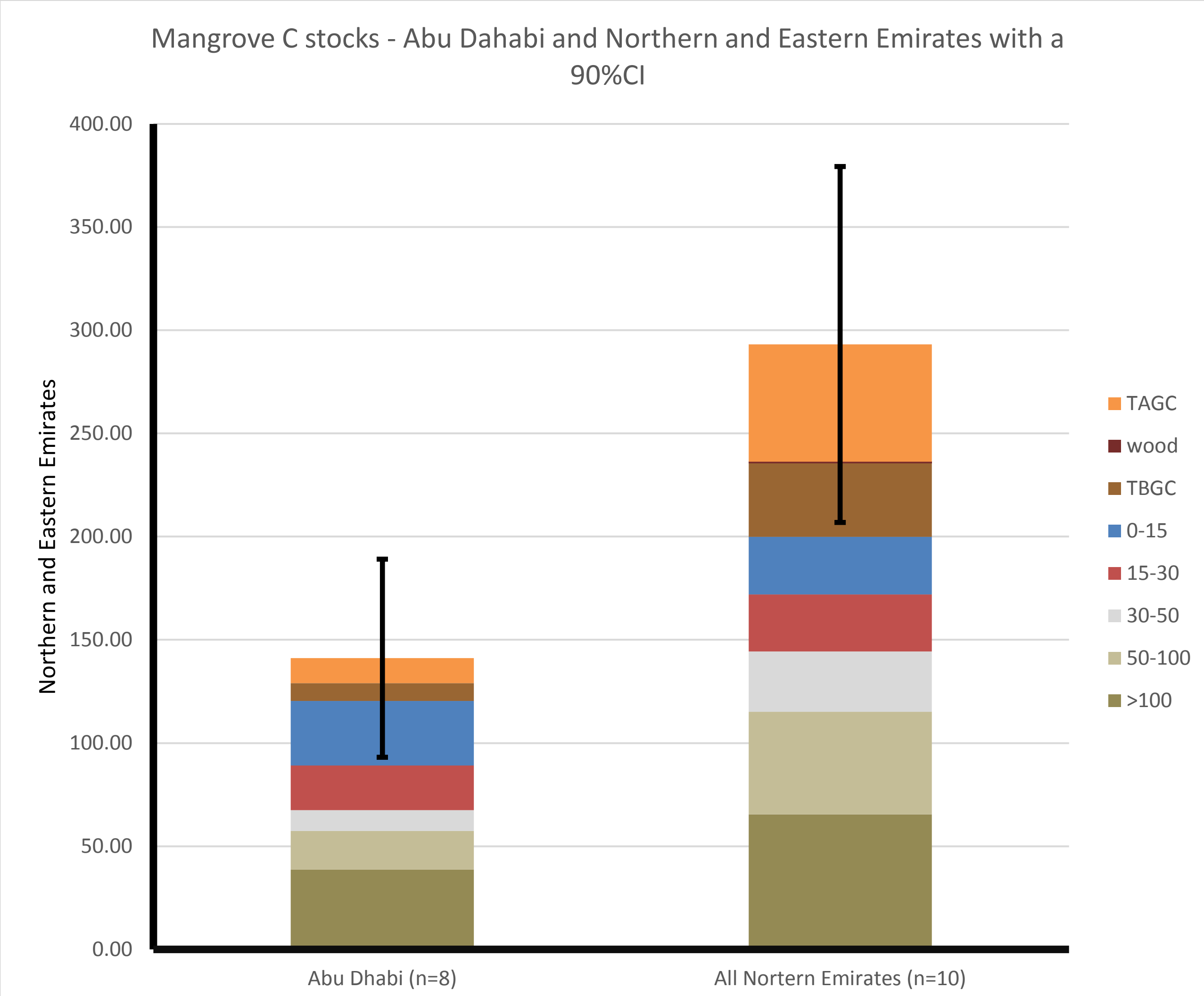


Note: Vertical bars represent one standard error.

Figure 13: Total ecosystem carbon stocks (Mg/ha) of sampled mangroves separated into those of the Sea of Oman, the Arabian Gulf (Northern and Eastern Emirates and those of Abu Dhabi Emirate, UAE.

Table 6: The ecosystem carbon stocks (Mg/ha) of the mangroves of the UAE separated into those of the Sea of Oman (Kalba site), the Northern on the Arabian Gulf, and those of the Abu Dhabi Emirate on the Arabian Gulf.

	Soils by depth (cm)					Plant components				
Site	0-15	15-30	30-50	50-100	>100	Above ground	Below ground	wood	Total C stock	SE
Oman (n=4)	22.87	29.75	40.39	83.15	101.92	78.93	30.51	1.79	389.30	95.52
Arabian (n=6)	31.44	26.23	21.57	27.52	41.11	42.16	38.97	0.00	229.06	50.86
All UAE (n=10)	28.01	27.63	29.10	49.77	65.43	56.87	35.59	0.71	293.15	47.05
(n=8)	31.22	21.69	10.07	18.76	38.64	12.02	8.71	0.00	140.48	25.33



Note: The carbon stocks are significantly different at the P<0.10 level. Vertical bars here represent the 90% confidence interval for mangroves sampled in these two regions.

Figure 14: Ecosystem Carbon stocks of the mangroves of the Abu Dhabi Emirate and the Northern and Eastern Emirates.

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Appendix A. Photo gallery of field campaign.

Umm Al Qwain

Ras al Kaimah

Dead mangroves adjacent to the sampled Ras Al Khor site in the background

Old mangroves at the Kalba sites

Old mangroves at the Kalba sites

Old growth mangroves, Kalba

Tree and wood measurement team - Kalba sites

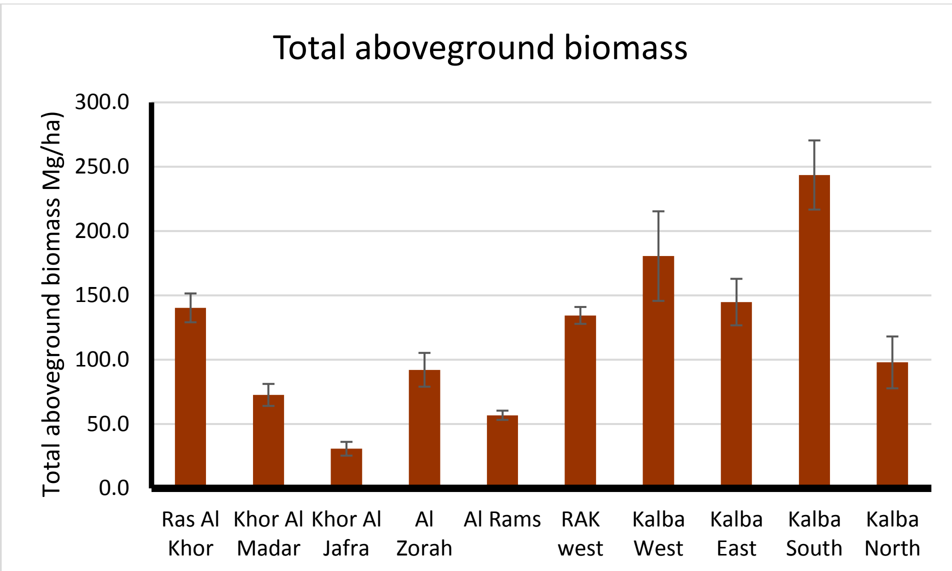
Field Crew - Kalba sites

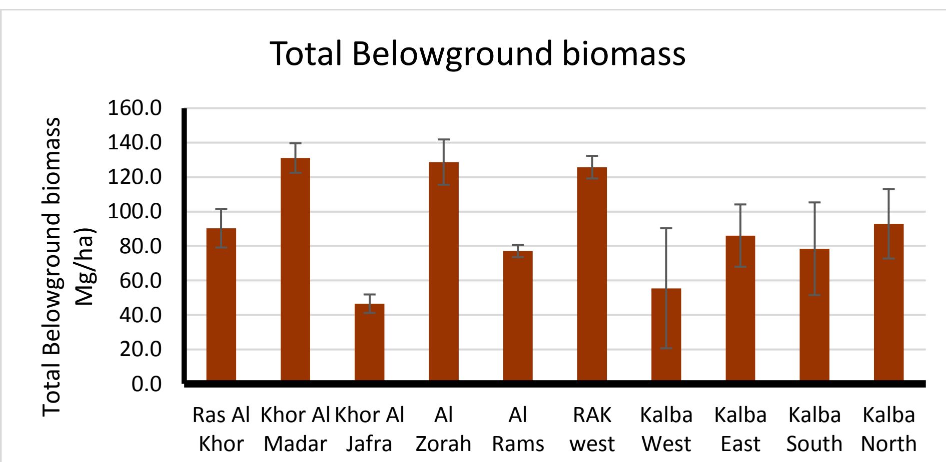
Field crew at Al Rams

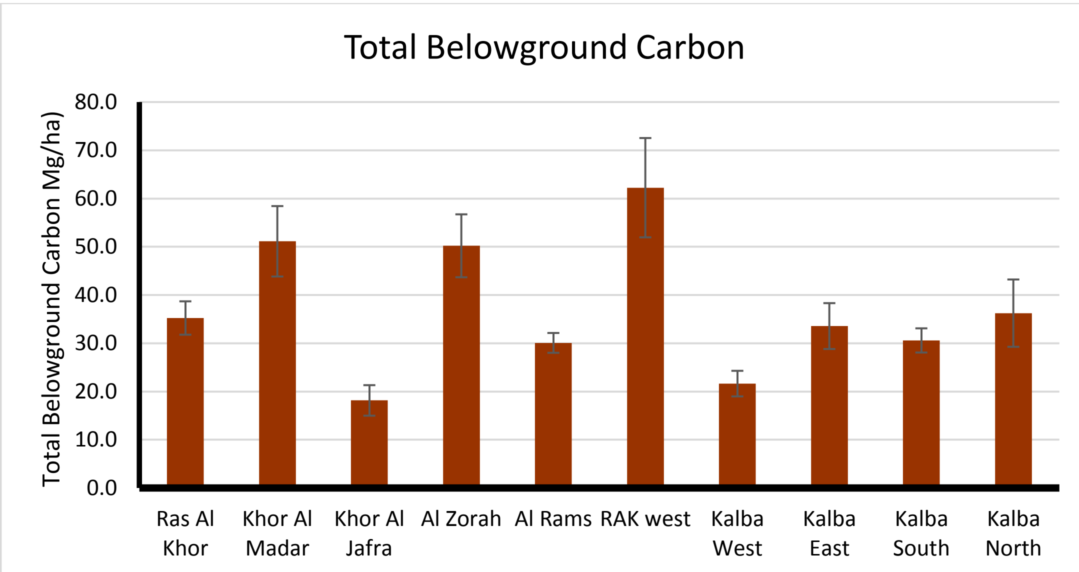
Ras Al Khor, Dubai

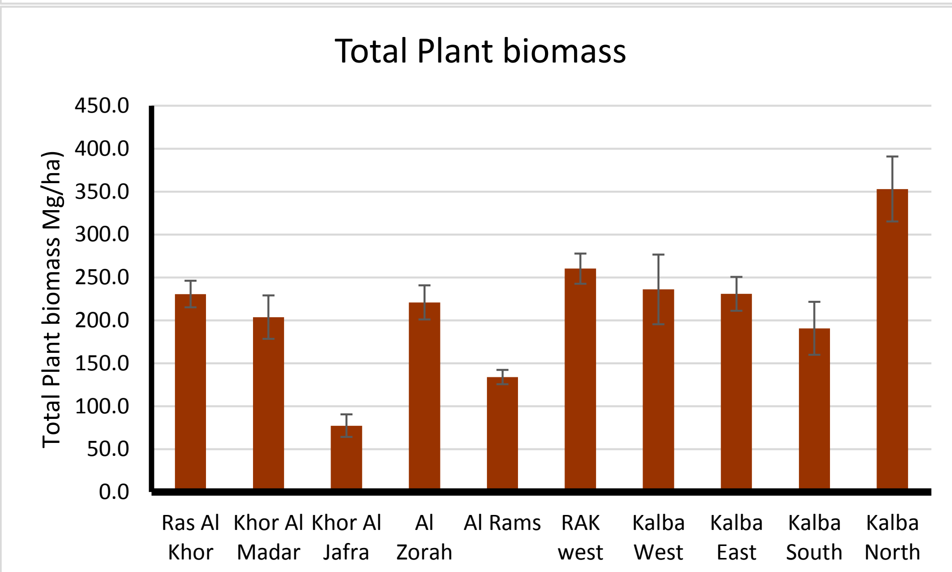
Al Rams

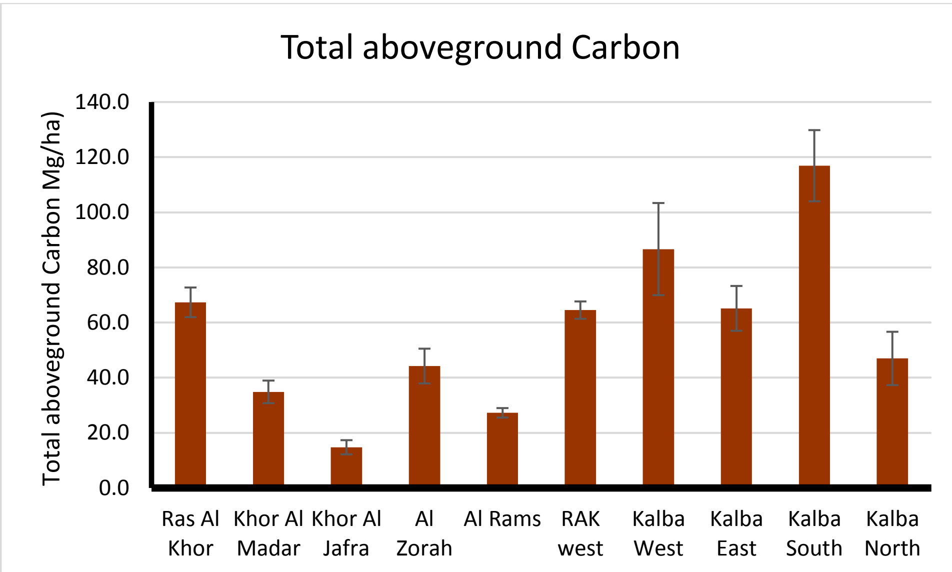
Appendix B. Descriptive tables and figures of data collected for the northern mangroves November 2014.

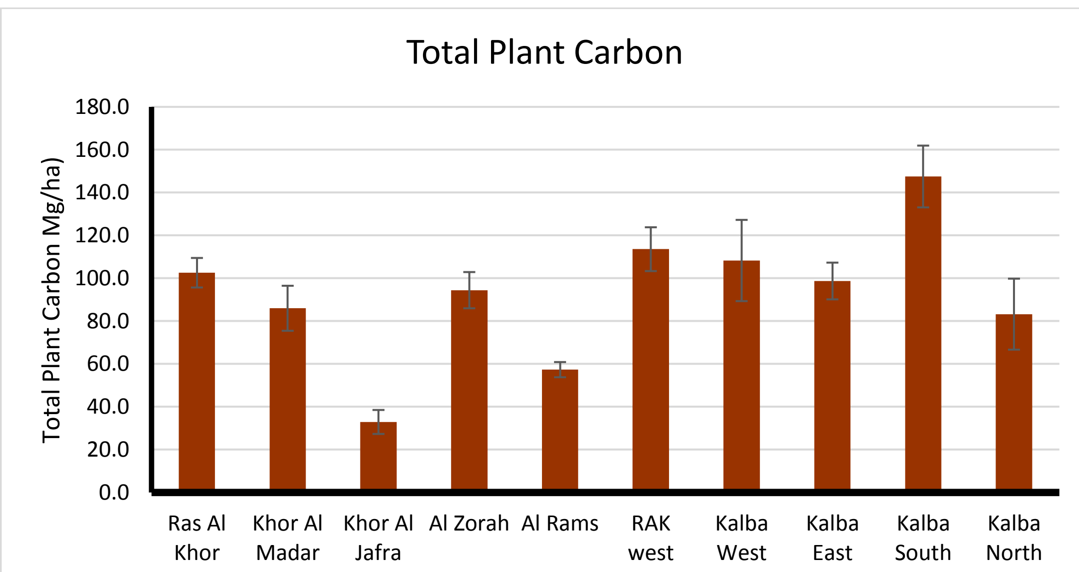


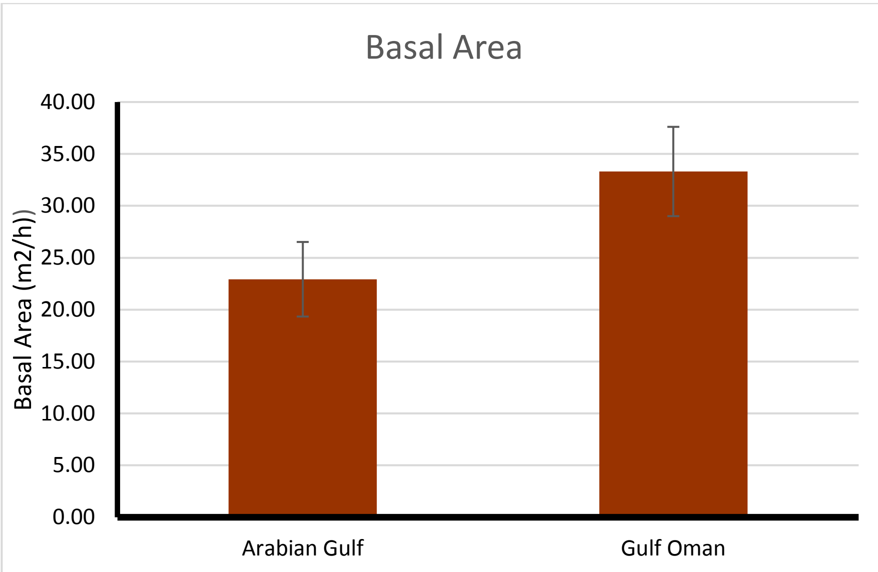


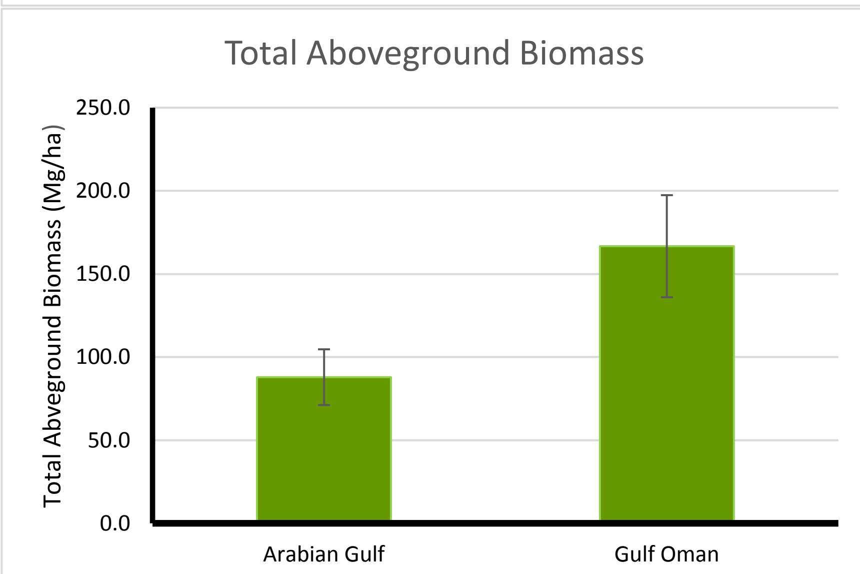

Total Belowground Carbon
Total Belowground Carbon Mg/ha)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Ras Al Khor
Khor Al Madar
Khor Al Jafra
Al Zorah
Al Rams
RAK west
Kalba West
Kalba East
Kalba South
Kalba North


Total Plant biomass
Total Plant biomass Mg/ha)
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Ras Al Khor
Khor Al Madar
Khor Al Jafra
Al Zorah
Al Rams
RAK west
Kalba West
Kalba East
Kalba South
Kalba North


Total aboveground Carbon
Total aboveground Carbon Mg/ha)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Ras Al Khor
Khor Al Madar
Khor Al Jafra
Al Zorah
Al Rams
RAK west
Kalba West
Kalba East
Kalba South
Kalba North


Total Plant Carbon
Total Plant Carbon Mg/ha)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Ras Al Khor
Khor Al Madar
Khor Al Jafra
Al Zorah
Al Rams
RAK west
Kalba West
Kalba East
Kalba South
Kalba North


Basal Area
Basal Area (m2/h))
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Arabian Gulf
Gulf Oman


Total Aboveground Biomass
Total Abveground Biomass (Mg/ha)
250.0
200.0
150.0
100.0
50.0
0.0
Arabian Gulf
Gulf Oman

الإمارات العربية المتحدة
وزارة البيئة والمياه

بمشاركة

AGEDI
مبادرة أبوظبي العالمية للبيانات البيئية
Abu Dhabi Global Environmental Data Initiative

Appendix C. Special report on the mangroves of Ras Al Khor, Dubai

Narrative of Ras Al Khor
Based upon field observations and data analysis of the Northern and Eastern Emirates mangrove survey
J Boone Kauffman
May 2015

بدعم من

هيئة البيئة أبوظبي
Environment Agency ABU DHABI

Table 1. General description

Ras Al Khor, Dubai	Really tall stands of mangroves (some of the tallest in the UAE >5m in height); soils were deep sands (>2 m depth with a small peat layer at the surface (≈5cm)). The site was adjacent to a large and recent die-off; not likely of natural causes; appeared to be likely caused as a result of a pollution plume.

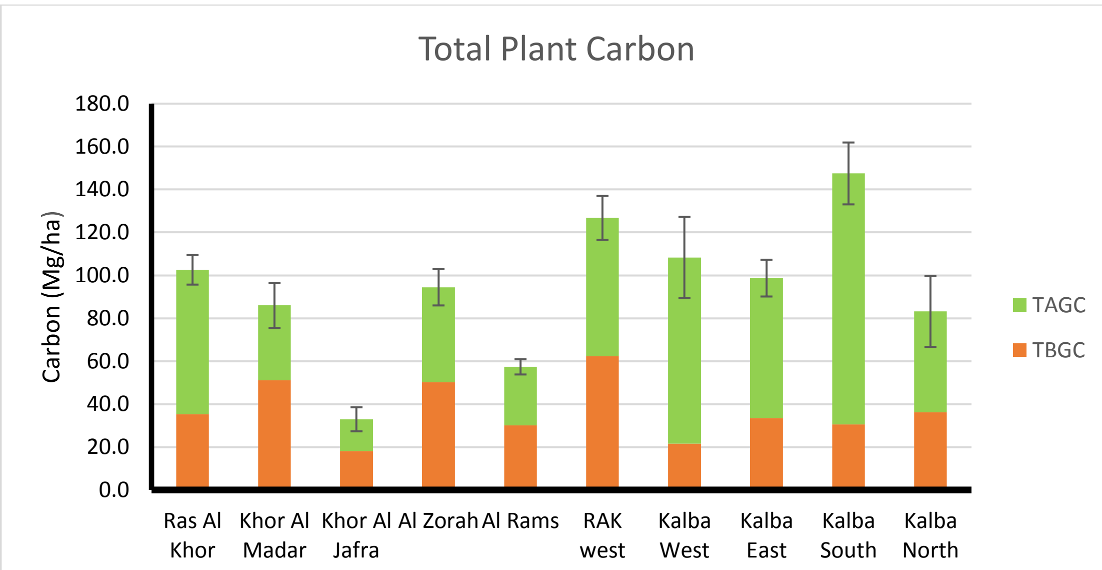


Figure 4. Total carbon pools found in the mangrove trees (aboveground and belowground, Mg/ha) of sampled mangroves of the Northern and Eastern Emirates, UAE. Vertical bars represent one standard error. From Kauffman and Crooks (2015)

Results of the Ras Al Khor site analysis

- These were among the tallest mangroves sampled in the UAE.
- Total aboveground biomass of the mangroves was 140 Mg/ha. Only a few sites at Kalba exceeded this site in aboveground biomass
- The total ecosystem carbon stock of the Ras Al Khor site was 341 Mg C/ha. This was the third largest carbon stock sampled of all mangroves in the UAE. However, the sampled site was a randomly selected site. It is likely that larger stands exist in Ras Al Khor.

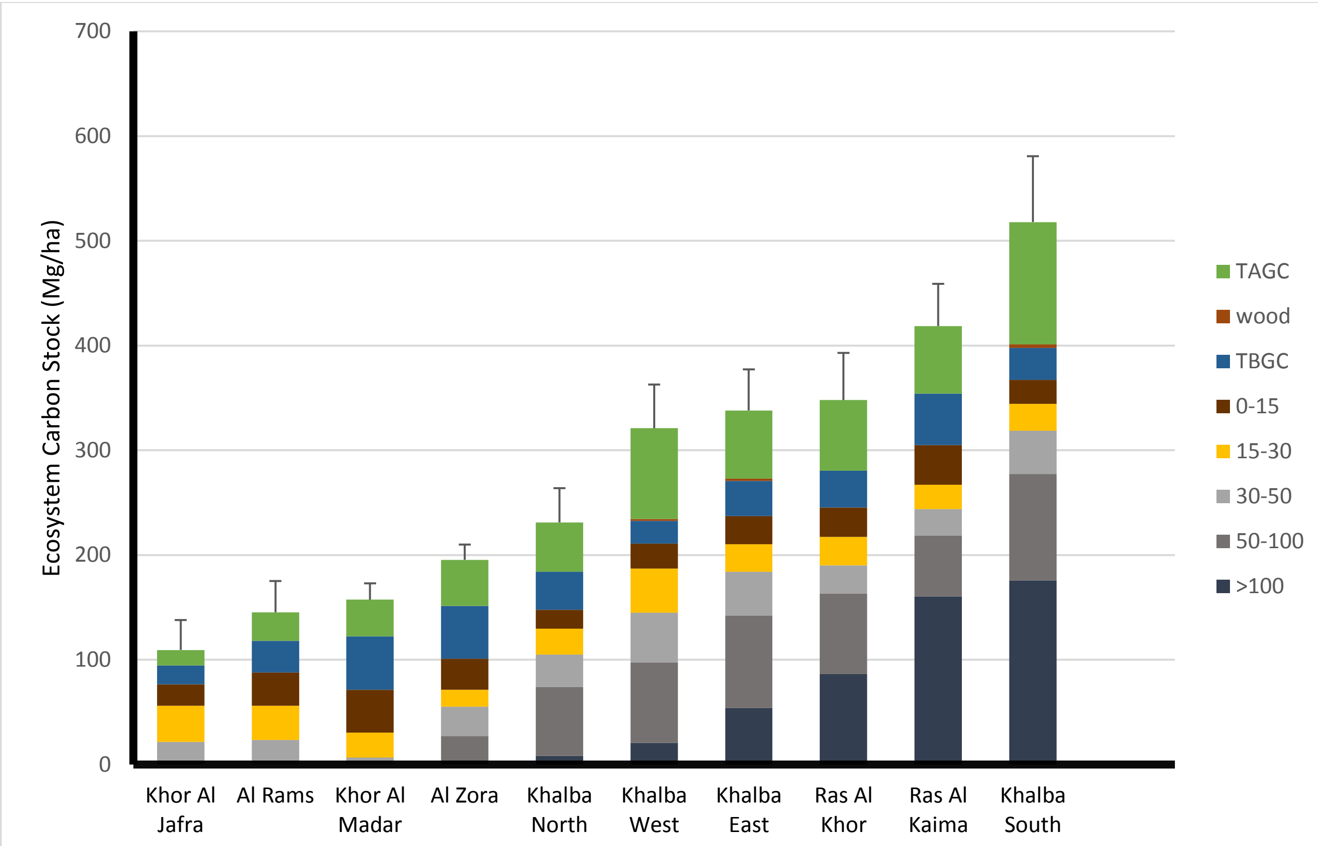


Figure 10. Total ecosystem carbon stocks (Mg/ha) of sampled mangroves of the Northern and Eastern Emirates. UAE. Vertical bars represent one standard error.

Table. Carbon stocks (Mg/ha) of mangroves of the northern mangroves, United Arab Emirates. Means are in bold the standard errors (SE) are normal. From Kauffman and Crooks (2015)

Site		0-15 cm	15-30 cm	30-50 cm	50-100 cm	>100 cm	Total soil	TAGC	TBGC	wood	Eco C stock
Al Khor	**mean**	**28.0**	**27.0**	**27.1**	**77.0**	**86.2**	**245.33**	**67.3**	**35.2**	**0.0**	**347.9**
	SE	5.8	8.7	6.7	29.7	26.0	61.34	5.4	3.5	0.0	45.1

General Recommendations relating to Ras Al Khor

- **Ras Al Khor** has a huge potential for conservation education. Access should be created so people can observe birds, the natural beauty of the area and gain an appreciation on mangroves and other natural systems.
- Ras Al Khor is a magnificent mangrove near the center of Dubai. Managers should consider construction of a public boardwalk and interpretive signs to educate the public on the values of mangroves. Access should be created so people can observe birds, the natural beauty of the area and gain an appreciation on mangroves and other natural systems.
- Of great concern was the presence of a large area that had experienced a sudden die-off of healthy mangrove trees of all ages. That the die off I visited at Ras Al Khor was from some toxic plume that killed the mangroves. It was a complete die off of all mangroves regardless of age class. This phenomenon has been observed by me in other sites where chemical spills into mangroves have resulted in near complete mortality. In contrast I have not observed natural die-offs such as this in any site throughout the world. Even severe events such as typhoons does not result in such high and complete mortality.
- **Unfortunately only one mangrove sites was sampled at Ras Al Khor. Given its high degree of structural diversity and presences in one of the world's great urban areas, more plots and studies should be conducted here to determine the ecosystem services and values of this site.**
- All urban mangroves of the UAE are greatly threatened by land use. They are being destroyed as part of urban growth and their hydrology has been greatly disrupted. Clearly toxic pollution accidents are a factor causing damage such as was observed in Ras Al Khor. Conservation of these globally unique, important and valuable ecosystems is warranted.

Photo of the mangrove die off at Ras Al Khor. There were very few surviving individuals within the die-off area.

Photo of the edge of the mangrove die-off. We sampled the mangrove in the background of this photo.

The loss of mangroves at Ras Al Khor to development. Development at the edge can disrupt the natal hydrology of the area and can be a source of contaminants into the mangroves.

Appendix D Data sheets utilized in the Abu Dhabi Blue Carbon study

Plot Meta Data

Project:

Forest Type: ____________________ Name of area sampled: ____________________

Date: _________Direction of central transect___________ Length __________________

Crew Members: ____

Plot Location/Directions
GPS Coordinates:
Plot 1
Plot 2
Plot 3
Plot 4
Plot 5
Plot 6
Topography:
Landscape position:
Disturbance:
Additional Notes:

Overstory Vegetation

PROJECT NAME:

SITE________________FOREST TYPE__________________ Plot size (7 Meter radius if dbh is >5cm; 2 m if dbh is <5cm or note differently here) ____________

Date: _______________ **Data /Recorder**____

PLOT	DBH	Crown diam	L/D	Status /class		PLOT	DBH	Crown diam	L/D	Status/ class

Data Entry: Name__________________Date________Checked by___________Date____________

Wood Debris

Project:_________________

Four, 14m transects at 45° to subplot center axis. Medium=2.5-7.6cm (9m-14m) Large ≥ 7.5cm (2m-14m count and measure).

SITE___________________________

Date:_____________Data collection_______________Data Recording ___________________

PLOT	TRANSECT	>7.5cm sound						>7.5 rotten					2.5-7.5				

Data Entry: Name__________________Date________Checked by___________Date____________

Soil samples for Carbon and bulk density

PROJECT: SITE Name ____________

Vegetation type ________________Type of sampler used___________

Date:_____________ Data Collection/Recorder____________Size of samples collected_______

Plot number	Soil Depth	Can Number		Plot number	Soil Depth	Can Number
