Mangrove Soil Carbon Sequestration of the United Arab Emirates: Trial Application

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

UNITED ARAB EMIRATES
MINISTRY OF CLIMATE CHANGE
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UAE Mangroves Annual Carbon Sequestration

Abu Dhabi Global Environmental Data Initiative (AGEDI)
Ministry of Climate Change and Environment

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About The Report

In partnership with the Ministry of Climate Change and Environment, the project aims to quantify annual carbon sequestration rates of mangroves in the UAE through radiometric means: Lead-210 and Caesium-137. Such methods offer the most appropriate means to determine carbon sequestration rates for national inventories and coastal management planning.

The project findings aim to present an opportunity to incorporate carbon sequestration dating within national policies and strategies. This test pilot assessment of mangrove annual carbon sequestration rates in the UAE should be viewed as a highly exploratory and preliminary test case.

Acknowledgments:

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A special thank you to the Principle Investigators, Dr. Stephen Crooks and Katrina Poppe, for their passion and dedication towards advancing blue carbon science, and for sharing their time and expertise.

Executive Summary

The UAE Annual Mangrove Soil Carbon Sequestration Project is a follow up to the Abu Dhabi Blue Carbon Demonstration Project, commissioned by the Abu Dhabi Global Environmental Data Initiative (AGEDI) in partnership with the Ministry of Climate Change and Environment (MOCCAE). This project provides a trial to test determination of mangrove soil carbon sequestration rates across the Emirates using radiometric dating techniques. This and prior projects improve understanding of carbon storage and the other services that coastal and marine Blue Carbon ecosystems provide across the United Arab Emirates.

Radiometric dating by laboratory measurement of amounts of lead radioisotope ^{210}Pb in the soil column, together with carbon density data, is the most effective means to determine soil carbon sequestration at the sub-century timescale. This information can be supplemented with identification of Caesium (^{137}Cs) deposits within sediments from historic nuclear emissions.

In discussions with Environment Agency – Abu Dhabi, a decision was made, in a limited first phase, to focus on a single common landform, Khors (coastal lagoons) found in Abu Dhabi and Northern Emirates. Sabkha and open coast remain unsampled. Field sampling was conducted at 5 khors (coastal lagoons): Eastern Mangrove (Abu Dhabi) Ras Al Khor (Dubai), Khor Ras Al Khaimah and Khor Hulaylah (Ras Al Khaimah) and Khor Kalba (Sharjah).

Standard field and analytical approaches were used to enable comparison with a growing global dataset on carbon sequestration rates mangrove ecosystems. Two sediment cores were collected from each khor for a total of 10 cores. The first two cores analysed, those of Khor Kalba (KK1 and KK2) are reported here, with subsequent analysis for the remaining 8 cores to continue through 2020.

Carbon sequestration rates from Khor Kalba were calculated as 63.75 ± 7.08 g C_{org} m^{-2} yr^{-1} at KK1, and 42.72 ± 4.50 g C_{org} m^{-2} yr^{-1} at KK2. These rates are higher than other reported rates from this arid region, with 15 ± 1 g C_{org} m^{-2} yr^{-1} reported for Red Sea mangroves (Almahasheer et al. 2017) and 19 ± 11 g C_{org} m^{-2} yr^{-1} for western Arabian Gulf mangroves (Cusack et al. 2018). The Khor Kalba sequestration rates are lower, however, than global mean sequestration rates of 163 g C_{org} m^{-2} yr^{-1} (Breithaupt et al. 2012) and 170 g C_{org} m^{-2} yr^{-1} (Pérez et al. 2018).

Carbon sequestration rates from Khor Kalba are meaningful rates for soil carbon sequestration given that they continue year after year as long as the mangrove remains healthy. As such the mangroves of the UAE are contributing to climate mitigation.

These first results are encouraging that soil carbon sequestration rates can be gathered from the mangrove forests in the Khors of the United Arab Emirates. We look forward to the results from the other cores.

Introduction

Project Context

"Blue Carbon" refers to the functional attributes of coastal and marine ecosystems to sequester and store carbon. Blue Carbon ecosystems of the United Arab Emirates (UAE) include mangrove forests, salt marshes and seagrass beds. Another potential Blue Carbon ecosystem identified as a result of prior projects are cyanobacterial "blue-green algal" mats (hereafter called algal flats). When these ecosystems are destroyed, buried carbon can be released into the atmosphere and ongoing sequestration is lost, 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 important cultural and social values.

A prior study, the Abu Dhabi Blue Carbon Demonstration Project quantified carbon stored and other services provided by coastal and marine Blue Carbon ecosystems along the Abu Dhabi coast. This contributed to the improved understanding of the relatively new concept of blue carbon on a regional and international level (Crooks et al., 2013; AGEDI, 2013; Crooks et al., 2014; AGEDI, 2014; Campbell et al., 2014; Schile et al., 2015).

This was followed up with a targeted assessment of mangrove carbon stocks across the northern Emirates (Kauffman and Crooks, 2015). These projects enhanced local capacity to measure and monitor carbon in coastal ecosystems and to manage associated data. The project also 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 project, this study tests an approach for quantifying soil carbon sequestration within mangroves of the United Arab Emirates. Five sites are sampled site (Eastern Mangrove, Abu Dhabi; Ras Al Khor, Dubai; Khor Ras Al Khaimah and Khor Hulaylah, Ras Al Khaimah; and Khor Kalba, Sharjah). Where areas of healthy and degraded mangroves are identified to be occurring within a given mangrove area, one core was collected at each location to provide a pair-wise comparison of impacts of mangrove health on soil carbon stocks and sequestration rates.

Carbon sequestration will be determined through radiometric means (^{210}PB). Such methods offer the most appropriate means to determine carbon sequestration rates for national inventories and coastal management planning. These new data points will inform future sampling to support the overall national Blue Carbon account for the UAE and across the region.

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* and the Global Environment Facility's (GEF) Blue Forests Project, of which AGEDI is a partner. 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.

Project Setting

The marine and coastal environment of the United Arab Emirates hosts a myriad of fish and marine organisms, living in diverse and unique environmental habitats (MOCCAE, 2015). For generations, the people of the UAE have relied on the coastal and marine environment

*http://thebluecarboninitiative.org/

as one of their main sources of income (MOCCAE, 2015). With the vision and direction from His Highness the late Sheikh Zayed Bin Sultan Al Nahyan, the natural 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 extension projects to the Northern Emirates in order to explore the values which coastal ecosystems provide the UAE, and to help preserve our environmental and cultural heritage. This project is commissioned by the Abu Dhabi Global Environmental Data Initiative (AGEDI) on behalf of EAD.

Science Team

The Principal investigator of this study is a member 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 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 a founder of Silvestrum Climate 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 the Source Lead to the US Environment Protection Agency with responsibility coastal wetlands in the National GHG Inventory of Emissions and Sinks.

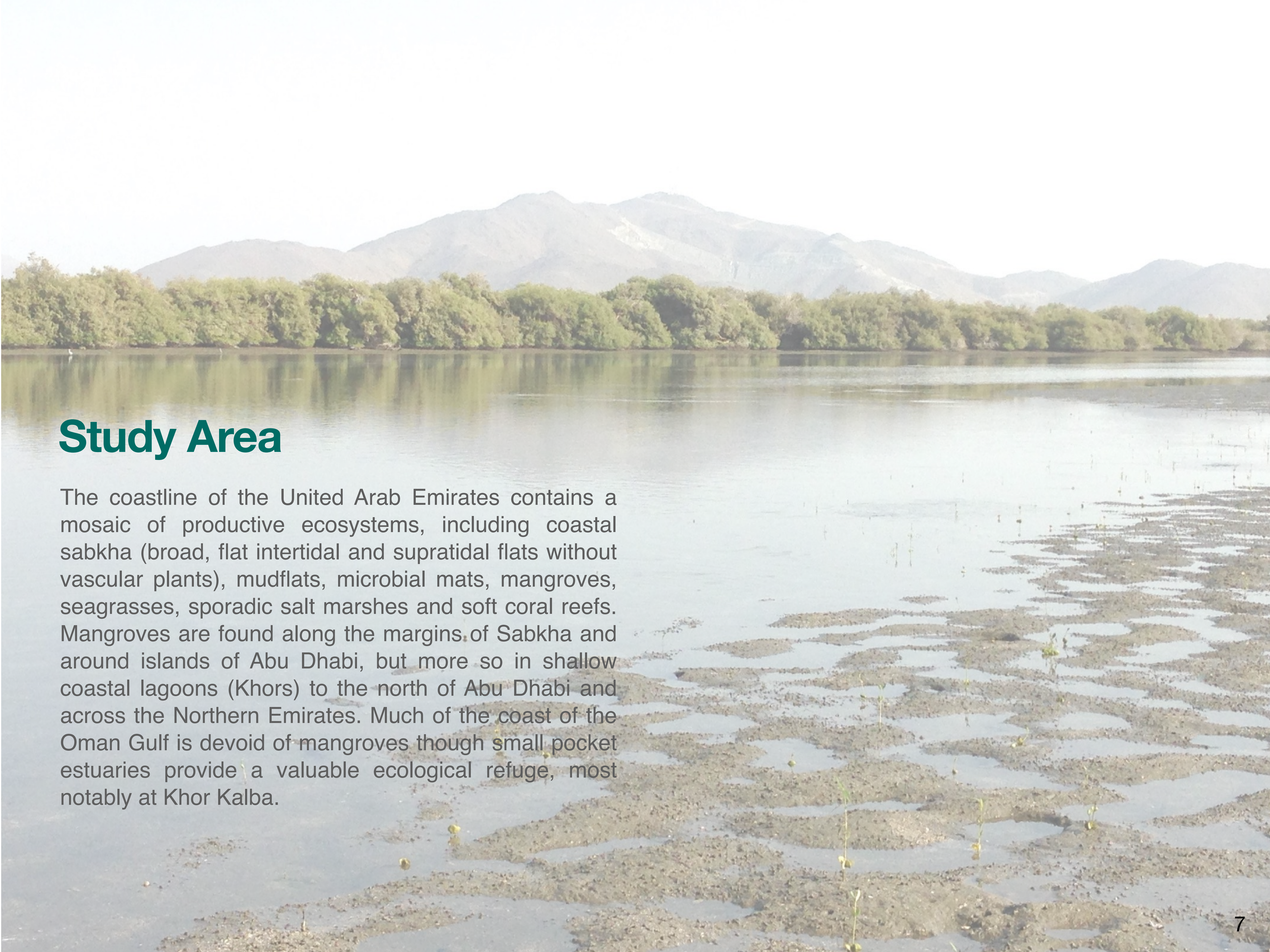
Ms. Katrina Poppe is a Research Associate at Western Washington University with 7 years of experience as an estuarine ecologist, focusing on coastal blue carbon research in marsh, seagrass, and forested coastal wetlands, as well as coastal ecogeomorphology and sediment dynamics, and restoration monitoring. Katrina has led blue carbon lab analyses (including radioisotope analyses for accretion rates) for a number of projects from a variety of coastal environments.

Dr. John Rybczyk, Professor, has over 30 years of experience as an estuarine geomorphologist/ecologist in the United States and internationally, including extensive blue carbon research experience. Dr. Rybczyk will serve as technical advisor for project laboratory work.

Capacity Building

During the course of this project, the research team was joined in the field by staff of AGEDI, including experts and volunteers from the Environment Agency - Abu Dhabi, Dubai Municipality, Ministry of Climate Change and Environment, Ras Al Khaimah Environment Protection and Development Authority, and Sharjah Environment and Protected Areas Authority. Training was provided on sample collection methods.

A meeting was held at the Ministry of Climate Change and Environment with senior staff to discuss the project as well as observations on the health of mangroves.



Study Area

The coastline of the United Arab Emirates contains a mosaic of productive ecosystems, including coastal sabkha (broad, flat intertidal and supratidal flats without vascular plants), mudflats, microbial mats, mangroves, seagrasses, sporadic salt marshes and soft coral reefs. Mangroves are found along the margins of Sabkha and around islands of Abu Dhabi, but more so in shallow coastal lagoons (Khors) to the north of Abu Dhabi and across the Northern Emirates. Much of the coast of the Oman Gulf is devoid of mangroves though small pocket estuaries provide a valuable ecological refuge, most notably at Khor Kalba.

The UAE is an arid country. Air temperatures seasonally range from 12^{o}C to 50^{o}C and water temperatures at the coastal margin ranging between 10^{o}C to 36^{o}C (EAD, 2007).

Average annual rainfall is <100 mm and much less than evaporation rates of 1000 – 2000 mm. Salinity in the Arabian Gulf is high due to restricted tidal exchange and high rates of evaporation. Lower salinities are found on the ocean coast of the Emirates as well as in localized areas at urban water outflows, through drainage wadis and upwelling seeps at the base of mountains.

With the exception of a few planted *Rhizophora* saplings, the UAE hosts a single species of mangrove, *Avicennia marina*. *Avicennia* is a robust species, capable of tolerating the temperature fluctuations most extreme latitudinal range of mangrove forests and in environments with soil salinities up to 80 PSU (Crooks et al., 2013). In khor settings mangroves have existed in the same location for decades and possibly centuries with rising sea level rise. At the same time these khors are under stress from encroaching development, which is impacting the health of mangrove forests. Observations have been made by agency scientists of patches of dieback in mangrove forests.

Site Selection

This investigation studied carbon accumulation in mangrove soils from regionally representative khors. Five Khors were selected though discussions with staff from AGEDI and regional agency partners. Two cores were collected from each Khor, attempting to identify and contract apparently more healthy and less healthy locations (Table 1).

Characterization of health was based upon agency staff experience, variation in interior mangrove cover observed from remote sensed imagery, and observations by the team in the field. Mass mortality of patches of mangroves in a forest interior (sometimes known as a mangrove heart attack) is often an indication of stress. This is exacerbated when only a single species is present as there is not the opportunity for a second species to occupy the open space created. Standing water in the mangrove during low tide is a clear driver of stress in a mangrove forest. The presence of barnacles on pneumatophore, roots trunks and even branches may be an indicator that the mangrove is subject to high flooding frequencies.

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

Core	Site	Emirate	Collection date	Latitude (deg/min/sec)	Longitude (deg/min/sec)
EM1	Eastern Mangroves	Abu Dhabi	9/2/2019	N 24° 27' 09.5"	E 54° 26' 22.5"
EM2	Eastern Mangroves	Abu Dhabi	9/2/2019	N 24° 26' 44.2"	E 54° 25' 10.6"
RAK1	Ras Al Khor	Dubai	9/3/2019	N 25° 11' 22.9"	E 55° 19' 30.3"
RAK2	Ras Al Khor	Dubai	9/3/2019	N 25° 11' 23.3"	E 55° 19' 20.2"
RW1	Khor Ras Al Khaimah	Ras Al Khaimah	9/4/2019	N 25° 46' 17.8"	E 55° 56' 54.7"
RW2	Khor Ras Al Khaimah	Ras Al Khaimah	9/4/2019	N 25° 46' 13.3"	E 55° 56' 59.3"
AR1	Khor Hulaylah	Ras Al Khaimah	9/4/2019	N 25° 53' 26.7"	E 56° 02' 01.3"
AR2	Khor Hulaylah	Ras Al Khaimah	9/4/2019	N 25° 53' 41.8"	E 56° 02' 53.4"
KK1	Khor Kalba	Sharjah	9/5/2019	N 24° 59' 57.8"	E 56° 21' 58.5"
KK2	Khor Kalba	Sharjah	9/5/2019	N 24° 59' 29.6"	E 56° 22' 09.0"

Methods

Field Sampling

Field sampling was conducted in September of 2019. Cores were collected by manually driving PVC coring tubes (10 cm internal diameter) to a depth of 50 cm into the sediment with a mallet. The bottom edge of the coring tubes had been pre-sharpened to help cut through any belowground plant material. To check for any sediment compaction during coring, the height of the sediment surface was measured to the top of the corer both inside and outside the core before removal, although compaction was generally minimal to absent. Immediately upon removal, cores were capped in the field and transported in a vertical position. Cores were extracted from the tubes later the same day, sliced into 2-cm increments, and stored in 8-oz. screw-top tin jars that preserved sample dimensions. Samples were oven dried at 60°C before shipping.

Analytical

Immediately upon arrival at the WWU laboratory, sediment samples were oven dried again at 60°C until a constant mass was reached, to ensure that any moisture absorbed during transport had been removed.

Samples were then weighed to determine dry bulk density:

Bulk Density = Sample Dry Weight / Wet Volume

Approximately half of each section was ground to a fine powder with mortar and pestle and passed through a 0.5-mm sieve. These ground subsamples were then used for the determination of organic content, carbon content, and radioisotope (^{210}Pb and ^{137}Cs) activity.

The organic matter (OM) content of each sample was determined by loss on ignition (LOI) using a Thermolyne furnace (type 48000). Approximately 12g of each subsample was burned at 500°C for 24 hours, and weighed before and after burning (Craft et al. 1991). Each sample's OM content was calculated as:

OM = Sample Dry Weight Before Burning – Weight After Burning * 100%

Organic carbon (C_{org}) content of each sample was calculated from OM content using an equation developed from a previous study of blue carbon stocks in the Northern Emirates (Kauffman and Crooks, 2015):

$C_{org} = 0.3588 * OM - 0.2896$ ($R^2 = 0.68$)

Carbon density was calculated for each 2-cm core section as the product of bulk density and C_{org} content:

C_{org} Density = Bulk Density * C_{org} Content / 100%

Sediment accretion rates were determined from the downcore distribution of excess ^{210}Pb activity, providing an estimate of centennial-scale accretion rates assuming the depositional rate of excess ^{210}Pb does not change over time. We used a Canberra Germanium Detector (model GL2820R, Mirion Technologies (Canberra) Inc., Meriden, CT), with gamma emissions recorded by Genie 2000 software (Canberra 2002) at 46 keV and 351 keV.

Excess (unsupported) ^{210}Pb was calculated as the difference between total ^{210}Pb activity (at 46 keV) and supported ^{210}Pb activity (at 351 keV) to distinguish between excess ^{210}Pb deposited at the surface and supported ^{210}Pb that has decayed from radium in the sediment.

We analyzed approximately 25 g of dried and ground subsamples from various depths through the sediment cores. Each sample was analyzed for 48 to 72 hours, until the counting error rates for total and supported ^{210}Pb dropped at least below 10% and ideally below 5%. With 48 to 72 hours required per sample, and multiple samples from various core depths to analyze, this typically totals 3 to 4 weeks per core. With the constant initial concentration (CIC) model (Robbins et al. 1978), a linear regression of the natural log of excess ^{210}Pb activity versus depth was used to determine the sediment accretion rate:

Accretion Rate = $-\lambda/s$

where λ is the half-life of ^{210}Pb (22.2 yr^{-1}), and s is the slope of the regression.

Downcore activity of ^{137}Cs was also analyzed to validate the ^{210}Pb results. Unlike ^{210}Pb, ^{137}Cs is not naturally occurring, but rather was deposited as fallout during nuclear weapons testing during the last century. ^{137}Cs activity was recorded at 662 keV simultaneously with the ^{210}Pb activity measurements. A downcore peak in ^{137}Cs activity is assumed to coincide with the peak of nuclear testing in 1963. The sediment above this layer is then assumed to have accumulated at a constant rate since 1963. If a distinct ^{137}Cs peak cannot be identified, this suggests ^{137}Cs mobility throughout the soil column due to high permeability, or displacement by highly charged monovalent cations such as sodium and potassium (Drexler et al. 2018, Foster et al. 2006), which would make ^{137}Cs an inappropriate tool for dating in this situation.

To account for different spectrometer counting efficiencies at different energy levels, a calibration standard was analyzed for each core. The standard was created by adding approximately 0.5 g pitchblende silica-ore standard (CRM 103-A, New Brunswick Laboratory, USDOE) to a previously analyzed sample.

Carbon sequestration rates were calculated as the product of the sediment accretion rate and the mean C_{org} density in the top 30 cm of the core, which is approximately the depth range used for the ^{210}Pb accretion rate analysis:

C_{org} Sequestration Rate = Accretion Rate * Mean C_{org} Density *10,000

Results

Sediment properties in the two Khor Kalba cores were roughly similar, although KK2 appeared to have a deeper organic layer. Both cores showed similar properties near the surface (in the top 6 cm), but the KK1 profile then declined in organic and carbon content with depth as it transitioned to sand and shell hash, while the KK2 profile remained fairly constant. Thus, KK2 had slightly higher mean values of organic content and carbon content, and consequently lower bulk density, when averaged over the top 30 cm of the core (Table 2). Measured values of bulk density, OM content, and C_{org} content for each 2-cm core section are shown in Figure 1 and Figure 2 and reported in Tables 2 and 3.

Sediment bulk density at KK1 ranged from 0.51 to 1.23 g cm^{-3} over the top 30 cm, with a mean (± SE) of 0.89 ± 0.07 g cm^{-3}. Bulk density at KK2 ranged from 0.43 to 0.66 g cm^{-3}, with a mean of 0.57 ± 0.02 g cm^{-3} (Figures 1 and 2).

Organic matter content at KK1 ranged from 5.13% to 15.48% with a mean of 9.21 ± 0.79%. At KK2, OM content ranged from 9.87% to 17.08% and averaged 11.91 ± 0.52%. Organic carbon content at KK1 ranged from 1.55% to 5.27% with a mean of 3.02 ± 0.28%. Organic carbon content at KK2 ranged from 3.25% to 5.84% and averaged 3.99 ± 0.19% (Figures 1 and 2).

Figure 1: KK1 soil profiles with bulk density, organic matter content, organic carbon (Corg) content, and Corg density.

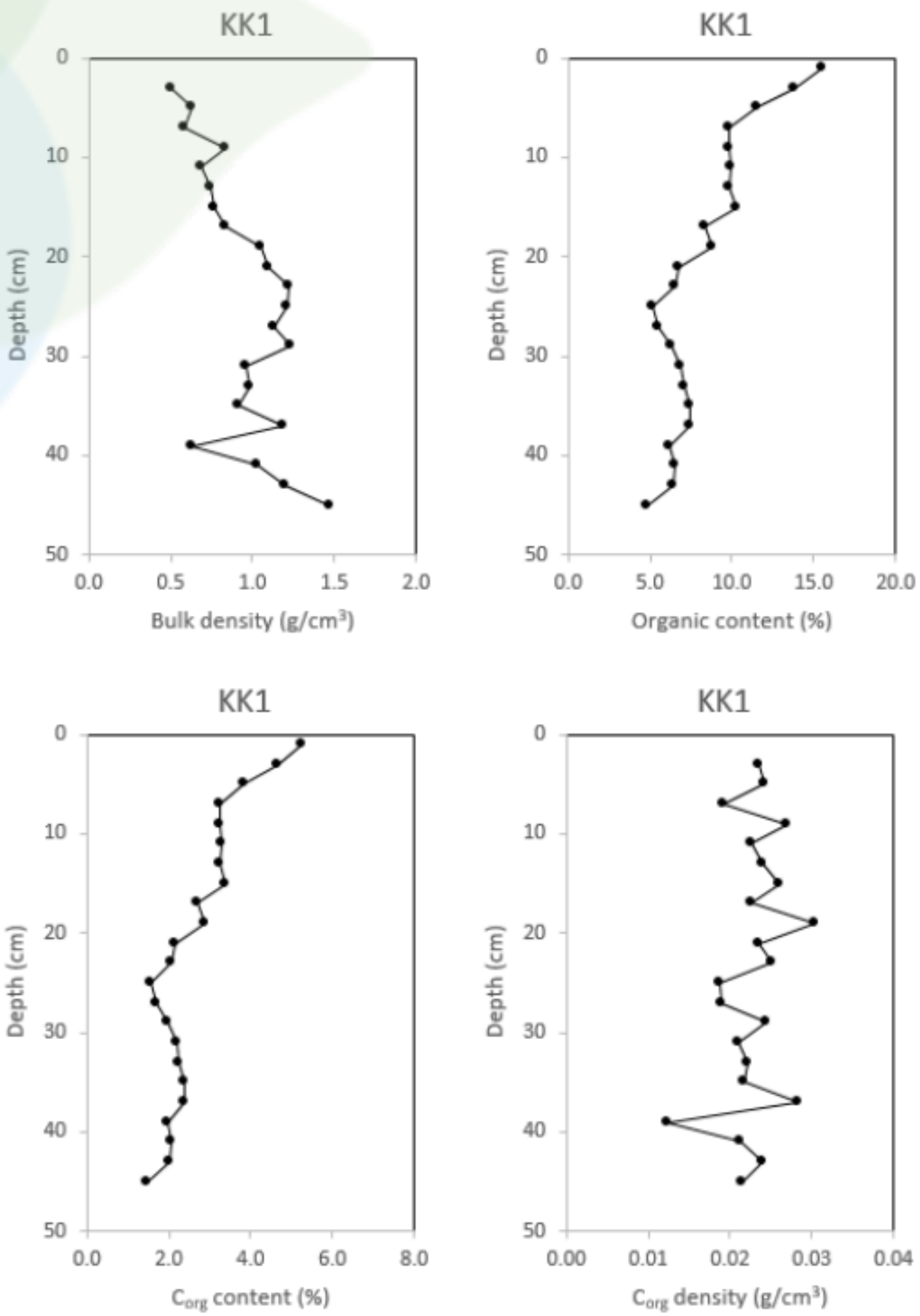


Figure 2: KK2 soil profiles with bulk density, organic matter content, organic carbon (Corg) content, and Corg density.

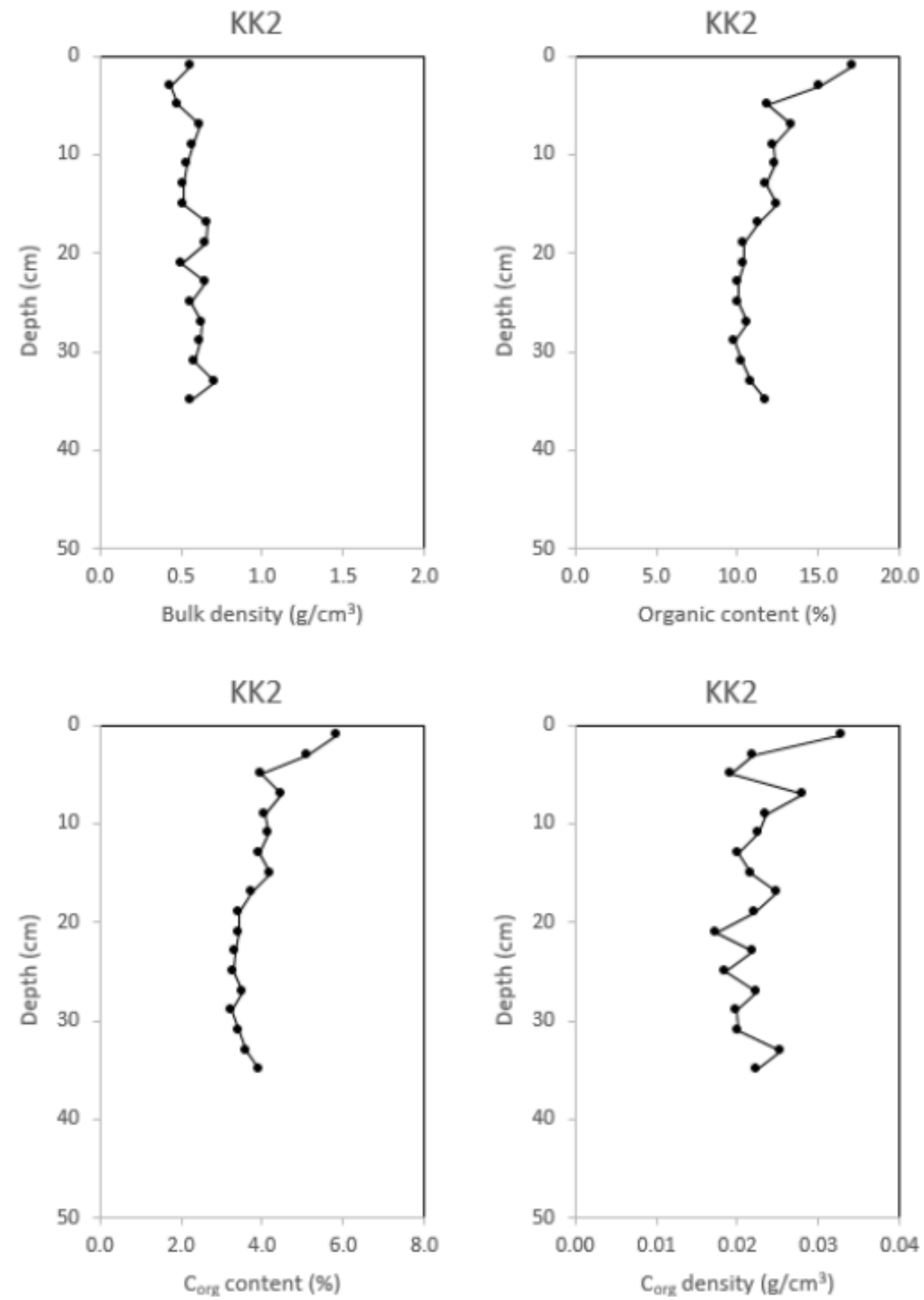


Table 2: Mean sediment properties in the top 30 cm, centennial-scale accretion rates, and carbon sequestration rates for two mangrove cores from Khor Kalba, UAE.

Mean Bulk Density (g/cm^3)	Mean Organic Matter Content(%)	Mean C_{org} Content (%)	Mean C_{org} Density (gC/cm^3)	^{210}Pb Accretion Rate (cm/yr)	C_{org} Sequestration Rate ($gC/m^2/yr$)
KK1	0.89	9.21	3.02	0.27	63.75
± SE	0.07	0.79	0.28	0.03	7.08
KK2	0.57	11.91	3.99	0.19	42.72
± SE	0.02	0.52	0.19	0.02	4.50

Sediment accretion rates as measured with ^{210}Pb were 0.27 ± 0.03 cm yr^{-1} at KK1, and 0.19 ± 0.02 cm yr^{-1} at KK2 (Table 2). The ^{210}Pb profiles from both cores included an approximately 6-cm subsurface layer in which ^{210}Pb activity was homogeneous rather than declining with depth (Figures 3 and 4). These layers could be interpreted as either mixed, from bioturbation or resuspension, or they could indicate a rapid depositional event. Corresponding layers in the ^{137}Cs profiles did not appear mixed, therefore the ^{210}Pb profiles were assumed to be demonstrating sporadic sedimentation events, and no mixed layers were eliminated from the analysis.

The ^{137}Cs profiles showed peaks indicating accretion rates of 0.16 ± 0.02 cm yr^{-1} at KK1, and 0.20 ± 0.02 cm yr^{-1} at KK2 (Figure 5). The ^{137}Cs rate corroborates the ^{210}Pb rate at KK2, but the two rates did not match as well at KK1. There is reason to believe, however, that, ^{137}Cs may be less likely to produce viable results in saline, sandy environments such as are found in UAE as these conditions increase ^{137}Cs mobility. The ^{210}Pb profiles also produced good quality profiles of exponential decay with regression R^2 values of 0.93 and 0.96 (Figures 3 and 4). Therefore, only the ^{210}Pb-based accretion rates were used in the sequestration rate calculations.

Figure 3: (A) Downcore distribution of excess 210Pb activity (± 1 S.D.) versus depth at KK1, and (B) regression of natural log of excess 210Pb versus depth, with slope used to calculate an accretion rate of 0.27 cm yr-1.

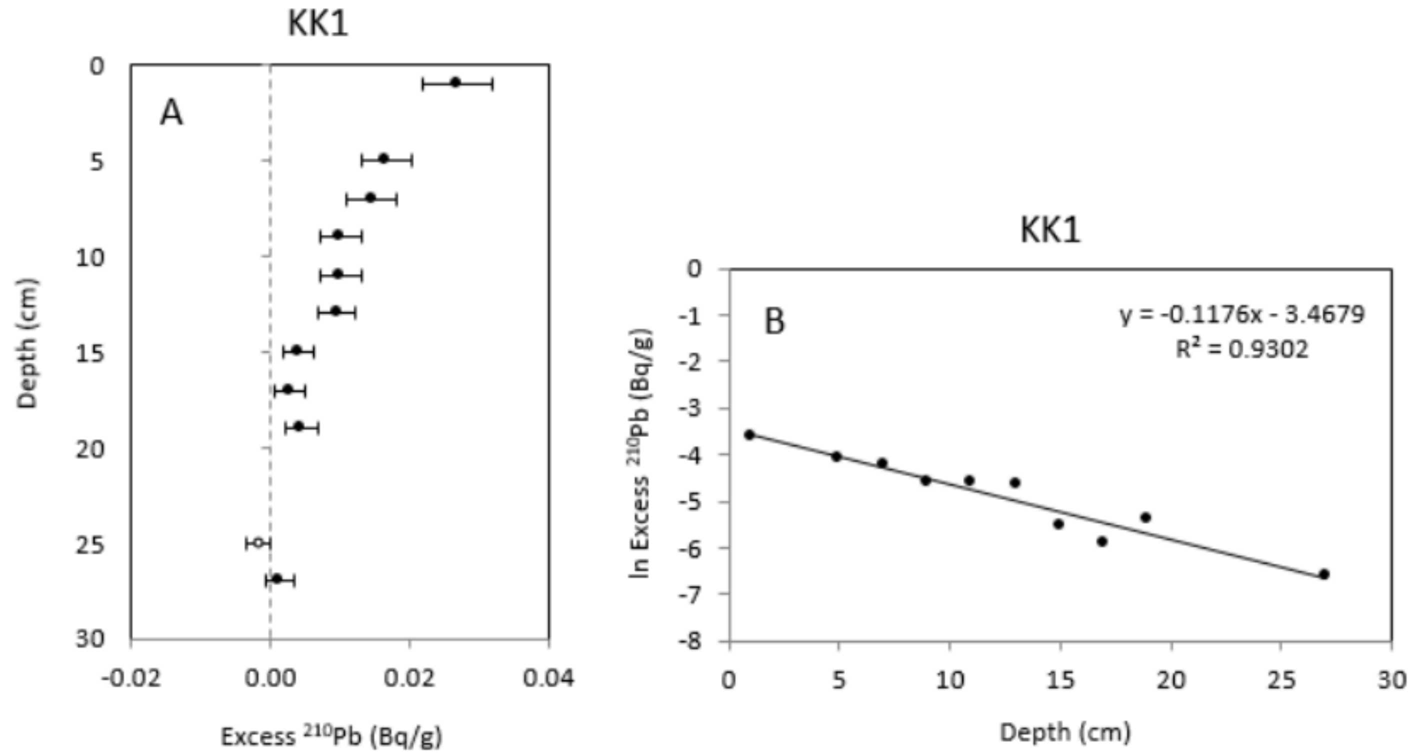


Figure 4: (A) Downcore distribution of excess 210Pb activity (± 1 S.D.) versus depth at KK2, and (B) regression of natural log of excess 210Pb versus depth, with slope used to calculate an accretion rate of 0.19 cm yr-1.

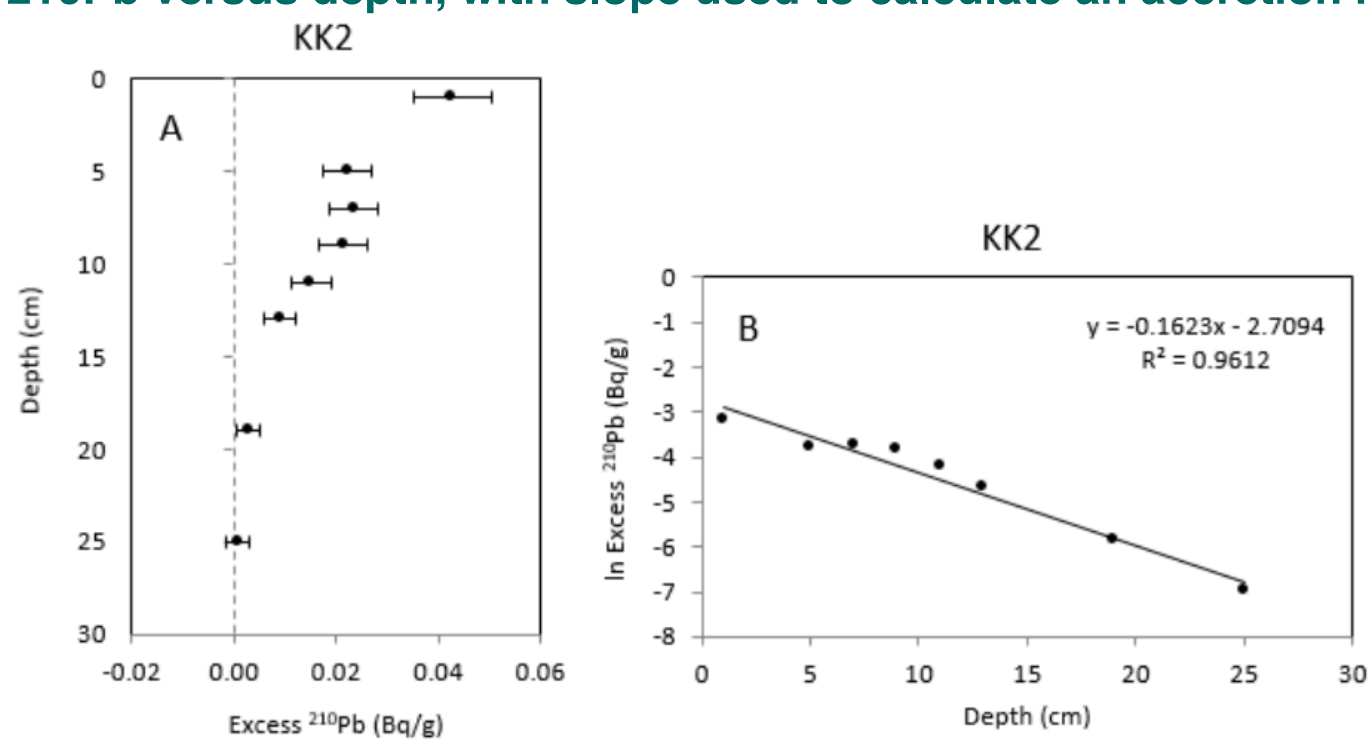
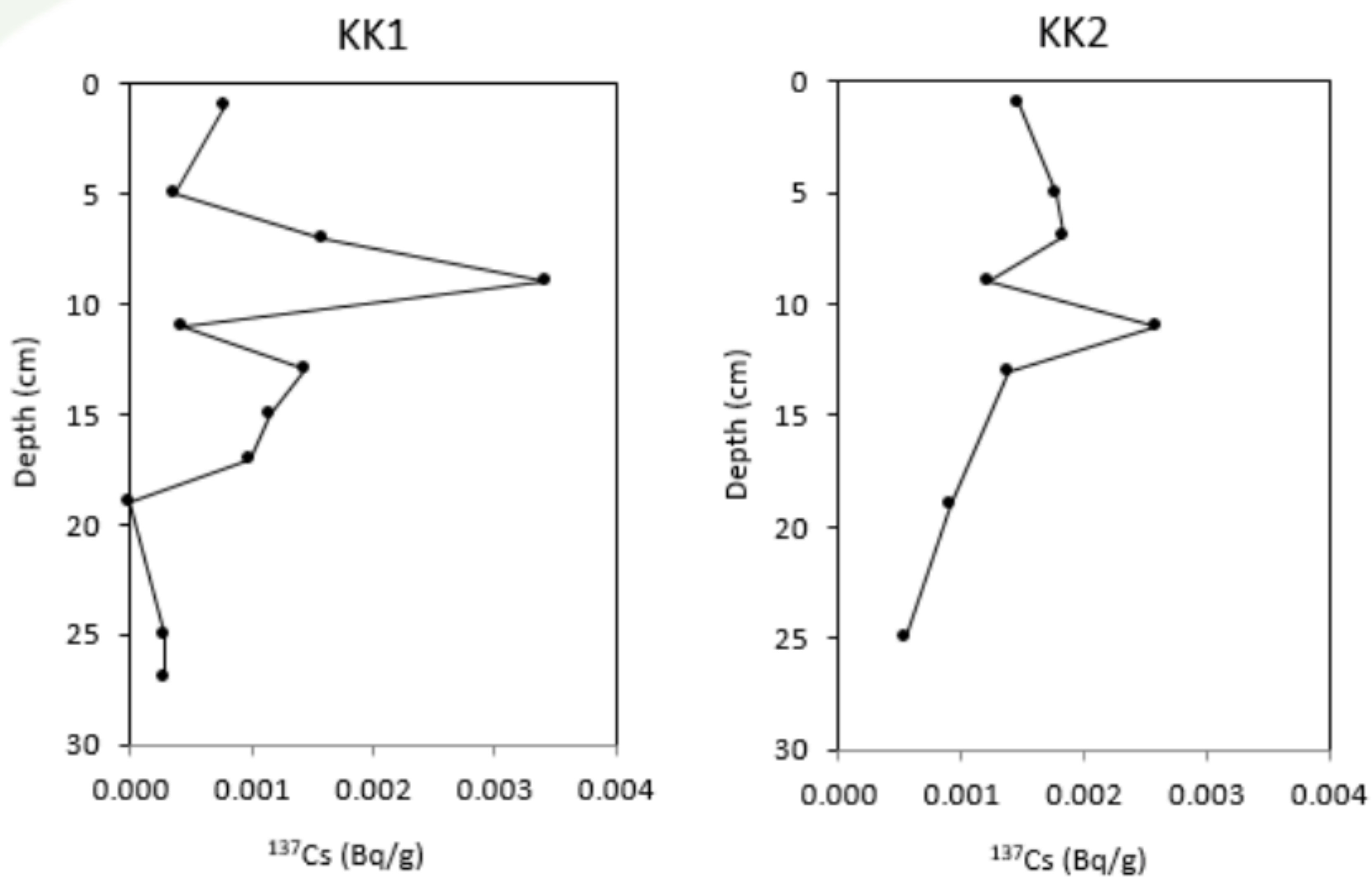


Figure 5: Downcore distribution of 137Cs from both KK1 and KK2.



The accretion rates reported here are similar to the mean mangrove rate of 0.21 ± 0.09 cm yr^{-1} reported from the Saudi coast of the Arabian Gulf (Cusack et al. 2018), and the mean rate of 0.22 ± 0.06 cm yr^{-1} reported from the Saudi coast of the central Red Sea (Almahasheer et al. 2017). The Khor Kalba rates are also comparable, if not slightly lower, than global mangrove averages of 0.28 cm yr^{-1} (Breithaupt et al. 2012, Pérez et al. 2018).

It is difficult to determine if UAE mangrove accretion rates are keeping pace with sea level rise (SLR) as regional observations of SLR are limited. However, Siddig et al. (2019) reported local SLR measurements from the west coast of the Arabian Gulf averaging 0.23 cm yr^{-1} (1979 – 2008), compared with satellite altimeter-based trends of 0.36 cm yr^{-1} for the Arabian Gulf and 0.28 cm yr^{-1} globally (1993 – 2018). Although the rate of SLR can vary regionally due to differences in vertical land movement, these reported rates from the western Arabian Gulf may provide some indication of expected rates on the UAE coast. Khor Kalba accretion rates of 0.19 and 0.27 cm yr^{-1} are roughly comparable, if not slightly lower, than available SLR rates for the Arabian Gulf, suggesting that the Khor Kalba mangroves are accreting sediment at a rate that keeps pace with current rates of sea level rise.

Carbon sequestration rates from Khor Kalba were calculated as 63.75 ± 7.08 g C_{org} m^{-2} yr^{-1} at KK1, and 42.72 ± 4.50 g C_{org} m^{-2} yr^{-1} at KK2 (Table 2).

These rates are higher than other reported rates from this arid region, with 15 ± 1 g C_{org} m^{-2} yr^{-1} reported for Red Sea mangroves (Almahasheer et al. 2017) and 19 ± 11 g C_{org} m^{-2} yr^{-1} for western Arabian Gulf mangroves (Cusack et al. 2018). The Khor Kalba sequestration rates are lower, however, than global mean sequestration rates of 163 g C_{org} m^{-2} yr^{-1} (Breithaupt et al. 2012) and 170 g C_{org} m^{-2} yr^{-1} (Pérez et al. 2018).

Next Steps

With the successful attainment of carbon sequestration values from the Khor Kalba site, the project team will continue processing the remaining 8 cores through 2020.

Table 3: Measured values of bulk density, and organic matter content, and calculated values of organic carbon (C_{org}) content, and C_{org} density at KK1.

Khor Kalba (KK) 1					
Section	Mid-depth (cm)	Bulk Density (g/cm^3)	Organic Matter Content (%)	C_{org} Content (%)	C_{org} Density (gC/cm^3)
0-2	1.0	-	15.48	5.27	-
2-4	3.0	0.51	13.84	4.67	0.02
4-6	5.0	0.63	11.57	3.86	0.02
6-8	7.0	0.59	9,89	3.26	0.02
8-10	9.0	0.83	9.83	3.24	0.03
10-12	11.0	0.69	9.96	3.28	0.02
12-14	13.0	0.74	9.88	3.25	0.02
14-16	15.0	0.77	10.24	3.39	0.03
16-18	17.0	0.84	8.32	2.69	0.02
18-20	19.0	1.05	8.86	2.89	0.03
20-22	21.0	1.10	6.77	2.14	0.02
22-24	23.0	1.22	6.58	2.07	0.03
24-26	25.0	1.21	5.13	1.55	0.02
26-28	27.0	1.13	5.49	1.68	0.02
28-30	29.0	1.23	6.35	1.99	0.02
30-32	31.0	0.96	6.92	2.19	0.02
32-34	33.0	0.98	7.10	2.26	0.02
34-36	35.0	0.92	7.40	2.37	0.02
36-38	37.0	1.19	7.43	2.38	0.03
38-40	39.0	0.63	6.24	1.95	0.01
40-42	41.0	1.03	6.56	2.07	0.02
42-44	43.0	1.20	6.41	2.01	0.02
44-46	45.0	1.47	4.87	1.46	0.02
Mean (0-30 cm)		**0.089**	**9.21**	**3.02**	**0.02**
± SE		0.07	0.79	**0.28**	**0.00**

Table 4: Measured values of bulk density, and organic matter content, and calculated values of organic carbon (C_{org}) content, and C_{org} density at KK2.

Khor Kalba (KK) 2					
Section	Mid-depth (cm)	Bulk Density (g/cm^3)	Organic Matter Content (%)	C_{org} Content (%)	C_{org} Density (gC/cm^3)
0-2	1.0	0.56	17.08	5.84	0.03
2-4	3.0	0.43	15.02	5.10	0.02
4-6	5.0	0.49	11.84	3.96	0.02
6-8	7.0	0.62	13.33	4.49	0.03
8-10	9.0	0.58	12.19	4.08	0.02
10-12	11.0	0.54	12.35	4.14	0.02
12-14	13.0	0.51	11.77	3.93	0.02
14-16	15.0	0.52	12.47	4.18	0.02
16-18	17.0	0.66	11.30	3.76	0.02
18-20	19.0	0.65	10.36	3.43	0.02
20-22	21.0	0.51	10.38	3.44	0.02
22-24	23.0	0.66	10.09	3.33	0.02
24-26	25.0	0.56	10.03	3.31	0.02
26-28	27.0	0.64	10.64	3.53	0.02
28-30	29.0	0.61	9.87	3.25	0.02
30-32	31.0	0.58	10.34	3.42	0.02
32-34	33.0	0.71	10.82	3.59	0.03
34-36	35.0	0.57	11.78	3.94	0.02
Mean (0-30 cm)		**0.089**	**9.21**	**3.02**	**0.02**
± SE		0.07	0.79	**0.28**	**0.00**

Conclusion

These first results are encouraging that soil carbon sequestration rates can be gathered from the mangrove forests in the Khors of the United Arab Emirates. We look forward to the results from the other cores.

Carbon sequestration rates from Khor Kalba (average 58.86 g C_{org} m^{-2} yr^{-1} are meaningful rates for soil carbon sequestration given that they continue year after year as long as the mangrove remains healthy. As such the mangroves of the UAE are contributing to climate mitigation. The values in khors are likely to be higher than mangroves found on open sabkha areas because of the high preservation potential found in accumulated muds of the Khors. This may explain the greater rates found at Khor Kalba than other reported rates around the Arabian peninsula, with 15 ± 1 g C_{org} m^{-2} yr^{-1} reported for Red Sea mangroves (Almahasheer et al. 2017) and 19 ± 11 g C_{org} m^{-2} yr^{-1} for western Arabian Gulf mangroves (Cusack et al. 2018). The Khor Kalba sequestration rates are lower, however, than global mean sequestration rates of 163 g C_{org} m^{-2} yr^{-1} (Breithaupt et al. 2012) and 170 g C_{org} m^{-2} yr^{-1} (Pérez et al. 2018) but in line with the CDM carbon finance Afforestation and Reforestation of Degraded Mangrove Habitat (AR-AM0014) methodology of 50 gC_{org} m^{-2} yr^{-1} or 0.5t C_{org} ha^{-1} yr^{-1}.*

An additional note on mangrove carbon sequestration. The carbon that is sequestered supports many ecosystem services. The soil carbon helps to bind the sediments and adds to the volume enabling the soils to build vertically and maintain the mangrove against sea level rise. The carbon that is stored in the soils reflects only a part of the carbon extracted from the carbon dioxide from the atmosphere. A larger proportion flows from the plants and soils to support the food chain of the birds, fish and mammals found in mangroves and nearby coastal waters. Some of this carbon will be deposited elsewhere in the marine ecosystem and so represents an additional but unquantified amount of carbon sequestration from mangrove systems.

Finally, small forests are recognized to have outsized ecological value in coastal systems because they provide critical habitat in the life cycle of many marine species and, for this reason, they are of heightened conservation value (Curnick et al., 2019). It is recommended that the governments of the UAE conserve and restore mangrove forest to maintain the richness of the UAE coastal ecosystem.

*https://cdm.unfccc.int/methodologies/DB/KMH6O8T6RL3P5XKNBQE2N359QG7KOE

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