Coastal development and mangroves in Abu Dhabi, UAE

E K Paleologos¹³, B A Welling², M E Amrousi² and H A Masalmeh²

¹Department of Civil Engineering, Abu Dhabi University, Abu Dhabi 59911, UAE
²Department of Architecture, Abu Dhabi University, Abu Dhabi 59911, UAE

E-mail: evan.paleologos@adu.ac.ae

Abstract. Mangrove forests are widely distributed in Asia, America, and Africa. These salt-tolerant bushes or trees grow at the intersection of fresh and saline waters in tidal lagoons, estuaries, and deltas creating rich ecosystems. They are used by communities for wood, and fish and shellfish harvesting, and they play an important role in soil stabilization and wave and flood modification by absorbing storm surges protecting coastal communities. Mangroves are threatened by human activities that include discharge of untreated wastewater that creates hypoxic conditions; structures, which interfere with material deposition and current circulation; and ship and boat movement, which create wake waves, or introduce ballast water. The highly salt tolerant species of Avicennia marina covers about 155 km² of the Abu Dhabi shoreline. Mangroves’ existence in some locations there is endangered by the intense coastal development and engineered shoreline modification taking place. Cement factories with heavy metal and other particle sea deposition; marinas, ports, canals, and seawalls constructed to provide residential sea views, and motorized boats modify hydrodynamic conditions and affect the settling of particles directing them seaward. Finally, the dredging that accompanies construction removes benthic communities and material modifying the seabed and may create conditions adverse to mangrove survival.

1. Introduction

Natural environments are important for metropolitan areas to support ecosystems, public health, social interactions, aesthetic needs, and to mitigate urban heat-island effects. Mangroves are bushes and trees that grow at the intersection of land and sea, at the mouth and surrounding areas of tidal lagoons, estuaries, and rivers, and they are partially emerged under the high-water tide. Mangroves compose one of the most bio-productive ecosystems and they consist of halophytes - salt-tolerant plants - that are viviparous - their fruits, seeds and hypocotyls are dispersed by water currents – they are anaerobic, and their leaves and roots can filter or expel salt. Their adaptation allows them to withstand saline environments, unstable soil with poor oxygen levels, high temperatures, and abundant sunlight [1].

Depending on their definition and habitat the number of species reported in the literature varies, but generally they are classified in two groups, the former consisting of 73 species that exist solely in mangrove environments, and the latter, the mangrove associates, capable of residing in non-typical mangrove environments. They are found in large number in about 60 nations and dominate coastlines in tropical and subtropical regions reaching maximum development between 25°N and 25°S. Mangrove distribution is divided, globally, into two hemispheres; the Atlantic East Pacific, which includes the East African coast, South Asia, the Pacific, and the islands down to Australia; and the Indo West Pacific, which includes West Africa, and the coasts of America and the Caribbean. The former is much richer in the number of species with a five-to-one ratio in the number of species found
between the two regions [1,2].

The countries with the largest areas of mangroves in Asia are Indonesia (2.5 million ha), Australia (1.1 million ha), Burma (812,000 ha), Malaysia (674,000 ha), Papua (553,000 ha), and Bangladesh (410,000 ha). In Africa large areas are found in Nigeria (973,000 ha), Senegal (440,000 ha), Madagascar (320,000 ha), and in Cameroon, Gabon, and Guinea with about 260,000 ha, each. In America the top country is Brazil (2.5 million ha), Mexico (660,000 ha), Panama (486,000 ha), Cuba (450,000 ha), Colombia (307,000 ha), and Venezuela with 260,000 ha [1]. Their latitudinal distribution is limited by the climate, as mangroves prefer areas where temperatures remain constant above 20°C. In addition to their temperature preferences, mangrove forests favor areas with an influx of freshwater, which mitigates the effect of sea water and the built-up of hyper-saline soils (salt flats). They do better in locations sheltered from storms, especially sediment-rich river deltas and tidal settings, with tide frequency and amplitude regulating mangrove immersion and together with land-based waters bringing nutrients, and removing carbon dioxide, and sulphurous and organic waste from mangrove sites. Thus, climatic and edaphic conditions are limiting factors to mangrove growth and development.

Mangroves are frequented by wildlife (figure 1) that includes, depending on the geographic region, mammals, reptiles and amphibians, migratory birds, and sea life. The roots provide surfaces to algae up to shellfish and hiding places from predators. Their leaves are eaten or as leaf litter in the water are fragmented by amphipods and crabs, and further broken down by micro-organisms into useful minerals and organics. Mangroves aerate the soil directly, by penetrating it with their roots, and indirectly, by the burrowing action of sea life that is hosted in their habitat [3].

Figure 1. Mangroves and Arabian red fox in a residential area of Abu Dhabi, UAE (photo by the authors).

Mangroves protect low-lying coastal areas from natural hazards such as tsunamis, hurricanes/cyclones, storms and flooding and intercept nutrients creating rich marine ecosystems. They mitigate the impact of natural hazards by reducing the force of wave currents, thus acting as buffer zones; modify coastlines and stabilize the ground with their roots, especially in prograding newly-created mud-flats; and prevent beach erosion [1,4]. The moderating effect of coastal mangrove forests to the impact of severe storms has been seen repeatedly, with a recent case illustrating this point taking place during the typhoon storm surge in Eastern Samar, Philippines. There, mangroves absorbed the storm surge, protecting a village nestled between two large mangrove forests, where, in contrast, neighbouring villages were only saved because of early evacuation measures [5]. FAO (Food and Agriculture Organization of the United Nations) [1] calls “coastal mangroves…vital shelter-belts, which afford protection to inland homesteads, agricultural crops, livestock and aquaculture.”

Mangroves provide food for coastal communities as they host a variety of fish, crab, shrimp, and
Molluscan species. They are used as firewood and in traditional communities as beams and poles for roofs and paneling, and boat building. Further products extracted from mangroves find applications in the food, drug, and beverage industry, as dyes and tannin for textiles and leather, and as components in household items [1].

Despite their numerous advantages, mangroves are being cut down to make room for infrastructure, or shrimp farming [6], whilst others are being replanted as part of conservation programs [7]. The current paper aims to present the state of affairs of the mangroves in Abu Dhabi, United Arab Emirates (UAE), and discuss some of the threats to them due to the rapid urbanization taking place along the coast of this country [8].

2. Anthropogenic threats to mangroves
The exponential growth of population has created significant pressures on coastal environments. Currently, more than 600 million people, or about 10% of the world’s population, reside in coastal areas, and 2.4 billion people live within 100km of a coast.

The United Nations estimates that about 245,000 km² of dead marine zones exist today, with that number doubling every ten years since the 1960s. 80% of the marine debris originates from land-based sources, with the remaining due to marine sources, such as marine transportation, exploration, and fishing. 60% to 80% of the marine debris consists of plastic with estimates that by 2050 almost all of the seabirds will have ingested micro-plastic [9].

Coastal development is the main threat to mangroves with coastal land use changes being responsible for about 20% to 35% loss in mangrove areal coverage. Untreated wastewater, either discarded directly or transported by waterways to the oceans is a significant factor for marine water pollution, and the same applies to fertilizers that by river transport can create hypoxic conditions (dissolved oxygen below 2-3 mg/l) at the receiving sea waters. Hypoxic waters exist extensively along the East Coast of USA and the Gulf of Mexico, the Bay of Biscay, France, the Calais Channel, and the North and the Baltic Seas.

In the Arabian Gulf, hypoxic sea waters are found between Bahrain and Qatar [10], while micro-plastic has been detected in a stagnation sea water zone above Qatar [11]. Heavy metals and chemicals used in desalination processes can contribute to mangrove degradation, decline in the number of invertebrates and fish, and reduction in ecosystem structural complexity. The heavy tanker traffic in the Arabian Gulf, of about 165,000 ship calls per year, apart from accidental spills and illegal tank washing, discharges ballast water originating from other parts of the world, thus introducing alien species in the Gulf [12]. The entry into force in 2017 of the international treaty on ballast water was motivated by the “devastating” effects of the introduction of new species in the waters of a region from other parts of the world and the “alarming increasing rate” of bio-invasions [13].

River modification through dams, channels, levees, and river diversion affects the balance between erosion by wave action and sediment deposition by river transport and flooding in deltas, resulting in coastal retreat and land subsidence, thus affecting mangrove habitat.

Dredging removes material and benthic communities from the sea bed and disposes spoils, modifying the topography of the sea bed by creating furrows, pits, and escarpments. Recolonization and recovery of most marine ecosystems at dredged sites ranges from 6-8 months in estuarine muds, to 2-3 years for sand and gravel, to about 10 years for communities in coarser material, respectively [14]. Coral reefs are very sensitive to turbidity disturbances created by dredging operations with survival rates ranging from a few days, for sensitive species, to about 5-6 weeks, for tolerant ones [15]. Dredging of channels to increase depth can kill young mangrove seeds or roots that are beginning to grow. It can result in mangrove loss and accumulation of roots and branches floating in the water, reducing sunlight penetration into the water that marine species rely on. It affects sea current distribution and sediment transport patterns in the vicinity of a modified site.

In tidal lagoons and canals in urban areas, such as those in Abu Dhabi, which are heavily engineered for real estate and multiple entertainment uses it has been reported [16] that planted mangrove seedlings are hard to be established as a result of the waves generated by boats and floating
debris discarded either by boat passengers or by strollers along the engineered coastal walkways (figure 2).

![Figure 2. Engineered lagoon modification with mangroves shown to the right, Abu Dhabi, UAE (photo by the authors).](image)

Coastal structures that include groin fields, ports and harbors, and seawalls, as shown in figure 2, all interfere with the dynamic material balance of accretion and erosion between land and sea, and modify the diffraction of waves around the port slits and other man-made structures emplaced in the sea, as well as the refraction of waves in the nearshore shallow waters.

3. Mangroves in Abu Dhabi, UAE

Castaneda-Moya et al [17] found that in Honduras the species Avicennia germinans or black mangrove, a shrub in coastal lagoons and brackish-water estuaries that grows in height just above the high-tide level was found in areas of high salinity ranging from 80 to 140 g kg\(^{-1}\), and the species Rhizophora mangle or red mangrove that grows on aerial prop roots in brackish coastline waters and swampy salt marshes was dominant under salinities of 38 to 57 g kg\(^{-1}\). In Abu Dhabi, where salinities range from 125 to 150 g kg\(^{-1}\) [11], the species of mangroves present is the highly salt-tolerant Avicennia marina or grey mangrove, covering an area of 155.2 km\(^2\), most of it being continuously planted the last 30 to 40 years [7].

Although, saline environments are required for mangroves, hyper-saline environments, such as those found in Abu Dhabi, require high suction by the mangrove roots in order to extract fresh water (because of the increasing with the salinity level negative osmotic pressure), and hence, the observed increase in coastal salinity that has resulted from the intense desalination activities taking place in UAE can lead to stunting of mangrove growth [1,3,12]. In addition the combination of desalination and energy production, which has intensified in the UAE due to an about 9% increase in energy demand annually, has increased sea water temperature by 7-8°C decreasing dissolved oxygen content, a condition that may affect both the mangroves and the marine life in coastal waters [12].

In general the sulphate acidification problem common to several mangrove sites is not encountered at the Abu Dhabi mangroves sites due to the presence of the particular mangrove species, the sandy nature of the soils, and the high levels of calcium carbonate in these sites [1,18].

FAO [1] estimated that in 1990 monetary terms a minimum value of the mangroves, based on the wood and fish obtained by mangrove forests in Fiji, was $3,000/ha. For the Abu Dhabi mangrove area this estimate, with an adjustment made for the buying power of the US dollar between 1990 and 2019, which is: 100 US dollars in 1990 is equivalent to the buying power of 194.49 US dollars in 2019 [19].
returns a minimum value of 90.6 million US dollars of wood and fish services provided by the mangroves.

The placement of cement factories in the vicinity of mangrove areas in Abu Dhabi (figure 3) with their emission of heavy metals, such as Cd, Pb, Hg, Ni, particulates, nitrogen and sulphur oxides, carbon monoxide, and other compounds into the atmosphere and their subsequent deposition in the water of the Gulf poses a threat to the mangroves and their ecosystems. In addition, the United Arab Emirates is very high in the list of countries with PM$_{2.5}$ pollution, and equally high are the anthropogenic NOx emissions in the Gulf region. In the Gulf, UAE is found immediately after Iran in NOx pollution with the large desalination and power plants being the major sources of this [12].

![Figure 3. Escarpment due to dredging and cement factories near mangroves, Abu Dhabi, UAE (photo by the authors).](image)

At the same time, the heavy engineering of the coast in the city of Abu Dhabi and its islands by intercepting the material transported from land can result in sand depletion at the beachfront. Structures set by the coast accumulate sand at their upstream side not allowing beach replenishment, and the action of the tide may result in loss of sand to deeper water. The creation of several marinas with the construction of seawalls in the place of the previously smooth land incline has eliminated in many cases natural beaches [20]. In addition, the small mouth of these ports to the sea (see figure 2) will result in the built up of sand at their entrance, which will require continuous dredging operations.

The creation of many artificial canals engineered to provide water views to residential towers has modified water currents in the shallow lagoons of Abu Dhabi, resulting in extremely slow movement of water through them followed by rapid development of algae in the waters. Dredging operations to build seawalls, and engineered walkways and entertainment areas, as well as provide motor boat access through the canals has created escarpments that have buried in some cases mangrove roots (figure 3).

Motorized boat access particularly in sheltered tidal lagoons and estuaries have been associated with beach erosion due to boat wake wave [21,22]. Recreational boat traffic impacts also the turbidity of the water. Although inducing the suspension of sediments may result in subsequent settlement of these particles back to their original location, a phenomenon which has a higher chance of occurring in areas of slow water circulation, small particles have long settling times and in engineered for water-recreation canals with relatively heavy traffic it is highly likely that these particles may be carried further seaward, resulting in beach erosion at the original locations [23].

The existence of several coastal roads and highways in Abu Dhabi connecting through multiple bridges the main island with the smaller islands introduces substantial quantities of zinc and microplastic to the waters from the wear of rubber tires and brake pads [18].
The continuous development of smaller islands around the city and the construction of bridges to connect them to the mainland is expected to further exacerbate pressures on the mangrove areas. Figure 4 indicates with red the approximate position of a soon to be constructed bridge that will span several small islands. It is clear that this bridge will further modify the hydrodynamic circulation inside the narrow lagoon that hosts the mangrove area at the bridge’s lower end, in an area that has already been heavily altered by marinas, seawalls, and other structures. The center of the lagoon, over which the bridge will pass, with its light greenish color indicates shallow water, which means that heavy dredging operations will have to take place for bridge pier construction. For the narrow inlet of the lagoon the deeper depths that will be created through dredging for bridge construction will increase the tidal prism and scouring may result at the bridge’s piers. Scour holes near the bridge piers in some cases have been seen to exceed depths of 30-40 m [24]. At the same time recreational boat crossing under the bridge from the marinas located at the site will result in material deposition at the outer edge of the mangrove, which may require mitigation measures. At any rate many bridges constructed at narrow inlets, such as the one shown in figure 4, required further engineering measures to stabilize the inlet and some had not reached their evolutionary equilibrium even after almost one hundred years. Thus, it appears that with the continuous construction taking place in Abu Dhabi, engineered structures, such as seawalls, ports harbors, bridges, groins, and jetties are those expected to provide coastal protection and the role of the mangroves will primarily be of aesthetic value with beach erosion control and habitat development probably going to be of secondary value [25].

4. Summary and conclusions

Mangrove are salt-tolerant bushes or trees growing at the intersection of fresh and saline waters in tidal lagoons, estuaries and deltas where they create rich ecosystems of fish and shellfish and providing shelter, food, and grounds for reproduction to mammals, reptiles, amphibians, and migratory birds. Mangrove forests are found extensively in several countries in Asia, America, and Africa.

Mangroves are used by communities for wood, and fish and shellfish harvesting, and they play an important role in soil stabilization and wave and flood modification by absorbing storm surges protecting coastal communities. They are threatened though by human activities, which include discharge of untreated wastewater that may create hypoxic conditions; engineered structures, which interfere with material deposition and current circulation; and ship and boat movement, which create wake waves, or introduce ballast water and alien species in a region from other parts of the world.
The highly salt tolerant mangrove species of Avicennia marina covers about 155 km$^2$ of the Abu Dhabi shoreline. Despite environmental regulations mangroves’ existence in Abu Dhabi may be at a precarious position as a result of the intense coastal development and engineered shoreline modification taking place in the country. Cement factories emit in the atmosphere heavy metals and other particles, later being deposited in the sea, thus degrading mangrove habitats. Marinas, ports, canals, and seawalls constructed to provide residential sea views modify hydrodynamic conditions in the tidal lagoons where mangroves reside and affect the settling of particles directing them seaward. Motorized boats create wave wakes, which have the potential to increase sea water turbidity disturbing sea bed sediments and affecting beach erosion. Finally, the dredging that accompanies construction in coastal environments removes benthic communities and material modifying the seabed and can create conditions adverse to mangrove survival.

Acknowledgments
The support from the United Arab Emirates Ministry of Higher Education & Scientific Research through the award of the research grant 2015-IR-742 to the first author is gratefully acknowledged.

References
[1] FAO (Food and Agriculture Organization of the United Nations) 1994 Mangrove Forest Management Guidelines available at: http://www.fao.org/3/ap428e/ap428e00.pdf
[2] MAP (Mangrove Action Project) 2019 Mangrove distribution available at: https://mangroveactionproject.org/mangrove-distribution/
[3] Healy T, Wang Y and Healy J-A eds. 2002 Muddy Coasts of the World: Processes, Deposits, and Function Vol 4, 1st ed. (Amsterdam, Netherlands: Elsevier Science.)
[4] Mazda Y, Magi M, Nanao H, Kogo M, Miyagi T, Kanazawa N and Kobashi D 2002 Coastal erosion due to long-term human impact on mangrove forests Wetlands Ecology and Management 10 1-9
[5] Santos M 2014 How a forest of mangroves saved a village from ‘Yolanda’ available at: https://newsinfo.inquirer.net/649122/how-a-forest-of-mangroves-saved-a-village-from-yolanda
[6] Ashton E C 2008 The impact of shrimp farming on mangrove ecosystems CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 3 doi: 10.1079/PAVSNRR20083003
[7] Environment Agency-Abu Dhabi 2014 Biodiversity Annual Report 2014 Status of Mangroves in Abu Dhabi available at: https://www.ead.ae/Publications/Status%20of%20Mangroves%20in%20Abu%20Dhabi%202014.pdf
[8] Van Lavieren H, Burt J, Feary D A, Cavalcante G, Marquis E, Benedetti L, Trick C, Kjerfve B, and Sale P F 2011 Managing the growing impacts of development on fragile coastal and marine ecosystems: Lessons from the Gulf (Hamilton, ON, Canada: United Nations University-Institute for Water, Environment and Health Policy Report)
[9] United Nations The Ocean Conference 2017 Concept paper on partnership dialogue 1: Addressing marine pollution p 10 available at: https://oceanconference.un.org/documents
[10] Diaz R J and Rosenberg R 2008 Spreading dead zones and consequences for marine ecosystems Science 321 926-9
[11] Paleologos E K, Farouk S and Al Nahyan M T 2018 Water resource management towards a sustainable water budget in the United Arab Emirates 4th IOP Conf. Ser.: Earth Environ. Sci. 191 01 2007, DOI: 10.1088/1755-1315/191/1/012007
[12] Paleologos E K, Al Nahyan M T and Farouk S 2018 Risks and threats of desalination in the Arabian Gulf 4th IOP Conf. Ser.: Earth Environ. Sci. 191 01 2008 doi: 10.1088/1755-1315/191/1/012008
[13] IMO (International Maritime Organization) 2017 International Convention for the Control and
Management of Ship's Ballast Water and Sediments (BWM) Adoption: 13 February 2004; Entry into force: 8 September 2017. http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships'-Ballast-Water-and-Sediments-(BWM).aspx

[14] Newell R C, Seiderer L J and Hitchcock D R 1998 The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed Oceanography and Marine Biology 36 127-78

[15] Erftemeijer P L A, Riegl B, Hoeksema B W and Todd P A 2012 Environmental impacts of dredging and other sediment disturbances on corals: A review Marine Pollution Bulletin 64 1737-65

[16] Wolanski E and Elliott M 2016 Ecohydrology solutions Estuarine Ecohydrology 2nd ed. Chapter 7 pp 219-67 (Amsterdam, Netherlands: Elsevier Science)

[17] Castaneda-Moya E, Rivera-Monroy V H and Twilley R R 2006 Mangrove zonation in the dry life zone of the Gulf of Fonseca, Honduras Estuaries and Coasts 29 751-64

[18] Gilmour C and Riedel G 2009 Biochemistry of trace metals and metalloids in Encyclopedia of Inland Waters, Academic Press, p 7-15, doi.org/10.1016/B978-012370626-3.00095-8

[19] CPI Inflation Calculator, Buying Power of $100 in 1990 http://www.in2013dollars.com/1990-dollars-in-2018

[20] Kraus N C and McDougal W G 1996 The effects of seawalls on the beach: Part I, an updated literature review Journal of Coastal Research 12 691-701

[21] Bilkovic D, Mitchell M, Davis J, Andrews E, King A, Mason P, Herman J, Tahvildari N and Davis J J 2017 Review of boat wake wave impacts on shoreline erosion and potential solutions for the chesapeake bay Edgewater 17-002

[22] Gourlay T 2011 Notes on shoreline erosion due to boat wakes and wid waves CMST research report 2011-16. Center for Marine Science and Technology, Curtin University, 10 p

[23] Bauer B O, Lorang M S and Sherman D J 2002 Estimating boat-wake-induced levee erosion using sediment suspension measurements Journal of Waterway, Port, Coastal and Ocean Engineering 128 152-62

[24] S L Douglass and J Krolak 2008 Highways in the Coastal Environment 2nd Edi. 2008 Hydraulic Engineering Circular 25 FHWA-NHI-07-096

[25] Prasetya G 2006 The role of coastal forests and trees in protecting against coastal erosion Regional Technical Workshop Coastal Protection in the Aftermath of the Indian Ocean Tsunami: What Role for Forests and Trees (Khao Lak, Thailand) pp 103-31