

Chapter 7

Mangrove Ecosystems of the United Arab Emirates



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7.1 UAE Mangroves in a Global Context

Mangroves are a taxonomically diverse group of halophytic (salt-tolerant) shrubs and trees that occur in the space between the high and low tides on tropical and subtropical coastlines, a harsh and highly dynamic environment that presents exceptional challenges to the species that inhabit it (Hogarth 2015; Primavera et al. 2018; Spalding et al. 2010; Tomlinson 2016). The term mangrove has been also used to refer to the broader intertidal communities formed by these trees plus their associated biota, which are referred to as ‘mangrove ecosystems’ hereafter. Mangrove plants that are exclusively restricted to intertidal habitats are defined as “true mangroves”, and they form forests often consisting of monospecific patches or bands fringing muddy shores, predominately occurring in areas of gentle wave conditions such as bays, deltas and estuaries (Hogarth 2015; Nagelkerken et al. 2008). Mangroves act as ecosystem engineers, stabilizing the soil and creating a habitat that is exploited by a range of other organisms, from microbial communities to diverse assemblages of fauna and flora. Mangrove trees and associates are uniquely adapted to conditions that include alternating desiccation and submergence across tidal cycles, low oxygen concentrations in the water, variable and often high salinity, and high air and sea temperatures inherent to the tropics.

Despite sharing several, complex morphological and physiological adaptations enabling survival in this environment, mangroves species did not evolve from a single common ancestor. In fact, true mangroves are a polyphyletic group (*i.e.* have

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evolved from multiple evolutionary ancestors) composed by around 70 species from up to 20 families, in which distinct mangrove types have likely evolved independently at least 16 times (Hogarth 2015; Primavera et al. 2018). Of all the mangrove species described, only the gray mangrove (*Avicennia marina*) naturally occurs in the coasts of the UAE. The genus of *A. marina* is named after the Muslim philosopher and father of modern medicine Ibn Sīnā (commonly known as Avicenna in the West; 981–1037 CE), and is locally referred to as ‘Al Qurum’ in the countries of the Arabian Peninsula.

7.2 Mangrove Ecology and Distribution in the UAE

Different species of mangrove occur throughout the tropics, as well as in a few warm subtropical areas. They can survive air temperatures as low as 5 °C, but are intolerant of frost. Mangrove distribution, however, correlates most closely with sea temperature, rarely occurring outside of areas where average daily temperatures fall below 20 °C (Hogarth 2015). Of all mangrove species, the gray mangrove has the broadest latitudinal and longitudinal distribution (Spalding et al. 2010; Tomlinson 2016), extending across the entire Indian Ocean and into the West Pacific as far as Japan and New Zealand (Fouda and Al-Muharrami 1996; Khalil 2015; Sheppard et al. 2010; Spalding et al. 2010). The broad geographic distribution of the gray mangrove is reflected in its presence across diverse environmental gradients (e.g. temperature, freshwater, sediment and nutrient supply, salinity, tidal range) and spatial settings (e.g. open coastlines, coastal lagoons, estuaries, deltas, coral fringes) (Duke 1990; Quisthoudt et al. 2012). The Arabian Peninsula represents one of the northernmost edges of the species’ distribution (Duke 1991; Spalding et al. 2010; Tomlinson 2016), as well as an environmentally stressful habitat characterized by extreme temperatures, aridity, and often extreme salinity (see Chaps. 3 and 4), factors known to be limiting for mangrove growth (Ball 1988; Lovelock et al. 2016; Sheppard et al. 1992).

Mangroves ecosystems represent the only evergreen forests in the UAE, covering approximately 156 km² of land along the coasts of the country (Fig. 7.1; Killilea and Burt, in prep). Coastal topography plays a major role in the patchy and scattered pattern of mangroves throughout the coasts of the UAE. Sheltered lagoons house approximately half of the mangroves in the nation. Remaining stands consist of relatively linear communities occurring across intertidal areas bordering a number of bays, islands and tidal creeks from the westernmost coasts of the UAE near Al Ruwais throughout Abu Dhabi coasts, Ras Al Khaimah and Umm Al Quwain in the north; Dubai’s single mangrove population consists of the planted stand at Ras Al Khor. Outside the Arabian Gulf, in the Sea of Oman, lies the only mangrove forest on the UAE’s east coast, in the Khor Kalba reserve near the border with Oman (Fig. 7.2; Al Habshi et al. 2007; Almahasheer 2018; Moore et al. 2014; Saenger et al. 2002; Saito et al. 2003).

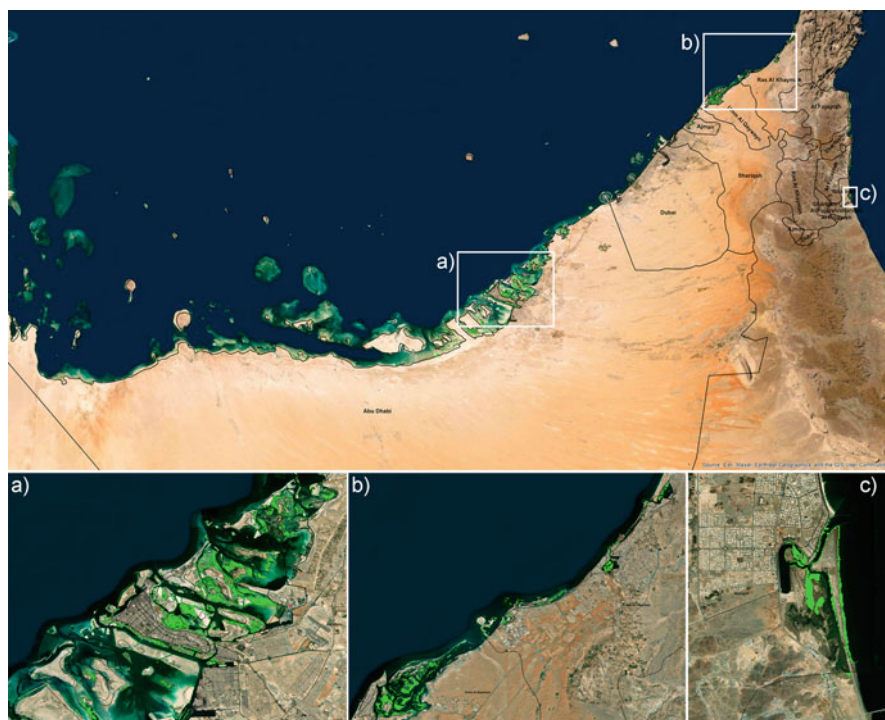


Fig. 7.1 Mangroves distribution. Top panel: Distribution of mangroves, shown in green, of the UAE created using GEEMMM in Google Earth Engine with Landsat imagery collected between 2020 and 2022 (method from Yancho et al. 2020). Bottom panel: provides detailed view of the areas indicated in the top panel (a) Abu Dhabi mangroves. (b) Ras Al Khaimah and Umm Al Quwain mangroves. (c) Khor Kalba mangroves. Basemap courtesy of ESRI “World Imagery” [basemap]. Accessed 20 March 2023 from <https://www.arcgis.com/apps/mapviewer/index.html?layers=10df2279f9684e4a9f6a7f08febac2a9> per the ESRI data use policy

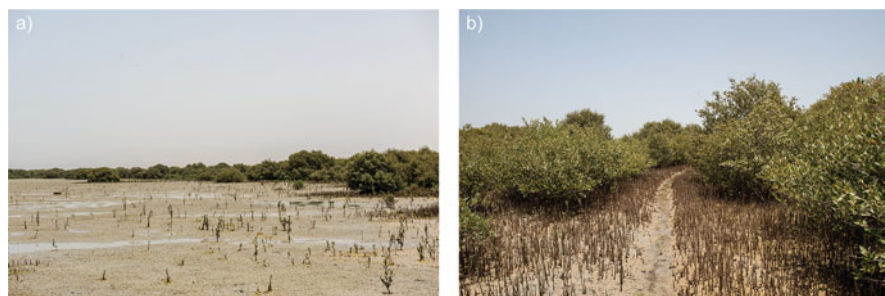


Fig. 7.2 Mangrove stands distribution in Ras Al Khaimah. (a) Linear mangrove stand fringing shoreline mudflats during low tide. (b) Mangroves growing along an inland tidal creek. Image credits: Vidhyaa Chandramohan

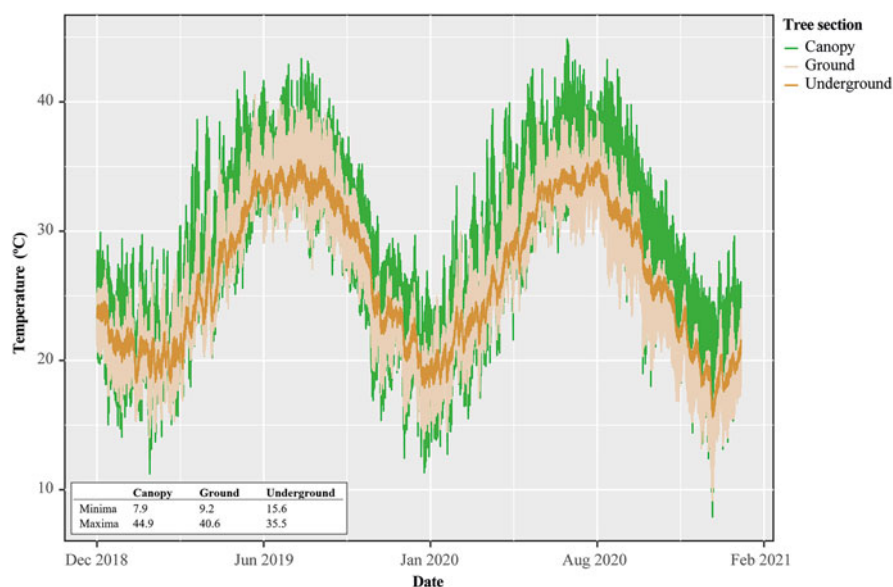


Fig. 7.3 Temperature variability through seasons in the mangroves of the UAE. Temperature records from ten different mangrove trees at Ras Ghurab, Abu Dhabi, measured at different heights through 2 years. Source: G. Friis, unpubl. Data

Distribution of contemporary populations of mangroves in the nation is not only limited by the coastal topography. Three main environmental factors constrain the occurrence of mangroves along UAE coastlines: wide seasonal variation in temperatures, high seawater salinity, and poor soil conditions (Al Habshi et al. 2007). Due to its geographic location in the northern subtropical high-pressure zone, the climate of the UAE is characterized by extreme aridity, with <150 mm of annual rainfall common across the country, and many areas experiencing <100 mm yr.⁻¹ (Al Habshi et al. 2007) (See also Chap. 3). The limited cloud cover results in high solar irradiance, causing land surface temperatures in many places to exceed 50 °C during summer days, with winter nighttime temperatures plunging below 8 °C due to the limited availability of vegetation and soil moisture to modulate temperatures (Patlakas et al. 2019). Coastlines of the UAE inhabited by mangroves are no stranger to these extremes. Two-year monitoring of temperatures at ten mangrove trees in a stand at Ras Ghurab Island, Abu Dhabi, revealed annual temperature ranges of 37, 30 and 25 °C in the canopy, on ground level and underground (~ 15 cm depth), respectively, with minimum and maximum temperatures ranging from 8 to 45 °C (Fig. 7.3). These records are highly congruent with previously reported thermal profiles in mangrove stands from the UAE (Al Habshi et al. 2007; Embabi 1993). Limited freshwater input and high evaporation rates also result in extreme salinity on the UAE's enclosed Arabian Gulf coast (Vaughan et al. 2019). Sheltered areas preferred by mangroves such as lagoons and bays present particularly high salinity levels, especially in summer. Generally, mangroves can grow when salt

concentrations stay below 45 to 50 ppm, yet there are records of salinity maxima in UAE mangrove stands ranging from 65 to 70 ppm in places such as Al Dabbiya, Khor Al Khuwair or Umm Al Quwain (Al Habshi et al. 2007; Shriadah 2000). High salinity is known to have significant impacts in the development and structure of mangroves, often resulting in stunted ‘dwarf’ trees, so that gray mangroves in the UAE rarely exceed the 5–7 m (Embabi 1993; Moore et al. 2014), while they can reach the 14 m in tropical environments. Only the mangrove system of the Khor Kalba reserve escapes this impact, to some extent. In contrast with the Arabian Gulf, the eastern coast of the UAE, bordered by the Sea of Oman, has normal oceanic salinity, and summer temperatures that are buffered by cold-water upwelling as a result of the Indian Ocean monsoon, resulting in a more moderate and less variable environment (Claereboudt 2019; Sheppard et al. 1992). Finally, studies on soil characteristics and chemistry revealed that mangroves of the UAE are restricted to substrates formed mostly by fine sand (95%) but with presence of silt and clay (5%), and are not observed on rocky soils or on pure sand beaches (Al Habshi et al. 2007). Nutrients such as nitrogen (N), phosphorus (P) and iron (Fe) known to be relevant for mangrove growth and survivorship (Almahasheer et al. 2016; Naidoo 2009) also occur in short supply in the soils of the UAE (Al Habshi et al. 2007; Moore et al. 2014), and their availability further determine the occurrence of mangrove ecosystems throughout the western and eastern coasts of the country.

Gray mangroves present several adaptative traits that enable their survival in the harsh environment of the intertidal zones of the UAE. As other mangroves species, they have mechanisms for salt uptake and excretion through specialized glands in the underside of the leaves (Howari et al. 2009). They also feature pencil-like roots of about 20 cm height, known as pneumatophores, which grow up above the ground to allow gas exchange for the mangrove roots to compensate for the anaerobic soils in which they grow. The root system of the gray mangrove is generally shallow, running horizontally and radially for several meters from the tree (Purnobasuki and Suzuki 2005), providing support to the substrate. Gray mangroves also produce buoyant seeds that can remain dormant for up to a year until they establish in a suitable environment (Alsumaiti et al. 2017). While these traits are shared by gray mangroves throughout their entire distribution, populations from the UAE, and in particular those occurring on its western Arabian Gulf coast, have seemingly developed specific adaptations to the local environmental conditions, such as more complex cuticular waxes coating the leaf surfaces to protect against water loss (Dodd et al. 1999) or genetically-based changes in physiological traits to cope with aridity, temperature and salinity extremes (Friis et al. 2022).

7.3 Ecological Importance and Diversity Supported by UAE Mangrove Forests

7.3.1 *Ecological Functions, Interactions and Productivity of Mangrove Trees in Coastal Ecosystems of the UAE*

Mangrove trees modify the conditions of their habitat by maintaining a relatively stable balance between deposition and erosion in intertidal zones. Anatomical structures such as pneumatophores and other kinds of aerial roots provide hard substrata in otherwise soft-sediment soils, creating an environment that is, in turn, exploited by a range of fauna and flora occurring not only at mangrove forests themselves, but across multiple, interconnected marine and terrestrial habitats (ElAmry 1998; Nagelkerken et al. 2008; Primavera et al. 2018). They are also major contributors of energy flow to detritus-based marine food webs (Jennerjahn and Ittekkot 2002), and provide several important functions such as shelter areas, nurseries, breeding and nesting grounds and feeding habitat (ElAmry 1998; Nagelkerken et al. 2008).

Although it is reasonable to assume that the ecological functions of mangroves in the Emirates are comparable to those in other tropical and subtropical regions, the specific mechanisms and relevance of UAE mangroves in the coastal biological systems remain relatively understudied. Little is known, for example, about insect species potentially involved in mangrove pollination in the UAE. Documented pollinators of *A. marina* in other parts of its distribution, such as the honeybee (*Apis mellifera*) or the oriental blue fly (*Chrysomya megacephala*), occur in the UAE, but studies confirming the role of these or other species in mangrove pollination are lacking. In terms of productivity, UAE mangroves have strikingly high biomass and primary productivity rates considering the harsh environment they inhabit. The standing biomass can reach 110 tons per hectare in dense mangroves (Saito et al. 2003). Litter fall estimates range from 5.1 to 8.5 tons per hectare per year depending on the height of the surveyed stands (Spalding et al. 2010), a highly significant input of inshore organic matter in this arid region where primary productivity is so limited (Spalding et al. 2010; See Box 7.2). However, net fluxes of organic matter towards other oceanic or terrestrial ecosystem have not been estimated in the UAE. Despite the lack of information, the role and importance of UAE mangrove as ecosystem engineers is reflected in the diverse biotic communities they support, including arthropods, mollusks, birds, fishes and other plant species. The most relevant and iconic of these species are detailed next.

7.3.2 *Crabs*

Brachyuran crustaceans, commonly known as crabs, are an important, often dominant element within the faunal assemblages of the intertidal habitats of the Arabian



Fig. 7.4 Crabs and mollusks in UAE mangrove ecosystems. (a) *Metopograpsus messor* and *llyograpsus paludicola* crabs forage by mangrove pneumatophores, Umm Al Quawain. (b) Mud snails *Cerithidea cingulata* crowd in the sediments of a mangrove forest, Umm Al Quawain. (c) Barnacles on a dead mangrove branch in the Eastern Mangroves Park, Abu Dhabi. (d) The giant mudcreeper (*Terebralia palustris*), a locally endangered species that can only be found in the mangroves of Khor Kalba in the UAE. Images credit a–c: Vidhyaa Chandramohan. Image credit d: From Fig. 7.2 in Lieb et al. (2010), reproduced under the terms of the Creative Commons Attribution License (CC BY 2.0)

Gulf, including those covered by mangroves (Apel and Turkey 1999). Like mangrove trees themselves, crabs play a key role in the ecosystem, promoting nutrient recycling and shaping the structure of mangrove forests (Nobbs and Blamires 2015). Their activity affects the availability of resources for other mangrove-associated organisms through burrow construction and maintenance, shredding of plant litter, and by modifying the activity and distribution of the sediment microbiota (Nobbs and Blamires 2015). Along the UAE's Arabian Gulf coast, crab communities in the mangrove ecosystems are dominated by species of the families Ocypodidae (16 species) and Grapsidae (4 species), with as well as representation by the families Portunidae (like the mangrove crab, *Scylla serrata*), Majidae, Xanthidae, and Leucosiidae (Al-Ghais and Cooper 1996; Apel and Turkey 1999; Cooper 1997). Most commonly seen species are the grapsids *Metopograpsus messor* and *llyograpsus paludicola* (Fig. 7.4). Crab diversity is seemingly higher in the northeast of the UAE coasts inside the Arabian Gulf according to the most complete survey published to date (Apel and Turkey 1999), due to the conspicuous absence of fiddler crabs (genus *Uca*) in the southern and western Gulf (Apel and Turkey 1999). In addition, a diversity survey conducted in the Khor Kalba reserve (Aspinall et al.

2002) revealed the presence of two other species absent within the Gulf: *Clibanarius longitarsus* and *Perisesarma guttatum*.

7.3.3 Mollusks

Several species of marine mollusks (clams, snails, whelks, etc.) can be found in the soft sediments and flats inhabited by the mangroves of the UAE, yet their general distribution is only partially determined by the presence of mangrove trees (Grizzle et al. 2018). Bivalves occurring in high densities in mangrove forests include the hooded oyster (*Saccostrea cucullata*) and the Venus clam (*Circenita callipyga*). Among other gastropods we can find the crown turban snail (*Lunella coronata*), the mud snail species *Cerithidea cingulata* (Fig. 7.4) or the sea snail species *Hexaplex kuesterianus* (Grizzle et al. 2018). Barnacles are occasionally present on the pneumatophores, mostly *Euraphia withersi* but also *Balanus amphitrite* and *B. trigonus* (John and George 2004). In addition, in the Khor Kalba mangroves of the east coast we can find the giant mudcreeper (*Terebralia palustris*, Fig. 7.4). This gastropod was once common in the western coasts of the country, as well as an important food resource for local human communities, as proven by its presence in shell middens found by prehistoric settlements (Aspinall et al. 2002; See Sect. 4). However, habitat destruction and other environmental pressures likely drove the giant mudcreeper to the extinction in the southern Arabian Gulf (Aspinall et al. 2002).

7.3.4 Fishes

Mangrove ecosystems are also known to play an important role in sustaining different fish species through various ecological functions. The specific relevance of mangroves for fish diversity in the UAE is, however, not well characterized, and potential connections between mangroves ecosystems and fish-exploited habitats such as seagrass and reefs remain understudied in the region. A fish population survey conducted in mangrove swamps in Abu Dhabi, Umm Al Quwain and Ras Al Khaimah (Al-Ghais 1993) identified two evenly distributed, dominant species in this habitat: the Arabian toothcarp (*Aphanius dispar*) and the common silver-biddy (*Gerres oyena*). A large number of juveniles were also recorded, some of which were species of high economic interest such as *Lutjanus fulviflamma*, *Liza macrolepis*, *Sparus sabra*, *Pseudohombus javanicus* or *Cynoglossus* sp. Small bottom-dwelling fish such as blennies and gobies were also found, sometimes in large numbers (Al-Ghais 1993).

7.3.5 Birds

The coasts of the UAE serve as an essential breeding and non-breeding area for vast numbers of birds (Aspinall 1996; Shah et al. 2018). Mangrove habitats in particular support a rich diversity of avian life, yet the importance of mangrove ecosystems to the avifauna has not been documented in depth in this region. Two UAE resident species of heron are known to heavily rely on mangroves: the western reef heron (*Egretta gularis*, Fig. 7.5a) and the striated heron (*Butorides striata*). These species use the mangrove forest as foraging habitats and for nesting, yet they are not restricted to them (Shah et al. 2018). In the east coast, the mangroves and mudflats



Fig. 7.5 Birds in UAE mangrove ecosystems. (a) Western reef herons (*Egretta gularis*) perching in the Eastern Mangroves Park, Abu Dhabi. (b) Kalba white-collared kingfisher (*Halcyon chloris kalbaensis*). (c) Greater flamingos (*Phoenicopterus roseus*) in Bul Syayeeef. Image credits: Oscar Campbell

of Khor Kalba are critical to the survival of an endemic subspecies of the white-collared kingfisher, the *Halcyon chloris kalbaensis* (Fig. 7.5b), which breeds nowhere else in the world (Aspinall et al. 2002). The white-collared kingfisher nests in holes in mangrove trees, and feeds on crabs present in the mudflats and from among the mangrove's pneumatophores during low tides (Aspinall et al. 2002). Khor Kalba is also the only place of the UAE where we can find the Sykes's warbler (*Hippolais rama*), although it is not rare in other regions of the world (Aspinall et al. 2002). A celebrated bird species in the UAE is the greater flamingo (*Phoenicopterus roseus*, Fig. 7.5c). An usual winter visitor, it started breeding in Abu Dhabi only three decades ago (S. B. Khan et al. 2017). Since 2009, flamingos have been regularly breeding in Bul Syayeeef, a marine area in Abu Dhabi of particular importance due to the presence of large stretches of inter-tidal mudflats, mangroves and salt marshes. Other winter visitors include species of interest like the Western Marsh Harrier (*Circus aeruginosus*) from Central Asia, or the Greater Spotted Eagle (*Clanga clanga*), a species of global conservation concern. Up to 20 of them can be seen each winter at Ras al Khor in Dubai (Oscar Campbell, *pers. comm.*). The Western Cattle Egret (*Bubulcus ibis*) also winters in Abu Dhabi, and every night they fly to the mangroves to roost. Other species in the UAE use mangroves for roosting, including the iconic Purple Sunbird (*Cinnyris asiaticus*) or various dove species.

7.3.6 Plants

Only a reduced number of plant species are able to cope with the environmental conditions found in the mangrove habitats, beside *A. marina* itself. The most common is the amaranth shrub *Arthrocnemum macrostachyum*, easily found along the inland limits of mangrove bands (Böer and Saenger 2006). The parasite plant *Cistanche tubulosa* (Fig. 7.6b), known as the dessert Hyacinthus, is also common, and easy to spot during its reproductive period in March and April. The species *Salicornia europaea*, cultivated for oilseed and as a fodder crop in various parts of the world, grows along with mangrove trees on the edge of the large Khor Al Beida in Umm Al Quwain (Shahid 2017). At some mangrove stands across the UAE, pneumatophores often appear shrouded by curtain-like growths of green filamentous algae, principally *Chaetomorpha linum* and *Cladophora nitellopsis* (John and George 2004).

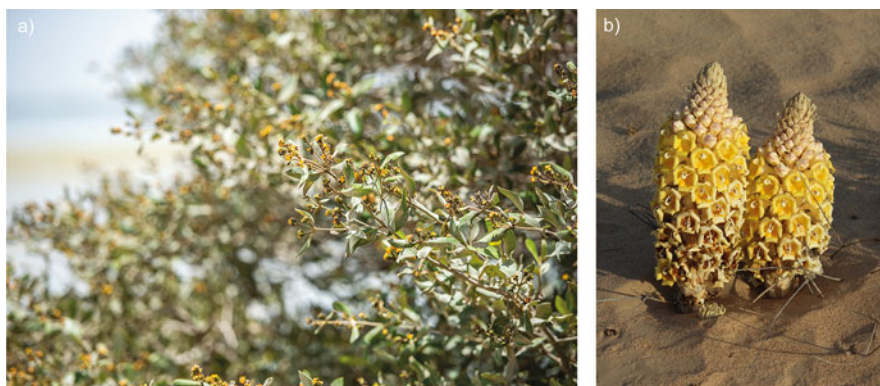


Fig. 7.6 Plant associates in UAE mangrove ecosystems. **(a)** Flower detail of a mangrove tree, Ras Al Khaimah. **(b)** Dessert Hyacinthus (*Cistanche tubulosa*). Images credit a: Vidhyaa Chandramohan. Images credit b: [Cistanche tubulosa Huqf 2.jpg](#) by Diorit, reproduced under the Creative Commons Attribution-Share Alike 4.0 International license ([CC-BY-SA-4.0](#))

7.4 Cultural and Economic Importance of the Mangrove Ecosystem in UAE

Mangrove ecosystems in the UAE have historically been an important cultural and economic resource (Uerpmann and Uerpmann 1996; Beech and Kallweit 2001; Beech and Hogarth 2002), while in other parts of the world they had been viewed as having limited economic or cultural value (Lugo and Snedaker 1974). There is extensive archeological evidence of mangrove ecosystems being an important regional food resource. Mangrove associated mollusks (*Terebralia palustris*, Fig. 7.5) have been found in the middens of archeological sites in Ras al Khaimah dating back to the Stone Age, and in Kalba dating back to the Bronze Age (Beech and Kallweit 2001; Goudie et al. 2000; Lindauer et al. 2017). Three other archeological sites across the UAE have found remains of mangrove crabs (*Scylla serrata*) in middens providing further support regarding the importance of mangrove ecosystems as a food resource (Beech and Hogarth 2002). Additional archeological sites, from 6000 ybp in Ras al Khaimah, found fish bones and oyster shells with mangrove root impressions further supporting a long history of mangrove ecosystems economically supporting the Arabian Gulf region (Uerpmann and Uerpmann 1996).

Direct uses of mangroves include timber and camel fodder. Camels have been observed eating mangrove leaves and it has been suggested that they were historically used as camel fodder (Lieth and Lieth 1993; Llewellyn-Smith 2012). The presence of mangrove stumps provide evidence of harvesting the trees (Goudie et al. 2000), and the wood was an important resource for home construction and boat building in the region (Beech and Hogarth 2002).

The discovery of oil and changing economy of the twentieth century resulted on less direct dependence on coastal ecosystems, and an increase in coastal development and environmental pressure on mangrove ecosystems. In the late 1970s H.H. Sheikh Zayed bin Sultan al Nahyan, President of the UAE., initiated plantings of both native and introduced species of mangroves in the UAE and restricted the harvesting of mangroves (Lieth and Lieth 1993; Saenger et al. 2002). Ultimately, *A marina*, the local mangrove species was the only species that successfully established in the UAE (Lieth and Lieth 1993). During the 1980s and 1990s, there was scientific and economic interest in creating plantations of halophytic species to create agricultural benefits without straining freshwater resources which included a research conference in Al Ain in December 1990 that resulted in several research papers on mangroves (Lieth and Al Masoom 1993).

The twenty-first century brought a change in the cultural and economic value of mangrove ecosystems from agricultural ecosystems, where resources are extracted, to ecosystems that need protection. Through protection and planting programs developed in the previous decades there was a near doubling in the extent of mangroves in the UAE. Recent interest in mangroves has been focused on their environmental and recreational value.

In 1995 0.96% of the UAE gross national product was from tourism this increased to 9.2% in 2019 which corresponds with 20 million more visitors per year (“Tourism in the United Arab Emirates” 2022). Mangrove parks provide an opportunity for visitors to experience the natural resources of the UAE. Kayaking tours are a popular way to explore the Mangrove National Park in Abu Dhabi and the mangrove ecosystems in Ras al Khaimah. Ras al Khor in Dubai provides a walkway and hides where tourists can observe flamingos, while in 2011 their logs only included 950 tourists they represented 88 different countries (Ryan et al. 2012). These sites not only attract international tourists but also provide educational opportunities for local schools. The link between education, tourism and conservation were highlighted during a visit to the UAE by Prince William in February 2022 when his schedule included planting mangroves in Jubail Mangrove Park, which opened in January 2020 to help protect biodiversity and raise awareness of the UAEs mangrove ecosystems (Forster and Maxwell 2022).

While mangroves provide eco-tourism opportunities, the economic growth of the region has led to habitat loss and environmental degradation in some areas. At the same time there is an increasing interest by residents of the UAE to protect these ecosystems. The majority of residents recently surveyed in Ras al Khaimah supported preservation of the mangroves over economic development, but this desire to protect these ecosystems does not seem to be driven by a knowledge of the ecosystem services they provide (Assaf et al. 2022). Whether or not the general public can clearly identify the environmental and economic value of these ecosystems there has been an increased interest in seeing these ecosystems continue to thrive.

Box 7.1 Evolution and Diversity of Arabian Mangroves

The evolutionary processes that led to the colonization and adaptation by *Avicennia marina* to the harsh environment of the western coasts of the UAE and the rest of the Arabian Gulf represent a fascinating mystery for evolutionary biologists. The diversification of the different varieties of *Avicennia marina* has been dated at approximately 3 million years ago (Li et al. 2016), with the variety *A. m. marina* occupying the largest fraction of the species distribution, from the coasts of East Africa and the Arabian Peninsula to the southern coast of Japan and the Western and Northern coasts of Australia, throughout the Indian Ocean to the South of China. However, the Arabian Gulf is a very young sea. Being as shallow as 36 m on average, the Arabian Gulf was completely drained during the peak of the last glaciation, which encompassed the period from 115,000 to 12,000 years ago, approximately. It was not until 12,500 years ago that the infilling of the southern basin of the Gulf started, and present shorelines were not reached until just 6000 years ago (Lambeck 1996). It was assumed, therefore, that the gray mangrove populations of the Arabian Gulf were the result of a recent colonization that followed the formation of the enclosed sea after the last glacial maximum, an extraordinarily short period of time in evolutionary terms during which, nevertheless, the mangroves were able to adapt to the exceptionally stressful environment of the region. However, analyses based on genetic data suggest an alternative, unexpected scenario. Phylogenetic analyses reconstructing the evolutionary relationships among mangroves of the UAE both inside and outside the Arabian Gulf reveals that these populations are highly differentiated, and that the differentiation process started around 32,000 years ago, before the last glaciation peak (Friis et al. 2022). In other words, mangrove populations from the Arabian Gulf are older than the Gulf itself, and they seemingly survived in relict ‘marine swamps’ during the last glacial period, a pattern never documented before for any marine taxa in this region. Genetic indices such as nucleotide diversity and heterozygosity, reveal higher levels of genetic diversity in the mangroves of the east coast compared to those within the Arabian Gulf, where the reduced habitat availability during the glaciation seemingly resulted in more genetically depauperate populations. Furthermore, the Tajima’s D index, a parameter that correlates with recent

(continued)

Box 7.1 (continued)

demographic growth, shows a more pronounced pattern of population expansion in the UAE mangroves from within the Gulf, congruent with a demographic recovery following the end of the glaciation and rise of the sea levels (Fig. 7.B1.1).

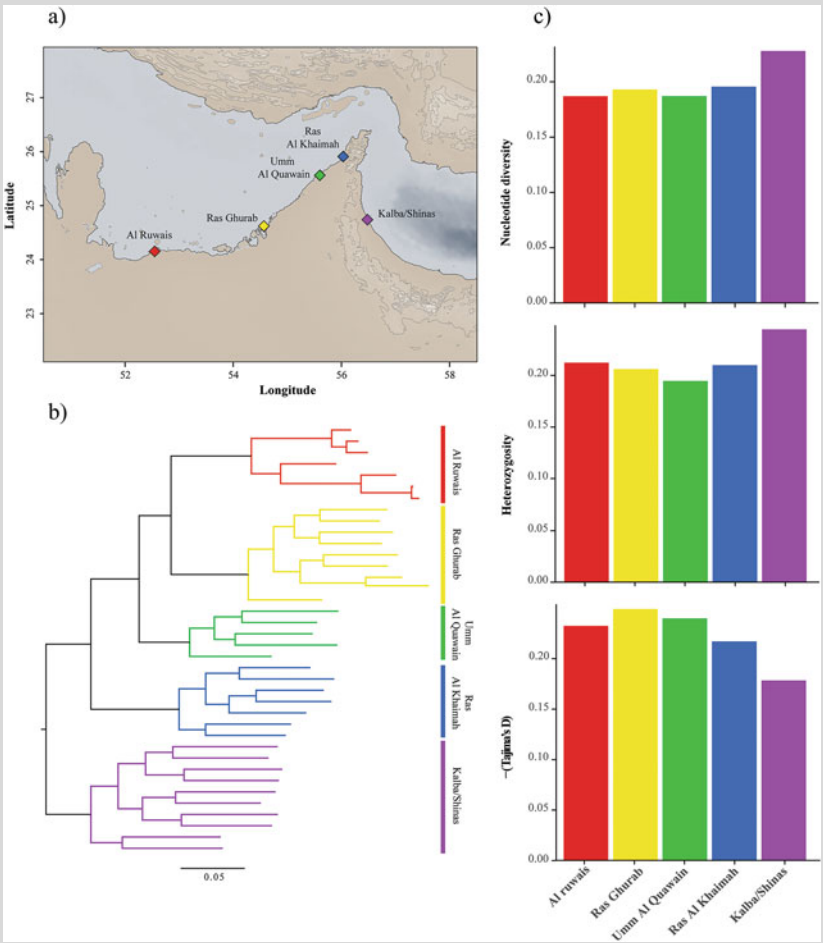


Fig. 7.B1.1 Evolutionary history and genetic diversity in UAE mangroves. **(a)** Geographic location of the analyzed mangrove populations. **(b)** Phylogenetic tree. Each terminal branch represents an individual, colored by population of origin. Internal branches represent evolutionary relationships among mangrove populations. Branch lengths depict genetic distance among individuals (substitutions per site). **(c)** Estimates of genetic diversity (nucleotide diversity and heterozygosity) and demographic expansion (Tajima's D). Data source: G. Friis, unpubl. Data

Box 7.2 Mangroves as Blue Carbon Ecosystems

Measurements of global average atmospheric carbon dioxide (CO₂) provided by the National Oceanic and Atmospheric Administration (NOAA) hit its highest ever peak in May 2022 at an average of more than 420 parts per million, a 50% higher concentration than in pre-industrial times. Along with mitigation strategies to reduce emissions derived from fossil fuel combustion, approaches to fight against climate change include nowadays strategies supporting CO₂ uptake and storage in what have been named ‘blue carbon’ ecosystems, *i.e.*, ecosystems with high carbon sequestration rates through plant growth and accumulation of organic matter in the soil. Vegetated coastal ecosystems present significant potential for organic carbon storage (Donato et al. 2011; Mcleod et al. 2011). Mangroves are among the most carbon-rich forests in the tropics, conspicuously contributing to carbon sequestration along with other oceanic and coastal ecosystems such as seagrasses, algae, salt marshes and other plants in coastal wetlands (Chmura et al. 2003; Donato et al., 2011). Dynamics of carbon sequestration and storage have been well documented in humid and tropical climates, but they have drawn less attention in arid regions such as Arabia. A recent study led by Schile et al. (2017) measured whole-ecosystem carbon stocks in multiple sites across the UAE in natural and planted mangroves, as well as in salt marshes, seagrass beds, microbial mats, and coastal sabkha. The study reports that naturally occurring mangroves held significantly more carbon than other vegetated ecosystems in the Emirates, both in terms of biomass and soil organic matter, for an average of 218 tons of carbon per hectare overall, a storage capacity 64% higher than the next blue carbon ecosystem in the region (the microbial mats) and a 106% higher than planted mangroves. Schile et al.’s work reveals UAE mangrove ecosystems as critical for carbon sequestration compared to other blue carbon ecosystems in the region, and provides evidence that mangrove restoration programs may not consistently promote the successful establishment of mature mangrove ecosystems. Given the UAE’s interest in carbon reduction (e.g. hosting COP-28 in 2023 and aiming for net-zero emissions by 2050), conservation of local mangrove forests is therefore of key importance in supporting the national goals for combatting climate change (Fig. 7.B2.1).



Fig. 7.B2.1 Activities to increase carbon storage capacities of ecosystems in Abu Dhabi. (a) Participants of a plantation event in the Jubail Island Park. (b) Recently planted mangrove trees a part of an afforestation program. Image credits: Vidhyaa Chandramohan

7.5 Threats

The global area of mangroves is decreasing. Forests that once extended across three-quarters of the tropical and subtropical coastlines have been reduced in area by as much as 25% to 50% worldwide since 1980 (Giri et al. 2011; Hamilton and Casey 2016; Spalding et al. 2010; Thomas et al. 2017), with profound consequences for biodiversity and for the services and goods provided by these ecosystems (Carugati et al. 2018; Nagelkerken et al. 2008). Estimates of annual mangrove loss range from 0.16% to 2% (Alongi 2015; Hamilton and Casey 2016), mostly due to coastal urbanization and agricultural expansion, dredging, eutrophication or pollution, as well as changes related to global warming.

The UAE is not a stranger to these environmentally harmful processes. The coastal areas of the country have undergone remarkable modifications over the past half-century, with rapid economic and population growth following the 1970s oil boom leading to intense urban development, particularly in coastal zones that now support sprawling mega-cities (Burt 2014; Van Lavieren et al. 2011). While much of the early urbanization resulted in the growth of cities behind the coastline, since the early 2000s there has also been a dramatic increase of reclamation and infilling into coastal seascapes for creation of high-end waterfront real estate (Friis and Burt 2020). Today, the 50 km length of natural coastline in Dubai has expanded to over 250 km when including the perimeter of man-made islands (Burt et al. 2009), where real estate development occurred along with extensive dredging and infilling to support coastal port and oil infrastructures (Burt 2014; Burt et al. 2017; Burt et al. 2016). Such changes have resulted in substantial degradation and loss of diverse coastal ecosystems, including mangroves (Burt 2014). Khan and Kumar (2009), for instance, documented mangrove cover losses at specific sites of the UAE ranging from 49 to 618 ha between 1972 to 2000, a 20% decline from the original area, as a result of extensive land reclamation for coastal infrastructure development. In turn, surveyed sites unaltered by human constructions registered significant increases of mangrove cover over the same period. Direct modification and destruction of the habitat due to infrastructure development and land reclamation are not the only threats for mangrove forests derived from coastal urbanization. Different reports show that mangroves in the UAE have suffered negative impacts due to other changes, such as hypoxic conditions resulting from the discharge of untreated wastewater, structures interfering with natural sedimentation processes and water circulation, or depletion of fresh water resources (Khan and Kumar 2009; Lokier et al. 2018; Paleologos et al. 2019).

Sea level rise as a consequence of global warming also represents a threat for mangrove forests (Lovelock and Ellison 2007), including the mangrove ecosystems in the shallow Arabian Gulf, and particularly along the low-lying UAE coast (Alsumaiti et al. 2017). It has been argued that intertidal communities could migrate vertically in response to changes in sea level. However, mangrove trees cannot keep pace if the rate of change in elevation of sediment surfaces suitable for rooting and growth is exceeded by the rate of change in relative sea levels (Gilman et al. 2008). Hard infrastructure such as seawalls and roads bordering the coasts can also prevent the landward migration of mangroves and their associated biota. Under this scenario, sea level rise is likely to cause recurrent, long-term inundations of the lagoons and bays favored by mangrove forests, modifying the level and conditions of the intertidal zone inhabited by mangroves, which include changes in sedimentation processes and coastal morphology. An interesting study conducted by Lokier et al. (2018) focused on the effects of contemporary sea level rise on sedimentary systems and shoreline morphology in a specific site of Abu Dhabi, near Khor Qantur. Among other processes, they documented the formation of higher-level sand bars that isolated, buried and ultimately destroyed several mangrove stands in the locality. Arguably, the events observed during the study can be extrapolated to the foreseeable scenarios of sea level rise due to global warming. Indeed, eustatic changes projections reported by the Environment Agency of Abu Dhabi (2009) revealed that the effects of sea level rise may flood the totality of the current mangrove area by 2100.

Changes in temperature and precipitation of anthropogenic origin are also widely affecting mangrove ecosystem in the UAE and around the world (Gilman et al. 2008; Lovelock and Ellison 2007; Lovelock et al. 2016). Arabian mangroves already experience some of the highest temperatures registered across their tropical and subtropical distribution during the summer, as well as highly limiting cold temperatures in winter, revealing a remarkable tolerance of the local populations to extreme thermal stress. However, increasing temperatures will likely have a negative impact in the mangroves of the UAE, and while globally, it may favor the expansion of the species polewards, it can also result in the local disappearance of the species in the region if critical physiological limits are met (Lovelock et al. 2016; Osland et al. 2017; Peer et al. 2018). Temperatures exceeding 35 °C negatively affect the patterns of flowering, fruit development and root formation, and photosynthesis is highly impeded when leaf temperatures reach the 38 to 40 °C for most mangroves species (Alsumaiti et al. 2017; Gilman et al. 2008). In addition, climate change is also likely to result in lower levels of precipitation for the subtropical dry regions. Reduced rainfall in an already super-arid environment, along with increased evaporation and higher salinity, will lead to decreased net primary productivity, growth and seedling survival (Gilman et al. 2008). Indeed, genetic analyses reveal parameters such as maximum temperature of the warmest month, annual precipitation or salinity maxima as the most important ecological pressures driving local adaptation in Arabian

mangroves (Friis et al. 2022), which suggests that drastic changes in such variables can easily result in severe, negative impacts on these ecosystems.

7.6 Management and Conservation Status

Mangrove management and conservation has led to a net increase in mangrove area in the UAE, especially over the last 20 years (Fig. 7.7). Coastal development benefitted mangroves in some areas by decreasing salinity and increasing nutrients and other areas were built on (Embabi 1993). In response the pressures put on mangroves by development and overexploitation, H.H. Sheikh Zayed bin Sultan al Nahyan, President of the UAE, temporarily banned the harvesting of mangroves and initiated several programs to plant mangroves (Lieth and Lieth 1993; Saenger et al. 2002). By the late 1980s, there were 17 mangrove stands mapped in the UAE, but the actual area was not provided (Embabi 1993). Additionally, the Ras a Khor mangrove

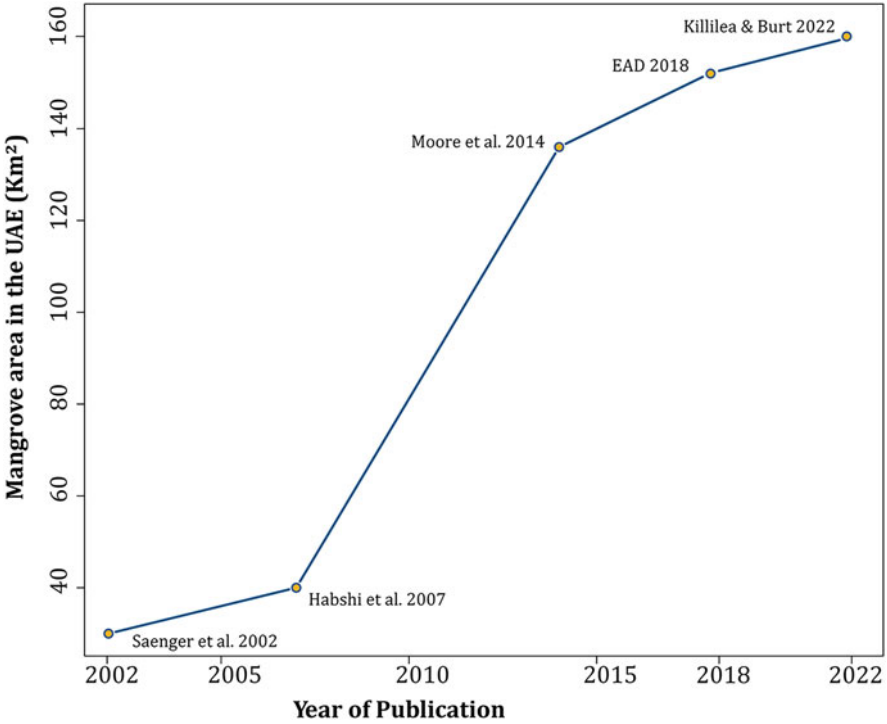


Fig. 7.7 Historic changes in mangrove cover in the UAE. Growth of mangrove cover as a result of the afforestation programs undertaken in the last 20 years. Data assembled from: Saenger et al. (2002), Al Habshi et al. (2007), Moore et al. (2014), Environment Agency Abu Dhabi (EAD, 2018), Killilea and Burt (*in prep*)

wetland in Dubai, was developed and planted in the 1980s and is a designated Ramsar Site due to its ecological importance.

Today, the UAE has five wetlands that include mangroves and have been designated as internationally important Ramsar Sites. There are also nationally protected sites such as the Mangrove National Park in Abu Dhabi. The UAE Ministry of Climate Change and the Environment is responsible for preserving biodiversity and developing policies and programs to mitigate climate change. In 2020, the Ministry implemented a marine environment rehabilitation program, that supports the cultivation of 100,000 mangrove seedlings to help restore degraded habitats as well as to plant new mangrove forests (“Ministry of Climate Change and Environment Implements Marine Environment Rehabilitation Program” 2020).

The majority of mangrove forests are either managed by the government of the local emirate or private landowners. For example, Ras al Khor is protected by the Dubai municipality (Ryan et al. 2012). Three of Ras al Khaimah’s mangrove sites are owned by the Ras al Khaimah government, and the fourth is primarily owned by a real estate development that is protecting the site (Llewellyn-Smith 2012). The Environment Agency of Abu Dhabi protects several existing sites in Abu Dhabi and partnered with the Tourism Development and Investment Company (TDIC) to plant 750,000 saplings of mangroves on Saadiyat island (Alsumaiti and Shahid 2019). While formal protection status may be limited, the extensive resources going into planting and protecting mangroves is having a positive impact on these ecologically important ecosystems.

7.7 Recommended Readings

Additional information on the mangroves of the UAE can be found in Dodd et al. (1999); Friis and Burt (2020); Friis et al. (2022); Friis et al. (2021); Spalding et al. (2010).

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