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Review Paper

Mangroves of Abu Dhabi Emirate, UAE, in a Global Context: A Review

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Abstract

The purpose of this paper is to increase the understanding of the valuable mangrove ecosystem in the United Arab Emirates (UAE). The survival of this national treasure is very important to the UAE natural ecosystem and the sustainability of the country. This paper introduces the reader to the mangrove ecosystems of the UAE, specifically Abu Dhabi Emirate within a global context. The physical and ecological characteristics, the spatial distribution, and the economic and ecological benefits of mangroves were discussed. Furthermore, this document outlined the major anthropogenic and natural threats to the mangroves. Finally, activities to enrich mangroves in Abu Dhabi were explained. The characteristics of mangrove species vary regionally depending on several environmental factors. There are fewer mangrove species that grow in tropical arid regions compared to tropical wet regions. The difference in climate between the two regions affects the growth and health of these species. Mangroves are distributed along shorelines of over 118 countries. Several factors determine this distribution, including climatic zones and coastal processes. Mangrove ecosystems are natural resources of global importance and are of special significance to the UAE since they provide various benefits. Mangroves are threatened by both anthropogenic and natural agents. The destruction of these forests can have serious impacts. Therefore, several governmental and private entities have worked together to maintain these forests by increasing public awareness, enforcing regulations, and establishing marine protected areas and mangrove plantations.

Keywords: *Abu Dhabi's Mangroves; Characteristics; Spatial Distribution; Benefits; Threats; Enrichment.*

Introduction

Mangroves are one of the various types of littoral trees that mostly inhabit the sheltered coastlines within the intertidal zone of tropical and subtropical regions near the equator. Mangrove forests are of vital importance, representing a crucial part of the coastal ecosystem in the world. Additionally, mangroves are among the most productive ecosystems. They are associated with numerous benefits to the environment and the society. Among other things, they constitute a source of food for animals and human beings, provide an excellent geographical cover and control water quality (Food and Agricultural Organization of the United Nations (FAO), 2007). Mangrove forests are of significant importance to the arid Arabian Gulf region, including the United Arab Emirates (UAE). The eastern coasts of the UAE stretch for more than 644 kilometres along the southern shore of the Arabian Gulf. More than 70% of the total mangroves are found along the coasts and islands of Abu Dhabi Emirate.

The importance of mangrove forests has resulted in increased research studies from several perspectives (Inoue et al., 2011; Fry and Cormier, 2011). Early research studies on mangroves were mostly aimed at understanding mangrove trees and their uses in coastal areas (Aksornkoae et al., 2004). Human population is growing, which in turn has had major implications on the ecosystem. Therefore, recent research on mangroves has focused on the interaction between human and mangrove forests. Such studies, which involve analytical examination of human activities on mangrove forests, make use of recent technologies such as remote sensing and geographic information systems (GIS) (Sari and Rosalina, 2016; Yusuf et al., 2017). According to Kuldeep and Kamlesh (2011), the uses of these technologies in studying human-mangrove forests interaction enable researchers to map and monitor changes taking place over time.

The increase of human population in the last decades has been associated with various issues that affect mangrove forests. Among these issues is the global warming which is believed to be due to human activities. Increased human activities and global warming pose major threats to mangroves and their environment, which puts mangroves at a risk of extinction. Therefore, there is a dire need to embark on sustainability efforts aimed at protecting and preserving mangroves. Consequently, most recent research studies have concentrated on management of mangrove ecosystems (Chong, 2006; Datta et al., 2012), efforts aimed at rehabilitating mangroves, and other studies aimed at contributing towards mangroves sustainability (Powel and Osbeck, 2010). Although the literature on mangrove forests is extensive, with numerous case studies on the subject being conducted all over the world, mangrove studies in arid regions such as the Arabian Gulf region have been lacking. Therefore, the primary purpose of this

paper is to address six main points concerning mangrove ecosystems in the Arabian Gulf region within a global context. Firstly, this paper describes the main characteristics of mangrove ecosystems in the Arabian Gulf region and how they differ from mangroves in other regions. This paper also compares the current status and spatial distribution of global mangroves and mangrove swamps in Abu Dhabi. The paper also discusses the importance of these mangrove forests to the people and the environment of Abu Dhabi as well as the main threats to mangroves within the Arabian Gulf region. Finally, the paper addresses the measures taken to maintain and enhance mangrove forests in Abu Dhabi.

Characteristics of Mangrove Ecosystems

The characteristics of mangrove species vary regionally in response to several environmental factors such as rainfall, atmospheric temperature, sea surface temperature, water salinity, soil, and oxygen. There are several differences between mangrove forests in tropical arid environments and mangrove forests in tropical wet environments. One major difference is the number of mangrove species within the two regions. There are fewer species of mangrove that grow in tropical arid regions compared to tropical wet regions (McLeod and Salm, 2006).

The favorable climate conditions in tropical wet regions support the growth of many mangrove species such as *Sonneratia caseolaris* and *Bruguiera gymnorrhiza*. Because the tropical arid region is a harsh environment for mangrove species as it does not provide the basic essentials required for the growth of mangrove species, only few species such as *Rhizophora mangle* and *Avicennia germinans* can grow there. However, studies showed that few species such as *Avicennia marina* can grow in both arid and wet regions despite the difference in climate and other resources essential for growth (Food and Agriculture Organization of the United Nations (FAO), 2007). A. marina is widely spread and it is one of the fastest growing and fastest regenerating mangrove species due to its ability to tolerate extreme weather conditions, hyper-saline conditions, and various pests and diseases (Howari et al., 2009).

Moreover, the difference in climate between the two regions, tropical arid and tropical wet, does not only affect the number of mangrove species, but the growth and health of these species as well. For example, rainfall plays a very important role in determining the species richness and growth (Wilkie and Fortune, 2003). It has become evident through research that the average height of mangrove trees in a tropical arid environment does not usually exceed five meters. The tree has a lower productivity because of low precipitation, high water temperature, and high-water salinity. On the contrary, the height of mangrove trees in wet environments may reach up to forty meters. The tree also has a higher productivity due to high precipitation. Furthermore, in tropical wet regions the availability of fresh water from rivers promotes the growth of different species. This is not the case in tropical arid areas where growth is limited by the presence of salty water, dry climate, and high water and air temperatures.

Additionally, in tropical wet regions where climate is conducive to growth, a large coverage of closed canopy mangrove evergreen forests is expected, with exceedingly varied species. In contrast, tropical arid regions where climate is unfavorable, a small coverage of open canopy mangrove forests is expected, with a limited number of species (McLeod and Salm, 2006).

Because of climactic differences in both regions, two categories of mangroves can be recognized in terms of salinity tolerance. While Mangrove species in arid environments have an extensive range of about 80% tolerance, mangrove species in wet environments contain a lower range of approximately 40% tolerance (Feller and Sitnik, 1996). As previously noted, mangrove forests in tropical wet environments obtain plentiful fresh water from rivers. The availability of fresh water and high amounts of precipitation decreases the levels of water salinity in these environments. However, mangrove forests in tropical arid regions such as the Arabian Gulf not only lack abundant fresh water but also exist in environments characterized by salty water. In Abu Dhabi, for instance, the severe arid climate conditions further impact the water salinity. This situation is explained in a UAE Ministry of Energy report which states: *"Straddling the Tropic of Cancer, Abu Dhabi has a sub-tropical hot arid climate. The weather is warm and sunny in the winter months of November through February with minimum temperatures averaging above 20°C; but it is hot and humid during the summer months of June through July with maximum temperatures averaging above 35°C. Rainfall is virtually non-existent, with occasional short showers occurring mainly in winter"* (UAE Ministry of Energy, 2006).

Due to the hot arid climate in the region, the rate of evaporation in the Arabian Gulf is ten times the input from rivers and rainfall. This high rate of evaporation causes high salinities of around 40ppt in open waters, which can be exceeded further in inshore waters and coastal lagoons. In addition to high salinity, the seawater surface temperature in winter is around 10°C, while in summer; it can exceed 39°C. Thus, the Arabian Gulf has greater salinity levels and higher annual temperature fluctuation than most other seas in the world (Saenger et al., 2002). Due to the harsh climate condition and high saline seawater environment, there is only one species of mangrove capable of surviving this type of climate.

A. marina is the only native mangrove species that grows naturally in Abu Dhabi at a time when there are more than 50 species of mangroves found worldwide. The species, also known as the grey mangrove, is named after the great Muslim Philosopher Ibn Sina (Avicenna) 981- 1037 C.E. (Boer and Aspinall, 2009). The grey mangrove is the only mangrove species which does well in the arid Arabian Gulf environment, where it is locally referred to as Al-Qurum. However, historical records demonstrate that one other mangrove species, *Rhizopohra mucronata*, once grew in Abu Dhabi. This species has extinct in the entire Arabian Gulf region due to wood cutting and over-exploitation (Vistro, 2010). The species are well adapted for the driest and most saline habitats as its predecessor was ages ago.

The grey mangrove in Abu Dhabi possesses several adaptation characteristics. They can grow in flooded terrestrial ecosystems as well as in acidic, anaerobic soils. The soils in which mangroves grow are made mainly of sandy silt, which are white calcium

carbonate sediments (Vistro, 2010). Mangrove trees have mechanisms which help in salt uptake and extraction of water molecules thereby excreting the salt through the leaves (Howari et al., 2009). According to Embaby (1993), these species need calm areas and enclosures since they cannot perform well in high-energy wave areas. The average height of the mangrove trees found in Abu Dhabi is four meters (Anwahi, 1994). Furthermore, Alsumaiti (2014) indicated that most mangrove trees in Abu Dhabi do not exceed seven meters in height. Mangroves have short and branchy stems. They also have thick, salty-tasting leaves with pencil-like roots which develop above the soil surface. The root system of these mangroves is generally shallow. The aerial roots grow to a height of about 20 centimeters and a diameter of one centimeter, which allow the plant to absorb oxygen (Vistro, 2010). Furthermore, the grey mangrove possesses other ecological characteristics that improve its ability to populate the Abu Dhabi region. From early life stages, mangroves are adaptable. They can adjust to new conditions, propagate and survive in changing water environments. Every mangrove yields buoyant seeds which can float and spread in water. Unlike other land plants, many mangrove species are viviparous and their seeds can germinate while attached to the parent plant. Their healthy seedlings can drop into water once mature after they have germinated and grown within or outside the fruit. Then, their long and hazardous journey to find a suitable flourishing location begins. Water currents transport the seedlings over long distances. Desiccation is not a problem to the propagules as they can remain dormant for a couple of months to a year till they can find a suitable environment. In order for the propagule to take root, its density must lessen so it can float vertically rather than horizontally, improving its ability to lodge within the mud or roots. If it fails to take root in one specific area, it changes its density again and floats away to continue searching for a more suitable home (Environmental Atlas of Abu Dhabi Emirate (EAD), 2011). These characteristics allow *A. marina* to survive the harsh arid environment of Abu Dhabi.

Spatial Distribution of Mangrove Ecosystems

Mangrove forests can be found along the shoreline of over 118 countries and territories (Giriet al., 2011). The distribution of mangroves is shown in Figure 1. This global distribution of mangrove forests is determined by several factors. For instance, climatic factors such as moisture and temperature play a major role in the distribution of these forests. However, coastal processes like coastal currents, tidal mixing, tidal fluctuation, wave energy, salinity, and sedimentation influence the distribution of mangroves in some regions by affecting propagule establishment (McLeod and Salm, 2006). Reflecting on a latitudinal perspective, it is clear that mangroves are dispersed throughout the subtropics and tropics. Through this distribution, mangroves reach their utmost growth between 25° S and 25° N (Gilman et al.,2008). Estimations of global mangrove area vary from 12 million hectares to 20 million hectares. However, in 2010, the total mangrove area globally was estimated at approximately 15,236 million hectares (Spalding et al., 2010). According to FAO's mangrove assessment study entitled *The World's Mangroves 1980-2005*, "the world has lost around 3.6 million hectares of mangroves since 1980, equivalent to an alarming 20% loss of total mangrove area".

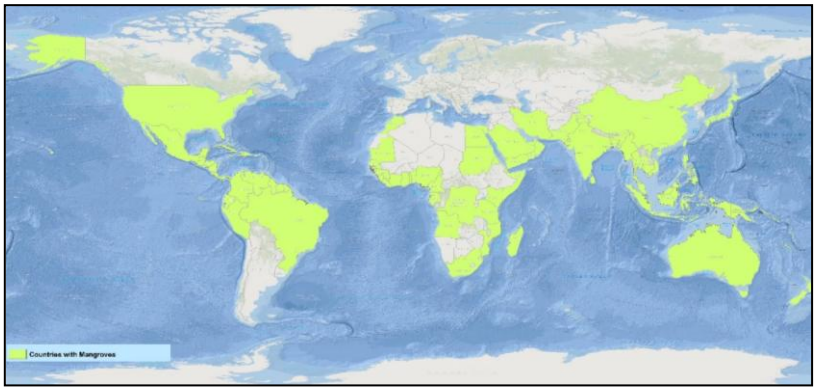

Fig 1. Global distribution of mangrove forests (Data source: FAO, 2017).

The mangrove forests in the United Arab Emirates are an integral part of the coastal ecosystems, as they cover thousands of hectares of land along the shoreline of the country (Figure 2). Occurring naturally along several eastern coastal areas and islands, especially around Abu Dhabi - the largest emirate, the mangroves stretch several hundred miles around the Arabian Gulf. This particular region provides the lowest floral biodiversity, compared to other mangrove forests, since the Gulf represents a very dry mangrove ecosystem. As previously mentioned, this arid climate only allows the survival of one species of the mangroves, the *A. marina*, which are both hardy and adaptable. (Al-Habshi et al., 2007). This species covers about 70 km^2 with a standing biomass of 70-110 tons per hectare (Blasco, Carayon, and Aizpuru 2001). Abu Dhabi mangrove swamps represent about half of the mangroves throughout the Arabian Gulf Region. Abu Dhabi Emirate has tidal lagoons, which account for over 70% of the natural mangrove forests in the UAE. Furthermore, mangrove forests are present between Ras Ghanada in the northeast to Marawah Island further west (Tamaei, 1999).

The success of mangroves throughout the region has led to the mapping and documenting of the coastal ecosystem. Embaby (1993) used satellite images and topographic maps to study the geographical distribution of mangrove forests in the United Arab Emirates. His study concluded that certain environmental aspects influenced the areas where mangrove swamps were found. Four groups were identified to capture aspect identification, including geomorphologic features of the area, climatic conditions, constructed modifications, and water characteristics. Embaby concluded that the geomorphologic and ecological conditions existing on the shoreline of the UAE are conducive for the growth and development of *A. marina*, which can endure arid climate conditions and highly saline water. Not only are there natural mangroves, but there have also been significant plantations of mangrove established in Abu Dhabi. Realizing the environmental significance of mangrove ecosystems to Abu Dhabi Emirate has

compelled government organizations, several private land owners and private companies to instigate efforts to institute *A. marina* plantations on suitable, but presently barren inter-tidal or dredged areas (Vistro, 2010). Young mangrove plantations can be found at many locations in Abu Dhabi. For example, Al Sammaliah Island boasts one of the largest artificial *A. marina* plantations in the world, covering an area of approximately 8 km² (Saenger et al., 2004). Furthermore, around 800,000 mangrove trees were planted on the coast of Saadiyat and Jubail islands. Nevertheless, due to inadequate understanding of plantation procedures and techniques, the continued existence and growth outcomes are often lower than anticipated (Vistro, 2010).

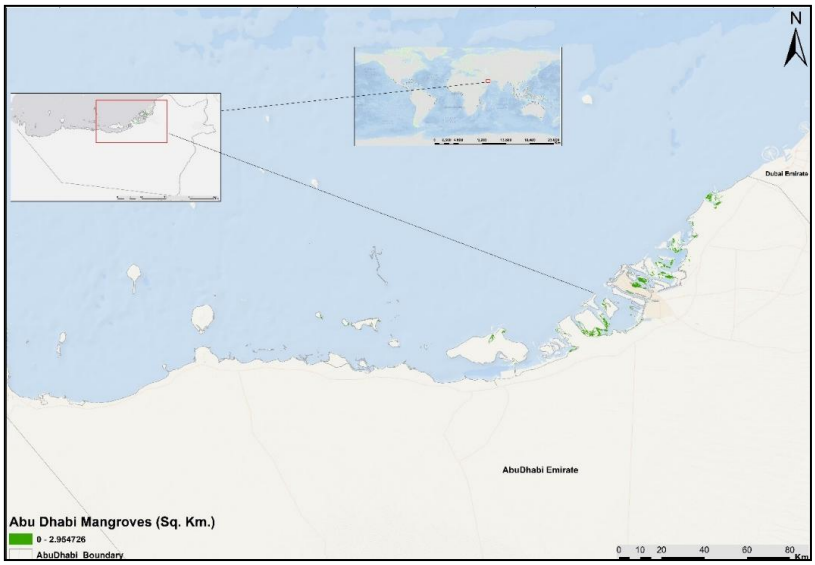

Fig 2. Distribution of mangrove forests around Abu Dhabi (Data source: EAD, 2017).

Given the urgent need to map the mangrove, remote sensing and GIS technology have assisted in establishing spatial mangrove patterns and detecting any changes therein (Heumann, 2011). Satellite imagery and digital image processing have greatly aided our appreciation of the extent of the mangrove forest and conditions along the coastline of Abu Dhabi. Such imagery indicates a significant reduction in mangrove distribution, a situation associated with reclamation, industrialization, urbanization, dredging, degradation of water quality, as well as other human activities (Yagoub and Kolan, 2006; Al-Habshi, 2005; Blasco et al., 2001). Even though remote sensing can be an important tool for mapping mangroves, accurate mangrove area estimates are difficult to obtain (Jensen, 2005). But, such estimates are now urgently needed for both local and global levels to effectively study, manage, conserve and sustain these valuable coastal ecosystems.

Ecological and Economic Benefits of Mangrove Ecosystems

Mangrove ecosystems are natural resources of global importance and are of special significance to the United Arab Emirates, since mangroves are the only coastal forests that link land and sea. They provide many ecological and economic benefits. For example, they serve as habitat for a variety of organisms; help in pollution control; provide a source for lumber and energy, and offer recreational and educational opportunities.

Habitat for organisms

In Abu Dhabi, the mangrove ecosystem acts as high-quality habitats for a number of both marine and terrestrial organisms. Coexisting with flora and fauna, the ecosystem acts as breeding grounds for a variety of organisms and maintains a complex aquatic food web. Organisms such as birds, mammals, reptiles, fish, shellfish, insects, fungi, algae and seagrass all enjoy symbiotic relationships with mangrove trees within the ecosystems (Nagelkerken et al.,2008). For example, many migratory species, such as sea birds depend on mangroves for part of their seasonal migrations. They find safe nesting and egg laying areas in these vast forests (Aspinall, 1996). In fact, mangrove forests and tidal lagoons in Abu Dhabi host up to 300,000 sea birds during the main migratory season. Moreover, mangrove forests offer refuge and nursery grounds for 75% of all tropical juvenile fish species in the world (State of the Environment–Abu Dhabi, 2012).

Pollution Control

Mangroves control pollution in air and water. First, they maintain water quality by acting as biological filters, separating sediments and nutrients in polluted areas along the coast (Marshal, 1994). As an example, terrigenous sediments and nutrients eroded from the environment are filtered by mangrove forests before being deposited in coral reefs. This buffering capacity of mangrove ecosystems ensures the health of coral reefs by improving the oligotrophic conditions needed by coral reefs to limit algae growth (Ellison, 2004). Moreover, the nutrients supplied by mangroves promote the growth of seagrasses and coral reefs. Not only do mangrove forests protect other coastal ecosystems from excessive sedimentation but also prevent water contamination by removing heavy-metal and agrochemical pollutants from the water, as these contaminants adhere to sediment particles (Silva et al., 1990).

Second, Mangrove forests reduce coastal pollution through the sequestration of carbon, thus greatly reducing the amount of carbon emission in the coastal areas (McLeod and Salm, 2006). Mangrove trees act as a sink for CO2 by fixing carbon during photosynthesis and storing excess carbon as biomass. As the tree's biomass increases, the carbon held by the plant also increases

the carbon stock (Bipal et al. 2009). Several studies have suggested that mangrove forests store a relatively large amount of carbon compared to other types of forests (Komiyama et al., 2008). Therefore, the loss of mangrove forests may have an impact on the global carbon budget. Cebrain (2002) estimated that "a loss of about 35% of the world's mangroves has resulted in a net loss of 3.8 x 10^{14}g C stored as mangrove biomass".

Third, they act as natural barriers against ocean waves along the shoreline of Abu Dhabi. They protect the coastline and coastal facilities from erosion and destruction caused by strong waves, ocean currents, and winds (Vistro, 2010). For example, because of their enormous roots, mangrove trees absorb and dissipate large wave's forces and storm surges, which could have caused property damage and even loss of human life. Their protective capacity was clearly demonstrated during Indian Ocean tsunami of December 2004.Several studies (e.g. The Environment Agency study) of the coastline following this disaster indicated areas with mangrove forests survived the worst of the tidal impacts with minimal damage incurred. Fragile coastal habitats and thousands of human lives were spared by the presence of these forests (Environmental Atlas of Abu Dhabi Emirate (EAD),2011).

Lumber and Energy Source
Besides helping to control pollution, the mangroves once supplied forestry products like timber, firewood and charcoal in many parts of the world due to its high calorific values. Historically, mangrove trees were used to produce quality timber for construction purposes in Abu Dhabi. The wood was used for constructing homes and ships due to its hardness and high resistance to rot and termites. They also help to provide energy, acting as fuel in the form of firewood and charcoal. However, after the discovery of oil, mangrove trees are no longer used as a source of energy or lumber in Abu Dhabi (Saenger et al., 2002).

Recreational and Educational Opportunities
In addition, mangrove ecosystems provide scenic landscapes for recreational purposes along the shores. Mangrove forests in Abu Dhabi are a regular ecological destination for tourists and education. In the case of tourism, individuals from across the world visit Eastern Mangrove Lagoon National Park in Abu Dhabi to enjoy activities such as kayaking and the watching of fish or crustaceans' schools. Furthermore, the mangroves in the park also attract a large number of birdwatchers who are interested on bird (e.g. reef heron) migration during the spring and summer seasons. Many people also visit these areas for fishing, boating, snorkelling and other recreational endeavours (Abu Dhabi Government, 2012). Mangrove forests are also used to educate students at different levels of education about the environmental and socio-economic importance of forest. In other words, fauna and flora associated with the mangroves foster tourism as well as recreational and educational opportunities; all of which bring income into the economy (Ashton and Macintosh, 2002).

Major Threats to Mangroves
Mangrove ecosystems are important in many regions throughout the world. It is, therefore, important to understand what factors represent a threat to these vital ecosystems. Most worldwide biodiversity habitats are threatened, but the mangroves are threatened the most by both anthropogenic and natural sources (Lovelock et al., 2015). Mangroves once occupied three-quarters of tropical and subtropical coastlines throughout the world. However, only about one-half remain today (Upadhyay, Ranjan and Singh, 2002). It is estimated that mangrove ecosystems are reduced by 2% annually due to eutrophication, toxic-chemical pollution, agricultural expansion, urbanization, and water quality and quantity changes (Valiela, Bowen and York, 2001). In many countries such as the United Arab Emirates, much of the human population resides in the coastal zones, with human activities jeopardizing the integrity of mangrove forests (McKee, 2004). Other factors threating mangroves include climate change and global warming (Gilman et al., 2008).

Anthropogenic Threats to Mangroves
As the population in Abu Dhabi increases, human activities continue to intensify. The last 30 years have seen many mangroves lost due to urbanization and industrialization (Yagoub and Kolan, 2006). Examples of urban developments that have threatened mangroves include the Reem and Saadiyat islands, whose mangroves were destroyed by half, as well as the dredging of a shipping channel towards the Musaffah industrial area. These urban and industrial development projects coupled with population growth affect mangroves by altering the hydrological cycle which vital for the quality of aquatic habitats and ecological stability of their ecosystems. The hydrological cycle controls several processes such as transport of pollutants, water chemistry, pattern of nutrient fluxes, erosion, and consequently some of the ecosystems features like rate of productivity and decomposition (Wagner et al., 2007).

Oil spills from the oil industry, which constitutes the mainstay of the economy of Abu Dhabi, also pose a major threat to the mangroves. The spills come from oil extraction, oil exploitation, and transport activities. Most oil is extracted offshore and oil exploration and extraction operations are largely self-managed and regulated by the oil companies (Boer and Aspinall 2009). Although Abu Dhabi's mangrove species, namely the *A. marina*, have some degree of oil resistance, this degree of resistance depends on the magnitude of contamination. Generally, as long as the aerial roots are not fully subjected to oil smear, the mangrove usually survives the oil contamination.

Other sources of problems for mangroves include solid waste management practices such as landfills and coastal dredging. The impact of these activities depends on their magnitude. Many of these anthropogenic practices may cause a prolonged period of drought and/or cases of water logging, which may result in oxygen inhibition, as well as causing salinization. These effects lead to the destruction of mangroves. To prevent the damage, it is advisable to ensure that mangroves get exposed to sufficient air keeping tides at low levels without interruption. The aerial roots of mangroves, otherwise known as pneumatophores, should

always remain exposed to open air. In addition, waste management activities such as landfills should not be constructed near the mangrove ecosystems (Howari et al., 2009).

Urbanization projects change the patterns of water movement in the coastal area of Abu Dhabi. An increase in impervious surfaces and the use of storm sewers has caused an increase in the amount of sediments and pollutants in the coastal area. Parts of the shoreline are affected by an abundance of sediment or by erosion. Both sediment and erosion jeopardize mangrove species. Because of erosion, the shoreline is either washed away or becomes so steep that it impedes the flow of water within mangrove swamps. Additionally, six islands have been built from waste material in the waters west of Abu Dhabi (Al Ashram, 2008). These recent islands represent an impediment for mangrove forests. Furthermore, the development of the Eastern Mangroves Resort has caused further upheaval. New channels have been dredged to make the area more accessible to boats. Other threats include liquid waste disposal from urbanization and industrialization, diversion of freshwater runoff from dredging, and recreational activities, such as camping and boating; all of which contribute to the decline of mangrove distribution and density in Abu Dhabi (Howari et al., 2009).

Natural Threats to Mangroves

Beside human activities that threaten mangrove ecosystems in Abu Dhabi, natural threats such as climate change have significant destructive effects on the growth of mangroves and their environment. The primary climate factors that affect mangrove forests include changes in sea-level, temperature, precipitation, CO2 concentration, and storms and hurricanes (Gilman et al., 2008).

Sea-level Rise

The last decades have witnessed an increase in the number of human activities and industrial operations that have critically contributed to global warming. As a consequence of global warming, the mean sea level has risen posing a great threat to mangrove forests and the coastal ecosystems (Field, 1995; Lovelock and Ellison, 2007). If the rate of change in the elevation of mangrove sediment surface is exceeded by the rate of change in relative sea-level, then mangrove swamps and other coastal ecosystems will be threatened by inundation. The direct effects of sea level rise will be increased by water depth and variations in tidal prism of the coastal zones. Changes in tidal prism or changes of water volume that enters and trapped in mangrove swamps could influence the growth of mangrove trees (Mazda et al., 1995). Furthermore, Neckles (1999) points out that rises in sea levels alter water movement and increase seawater intrusion into coastal zones, threatening to inundate mangrove trees which cannot move inland due to coastal development.

According to the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report, sea levels are expected to rise between 0.28m and 0.98m by the end of 21st century but these numbers do not include "uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow" (IPCC, 2014). The report notes that the actual fluctuations in sea level rise will largely depend on global temperature rise and glaciation effects on the polar caps. An earlier report by IPCC (2001) stated that the sea levels are expected to rise significantly over centuries whether or not climate destabilization occurs. Estimates suggest that, by 2100, the sea levels can rise above 10 meters depending on the greenhouse gases emissions scenario considered (IPCC, 2007).

The sea level rise is anticipated to have far-reaching effects on mangrove forests and coastal ecosystems in the shallow Arabian Gulf, particularly in Abu Dhabi. Mangrove forests survive best above sea levels because their roots need to be exposed and be free from inundation for the majority of the day (Nelson et al., 1994). Sea level rise is expected to cause constant inundation, which will deprive trees of oxygen. While at the same time new trees will be unable to take root because of seed floatation. Studies conducted by Abu Dhabi Environmental Agency (Inundation Analysis of Coastal Areas, 2009) revealed that the effects of sea level rise discussed above may wipe out the extensive mangrove forests in Abu Dhabi by 2100.

Storms and Hurricanes

Storms and hurricanes are environmental factors that have profound effects on mangrove forests and other coastal ecosystems around the world. Mangrove trees are adversely affected by typhoons and hurricanes. Such storms expose mangrove trees' shallow root systems and cause the soils to be non-cohesive. This results in the tree falling due to the strength of the storm. Though mangroves grow quickly, the affected trees may not recover. Hurricanes and typhoons have the potential of destroying vast mangrove forests (Lugo and Snedaker, 1994). Global climatic experiments reveal that if global warming continues, then the frequency and intensity of tropical cyclones and storms are expected to increase. The extent of these changes depends on the extent of climatic changes. According to IPCC's third assessment report (2001), a rise in sea surface temperature of 2° to 4°C will lead to an increase of 10% to 20% in cyclone intensity; thereby, jeopardizing mangroves by causing defoliation of mangrove trees and increasing tree mortality (Elsner et al., 2008; Knutson et al., 1999; Henderson-Sellers et al., 1998; Royer et al., 1998; Krisnamurti et al., 1998).

Additionally, an increase in storm frequency and intensity will alter mangrove sediment elevation because of the effects of soil erosion, soil deposition, peat collapse, and soil compression (Cahoon, 2006). Tsunamis, though not affected by climate change, can cause destruction of mangrove forests along with other costal ecosystems at the same time (Houghton et al., 2001).

However, storms are limited in the Arabian Gulf which witnesses calm or light seasons forty percent of the year. Despite this, significant storms can hit the Gulf region. As explained by El-Sabh and Murty (1988), the Gulf is influenced by extra tropical weather systems due to the Strait of Hormuz that lies in the boundary region between east-to-west and west-to east travelling tropical cyclones. For instance, the Gonu cyclone, which was the strongest cyclone in the Gulf region, hit only a few parts of

Oman, Iran, and the United Arab Emirates in June 2007, yet still caused over 70 deaths and about $4.3 billion in damages (Evan and Camargo, 2010). Cyclones such as Gonu, are a direct result of climate change and can threaten mangrove forests and other coastal ecosystems. Shamal winds (north-western winds) present a potent threat to the mangrove forests and coastal ecosystems in the Arabian Gulf. Shamal winds genesis may also be another factor that can cause a surge in storm frequency and intensity in the Gulf. The Arabian Gulf, especially in the southwest, is subjected to large amplitude storm frequencies and intensity from either tropical or extra tropical cyclones. However, the shallower depth of the Arabian Gulf may limit the effects of storm surges on coastal ecosystem and the mangrove forests. Fortunately, Abu Dhabi is less affected by Shamal winds than other areas in the region (El-Sabhand Murty, 1988).

The severity of the above conditions will increase in the coming century due to the frequency and intensity of summer tropical cyclones in the north Indian Ocean. Scientists point out that if these conditions persist, strong cyclones similar to Gonu may likely occur in the Arabian Sea. This will increase the vulnerability of UAE coastal region to the effects of these changes (Evan and Camargo, 2010).

Cyclones are usually associated with storm surges that cause flooding. Flooding can increase sea levels and also increase sediment levels that affect mangroves and mangrove ecosystems. The mangrove forests and mangrove ecosystems are finally destroyed due to high sedimentation and rise in sea levels (Lugo and Snedaker, 1994). Flooding tends to interfere with the gaseous exchange leading to the death of root tissues and trees.

Temperature, Precipitation, and Carbon Dioxide (CO_2)

One of the main factors influencing mangrove distribution is temperature. This is because it controls their latitudinal distribution. Mangroves do well in areas where the average temperature is about25ºC in the hottest month (Hutchings and Saenger, 1987). However, due to destructive human activities, the earth has progressively been warming up. Over the past decades, many changes have taken place in the Arabian Gulf in connection to marine habitats. The habitats are usually interesting to scholars due to the high levels of salinity stress and temperatures they experience (Saenger and Moverly, 1985). However, increasing temperatures brought about by climate change deteriorate the state of mangrove forests. In addition, seasonal variations exceed 5ºC which greatly affects these species. At temperatures beyond 25ºC, most mangrove species experience a decline in the rate of leaf formation. Temperatures beyond 35ºC negatively affect the patterns of flower and fruit formation, root formation and the laying down of seedlings. At leaf temperature of 40 ºC almost no photosynthesis occurs (Andrews et al., 1984; Clough et al. 1982). Increasing global average temperatures will also cause an increase in the sea-surface temperature, which will negatively affect mangrove species by changing the species composition and changing phenological patterns. Additionally, warmer water will contribute to increased incidence of marine diseases and expansion of harmful invasive species which will affect mangrove forests and other coastal ecosystems as well (Gilman et al., 2008). As already stated, increasing global average temperatures will increase the rate at which the sea level rises. According to Tan and Zhang (1997), this may end up forcing the mangroves to move inland. However, in many places in the world, mangrove rarely migrate inland due to human settlement and the likelihood of decreased width of the forests in higher sea level areas. This essentially illustrates the risk that is posed by increasing temperatures on mangrove communities.

In addition, changes in the patterns of precipitation will have massive effects on the growth of mangrove species. According to IPPC's fourth assessment report (2007), increases in precipitation are projected for tropical wet regions; while decreases in precipitation are projected for the subtropical dry regions. In other words, wet regions will get wetter and dry regions will get drier. In tropical wet regions, the rates of precipitation are expected to increase by 25% by the year 2050 as a result of global warming (Houghton et al., 2001; Walsh and Ryan, 2000). This increase in the levels of precipitation could enhance range, diversity, productivity, and growth rates of mangroves. On the other hand, mangrove forests in arid regions are at a high risk from precipitation changes. This is because decreased precipitation will increase water and soil salinity, resulting in decreased mangrove diversity, productivity, growth rates and seedling survival (Field, 1995; Snedaker, 1995).

Due to its location, the Arabian Gulf receives very low and irregular rainfall. Typically, the rainfall is below 150mm a year, and in the northern and central parts of the Arabian Gulf it can be as little as 50mm. Since the region does not benefit from the barometric depressions that occur in the summer, most receive rainfall ranging from 100-300 mm/yr. Sometimes sporadic rainfall accompanied by heavy precipitation occurs in limited areas. This may then be followed by dry spells that are usually long. There are two main sources of rainfall in the Arabian Gulf: winter cyclones and rainfall from Indian Ocean. The main one, winter cyclones, travels across the eastern section of the Mediterranean, and they are deflected towards the south into the Gulf by north-westerly (Shamal) winds. The less significant rainfall comes from the Indian Ocean (Alsharhan et al., 2001).

However, climate change is likely going to negatively impact the Gulf region. This will most likely result in an increase in the intensity and frequency of hot and dry weather conditions (Allan, 2001). The existing harsh weather conditions compounded with the potential climate change effects**,** such as decline in precipitation, will negatively impact the mangroves. The impacts may turn out to be disproportional due to the vastness of the region and the fact that extreme climatic conditions are by now common (Krichak et al., 2000). The decline in rainfall and precipitation will greatly affect the seed survival of mangrove communities thus incredibly minimizing their survival rates. The size of the area covered by these species is also going to decrease as their population reduces.

CO_2 levels are increasing all over the world and the case is no different in the Arabian Gulf. Globally, the atmospheric CO2 increased up from 280 ppm in the year 1880 to 379 ppm (IPCC, 2007) and most recently to 400 ppm. Most of this CO2 comes

from fossil fuels and ends up being absorbed into the ocean. This essentially changes the chemistry of ocean water. Changes in CO_2 concentration due to climate change have created a dichotomous condition for the mangroves. On one hand, increased CO_2concentration is good for the mangroves, since it increases the growth rate of mangrove plants as this gas enhances photosynthesis. Furthermore, increased levels of CO_2 have been found to regulate water loss in some species. On the other hand, this increase in CO_2 is causing a massive degradation to coral reefs, which offer protection to the mangrove plants from wave action (Hoegh-Guldberg, 1999). However, Scholars are uncertain how the positive or even negative effects will impact the mangroves over time. They all agree that more research is needed (Gilman et al., 2008; IPCC, 2007; Houghton et al., 2001).

The increase in the CO_2 concentration may translate to an increase in the growth rate of mangrove species in the Gulf. However, Ball et al. (1997) argued that an increase in CO_2 concentration had no effect on mangrove forests growing in hyper-saline environments. Coupled with reduced rainfall, this may result in some level of stress for these species, yet not all species respond equally to such stresses. For example, nutrient levels, salinity, and temperature may all influence the way a mangrove species reacts to increased CO_2 levels. Therefore, as sea and air temperatures increase coupled with a reduction in precipitation, mangrove plants in the Arabian Gulf stand the risk of reduced rates of growth leading to their disappearance.

Mangrove Enrichment

Mangrove ecosystems are essential to many countries in the world, including the United Arab Emirates. Nevertheless, key areas of mangrove forest have been removed and destroyed because of urban development and other human activities (McKee, 2004). Furthermore, climate change poses additional threats to mangrove ecosystems. According to Houghton et al. (2001), human reclamation of wetland will represent a 37% loss of global wetlands by 2080.This does not include the impacts of the sea level rise, which boost this percentage an additional 25%. Therefore, Houghton estimated that over 60% of the total wet land in the world will be lost by the year 2080.

The destruction of these forests can have severe impacts. Mangroves prevent soil erosion, control pollution by filtering out wastes, preserve the water cycle and absorb excess water during floods, prevent the land from effects of storms, and play a vital role in lessening carbon emissions; thus, contributing to reducing the effects of climate change (Conservation International,2008). Destruction of these forests can evidently have detrimental consequences in Abu Dhabi. Therefore, several governmental bodies, agencies and private organizations have worked together to ensure maintaining and enhancing these vital forests in the Arabian Gulf region by increasing public awareness, enforcing regulations and laws, establishing marine protected areas and mangrove plantations (Vistro, 2010).

Firstly, it is essential to increase the public awareness regarding mangrove forests. An increased appreciation and understanding of these valuable resources by the public is necessary in the efforts to maintain the current mangrove forests in Abu Dhabi. This, in turn, will guard the forests against the deliberate activities of private and public development and minimize inadvertent damage caused by inappropriate use. Participation of local communities in activities such as construction of boardwalks, mangrove studies and observation platforms can be utilized as avenues for carrying out public education, which allows the public to appreciate the society, and informal learning programs through field training (Saenger et al., 2002). The Environment Agency in Abu Dhabi has organized several awareness programs, which have been used to restore and conserve mangrove forests in Abu Dhabi, such as *"Buy Art and Save Mangroves".* The program advocates for the purchase of a novelty item with a celebrity's art work and message of hope on it. It is projected to pass knowledge about the deteriorating condition of mangroves and also to raise funds to save mangroves. The funds collected are used to organize monthly community clean ups which will help to save the Abu Dhabi mangrove forests. Furthermore, international mangrove action day is marked by the Abu Dhabi environment agency on 26th July. People, on that day, are urged not to litter around mangroves. This is because plastic bags prevent growth of mangrove trees and also release pollutants which are harmful to mangrove health (Abu Dhabi Government, 2012).

Secondly, several environmental laws and regulations have been implemented to prevent occurrences of environmental damage. A regulatory framework, which includes a full range of enforcement tools, including prosecution, inspections, and campaigns in order to save the heritage of Abu Dhabi has been established. Furthermore, in 1993, the UAE Federal Environment Agency was established and mandated to implement national environmental legislation to protect the natural resources of Abu Dhabi and manage the environment of the Emirates (Aspinall, 2001).

Thirdly, the establishment of marine protected areas is one of the most common methods of conserving mangrove ecosystems. The environment Agency in Abu Dhabi has established several protected areas and reserves such as Al Yasat Marine Protected Area, Abu Al Seyayef Marine Protected Area, Marawah Marine Biosphere Reserve and Al Wathba Wetland Reserve. By the end of 2008, an area of 5019 km² has been declared marine protected areas in Abu Dhabi, which represents5% of the entire area of the Emirates. It is projected that other prospective sites for marine protection make up about 7% of the maritime biome, or 4% of the entire area of the Emirates (Nelson and Rghei, 2008). The protected areas help in conserving valuable species of mangroves. These species are then reproduced in captive breeding centers. It has also helped in conserving other types of marine and terrestrial species. Additionally, in the absence of fishing activities inside the protected areas, fish and other aquatic animals can now grow to maturity and increase in large quantities (Aspinall, 2001).

Finally, increasing the total area under mangroves by establishing mangrove plantations is one of the most significant approaches of enhancing the mangroves of Abu Dhabi. Extensive mangrove plantations were established in Abu Dhabi in the late 1970's by buying and planting the seeds and plantlets of hybrid species of mangroves, particularly on Sadiyat Island (Saenger et al., 2002). Experimental mangrove plantations were established in the mid 1980's on Mubarraz Island using locally gathered propagates,

which were used for basic experiments, to identify the noteworthy environmental factors necessary for the successful establishment and development of mangroves (Kogo, 1988).Since then, a number of other plantation projects have been established using the indigenous populations of *A. marina*, including the projects on Al Sammaliah Island, Al-Abyad Island and at Ras Al Sidre, beside the widespread municipal plantations around Abu Dhabi (Saenger et al., 2002).

Mangrove plantations can be noticed in many areas in Abu Dhabi. Nonetheless, due to the inadequate knowledge on plantation procedures, coupled with the harsh, arid environment of Abu Dhabi, the survival and growth outcomes are often below expectations (Vistro, 2010). More research and development programs were initiated by Environment Research and Wild Life Development Agency (ERWADA) and Abu Dhabi Environment Agency (EAD) to improve plantations techniques for *A. marina* and enhance the possibilities of reviving the extinct *R. mucronata*. Additional research has been initiated to find ways to reduce the effect of sea level rise to ensure continued survival of mangroves and wetlands communities (Aspinall, 2001).

Conclusion

Mangrove forests play an important role in the ecosystem, offering a number of benefits to both the environment and the society. Various researchers have embarked on extensive research on the subject. The worldwide rapid evolution of technologies such as remote sensing and GIS has assisted in studying the interaction between humans and the mangrove forests and in monitoring their change over time.

Mangrove forests in the Arabian Gulf region offer an important insight into the nature of the forests. However, due to ongoing paucity of research in the region on the subject, there is a significant knowledge gap that needs to be addressed. This paper is an attempt to address some of the issues related to the mangrove ecosystems in the Arabian Gulf region, which has been neglected by various researchers.

The paper has discussed the characteristics and composition of the mangrove forests in the Arabian Gulf region, maintaining that mangrove forests vary across regions. It has demonstrated that the number of mangrove species is much lower in tropical arid environments than in tropical wet environments. The paper has argued that it is difficult for most mangrove species to survive the harsh arid environments of the Gulf region. However, it has noted that very few species possess characteristics that allow them to survive in such environments. There is, therefore, a need for effective studies to evaluate the situation of mangrove forests in the region, with a view to conserving its valuable coastal ecosystems.

This paper has also highlighted some of the ecological as well as economic benefits that can be derived from mangrove ecosystems. It has argued that the ecosystem provides habitat for various organisms; plays a major role in controlling air and water pollution; provides educational and recreational opportunities, noting the potential of mangrove forests in Abu Dhabi as a source of revenue if effectively preserved.

In spite of the various benefits of mangrove forests to the society, they are facing a number of anthropogenic and natural threats worldwide. It is acknowledged that the once prosperous mangrove forests that occupied three-quarters of the tropical and subtropical coastlines no longer exist and that they have been reduced to close to half the original population. Some of the major threats to mangrove forests include toxic-chemical pollution, agricultural expansion, urbanization, and eutrophication. Mangrove forests are also under threat from natural causes such as changes in sea levels, hurricane, and storms as well as high temperatures, low precipitation and high concentration of carbon dioxide.

It goes without saying that this vital ecosystem needs to be protected from all sorts of threats. In recent years, different organizations worldwide initiated intensive research to ensure the continued survival of mangroves. However, there are still significant gaps in people's understanding of the importance of mangrove ecosystems.

There are mangrove forests in various areas of Abu Dhabi emirate. However, many people are still ill-educated about these forests, making them seriously vulnerable to encroachment. It is, therefore, important that activities that enrich mangrove forests such as increasing public awareness regarding mangrove forests be carried out and promoted and new environmental regulations to conserve the forests be introduced. Establishing marine protected areas and increasing total areas of mangrove through establishing mangrove plantations are other significant approaches of enhancing the mangroves.

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