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Avicennia marina around Qatar: Tree, Seedling and Pneumatophore Densities in Natural and Planted Mangroves using Remote Sensing

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Abstract: Based on satellite images from all study sites along the east coast of Qatar, natural mangroves cover an area of 797.6 ha while planted stands cover 182.9 ha. On the west coast planted mangroves cover a small area of about 1 ha only, probably due to high salinity of seawater and contaminated sediments. The density of *Avicennia marina* trees in natural mangroves, at the upper tidal level is about 2800/ha, and slightly higher at the middle mangroves (about 3050/ha). In general after several replanting works over the past 23 years, planted mangroves also showed robust stands, with tree density ranging from 1,100/ha to 2,100/ha. However on the west coast tree density of planted mangroves is very low at 200/ha and restricted only to the middle tidal zone. In natural mangroves tree height ranges from 1 to 6m while in planted stands, from 1 to 3m only. On the west coast, the mangroves are stunted, with maximum tree height of 1m, probably due to high seawater salinity especially in summer where it can reach 59.1. Seedling density is also high (ranging from about 933/ha to 1,466/ha) in natural and planted mangroves on the east coast, but absent in planted stand on the west coast. On the east coast natural mangroves produced abundant pneumatophores, with density ranging from 86/ m^2 to 516/ m^2 while in planted mangroves the density is lower, and ranges from 88/m^2 to 308/ m^2. Planted mangroves performed poorly on the west coast with low pneumatophore density (30/m^2). In general pneumatophore density is higher in the middle mangroves than in the upper mangroves to facilitate efficient gaseous exchange during low tide.

Keywords: *Avicennia marina;* Qatar; tree; seedling; pneumatophore; density; remote sensing

1. Introduction

Mangroves cover about 15 million ha of coastlines in 123 tropical and sub-tropical countries (Spalding and Blasco, 1997). However much of existing mangroves are degraded (Giri et al., 2010) or in serious decline owing to the expansion of human settlements, extensive commercial aquaculture and the impact of tidal waves and storm surges (Zhang et al. 2012). For these reasons, International organizations and government agencies in several countries are urgently implementing mapping and monitoring programmes to measure the extent of the decline of these important ecosystems (Green et al., 2000). This is because remote sensing technology allows information to be gathered from the environment of mangrove forests, which otherwise, logistically and practically, would be very difficult to survey.

Avicennia marina tends to fringe tidal fringes (Wells 1982), can colonise higher ground and survive in wider range of environments than any other mangrove species (Clough, 1982). Thus in Qatar this species was chosen for mangrove afforestation along barren coastal areas in 1981 (Suda and Al-Kuwari, 1990) through technical collaboration between The Japan International Cooperation Agency (JAICA) and The Ministry of Municipal Affairs and Agriculture. Most of the planted areas are near coastal inlets and lagoons. The largest area was at Umm Al Hul, the second at Al Mafjar and the third at Fuwairit. Early afforestation efforts were futile as seedlings were often uprooted by strong waves or damaged by foraging camels. Following repeated replanting works, planted mangroves are now well established in various localities along the east coast. Unfortunately due to rapid coastal developments over the last 10 years, most of the planted mangroves at Umm Al Hul have been destroyed for infrastructure developments, including the development of new ports and oil industries.

Except for comparative study on the macrofauna in natural and replanted mangroves (Al-Khayaat and Jones, 1999) and a recent investigation on the mangrove trend in Al Thakira using remote sensing (Balakrishnan, 2012), there has been no monitoring on post-planting mangrove establishment or success, in Qatar. Hence the present study using remote sensing and ground truth studies is timely to determine the present status of natural and planted mangroves in the country. The focus is on stand coverage and estimates of tree, seedling and pneumatophore densities in natural and planted mangroves.

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2. Materials and Methods

2.1 Remote sensing

In this study ancillary data are extracted from plant-environment relationships, and then incorporated with remotely sensed data into the mapping model in order to improve the quality of the final map. Ancillary data were incorporated at three different stages: before (pre-classification), during, and after (post classification) the mapping process. The non-parametric model of artificial neural networks (Berberoglu et al., 2004) and the inference engine of expert systems (Comber et al. 2004; Schmidt et al. 2004) were followed. Similar to many other plants, mangroves have strong relationships with the surrounding environment. The occurrence of mangrove species at a certain location is often related to surrounding ecological gradients such as elevation, tidal inundation, water salinity and soil pH (Macnae, 1968). Thus mangroves grow within their own niches. In many cases, this phenomenon causes strip-like patterns (or mangrove zonation) parallel to the tide lines that are usually found in tropical mangrove forests (Vilarrubia, 2000; Satyanarayana et al., 2002)

Since the mangroves grow along the coastline, the coastline boundary was used to mask the land areas from the Pleiades-1A images. This operation excluded the coastal vegetation comprising of palm trees, vegetable farms, halophytes and grassy recreational areas from the Pleiades-1A images. The vegetation associated with the mangroves such as halophytes and exposed algal mats could not be excluded. The masked Pleiades-1A images are used to create NDVI images. The most widely used technique for detecting vegetation with remotely sensed images is the Normalized Difference Vegetation Index (NDVI). Studies using NDVI and other vegetation indices are varied and include those involved with local, regional, and global mapping of vegetation (Townsend and Justice, 1986). The Normalized Difference Vegetation Index (NDVI) is defined as: NDVI = (NIR-R) / (NIR+R). NDVI for Pleiades-1A image is calculated using Pleiades-1 bands 3 (600 – 720 nm) and 4 (750- 950 nm).

2.2 Ground truth studies

Ground truth studies were conducted between November 2012 and May 2013 near two natural mangrove stands at Al-Khor and Al-Thakhira, and near planted mangroves at four locations at Simaisma, Fuwairit, Al Mafjar (east coast) and at Zekreet (west coast) (Figure 1).

All study sites support pure stands of *Avicennia marina*. Stations were located at the upper (50 m from shoreline) and middle (200m from shoreline) tidal levels for samplings on tree, seedling and pneumatophore densities.

2.3 Physical and hydro-chemical data collection

Sediment samples were collected from each station to a depth of 30 cm with a corer an dried in the laboratory and the silt and clay (mud content) determined by passing it through a 0.06 mm sieve which includes both fractions (Tait, 1981). Water temperature, salinity, pH and dissolved oxygen content were measured using suitable all-purpose portable meters. Salinity was measured using the Practical Salinity Scale. Three measurements were taken for each parameter and averaged for each season. Three samples were taken (for each data for the physical and hydro-chemical parameters) from areas between the upper and middle mangroves to represent data for the study site.

2.4 Tree, seedling and pneumatophore densities, and heights

Rapid assessments were conducted, to estimate the density of trees, seedlings and pneumatophores, including the height range of trees and seedlings at all study sites. At each site tree density was counted within a study plot measuring 10m x 10m, while for seedling density the value is an average from counts within 3 sub-plots measuring 1mx 1m. Seedling and pneumatophore densities were also obtained from the average counts from three sub-plots measuring 1m x 1m. All study and sub-plots were located at random within mangroves at the upper and middle tidal levels.

3. Results and Discussion

3.1 Satellite images

The development of vegetation indices from satellite images, have facilitated the process of differentiating and mapping vegetation by providing valuable information about structure and composition. In tropical dry forests, the Normalized Difference Vegetation Index (NDVI) from Landsat indicates overall green biomass, canopy closure, tree density, and tree species diversity (Krishnaswamy et al., 2004; Feeley et al., 2005). Thus it is a good tool for studying the vegetation. NDVI capitalizes on the strong energy absorbed by the chlorophyll in the red portion of the electromagnetic spectrum (RED), and on the energy scattered by the internal structure of leaves in the near-infrared (NIR), and uses this contrast as an estimate of vegetation greenness, by the formula: NDVI=(NIR–RED)/ (NIR+RED). The result is an image with a continuum of pixel values that range from –1 to +1. In general terms, negative values correspond to non-vegetated surfaces, while positive correspond to vegetated ones, although the lower NDVI values for vegetation usually start in 0.2-0.3. In areas where vegetation canopies do not achieve complete coverage, the NDVI is susceptible to the spectral influence of the soil, giving the possibility of uncertainties in interpretation (Peters and Eve, 1995). However, this effect can also increase the length of the gradient of NDVI of certain vegetated surfaces, and could potentially improve the separation of land cover classes along this gradient. A collection of NDVI samples that reflects the variations in canopy closure and vegetation coverage might help elucidate the implication of those uncertainties. The NDVI images as shown in the figures 2 and 3 for Al Khor and Al Thakira) are further converted into GIS vector format (Figures 4 a-f).

3.1.1 Satellite maps

Figure 1 shows the locations of all study sites in Qatar while Figure 4 a-f give the map of mangrove areas at each study site at Al Mafjar (4a), Fuwairit (4b), Al Thakira (4c), Al Khor (4d), Zekreet (4e) and Simaisma (4e).

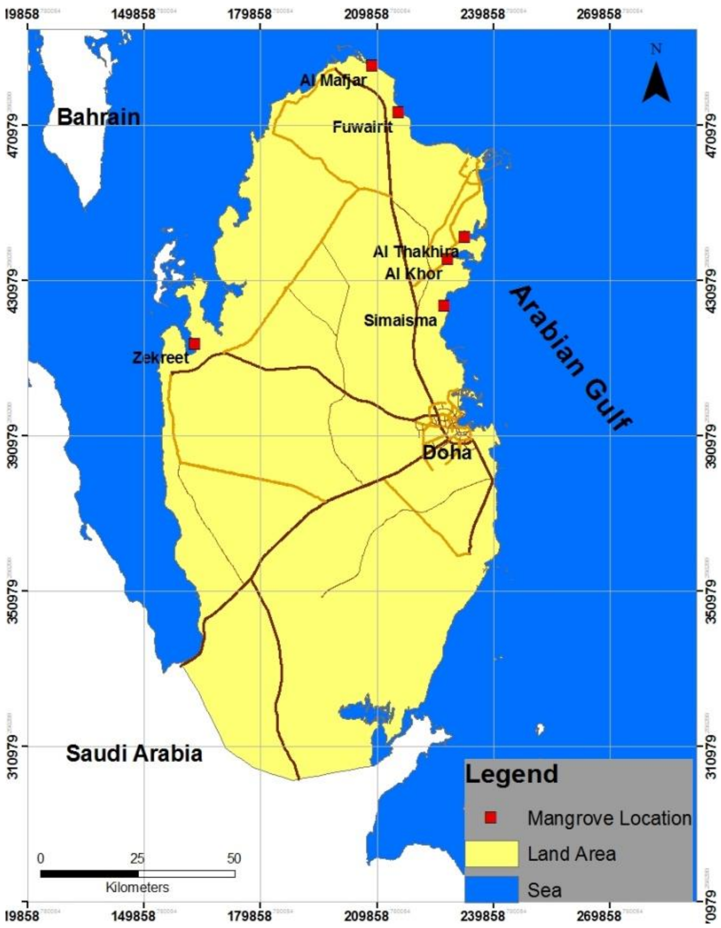

Figure 1: Mangrove Area Location Map

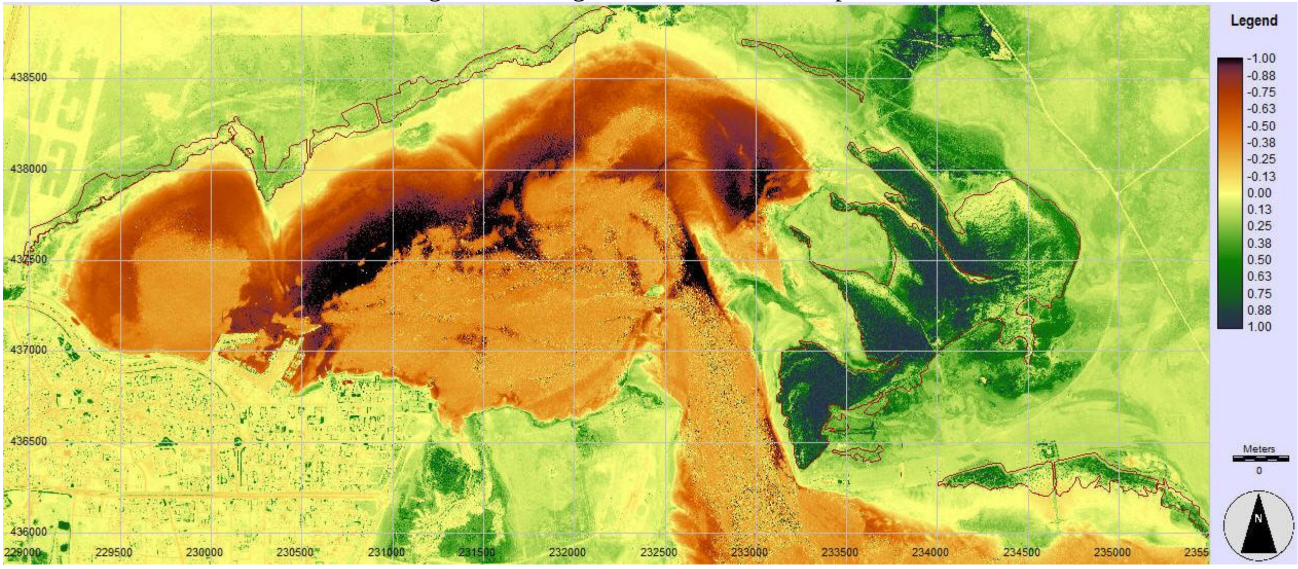

Figure 2: Normalized Difference Vegetation Index (NDVI) - Al Khor

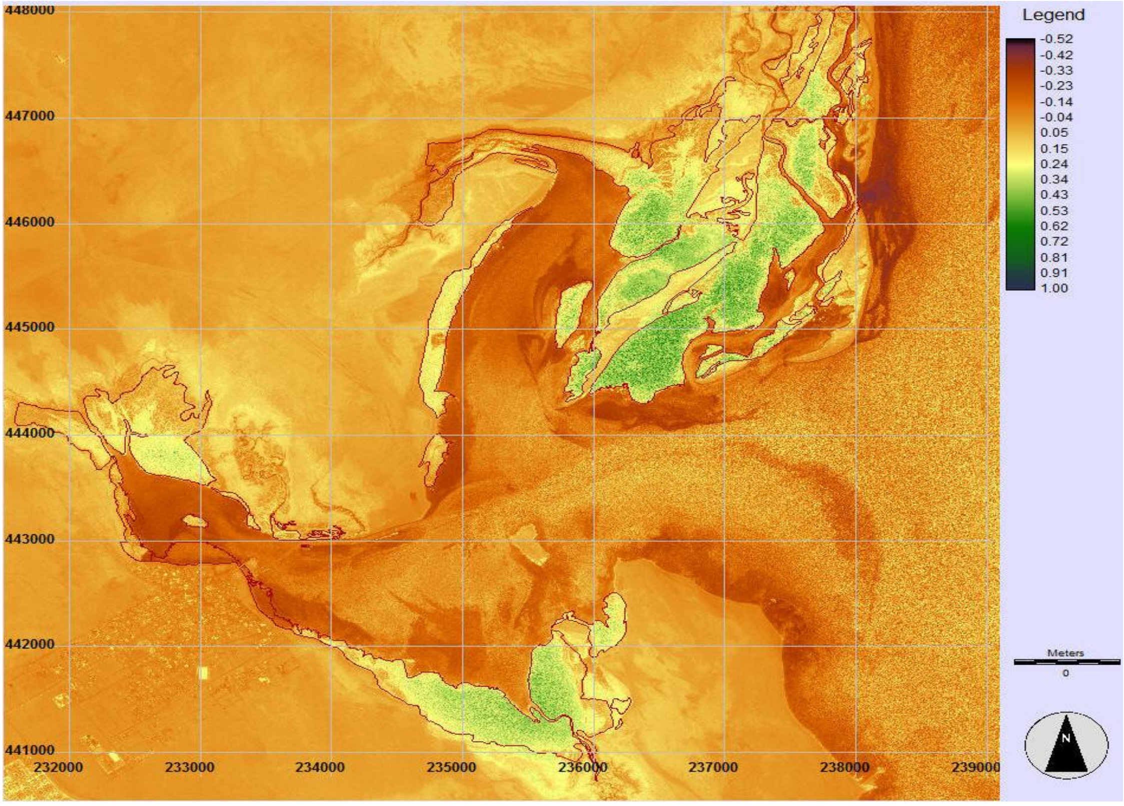

Figure 3: Normalized Difference Vegetation Index (NDVI)- Al Thakhira

Figure 4a - Al Mafjar

Figure 4b - Fuwairit

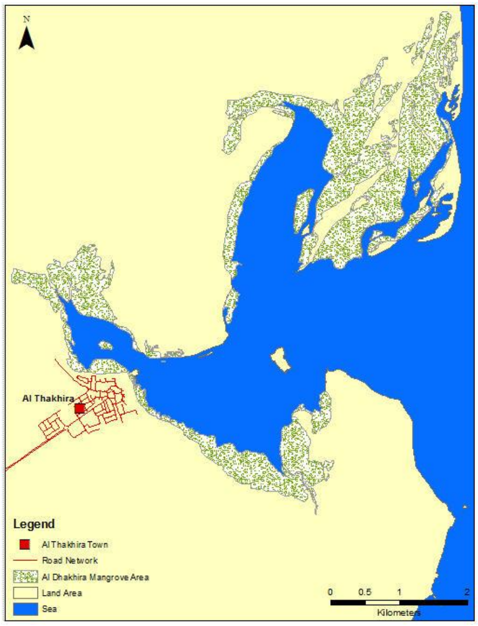

Figure 4c – Al Thakira

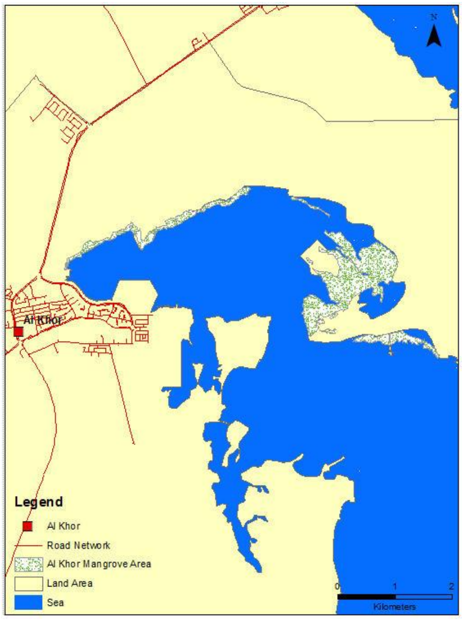

Figure 4d – Al Khor

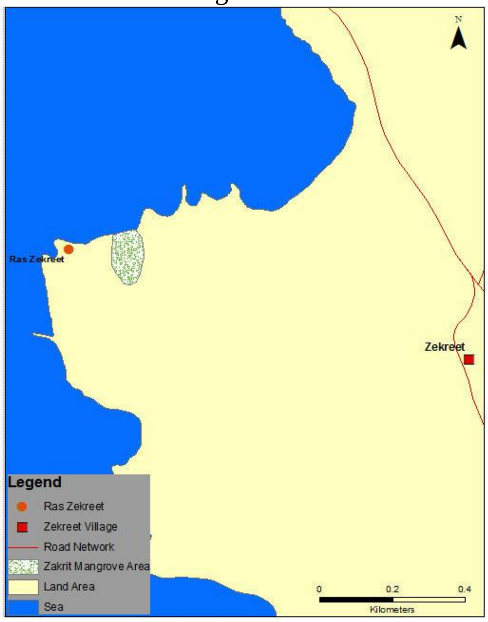

Figure 4e – Zekreet

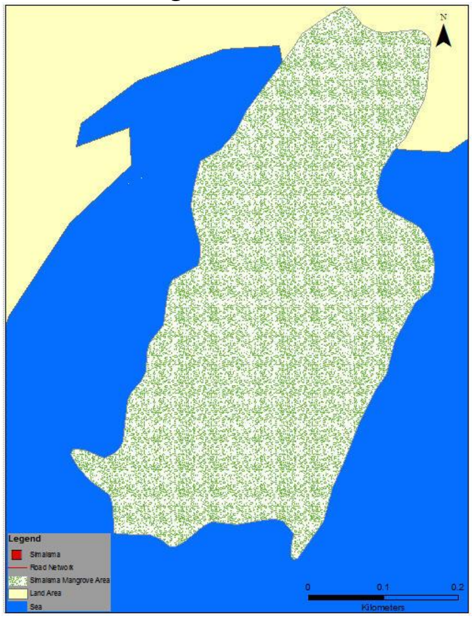

Figure 4f - Simaisma

Figure 4 a-f: Mangrove distribution at study sites at Al Mafjar (4a), Fuwairit (4b), Al Thakira (4c), Al Khor (4d), Zekreet (4e) and Simaisma (4f)

3.1.2 Existing natural and planted mangroves

Table 1 and Figure 3 give the mangrove area data and histogram respectively, based on calculations from the satellite images of all study sites. Extensive natural mangroves are found at Al Thakira (629.19 ha) and Al Khor (168.42ha). Afforestation efforts were most successful at Al Mafjar with planted mangroves covering 143.35 ha, followed by Fuwairit (20.59 ha) and Semaisma (19 ha). Planted mangroves at Zekreet cover only a small area measuring 1.11 ha.

Table 1: Mangrove area at the study sites based on satellite images

No.	Location	Area in hectares
1	Al Mafja	143.35
2	Fuwairit	20.59
3	Al Thakhira	629.19
4	Al Khor	168.42
5	Simaisma	19.00
6	Zekreet	1.11
Total Area		**981.66**

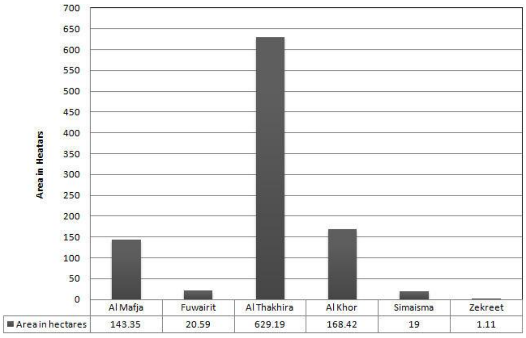

Figure 5: Histogram on mangrove area (ha) at the study sites

3.2. Description of natural and planted mangroves

3.2.1 The physical environment

In Qatar luxuriant stands of natural mangroves are found in areas with high mud contents such as at Al Thakira (65.2%) and Al Khor (38.8%) as shown in Table 2. Planted *Avicennia marina* mangroves have been successfully established on sandy substrates at Al Mafjar with the least mud content (16.5%). At other localities the planted mangroves grow in sandy substrates with mud contents ranging from 22.4 -28.2% (Table 2).

In general the mean annual salinity of seawater in natural mangroves is 45.6 at Al Thakira and 43.6 at Al Khor. In planted mangroves it ranges from 44 at study sites on the east coast and 51.8 on the west coast (at Zekreet). Declining and stunted mangrove stands are found at Zekreet that coincidentally has the highest seawater salinity in summer (59.1). In natural mangroves mean annual seawater temperature is around 29ºC while in planted mangroves it is ranges from 29-30ºC . The highest value (30 ºC) is from Zekreet.

In natural and planted mangroves, the mean annual pH of seawater is around 8.3. while the annual mean dissolved oxygen ranges from 5.0 and 5.7 mg/l. It is interesting to note that the annual mean dissolved oxygen of seawater at Zekreet is the lowest at 5 mg/l.

Table 2: Hydro chemical parameters at the study sites (Mud Content, and Salinity, Seawater Temperature, pH and Dissolved Oxygen (in Summer, Autumn, Winter and Spring)

Hydrochemical parameter **Location**	**Mud content (%) (+ - SE)**	**Seasonal Salinity** *| Seawater temp., ◦C* (Ann. Mean..+- S.E) **Sum. Aut. Win. Spr**	**pH/** *Dissolved Oxygen, Mg/l* (Ann. Mean.+- S.E) **Sum. Aut. Win Spr.**
1. **Natural Mangroves** **East Coast**			
1.1 Al Khor (Ras Matbah)	38.8 (3.6)	**44.8 44.8 41.4 44.2** **(45.6, + - 3.4)** *33.2 29.4 22.6 31.3* *(29.1, +- 4.0)*	**8.3 8.2 8.2 8.2** **(8.2,+- 1.4)** *5.2 5.4 6.3 5.8* *(5.7, +- 1.2)*
1.2. Al Thakira	65.2 (4.7)	**44.2 44.9 41.6 43.5** **(43.6, + - 3.3)** *33.2 29.2 22.6 31.3* *(29.0. +- 3.4)*	**8.2 8.2 8.2 8.1** **(8.2, +- 1.4)** *5.2 5.3 6.1 5.1* (5.4,+- 1.2)

2. **Planted mangroves**			
2.1 East coast			
2.1.1 Simaisma	27.0 (3)	**44.2 44.5 43.3 44.3** **(44.0, + - 3.3)** *33.3 29.4 22.5 31.1* *(29.0, +- 3.4)*	**8.3 8.3 8.2 8.2** **(8.3, +- 1.4)** *5.0 5.3 6.1 5.1* *(5.4, +-1.2)*
2.1.2 Fuwairit	28.2 (3.1)	**44.1 44.1 42.6 43.3** **(43.5, + - 3.3)** *33.3 30.4 21.8 30.2* *(28.9, +-3.5)*	**8.2 8.2 8.2 8.1** **(8.2, +- 1.4)** *5.0 6.3 6.0 5.0* *(5.6, +- 1.2)*
2.1.3 Al Mafjar	16.5 (2.3)	**44.5 44.1 42.4 44.5** **(43.9, +-3.3)** *33.2 34.8 20.9 30.3* *(29.8,+- 3.4)*	**8.2 8.3 8.3 8.2** **(8.3, +- 1.4)** *5.2 5.3 6.2 5.0* *(5.4, +- 1.2)*
2.2 West Coast			
2.2.1 Zekreet	22.4 (2.7)	**59.1 49.3 51.8 55.8** **(51.8, +- 4.1)** *35.5 34.8 20.9 30.3* *(30.4, +- 3.9)*	**8.3 8.4 8.2 8.3** **(8.3, +- 1.4)** ***4.5 5.1 5.4 5.0*** *(5.0, +- 1.1)*

3.2.2 Density of and height of trees in natural and planted mangroves

The estimates for the density of trees and seedlings are shown in Table 3. In this table, a tree is an individual plant that is more than 1m tall while a seedling is less than 1m.

Table 3: Estimates of tree, seedling and pneumatophore densities, and range of tree and seedling heights within upper and middle mangroves, in natural and planted stands

ELEVATION	**UPPER MANGROVES**		**MIDDLE MANGROVES**	
Location/ Hydrochemical data	**Tree**	**Seedling**	**Tree**	**Seedling**
1. Natural mangroves				
East coast				
1. Al Khor (Ras Matbah)				
a) Density no./ha	2,800	1,100	3,100	1,100
b) Height Range	1-3m	5-60cm	1.5 - 6m	10-70cm
c) Density of pnematophores, no/sq.m	86	-	516	-
2. Al Thakira				
a) Density , no/ha	2,800	1,333	3,000	1,000
b) Height Range	1–3m	10-70 cm	1.7 -6m	10-80 cm
c) Density of pneumatophores, no/ sq.m	158	-	308	-
2. Planted mangroves				
East Coast (after 23 years)				
1. Semaisma				
a) Density , no/ha	1,100	933	1,700	1,000
b) Height Range	1.5-2.7m	10 - 40 cm	1 -2.5m	10-80 cm
c) Density of pneumatophores, no/ sq.m	124	-	272	-

2. Fuwairit				
a) Density , no/ha	1,600	1,270	1,900	1,233
b) Height Range	1.5-3m	5 -30 cm	1.4-4.5m	5-60 cm
c) Density of pneumatophores, no/ sq.m	308	-	194	-
3. Al Mafjar				
a) Density , no/ha	2,100	1,466	2,600	1,100
b) Height Range	0.6 - 2m	5 - 40cm	1.5-4m	10-40cm
c) Density of pneumatophores, no/ sq.m	88	-	88	-
West Coast (after 3 years)				
1. Zekreet				
a) Density , no/ha	Nil	Nil	200	Nil
b) Height Range	Nil	Nil	0.5-1.0m	Nil
c) Density of pneumatophores, no/ sq.m	14	-	Nil	-

Based on field observations and estimates, natural mangroves support tree density of 2,800/ha in the upper mangroves, and between 3,000 and 3,100/ha in middle mangroves. These figures indicate dense, pure stands of *Avicennia marina*, including small, medium and big trees above 1m. Figures for planted mangroves are slightly lower, between 1,100-2,100 per hectare in upper mangroves and between 200-2,600 per hectare in middle mangroves. In natural stands, tree height ranged from 1-3m in the upper mangroves and 1.5 - 6m in the middle mangroves, while in planted mangroves tree height ranged from 1-3m in the upper mangroves and 1 - 4.5m in the middle mangroves. In general at all study sites mangroves are visually taller in the middle mangroves.

3.2.3 Seedling density and height in natural and planted mangroves

In natural stands, seedling density ranged from 1,100-1,333 per ha in the upper mangroves while seedling height ranged from 5-70 cm. In the middle mangroves seedling density ranged from 1,000-1,100 and seedling height, from 10-80cm.

In planted stands, seedling density ranged from 933-1,466 per hectare, with height ranging from 5- 40cm in the upper mangroves. It is noted that at Zekreet, there is no seedling on site. At all sites (except at Zekreet) in the middle mangroves, seedling density ranged from 1,000-1,233 per hectare and seedling height ranged from 5-80cm.

In general seedlings are more numerous and taller in the middle mangroves in both natural and planted stands. In mangrove silviculture a minimum density of 2,500 per ha is required to qualify for natural regeneration (Srivastava and Ball, 1984). At the study sites although the seedling density is lower than this figure, the mangroves actually show robust growth and regeneration The exception is at Zekreet where there is noticeable absence of seedlings and the mangroves are declining.

3.2.4 Pneumatophore density

At all study sites pneumatophores are numerous in the middle mangroves with density ranging from 30-516 per m^{-2}. Dicks (1986) reported more pneumatophores in water logged and polluted soils than in well-drained and clean soils. Saifullah and Elahi (1992) reported higher pneumatophore density ranging from 56-1,168 m^{-2} in *Avicennia marina* mangroves at Karachi (Pakistan). In general pneumatophores enable *Avicennia marina* to grow in oxygen-poor sediments. At low tide the numerous lenticels in the pneumatophores enable gas exchange, directly above the water surface and thus provide the needed oxygen that cannot be taken from the soil. During high tide the surface tension of the water prevents the inflow of water into lenticels therefore no gas exchange is possible while the pneumatophores are under water. Permanent inundation of pneumatophores can lead to the death of the root system and therefore the mangrove. Pneumatophores can grow within a radius of 10 meters around the trunk.

As shown in Figure 4 e and Table 3, only small clumps of mangroves are present at Zekreet, covering the smallest area (about 1 ha). The trees are stunted, probably due to the high salinity of seawater in the study site, particularly in summer (when the salinity can reach 59.1). According to Naidoo (2006) hydro-edaphic factors probably contribute to the high soil salinities, low water potentials, water stress and ion imbalance within tissues including P deficiency, which in interaction, can contribute to dwarfing in *Avicennia marina* at Richard's Bay, South Africa. Along the entire shoreline at Zekreet, oil slicks are visible and probably washed ashore from oil refineries nearby, and within the coastal lagoon. The absence of seedlings is probably also due to the effects of oil pollution (Duke et al., 2002, Grant et al., 1993).

However the luxuriant stand of *Avicennia marina* mangroves at Al Mafjar shows that the establishment of this species may not be seriously affected by oil spills because these are often encountered as hardened black masses along the coastline. In addition the site is exposed to strong sea currents that regular flush the shoreline habitats.

3.3 Mangrove restoration and conservation

At all study sites mangroves are already destroyed or threatened by rapid coastal developments including the development of petro-chemical industries (at Ras Laffan on the east coast and at Dukhan, on the west coast), cities (for example Lusail City about 10km north of Doha) and the new port (near Al Wakra). There is a need for greater commitments in terms of funding and the application of innovative and effective methods to increase mangrove areas in Qatar. A recent cost-effective integrated bio-technical technique, involving the construction of off-shore segmented wave-breakers (Hashim et al., 2010) for initial coastal protection and habitat stabilization, followed by conventional enrichment planting (Tamin et al., 2011) could be applied in Qatar to reestablish or restore mangroves that were destroyed during the construction of oil refineries, cities or ports near the coastline.

4. Conclusion

Based on calculations from satellite images, *Avicennia marina* mangroves at all study sites cover an area of about 981 ha, that also represent most of the existing stands in Qatar. To the untrained eye, in terms of stand structure and physiognomy it is difficult to differentiate between natural and planted stands as this species show robust growth especially in the middle tidal levels. On close inspection it can be seen that planted mangroves are shorter, as several replanting works have been carried out since the 1980's, due to failures in seedling establishment during the initial years. Indeed in areas with high seawater salinity and regular exposure to oil pollution, mangrove stands are visibly stunted. Today *Avicennia marina* mangroves at Simaisma, Al Thakira, Al Khor, and Fuwairit are threatened by coastal developments and pressures from increasing number of tourists to the area. To increase the mangrove area straddling the Qatari coastline, relevant government agencies should formulate plans for immediate mangrove restoration and conservation. Plans for coastal development should also incorporate wise use of mangroves as educational and recreational centres to ensure the survival of existing mangroves.

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