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(RESEARCH ARTICLE)

Reintroduction of red mangrove *Rhizophora mucronata* in Abu Dhabi Emirate, United Arab Emirates

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Abstract

Reintroduction of once existing red mangrove, *Rhizophora mucronata* trials were carried out in Abu Dhabi, United Arab Emirates. Propagules were procured from Pakistan and cultured in a greenhouse before they were planted alongside existing *Avicennia marina* forest in two sites of Abu Dhabi emirate, Abu Al Abyad and Ras Ghanada Islands. This study documents the present condition of the plants after 11 years of plantation. Long term survival rate was as high as 81% in Abu Al Abyad while Ras Ghanada experienced a very low survival rate at 10%, primarily due to external factors. In contrast, Ras Ghanada plants showed higher growth with the mean height stands at 2.06 m (SD ± 0.31m), while in Abu Al Abyad it is 1.53 m (SD ± 0.36 m). In Abu Al Abyad, more than one third (36.4%) of surviving plants showed reproductive phenology, whereas in Ras Ghanada it was only 10.3%, despite ~~of~~ greater height classes. Many Rhizophora were also noticed with well-developed stilt roots. This study showed that *Rhizophora mucronata* can be planted in Abu Dhabi, despite the Emirate's harsh climatic conditions.

Keywords: Mangrove; *Rhizophora mucronata; Avicennia marina*; Abu Dhabi Emirate; United Arab Emirates

1. Introduction

Mangrove vegetation is one of the most productive coastal ecosystems that protect the coast from shoreline erosion, natural calamities [1], sequester carbon [2] and provide natural nursery and habitat for varied phyla [3]. Despite its significance, the mangrove habitat is still declining globally due to urbanization, land reclamation, aquaculture and increased pressure from climate change [4]. Mangrove ecosystem, consisting of *Avicennia marina*, is the only evergreen forest in the arid region of the United Arab Emirates - UAE [5, 6, 7]. Contrary to the global trend, the mangrove coverage in the UAE has actually increased in the last few decades, particularly due to a number of large scale restoration programmes [8, 9].

In Abu Dhabi Emirate the mangroves cover an area of 10,384 ha of natural and planted mangroves spreading along 547 km of shoreline accounting for approximately 80% of the total mangrove forest area in the UAE. This forestation is considered a means of climate change mitigation, marine ecosystem and coastal protection [10, 11, 12]. It was reported that blue carbon ecosystems in Abu Dhabi Emirate are estimated to store over 41 million tonnes of carbon dioxide equivalent within the soil and biomass, and more than the Emirate's annual emissions from the oil and gas industry (26.40 million tonnes) or water and electricity (30.90 million tonnes) sectors [12, 13].

Red mangrove, *Rhizophora mucronata* is an important mangrove species in the tropical indo-pacific region [14] and the clustered matrix formed by the 'stilt roots', provide an important nursery ground for many commercially important fishes [3, 15] while above ground biomass is used as the nesting ground for varied native and migratory Avian groups [16]. This species was reported to exist 100 years back in UAE but disappeared from the area in historical times due to overexploitation of its timber for firewood, construction of traditional houses and for making small fishing boats [11,

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17, 18]. One of the most effective means of mangrove restoration procedure followed worldwide is to increase the mangrove plantation and UAE is not far behind in that process [12, 19]. In-fact UAE is one of the leading countries in the region where large scale mangrove restoration programmes are being undertaken, particularly due to the favourable government initiatives; but most of the plantation is restricted to the native *A. marina* species. Reintroduction of once existed *R. mucronata* in UAE is particularly rare. The first reintroducing attempt of *R. mucronata* was undertaken by Abu Dhabi Oil Company during 1983-86 in Mubarraz Island, where propagules were brought from Pakistan for growth experimental purposes [5, 20]. In 2008 the Department of the President's Affairs, now the Private Department of the President, in coordination with the Environment Agency-Abu Dhabi (EAD) launched a project to reintroduce *R. mucronata* in Ras Ghanada Island, North East of Abu Dhabi and eventually the plant flowered but further development of the study is unknown and lacks any published data [19, 21].

Reintroduction of a species in its proven habitat can only be successful if the causes of the extinction has been mitigated [22]. To our knowledge, the extinction of this species suggests that indiscriminate exploitation is the primary reason for the disappearance of the Rhizophora in UAE and we hypothesized that if the main drivers of the extinction are mitigated, the species might have the chance to return under a suitable environment. This has encouraged us to attempt and conserve this species in an isolated place where human activities are minimal. Additionally, reintroducing a species is only viable if the species is able to assimilate in the new environment and become self-sustained (reproductively mature) without further human intervention. Under this scenario, a pilot scale reintroduction programme was carried out for this species in Abu Al Abyad Island, Abu Dhabi. As a start, *R. mucronata* propagules procured from Pakistan in 2008 were cultured in greenhouse and on germination to seedlings they were planted inside the existing *Avicennia* forest on North East of the island.

In this article we document the development of this highly valuable mangrove species under the harsh climatic conditions of Abu Al Abyad Island and discuss the challenges involved to restore the *Rhizophora* species and the development of this species after 10 years of plantation. In order to draw a comparison, additionally we have also sampled the Ras Ghanada plantation which was left for a decade without any human intervention.

2. Study area

Abu Al Abyad and Ras Ghanada are both near shore islands in the Abu Dhabi Emirate but approximately 170 km apart from each other. Abu Al Abyad Island (24°14' N, 53°49' E) located on the southern basin of the Arabian Gulf and west of Abu Dhabi, the capital, is one of the largest near shore islands in Abu Dhabi Emirate. Ras Ghanada (24°49' N, 54°46' E) is also one of Abu Dhabi Emirate's important islands and it is about 90 kilometers northeast of Abu Dhabi. Abu Dhabi Emirate has an arid climate where in summer, which extends from June to September, air temperatures are very high exceeding 45 °C, while in winter, which extends from December to March, air temperatures drop to 12 °C or less. Seawater temperatures exceed 34 °C in summer and reach a minimum of 16 °C in winter. The rainfall is infrequent and irregular with less than 100 mm per year coupled with high evaporation rates (2-3 mm/day). The rate of exchange of the Arabian Gulf with adjacent seas is very low with the flushing rate estimated at about 5 years. This situation directly contributed to the unusually high levels of salinity reaching up to 40 ppt in the open areas and more than 45 ppt in enclosed areas. All these factors have restricted the diversity and abundance of marine life [23]. Likewise, this situation restricted the mangrove population in UAE to only the most adoptable monospecific stands of salt tolerant grey mangrove *Avicennia marina* (Forssk.) Vierh [5, 6, 7, 12, 23, 24, 25, 26, 27]. Like the Arabian Gulf area, the sediments throughout Abu Dhabi Emirate consist of medium to coarse sands from white calcium carbonate [18, 28].

The coasts of Abu Al Abyad and Ras Ghanada are typically characterized by low lying salt flats (Arabic "sabka") which is sparsely vegetated by salt marshes. Mangrove forest exists along the fringe of the natural channels. Abu Al Abyad is characterized by dense bed of seagrass meadows and discontinuous distribution of coral reefs, particularly on the north of the island also exists [29]. Also, Ras Ghanada is characterized by vast seagrass meadows situated adjacent to the coral area. Ras Ghanada coral reef is considered the UAE's healthiest and vibrant [27]. Both islands have experienced extensive dredging activities in the last couple of decades and thus resulted in new water passage along with muddy and sandy banks inside the island and increased area of muddy/sandy banks has promoted a large scale mangrove planting programme inside the island, managed by the Aquaculture and Marine Studies Center (AMSC). The planting efforts are limited to the grey mangrove (*A. marina*) species, the only naturally occurring mangrove species in the region. However, the plantation of *R. mucronata* in Abu Al Abyad was supervised by AMSC while for the Ras Ghanada it was done by EAD.

3. Procedure of *R. mucronata* in Abu Al Abyad Island

In an effort to test the efficacy of reintroducing the previously extinct red mangrove, *R. mucronata*, in 2008, 350 numbers of mature propagules were procured from Pakistan, almost similar latitudinal location but vastly differed in climatic condition between the source and planting site of Abu Al Abyad, UAE. The 350 propagules were first cultured in a greenhouse in 2.2 liter black plastic containers and were first irrigated with freshwater for three months until the formation of mature leaves. Then the seedlings were gradually introduced to seawater (42 ppt) within a month by adding seawater to increase salinity by 1.5 ppt/day. After one more month of acclimatization to natural seawater salinity (42 ppt), the plants, attaining 28.6% survival rate, were transferred to the selected plantation area in the island.

The seedlings were planted within the existing Avicennia forest in the northern part of the island, on the fringe habitat where the soil type is silty loam. Owing to lack of any established protocol for planting *R. mucronata* in UAE, the planting procedure followed was the same as that of *A. marina*. Each of the seedlings were either planted solitarily or clustered into a maximum of three plants in a plot of 2.5 m x 2 m. While clustered, the seedlings were in linear position with a maximum spacing between 1 and 1.5 m. Each plot was fenced in order to avoid animal grazing and any burial by drifted materials (seaweeds, plastics, wood etc.). A distinct planting procedure in Ras Ghanada is unknown to authors but it is understood that the planting procedure was almost similar to that of Abu Al Abyad (EAD, personal communication).

4. Data collection and observations

Although the seedlings of *R. mucronata* were planted in 2008, until 2018, there were no records of observation and sampling and that is due to lack of a support team. It was only in October 2018, we first made any scientific observation and since then data was recorded fortnightly. Lack of any observation for 10 years, however, reinforces that the seedlings were left unattended without any human intervention except occasional removal of debris from the enclosed barrier. During each observation, development of buds and subsequent flowering were recorded. By the time the observation started, one plant had developed flowers, besides having other mature buds. Rest of the plants were either with mature buds or none (Table 2).

There was no existing data available for Ras Ghanada until 2020. It is understood that each seedling in Ras Ghanada was protected by a fence, made of iron rebar and mesh and it was evident by observing the surviving *R. mucronata*, where almost all surviving ones are still closely clustered with the iron rebar. No data about the number of seedlings planted in Ras Ghanada in 2008 is available and therefore, an attempt was made to estimate the numbers by counting the remaining available fences of surviving and dead plants. As per the fence count, approximately 992 seedlings were planted in 2008.

5. Results

5.1. Survival

Long-term survival of plantation in Abu Al Abyad plots was high if compared to Ras Ghanada plots. A total of 55 plants are still surviving out of 68 plants after 10 years of plantation accounting to 80.88% survival rate. In Ras Ghanada, the survival is poor and stands at 9.78%, 97 plants were found alive from the estimated batch of 992 planted seedlings (Table 1).

Table 1 Summary of survival rate of *R. mucronata* plantation in Abu Al Abyad and Ras Ghanada Islands

Site	Planting Year	Source of Propagules	Number of Planted Seedlings (n)	Surviving Plants	
				Number	%
Abu Al Abyad	2008	Pakistan	68	55	80.88
Ras Ghanada	2008	Pakistan	992	97	9.78

5.2. Plant height

5.2.1. Abu Al Abyad

After 10 years of plantation, the plants reached a mean height of 1.53 m (SD ±0.36 m) (Figure 1A) which is significantly shorter than their parental source of Pakistan [30]. Based on the plant height, each individual was separated into 3 different classes, dwarf (<1.5 m), medium (1.5 – 2.0 m) and tall (>2.0 m). Our results indicated that most of the plants can be categorized as dwarf and medium height plants each representing 45% of total surviving plants (Table 2), while the number of tall plants is lower (only 9%) compared to other two classes.

Table 2 *R. mucronata* numbers, budding and flowering plants per each height class

Site	Mean height of the plants ±SD (m)	Plant classes based on height (m)	Number of plants (n)	Percentage in each class (%)	Number of budding plants in each class (n)	Total number of flowered plants in each class (n)
Abu Al Abyad (n=55)	1.53±0.36	<1.50 m (Dwarf)	25	45.45	3	0
		1.51-2.00 m (Medium)	25	45.45	14	1
		>2.00 m (Tall)	05	9.09	3	1
Ras Ghanada (n= 97)	2.06±0.31	<1.50 m (Dwarf)	02	2.06	0	0
		1.51-2.00 m (Medium)	43	44.33	3	1
		>2.00 m (Tall)	52	53.61	7	0

5.2.2. Ras Ghanada

Despite the low survivorship, Ras Ghanada plants demonstrated a mean height of 2.06 m (SD ±0.31m) (Figure 1B), which is significantly a higher growth pattern as compared to Abu Al Abyad plants. In this site, 53.61% categorized as tall (>2.0 m), a higher percentage of plants than Abu Al Abyad, while 44.33% categorized as medium (1.5 – 2.0 m), which is comparable with Abu Al Abyad (Table 2). Only 2.06% plants were found dwarf (<1.5 m).

5.3. Reproductive phenology

5.3.1. Abu Al Abyad

The most impressive achievement of the present plantation is the reproductive phenology of the surviving R. mucronata. More than one third of surviving plants (36.4% of surviving plants) have been observed with fully mature buds (Figure 1C) and 2 such plants were observed with flowers (Figure 1D). The reproductive phenology is positively correlated to the height of the plant. Taller plants are more reproductively mature than the medium height plants (Table 2). However, the tallest plant in our study (2.3 m) hasn't flowered yet. Dwarf plants didn't show any signs of flowering.

5.3.2. Ras Ghanada

Despite a better median height of 2.06 ± 0.31, only 10 plants (10.3% of surviving plants) were observed with fully mature buds and they all belong to either the medium or tall height class. Among them only 1 flower was noticed in a plant. In spite of more numbers of taller plants, the data is relatively low as compared to Abu Al Abyad (Table 2).

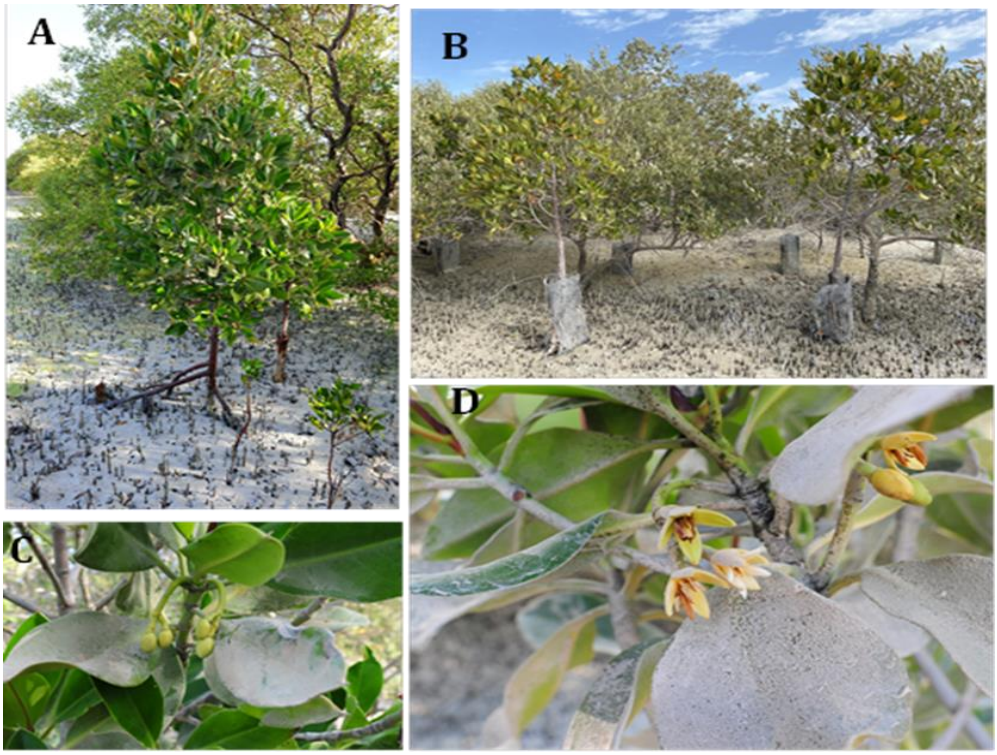

Figure 1 *Rhizophora mucronata* in Abu Dhabi Emirate. (A) A general view of *R. mucronata* in Abu Al Abyad; (B) A general view of *R. mucronata* in Ras Ghanada; (C) Reproductive behaviour of *R. mucronata* in Abu Al Abyad, mature buds and (D) Reproductive behaviour of *R. mucronata* in Abu Al Abyad, flowers

6. Discussion

This study showed that despite harsh climatic conditions, *R. mucronata* can be planted with high degree of success in the Emirate of Abu Dhabi. Although the two sites showed variable survival rates, it is assumed that the survival rate is directly related to the plantation site. In Abu Al Abyad, the saplings were planted in isolated places within the existing A. marina forest and the forest is inaccessible to wandering grazing animals (Gazelle), the only source of disturbance. Human intervention to the site is minimal or absolutely absent. Thus the plants had a better chance to survive. Other than this, the only natural disturbance could be attributed to the strong tidal current during tidal fluctuation and prevailing North-West wind, locally called "Shamal wind". Probably the disturbances caused by the Shamal wind and the resulting waves have been minimal as the seedlings were protected by the dense and mature Avicennia forest. It was reported that the use of Bamboo fence in front of the *R. mucronata* seedlings as a wave reducer gave the best effect on the survival and diameter of the plants [30].

The poor survival rate in Ras Ghanada is unclear but can be attributed to the easy accessibility to the planting site which is bordered by a concrete road. The only possible explanation to the poor survivability of Ras Ghanada is wandering Gazelle, as the animals are free to move anywhere in the island and have easy access to the site through the nearby road. Mangrove seedlings are a preferred source of food for Gazelle. Other natural disturbances like strong current and wind also prevail in this site but again the seedlings were well protected by the existing Avicennia.

This study shows that despite a low survival rate, the Rhizophora in Ras Ghanada has a higher growth rate as compared to Abu Al Abyad. One striking difference between these two sites is the salinity. The salinity in Ras Ghanada ranges between 43 and 44 ppt while the Abu Al Abyad site experiences a salinity range between 45 and 49 ppt. The stunted growth in Abu Al Abyad could be attributed to the harsh nature of the region where salinity often reaches higher than 49 ppt and never drops below 44 ppt. In-fact the dominant species A. marina too demonstrated similar growth trajectory in comparison to their Southeast Asian counterparts [8]. However, the fact that the soil in the mangrove forests in both Abu Al Abyad and Ras Ghanada is dominated by high sand increases the chances of a successful restoration of *R. mucronata* in these areas. It was reported that the type of substrate affects the success of planting *R. mucronata* which shows optimal growth on a substrate dominated by high sand content [31]. One possible explanation to the stunt growth of *R. mucronata* could be the spacing of two subsequent saplings, which is between 1 and 1.5 m. when they were clustered in a plot. Such spacing is not suitable for a large mangrove species like *R. mucronata*, as it increases the chance

of competition. In the present study, the impact of competition within the species was not tested. However, competition alone could not be the factor for the stunted growth, as the solitary plants too have demonstrated similar growth trajectory.

Our study has found an interesting aspect of the Rhizophora plantation in the Emirate. We believe that shading could play an important role in the improvement of the growth of Rhizophora. Since all the propagules were sourced from Pakistan, naturally they were not genetically adapted to the harsh climatic condition of this country, particularly during summer when the atmospheric temperature ranges between 45 and 48 °C in the coast. This study has found that those saplings which were planted in close association with fully grown A. marina, and normally shaded by them, have demonstrated better growth compared to the seedlings which were planted in relatively open spaces. Perhaps shading played an important role in the growth of seedlings during the initial phases of development. But more studies need to be done on this aspect.

This study has also found that most of the Rhizophora has well developed stilt roots and in many occasions has used it to anchor the plants. The success of the mangrove plantation can only be measured if the plants survive until they attain reproductive maturity without any human intervention and become a self sustained functional group. As evident in the Abu Al Abyad site, more than one third of surviving plants demonstrated reproductive maturity by producing matured buds and most of these plants falls under the medium and taller height classes. However, during the entire sampling period, not a single propagule could be noticed and this draws further research to this valuable mangrove species.

To address the question on how reintroducing of extinct species affects the native species, we observed no phenotypic changes to the Avicennia species which are closely associated to the Rhizophora. Perhaps, the number of planted Rhizophora used in this pilot scale in both sites is too small to affect a mature Avicennia forest. Despite evidence that reintroduction of *R. mucronata* in UAE has successfully demonstrated reproductive maturity in UAE [5], ours is the first to document the long term survival of planted *R. mucronata* which completed 11 annual cycles and become reproductively mature to produce flowers

7. Conclusion

This study demonstrated that despite the harsh climatic conditions, *R. mucronata* can be planted with high degree of success in the Emirate of Abu Dhabi. This study suggests that shading could play an important role in the establishment and growth of seedlings during the initial phases of development of *R. mucronata* and hence it recommends planting the saplings in close association with fully grown *A. marina* trees in order to provide shading to them. These findings encourage the expansion of the cultivation of *R. mucronata* saplings in large numbers in the middle of the existing *A. marina* forests, thus restoring the species that had once extinct.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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