Reforestation of grey mangroves (Avicennia marina) along the northern coasts of the Persian Gulf

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Abstract

Every ecosystem supports the lives of living things by providing direct and indirect benefits and services. Among these areas, mangrove forests are one of the most fertile ecosystems in the intertidal zones. These natural forests are one of the coastal ecosystems that not only provide a source of food for humans and animals, but also play a major role in protecting and stabilizing coastlines and controlling climate. Mangroves are a breeding ground and a safe habitat for a variety of marine vertebrates and invertebrates. Increasing gray mangrove forests, Avicenna marina along the north coasts of the Persian Gulf was performed. This article explains the experienced methods of propagation and foresting of this species. For the first time in the Persian Gulf, we reported a five-year evaluation of reforestation method of grey mangrove. Reforestation in the highest latitude of natural forests in the Persian Gulf did not have any side effects on growing of gray mangrove in the selected sites. As a result, increasing the area of gray mangrove forests in the Persian Gulf improves the ecosystems of the tidal area. Increasing the chances of fishing and improving the economic conditions of the local communities around this bay will be some of the results of mangrove forestation. Furthermore, this is the first report of a simple method to train all the steps of grey mangrove reforestation.

1. Introduction

Mangroves include shrubs and trees species that grow in the coastal intertidal zone (DeYoe et al. 2020). The special characteristics of mangrove species enable forests to withstand variable conditions such as floods and salinity stresses (Cahoon et al. 2021). Mangroves protect the coast and other species living underneath from the solar ultraviolet radiation (Lovelock et al. 1992). Mangroves can absorb carbon to reduce greenhouse effects (Sumarmi et al. 2021).

Mangrove protects coasts from cyclones, floods, sea level rise, coastal erosion, and wave action (Gijsman et al. 2021). The root networks of the mangroves contribute to stability of the coast lands by keeping the substrate firm (Pramanick et al. 2020). Mangrove ecosystems trap soil particles and also prevent soil erosion (Kathiresan 2012). This process provides clean water and nutritious food to the surrounding ecosystems (Kathiresan 2012). Mangrove swamps play an important role in trapping the sediments and sinking the nutrients (Mishra and Manish 2020). However, in areas where the mangroves are not grown, such as the most coastal lands of the north Persian Gulf in Bushehr province, Iran, the sediments become loose and increase turbidity of the tidal and subtidal zones (Haghshenas et al. 2019). Due to the loss of mangroves, floating sediments deposit on the associated marine ecosystems such as corals or seaweeds and destroy them (Zulkifli et al. 2017). Thus, mangrove plants provide protection to other aquatic environments. The mangrove ecosystem provides breeding grounds, sources of food, and nursery sites for many shellfishes and fishes (Haghshenas et al. 2019). The mangrove ecosystem often works on other invertebrate and vertebrate species and attracts them (Geisterfer and Guisnet 2018). They also provide protection to the flora and fauna associated with the ecosystem (Carugati et al. 2018). In addition to the mentioned ecological benefits, it seems that the extract of mangrove seeds, leaves and stems can be used in indigenous medicine and human, animal and plant pathogens (Carugati et al. 2018).

Despite the wide range of socio economic and ecological benefits provided by mangrove ecosystem, mangrove papulations have been decreasing over the past decades (Valiela et al. 2001). Although mangrove loss occurs in all countries, it occurs at a rate of about 90% in developing countries (Carugati et al. 2018). Mangrove forests are being lost due to urban development, agricultural land reclamation, industrialization, timber and charcoal production, urbanization, or coastal landfills, or are decaying due to the indirect effects of upstream land use and pollutions (Alongi 2002; Valiela et al. 2001). Their biodiversity is likely to be significantly reduced, as the number of species in the mangrove plants is directly related to the extent of the forest (Duke et al. 1998; Ellison 2002).

Mangrove forests have a tremendous capacity to trap atmospheric CO2 and produce oceanic carbon (Maher et al. 2018; Richards and Friess 2016). The supports that mangrove forests provide to marine food webs would be destroyed, mangrove-dependent fauna would be lost, and human communities around them would lose their benefits (Duke et al. 2007). On the other hand, coastal industrial developments associated with sea level rise and climate change require the conservation, protection and restoration of tidal wetlands (Barbier et al. 2008; McLeod and Salm 2006). Government laws and regulations, and basic educational structures are needed to communities that can reverse the process of mangrove extinction and ensure that future generations will benefit from these valuable resources (Duke et al. 2007). Mangrove ecosystems, especially in developing countries, are still decreasing at such an alarming rate that they may be completely extinct within the next 100 years (Carugati et al. 2018). During the last 20 years, the area of mangrove ecosystems in the world has decreased by 35% (Feller et al. 2017). However, the global rate of mangrove deforestation has slowed, with annual loss rates ranging from 0.2 to 0.7 percent (Carugati et al. 2018).

The genus *Avicennia* has been named in honor of the Iranian polymath Avicenna (980–1037) by Carl von Linnaeus (1707–1778) (Austin 1993; Linnaeus 1764). Eight species of genus *Avicennia* are usually recognized (Table 1). *Avicennia marina* is distributed in Egypt to South Africa, Madagascar, Seychelles, Aldabra, Comoro Island, Persian Gulf to Pakistan, South India, Sri Lanka, Andaman Island, Malay Peninsula, Indochina, Philippines, North Borneo, Sarawak, China, Taiwan, Japan, Australia, New Zealand, New Caledonia, and Solomon Island (Fig. 1). On the northern coasts of the Persian Gulf and Oman Sea, natural mangrove forests are estimated to be about 90 km^2 (Zahed et al. 2010) (Fig. 2). In these forests two mangrove species are found from Avicenniaceae and Rhizophoraceae including *Avicennia marina* and *Rhizophora macrunata*, respectively (Zahed et al. 2010). *A. marina* is dominant in the Persian Gulf natural mangrove forests (Zahed et al. 2010). The only existing report of the fossil species of *A. marina* in the Persian Gulf is related to Um al Nar port, Abu-Dhabi, UAE (latitude 24.454131 and longitude 54.518422) and the geological period of the Holocene (Plaziat 1995). By the way, the highest latitude in the Persian Gulf that has natural mangrove forest is in the protected area of Mel-e-Gonzeh (latitude 27.846732 and longitude 51.581421) (Zahed et al. 2010) (Fig. 3). The oldest available document and report on the protection of mangrove forests in Iran dates back to 1975 and the Mangrove War of Qeshm Island (Harrington 1975). These natural forests are currently protected and reforested by local communities, Department of Natural Resources, and Environment Department (Ghasemi et al. 2010).

Beside the natural forest protection, reforestation of mangrove wetland has several applications and benefits including sea water treatment (Wu et al. 2008), municipal wastewater treatment (Ghasemi et al. 2010), mitigating coastal floods and adapting sea-level rise (Takagi 2017; Takagi 2018). To the best of our knowledge, methodology for *A. marina* propagation and its reforestation has not been described. Therefore, we tried to share our five-year experience of reforestation of *A. marina* on the north coasts of the Persian Gulf.

Table 1
Species and distribution of the genus *Avicennia* based on the World Register of Marine Species (Dahdouh-Guebas 2021e)

Species	Distribution	References
Avicennia alba	Bangladesh, Brunei, India, Indonesia, Malaysia, Micronesia, Myanmar, North Pacific Ocean, Palau, Papua New Guinea, Philippines, Singapore, Solomon, Islands, Thailand, Vietnam	(Dahdouh-Guebas 2021a)
Avicennia balanophora	Australia	(POWO 2022a)
Avicennia bicolor	Costa Rica, El Salvador, Honduras	(Dahdouh-Guebas 2021b)
Avicennia germinans	Angola, Belize, Benin, Brazil, Cameroon, Caribbean Sea, Colombia, Congo, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Equatorial Guinea, Gabon, Gambia, Ghana, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Jamaica, Liberia, Mauritania, Mexico, Netherlands, Nicaragua, Nigeria, Panama, Peru, Sao Tome and Principe, Senegal, Sierra Leone, Suriname, Togo, Trinidad and Tobago, United States, Venezuela	(Dahdouh-Guebas 2021c)
Avicennia integra	Australia	(Dahdouh-Guebas 2021d)
Avicennia marina	Australia, Bahrain, Bangladesh, Brunei, China, Djibouti, Egypt, Eritrea, India, Indonesia, Iran, Japan, Kenya, Madagascar, Malaysia, Mozambique, Myanmar, New Zealand, Oman, Pakistan, Papua New Guinea, Philippines, Qatar, Saudi Arabia, Seychelles, Singapore, Solomon Islands, Somalia, South Africa, Spain, Sri Lanka, Sudan, Taiwan, Tanzania, Thailand, United Arab Emirates, Vanuatu, Vietnam, Yemen	(Dahdouh-Guebas 2021f)
Avicennia officinalis	Bangladesh, Brunei, India, Indonesia, Malaysia, Myanmar, Papua New Guinea, Philippines, Singapore, Sri Lanka, Thailand, Vietnam	(Dahdouh-Guebas 2021g)
Avicennia schaueriana	Belize, Brazil, Guyana, Netherlands, Trinidad and Tobago, Venezuela	(Dahdouh-Guebas 2021h)

2. A. Marina Reforestation Site And Soil Selection

Choosing a planting site is very important because good planting depends on choosing the best place (Table 2). Knowing the details needed to choose the best location saves time and money on the project. According to previous studies, mangrove forests are found on the lower slopes of coastal drainage basins around the world (Kjerfve 1990). Mangroves also prefer to grow on gentle and high slopes above sea level. (Lewis III 2005). To select the appropriate planting site, water characteristics such as tidal conditions, water salinity, water pH, soil characteristics such as slope, soil texture, soil type as well as the region's climate such as average rainfall and temperature and humidity of the region should be considered. Due to these cases, several suitable places for mangrove forestation was considered in our project in Bushehr province including Khor-e-Soltani (latitude 28.933059 and longitude 50.896734), Khor-e-Shekasteh (latitude 28.823673 and longitude 50.983015), Jainak coast (latitude 28.790090 and longitude 51.025520), and Chah-Talkh coast (latitude 28.826171 and longitude 51.015950) (Fig. 4).

Table 2
Site selection parameters for *Avicennia marina* cultivation (Golestani and Amiri 2021)

Parameters	Sub-parameters	Descriptions
Earth characteristics	Slope (percent)	0–1
	Height (m)	0–1
	Soil texture	Heavy
	Type of soil	Loamy-clay-sandy
	Electrical conductivity (dS/m)	< 36
Features of water	Tide (cm)	15–18
	Wave	Low
	Salinity (ppt)	28–38
	Electrical conductivity (dS/m)	< 36
	pH	6.1–8.5
Climate	Precipitation (annual average in mm)	200–2000
	Annual relative humidity (percentage)	65–75
	Temperature (annual average in °C)	25 – 22
	Temperature (absolute minimum in °C)	12–22
	Temperature (absolute maximum in °C)	30–35

Mangroves usually grow in areas close to forested areas, lands with good soils and streams, and areas where dead leaves accumulate (Sandilyan and Kathiresan 2012). However, the selected locations did not meet most of these criteria, rather they were all firth from which local seasonal floods flow into the Persian Gulf. Mangroves do well in areas where there is a combination of muddy and gravel sediments

(Madkour et al. 2014). They do not grow in sandy sediments (Arihafa 2016). Planting in areas that are not vulnerable to winds and waves is the single most important factor for high mangrove survival. Mangroves grow in areas where they are shielded from these harsh conditions (Arihafa 2016). More regular flooding stresses mangroves and causes them to die (Lewis III 2005). These mud and gravel sediments and shielded conditions can be found in firth of the Persian Gulf, which is locally called Khur. *A. marina* can grow on muddy flats with a high tidal level and high salinity, as well as periodic wave and wind impacts (AboEl-Nil 2001). *Avicennia* sp. has a spike-shaped aerating (or pneumatophores) root system that rises 20–30 cm above the ground. They can withstand the events with this root system (Hoai 2011).

Different soil factors, such as soil erosion, sedimentation rates, salinity, nutrient inputs, and soil quality, are said to have a significant impact on the occurrence, development, and structure of mangroves (Perera et al. 2013). On the drier side of the high salinity margin, *A. marina* may be planted (Kairo et al. 2001). Since *Avicennia* sp. shows the best growth response to approximately half the concentration of sodium chloride in seawater, it indicates that the normal habitat of this species is more likely to reflect its tolerance to high sodium levels rather than its optimal adaptation (Connor 1969). *A. officinalis*, *A. alba*, and *A. marina* are the three species. *A. officinalis* is found growing along rivers in richly organic muddy soil or in inner areas submerged in salt water. *A. alba* and *A. marina* can grow on muddy flats with a high tidal level and high salinity (25–30 ppt), as well as periodic wave and wind impacts.

3. Collecting And Planting A. Marina Seeds

Mangrove seeds are called "propagules" because, unlike most other plant seeds, they germinate when still attached to the tree (Van der Stocken et al. 2019) (Figs. 5A-C). This is an adaptation that allows them to grow quickly until they fall to the soil below once mature. Gray mangroves are relatively easy to plant in restoration sites. According to many local reports, harvesting gray mangrove seeds from trees and directly planting them in the soil of areas without the shade of mother star trees has had very little seedling success. Although this method can work, it has a much better chance if the seeds are first rooted and growth at least 50 cm before planting. Picked and dried propagules in the shade can be kept in dry and cool air for up to two weeks before peeling and planting.

After the seeds have been collected during August (lower latitude zones of the Persian Gulf) to September (higher latitude zones of the Persian Gulf), they were moved to prepared site with covered green shade net. Propagules were placed in plastic fresh water buckets and soaked with fresh water in the shade. To avoid overcrowding effects, buckets water was replaced every 12 hours. Self-remove the pericarps of propagules done during 5 days and the peeled seeds were separated to cultivate based on the modified previous method (Purnobasuki and Utami 2016) (Fig. 5B).

Black polythene bags (10 cm opening diameter × 12 cm height) were filled with soil and arranged in plastic basket (610 × 420 × 330 mm). The baskets were put in 10 cm deep fresh water pond allowing sands to be saturated with water prior to planting. The pericarp-peeled seeds were green in color without black marks and were placed vertically on the medium, the tips of the seeds were upside and the primary root side was pushed into the medium (Figs. 5C-D). Half of the seeds were above the medium surface. This method simulated natural germination conditions before sprouting their first leaves (Alleman and Hester 2011). Fresh water, drying of the pond, salt water and drying of the pond were used periodically to irrigate the seedlings. The pond water depth kept 5 cm during the nursery and let it dry one day per week. During November tip of the mangroves were cut and removed to let their stem grow widely, thickened and branched (Figs. 5E). Plants were moved to planting site between February to April.

An initial growth phase in a nursery improves seedling survival, especially the presence of shade and indirect light during growth prevents it from drying before four leaves are formed in the seedling. When setting up a greenhouse, these items should be considered: (i) Place the nursery where it has access to both saltwater and fresh water. Set it up by the sea, where it would be flooded by the tides or a river on a regular basis, but away from areas prone to severe flooding. (ii) Build a nursery where water, materials, and mangroves are easiest to come by. (iii) Take into account the distance between where the nursery is planted and the homes of those who work there. The closer the nursery is to the buildings; the more likely regular events would occur. However, ensure that the nursery is closely supervised, since the closer it is to homes, the more it would be exposed to threats from children and animals. (iv) In order to avoid cutting trees, if necessary, the nursery site should be established in an open area. It's ideal to have several trees in the nursery to provide shade in some areas. (v) Choose a location that drains well and is relatively flat and shallow for good drainage. If plants are constantly immersed in water, they will die.

4. Daily Activities At Nursery Site

Here's a rundown of things to do every day:

I. The act of watering. *A. marina* seedlings must be watered with freshwater and saltwater to keep the interval of three days' wet pool and one day's dry pool. Watering should be performed to acclimate seedlings until 4–6 months old.

II. In order to protect the newly potted seedlings from direct sunlight, they were placed in a shaded area. A greenhouse shade net was used for permanent mass production of nurseries. III. At least once a week, the nursery was weeded. Any plants that were not mangroves was removed.

IV. We did not use any pesticides or rodenticides.

5. Choose A Planting Pattern For

A. marina grows year-round; however, transferring the seedlings to the planting site in the wet season is better. Planting was avoided during high winds and/or high tides. If there was a flood, we did not plant anything. After the flood, we waited a few days before planting.

Mangroves can be planted using a variety of planting patterns, each with its own set of advantages. Most mangrove planting activities spread the mangroves evenly across the site. In this project, we combined the first and third planting patterns to increase the chances of seedling viability. The survival rate of seedlings after the first year was 90-95%. The following are the three most common patterns.

I. Planting in strips. Both types of sites may benefit from the conventional method of planting mangroves. Plant seedlings in rows with equal spacing between them. Plant with regular spacing if the site is covered from waves and wind. Reduce the spacing between seedlings if the site is exposed to medium to high winds or waves. Some seedlings may need to be transplanted to increase the space between shrubs or trees if they were planted close together and are doing well after two years.

II. Planting in an inverted V. This is appropriate for locations with moderate waves or winds. Seedlings should be spaced 25 to 50 cm apart in V-shaped groups of about 11 seedlings each. To deflect wave effect, plant so that the V's point faces the sea. Place each V between 1 and 1.5 meters apart. After two years, if all seedlings in the V pattern are developing well, plant new seedlings in the empty spaces.

III. Planting in clusters. This is ideal for locations with high waves or winds. Plant seedlings in small clusters 25 cm to 50 cm apart, with around 10 seedlings per cluster. Each cluster should be spaced between 1 and 1.5 meters apart.

6. Correct Planting Depth For

In the muddy selected sites, the seedling with one-side teared bags were pushed into the holes made by foot. Lower the seedling into the hole until the root collar is level with the top of the hole. This will require one people per seedling. The hole was filled with mud substrate with one hand while the other held the seedling at the same height. The substrate around the newly planted seedling was compacted. Since mangroves do not grow in straight lines in nature, don't worry about spacing your seedlings too closely. Depending on the function and natural conditions, the applied density on aggraded beaches ranges from 1600 plants/ha (2.5 m × 2.5 m) to 5000 plants/ha (2 m × 1 m). The spacing can range from 1 to 1.5 meters. Ensure that the tops of these plants are at least 25 cm above the water level while planting.

Within the field of mangrove planting, no fishing or navigation is permitted during the planting sites or for several years afterward. Cattle or camels should also be kept away from these mangroves to protect their growth.

7. Discussion

The areas that have been introduced in the field visit as areas susceptible to biological restoration mainly include areas with a slope close to zero, coastal estuaries and tidal areas with an average depth of one meter in full mode. Based on this, most of the areas prone to reforestation had optimum growth and survival rate more than 90 percent. Furthermore, all reforested trees started propagule production after age four. The stabilization of the forest was observed in all places after the fourth year, which can be mentioned in the indicators of reproduction, growth of new seedlings and survival of the wetland. In general, mangrove ecosystems are very vulnerable to various types of environmental disturbances and stresses.. They are plants that are sensitive to the formation of sludge, heavy sedimentation, waterlogging, waterlogging of surface water, and most importantly, oil and industrial pollution. These activities reduce the absorption of oxygen through respiration and increase the mortality rate of mangroves. Salinity above 90 ppt as a result of reducing the flow of fresh water and changing water level patterns due to the construction of dams, dredging, etc. causes the destruction of mangroves.

The most important natural factors affecting the development of mangrove forests are tidal regime, fresh water sources, bed type, drainage, water salinity, land slope, land use, climate, latitude, soil texture, humidity soil, the concentration of organic and mineral substances and the electrical conductivity of the soil (Safiari 2017). Three criteria and nine sub-criteria for the process of locating mangrove forest development areas and the identified criteria and sub-criteria using the Delphi method after screening including physical properties of the bed, chemical properties of the bed, tides, air temperature, water quality, climate type and rainfall as important criteria in locating have been introduced (Andon Petrosian et al. 2013).

In land identification, the most important factors affecting the growth and development of mangrove forests in the Qeshm Island, The Persian Gulf, Iran are tidal factors, soil saturation percentage, soil electrical conductivity, pH and soil texture, magnesium, sodium, sodium absorption ratio and the amount of soil sodium exchange (Dehghani et al. 2010). The shape and characteristics of the beach, water salinity and tides as conditions and factors affecting the distribution and establishment of mangroves are also introduced (Nagelkerken et al. 2008). Moreover, longitude and latitude, air humidity and temperature, tides, easy access to permanent fresh water, soil type (soil texture and its constituent elements, salinity and acidity) are the other factors affecting the formation of mangroves (Kamali and Hashim 2011). A map of suitable lands for planting mangrove species was prepared considering the criteria of soil texture, acidity, salinity, tidal area and land use pattern and weighting each criterion (Hossain et al. 2003).

In the land rehabilitation guide for mangrove cultivation that soil parameters including texture, density, percentage of rock formation, pH, electrical conductivity, amount of iron sulfide, amount of organic matter and mineral nutrients, ratio of carbon to nitrogen and soil moisture are very important in the successful establishment of this species in an area (Friess 2017). Reviewing the benefits of using low-cost principles in the re-establishment of mangrove forests in America showed that the important determining factors in the successful re-establishment and introduction of mangrove species in an area include the frequency and depth of inundation, wave energy, salinity and water and soil pH, soil type and texture, soil nutrients and slope (Gilman and Ellison 2007). Investigating the habitat of mangrove species in the coasts of India showed that while pointing out the importance of the elements in the soil in the success of planting mangrove trees, the salinity parameters, the pH of water and soil and soil texture are the most important parameters affecting mangrove communities (which have a large percentage of mangrove species) (Bhalla et al. 2008).

Regulating parameters (soil and water salinity, sulfide level and pH), resource parameters (soil nutrients, light and space) and periodic parameters of water (the duration, abundance and depth of waterlogging) are the most important parameters in the establishment of mangrove species (Berger et al. 2008). Regarding mangrove planting in order to rehabilitate saline and saturated agricultural lands, physical and chemical parameters of water and soil including pH, electrical conductivity, total dissolved solids, dissolved oxygen and salinity percentage in natural mangrove habitat in Pakistan have been considered. (Nazim et al. 2010). Despite the difference in water and soil characteristics, there is no significant difference in vegetation parameters in the two environments and in areas with high salt, saturated with water and unbearable for other species, mangrove is one of the few species that survives (Nazim et al. 2010).

The breakwater installation in an area with an almost regular tidal regime and with a maximum span of 2.3 meters, a gentle slope of 1% and in direct contact with waves with a height of less than one meter has led to the re-establishment of mangrove forests with a high percentage of mangrove species (Kamali and Hashim 2011). The temperature factor as one of the factors that affect mangroves in nature showed that mangroves face with a temperature of less than 15 degrees Celsius through the decrease in the rate of photosynthesis and the decrease in seedling growth indicated sensitivity (Simard et al. 2019). The results showed that the best conditions for the establishment of this species are in the range of water pH between 0.9 and 3. 8, the pH range of the soil is between 7.4 and 8.5 and the water salinity range is between 24 and 35 grams per liter and the type of soil is sandy loam, loamy clay (Bhalla et al. 2008). Mangroves become more dense under low salinity conditions and settle at salinities between 5 and 30 ppt (Joshi and Ghose 2003). Mangroves spend more energy to maintain water and proper ion concentration at high salinity conditions, so less energy is left for growth and primary production (Joshi and Ghose 2003). Also, high salinity reduces the leaf surface, increases the osmotic pressure of plant sap, increases the ratio of surface area to leaf weight, and decreases the amount of potassium, nitrogen, and phosphorus (Gilman and Ellison 2007). For maximum growth of mangrove species, the maximum is 50% (Safiari 2017).

The most important reason for the increase in the size of unsuitable areas for the growth and creation of mangrove forests in the areas planted in this study can be seen as the increase in construction, including the construction of roads, closing the entrances of fresh water, and closing the estuaries by increasing the area of shrimp breeding ponds or related channels with them, the construction of wharves and its destructive effects such as sedimentation or dredging, the destruction of the tidal zone by creating walls in these areas. The development of industries without taking into account the characteristics of the mangrove wetland ecosystem can cause the lack of flooding and the formation of a complete lagoon and increase of soil salinity, which can be considered as a limiting factor in establishment and planting of mangroves.

The benefits of rehabilitating mangrove wetlands in these places include increasing shelter for migratory birds, preventing of erosion of estuaries in tides and sea storms, increasing local fishing due to the increase in food for fish species with the expansion of wetlands, increasing tourist visits pointing out the places to plant mangrove trees, preventing the expansion of future industries due to the existence of laws restricting the presence of forest and also creating local and rural jobs for the residents around the wetland, from the production of saplings to the protection of the wetland. The services provided by mangrove forests are of significant importance to coastal communities and contribute to the sustainability and resilience of local economies (Hussain and Badola 2010). The costs and benefits of mangrove expansion with those created by aquaculture and forestry can achieve the goals of sustainability and equity as well as economic efficiency in coastal communities (Ron and Padilla 1999).

8. Conclusions

The need to increase the area of forests in the world due to increasing concerns about global warming causes non-governmental organizations to collaborate with governments to plant trees and expand forest areas. Mangrove tree as a species resistant to heat, salinity and adverse environmental conditions and with minimal need for maintenance or irrigation during growth is a useful choice for spreading on the shores of the Persian Gulf. In addition to the environmental benefits of mangrove forest expansion, its social benefits have prompted local human communities to expand mangroves. Based on our findings, *A. marina* is a useful species for increasing the area of mangrove forests on the northern shores of the Persian Gulf due to its characteristics and simplicity of propagation.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The data used to support the findings of this study are included within the article.

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Competing interests

Authors Zahra Farshid, Amin Tamadon, Alireza Hashemi, and Alireza Afshar are employed by PerciaVista R&D Co. Authors Reshad Moradi Balef, Amin Tamadon, Alireza Hashemi, Tabandeh Heidari Bafghi, and Alireza Afshar are members of the NGO Beauty Planet Association. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. We would like to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Authors' contributions

A. T., R. M. B., and S. K. conceived and designed the format of the manuscript. Z. F., T. Z, N. D., F. M., A. H., A. A., T. H. B., and H. B. collected the data, and drafted and edited the manuscript. R. B., and A. T. drew the Figures. All the authors reviewed the manuscript and all of them contributed to the critical reading and discussion of the manuscript. All authors have read and agreed to the published version of the manuscript.

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References

1. AboEl-Nil MM (2001) Growth and establishment of mangrove (*Avicennia marina*) on the coastlines of Kuwait. Wetlands Ecology and Management 9:421-428
2. Alleman L, Hester a (2011) Refinement of the fundamental niche of black mangrove (Avicennia germinans) seedlings in Louisiana: applications for restoration. Wetlands Ecology and Management 19:47-60
3. Alongi DM (2002) Present state and future of the world's mangrove forests. Environmental Conservation 29:331-349
4. Andon Petrosian H, Danehkar A, Ashrafi S, Feghhi J (2013) Application of delphi method for prioritization of Mangrove afforestation site selection criteria (case study: Grey Mangroves on north part of Persian Gulf, Iran). Environment and Development Journal 4:37-48
5. Arihafa A (2016) Factors influencing community mangrove planting success on Manus Island, Papua New Guinea. Conserv Evid 13:42-46
6. Austin D (1993) The nuance and wit of Carolus Linnaeus. The Palmetto 13:8
7. Barbier EB et al. (2008) Coastal ecosystem-based management with nonlinear ecological functions and values. Science 319:321-323
8. Berger U et al. (2008) Advances and limitations of individual-based models to analyze and predict dynamics of mangrove forests: A review. Aquatic Botany 89:260-274

9. Bhalla R, Ram S, Srinivas V (2008) Studies on vulnerability and habitat restoration along the Coromandel Coast. UNDP/UNTRS & FERAL, India
10. Cahoon DR, McKee KL, Morris JT (2021) How plants influence resilience of salt marsh and mangrove wetlands to sea-level rise. Estuar Coasts 44:883-898
11. Carugati L, Gatto B, Rastelli E, Lo Martire M, Coral C, Greco S, Danovaro R (2018) Impact of mangrove forests degradation on biodiversity and ecosystem functioning. Sci Rep 8:13298
12. Connor D (1969) Growth of grey mangrove (*Avicennia marina*) in nutrient culture. Biotropica 1:36-40
13. Dahdouh-Guebas F (2021a) World Mangroves database. *Avicennia alba* Blume. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
14. Dahdouh-Guebas F (2021b) World Mangroves database. *Avicennia bicolor* Standl. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
15. Dahdouh-Guebas F (2021c) World Mangroves database. *Avicennia germinans* (L.) L. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
16. Dahdouh-Guebas F (2021d) World Mangroves database. *Avicennia integra* N.C.Duke. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
17. Dahdouh-Guebas F (2021e) World Mangroves database. Avicennia L. World Register of Marine Species. http://www.marinespecies.org/aphia.php?p=taxdetails&id=235040 Accessed 2022-1-1
18. Dahdouh-Guebas F (2021f) World Mangroves database. *Avicennia marina* (Forssk.) Vierh. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
19. Dahdouh-Guebas F (2021g) World Mangroves database. *Avicennia officinalis* L. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
20. Dahdouh-Guebas F (2021h) World Mangroves database. *Avicennia schaueriana* Stapf & Leechm. ex Moldenke. World Register of Marine Species. https://www.marinespecies.org/aphia.php?p=taxdetails&id=235034. Accessed 2022-1-1
21. Dehghani M, Farshchi P, Danekar A, Karami M, Aleshikh A (2010) Recreation value of Hara biosphere reserve using willingness-to-pay method. International Journal of Environmental Research 4:271-280
22. DeYoe H, Lonard RI, Judd FW, Stalter R, Feller I (2020) Biological Flora of the Tropical and Subtropical Intertidal Zone: Literature Review for Rhizophora mangle L. Journal of Coastal Research 36:857-884
23. Duke N, Ball M, Ellison J (1998) Factors influencing biodiversity and distributional gradients in mangroves. Global Ecology & Biogeography Letters 7:27-47

24. Duke NC et al. (2007) A world without mangroves? Science 317:41-42
25. Ellison AM (2002) Macroecology of mangroves: large-scale patterns and processes in tropical coastal forests. Trees 16:181-194
26. Feller IC, Friess DA, Krauss KW, Lewis RR (2017) The state of the world's mangroves in the 21st century under climate change. Hydrobiologia 803:1-12
27. Friess DA (2017) Mangrove rehabilitation along urban coastlines: a Singapore case study. Regional Studies in Marine Science 16:279-289
28. Geisterfer A, Guisnet A (2018) Assessing the Effects of Mangrove Patch Size on the Density and Diversity of Bird Species in the Pablo Arturo Barrios Wildlife Refuge. McGill University,
29. Ghasemi S, Zakaria M, Abdul-Hamid H, Yusof E, Danehkar A, Rajpar MN (2010) A review of mangrove value and conservation strategy by local communities in Hormozgan province, Iran. Journal of American Science 6:329-338
30. Gijsman R, Horstman EM, van der Wal D, Friess DA, Swales A, Wijnberg KM (2021) Nature-based engineering: a review on reducing coastal flood risk with mangroves. Frontiers in Marine Science 8:825
31. Gilman E, Ellison J (2007) Efficacy of alternative low-cost approaches to mangrove restoration, American Samoa. Estuar Coasts 30:641-651
32. Golestani M, Amiri F (2021) Suitable Site Selection for Avicennia marina Plantation in the Coastal Region of Bushehr, using Best-Worst Multi-Criteria Decision-Making Method. Iranian Journal of Applied Ecology 10:15-33
33. Haghshenas A, Mirzaei M, Solgi E, Mohammadi Bardkashki B (2019) Water quality evaluation of the intertidal zone of pars special economic energy zone in different seasons by measuring the concentration of heavy metals and using WQI and TRIX. Iranian South Medical Journal 21:439-458
34. Harrington JFA Iran: wildlife research as a basis for management. In: Ecological Guidelines for the use of Natural Resources in the Middle East and South West Asia, Persepolis, Iran, 1975. International Union for Conservation of Nature and Natural Resources, p 128
35. Hoai TQ (2011) Technical guidelines in sea dike design. Vietnamese standards 14TCN 130-2002.
36. Hossain MS, Lin CK, Hussain MZ (2003) Remote sensing and GIS applications for suitable mangrove afforestation area selection in the coastal zone of Bangladesh. GeoIn 18:61-65
37. Hussain SA, Badola R (2010) Valuing mangrove benefits: contribution of mangrove forests to local livelihoods in Bhitarkanika Conservation Area, East Coast of India. Wetlands Ecology and Management 18:321-331
38. Joshi H, Ghose M (2003) Forest structure and species distribution along soil salinity and pH gradient in mangrove swamps of the Sundarbans. Tropical Ecology 44:195-204
39. Kairo JG, Dahdouh-Guebas F, Bosire J, Koedam N (2001) Restoration and management of mangrove systems—a lesson for and from the East African region. S Afr J Bot 67:383-389

40. Kamali B, Hashim R (2011) Mangrove restoration without planting. Ecological Engineering 37:387-391
41. Kathiresan K (2012) Importance of mangrove ecosystem. International Journal of Marine Science 2
42. Kjerfve B (1990) Manual for investigation of hydrological processes in mangrove ecosystems. Baruch Institute for Marine Biology and Coastal Research, University of …,
43. Lewis III RR (2005) Ecological engineering for successful management and restoration of mangrove forests. Ecological engineering 24:403-418
44. Linnaeus CV (1764) Avicennia germinans (L.) L. . Species Plantarum 2, 3:891 Sp. Pl
45. Lovelock CE, Clough BF, Woodrow IE (1992) Distribution and accumulation of ultraviolet-radiation-absorbing compounds in leaves of tropical mangroves. Planta 188:143-154
46. Madkour HA, Mansour AM, Ahmed AE-HN, El-Taher A (2014) Environmental texture and geochemistry of the sediments of a subtropical mangrove ecosystem and surrounding areas, Red Sea Coast, Egypt. Arabian Journal of Geosciences 7:3427-3440
47. Maher DT, Call M, Santos IR, Sanders CJ (2018) Beyond burial: lateral exchange is a significant atmospheric carbon sink in mangrove forests. Biology letters 14:20180200
48. McLeod E, Salm RV (2006) Managing mangroves for resilience to climate change. World Conservation Union (IUCN) Gland,
49. Mishra AK, Manish K (2020) Andaman mangrove sediments: source of nutrients and sink of heavy metals. Indian Journal of Geo Marine Sciences 49:156-166
50. Nagelkerken I et al. (2008) The habitat function of mangroves for terrestrial and marine fauna: a review. Aquatic Botany 89:155-185
51. Nazim K, Ahmed M, Khan MU, Khan N, Wahab M, Siddiqui MF (2010) An assessment of the use of Avicennia marina Forsk Vierh. To reclaim water logged and saline agricultural land. Pak J Bot 42:2423-2428
52. Perera K, Amarasinghe M, Somaratna S (2013) Vegetation structure and species distribution of mangroves along a soil salinity gradient in a micro tidal estuary on the north-western coast of Sri Lanka. American Journal of Marine Science 1:7-15
53. Plaziat J-C (1995) Modern and fossil mangroves and mangals: their climatic and biogeographic variability. Geological Society, London, Special Publications 83:73-96
54. POWO (2022a) Avicennia balanophora Stapf & Moldenke. the Royal Botanic Gardens, Kew. https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:861117-1#bibliography. Accessed 2022-1-1
55. POWO (2022b) Plants of the World Online. the Royal Botanic Gardens, Kew. https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:41194-1. Accessed 2022-1-1
56. Pramanick P, Mitra A, Zaman S, Mitra A (2020) Regulatory Service of Saltmarsh Grass in Context to Carbon Storage. Natural Resources and their Ecosystem Services. HSRA Publication, India

57. Purnobasuki H, Utami ESW (2016) Seed germination of Avicennia marina (Forsk.) Vierh. by pericarp removal treatment. Biotropia 23:74-83
58. Richards DR, Friess DA (2016) Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012. Proc Natl Acad Sci U S A 113:344-349
59. Ron J, Padilla JE (1999) Preservation or conversion? Valuation and evaluation of a mangrove forest in the Philippines. Environ Resource Econ 14:297-331
60. Safiari S (2017) Mangrove forests in Iran. Iran Nature 2:49-57
61. Sandilyan S, Kathiresan K (2012) Mangrove conservation: a global perspective. Biodiversity and Conservation 21:3523-3542
62. Simard M, Fatoyinbo L, Smetanka C, Rivera-Monroy VH, Castañeda-Moya E, Thomas N, Van der Stocken T (2019) Mangrove canopy height globally related to precipitation, temperature and cyclone frequency. Nature Geoscience 12:40-45
63. Sumarmi S, Purwanto P, Bachri S (2021) Spatial Analysis of Mangrove Forest Management to Reduce Air Temperature and CO2 Emissions. Sustainability 13:8090
64. Takagi H (2017) Design Considerations of Artificial Mangrove Embankments for Mitigating Coastal Floods–Adapting to Sea-level Rise and Long-term Subsidence. Natural Hazards and Earth System Sciences Discussions:1-19
65. Takagi H (2018) Long-term design of mangrove landfills as an effective tide attenuator under relative sea-level rise. Sustainability 10:1045
66. Valiela I, Bowen JL, York JK (2001) Mangrove Forests: One of the World's Threatened Major Tropical Environments: At least 35% of the area of mangrove forests has been lost in the past two decades, losses that exceed those for tropical rain forests and coral reefs, two other well-known threatened environments. Bioscience 51:807-815
67. Van der Stocken T et al. (2019) A general framework for propagule dispersal in mangroves. Biol Rev Camb Philos Soc 94:1547-1575
68. Wu Y, Chung A, Tam N, Pi N, Wong MH (2008) Constructed mangrove wetland as secondary treatment system for municipal wastewater. Ecological Engineering 34:137-146
69. Zahed MA, Rouhani F, Mohajeri S, Bateni F, Mohajeri L (2010) An overview of Iranian mangrove ecosystems, northern part of the Persian Gulf and Oman Sea. Acta Ecol Sin 30:240-244
70. Zulkifli M, Yunus M, Ahmad FS, Omar CM Spatial Management on Mangrove response to Sea Level Rise (SLR) in Kukup Island. In: IOP Conference Series: Materials Science and Engineering, 2017. vol 1. IOP Publishing, p 012065

Figures

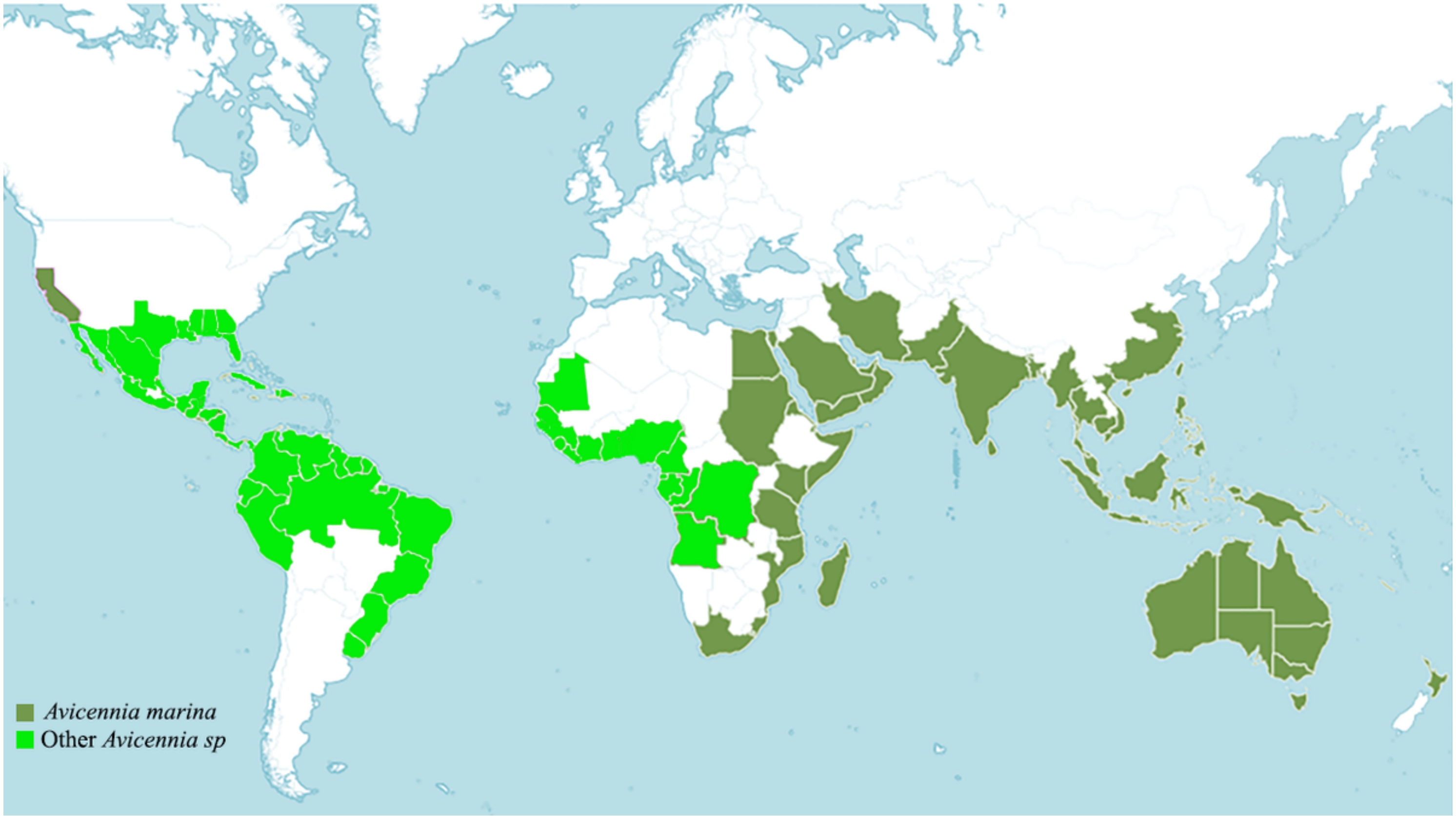

Figure 1

Countries with *Avicennia marina*and the other seven *Avicennia* species mangrove ecosystems in the world (POWO 2022b).

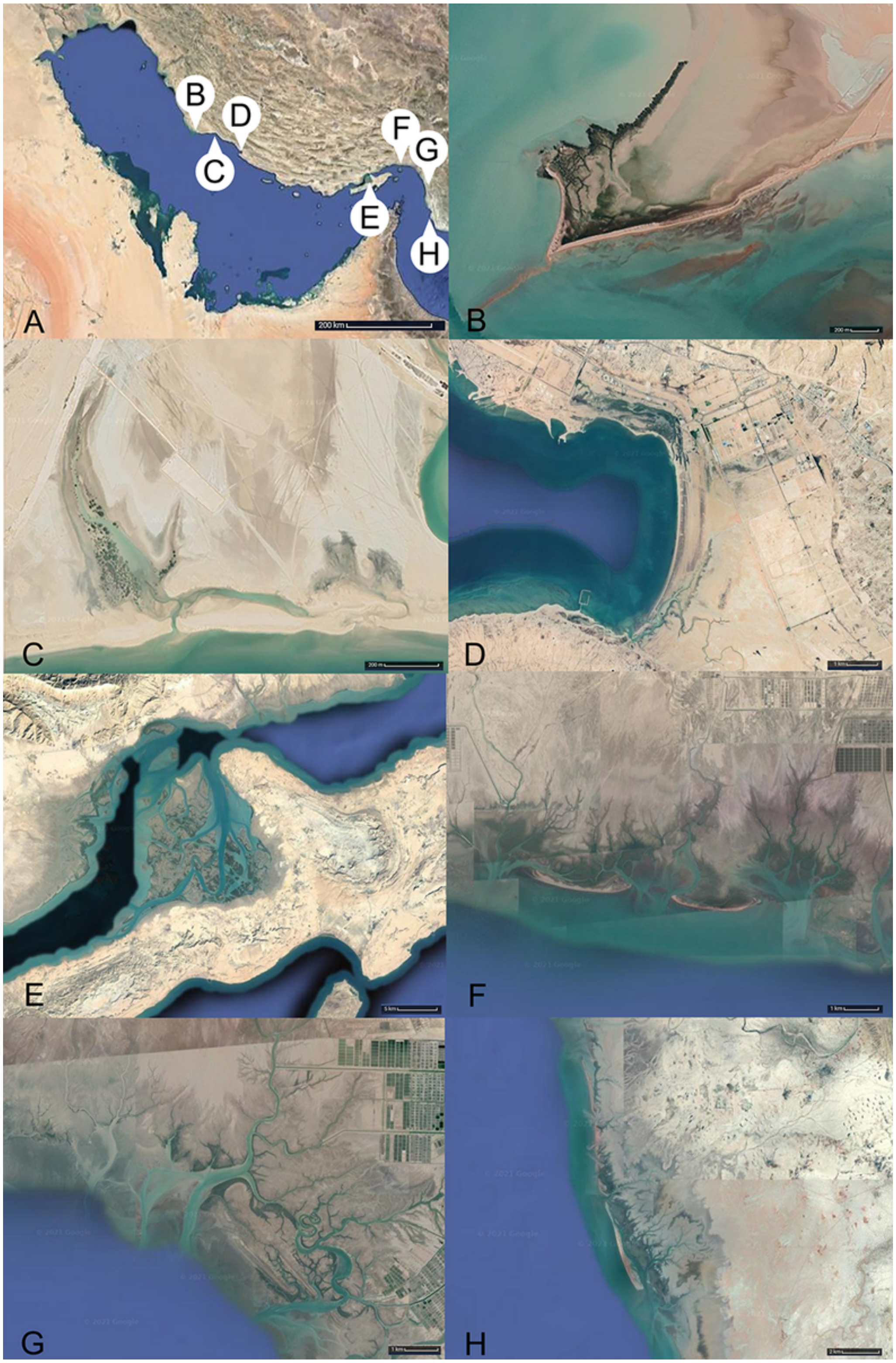

Figure 2

Locations of Iranian natural mangrove ecosystems, northern part of the Persian Gulf (A, scale = 200 km). B, Mel-e-Gonzeh (scale = 200 m). C, Dayer (scale = 200 m). D, Nayband bay (scale = 1 km). E, Khoran, Khamir, and Qeshm (scale = 5 km). F, Jalabi and Hassan-Langi (scale = 1 km). G, Tiyab and Kolahi (scale = 1 km). H, Sirik (scale = 2 km).

Figure 3

Aerial view of mangrove (*Avicenna marina*) forest of the highest latitude in the Persian Gulf that mangrove is growing naturally in Mel-e-Gonzeh Protected Area (latitude 27.846732 and longitude 51.581421)

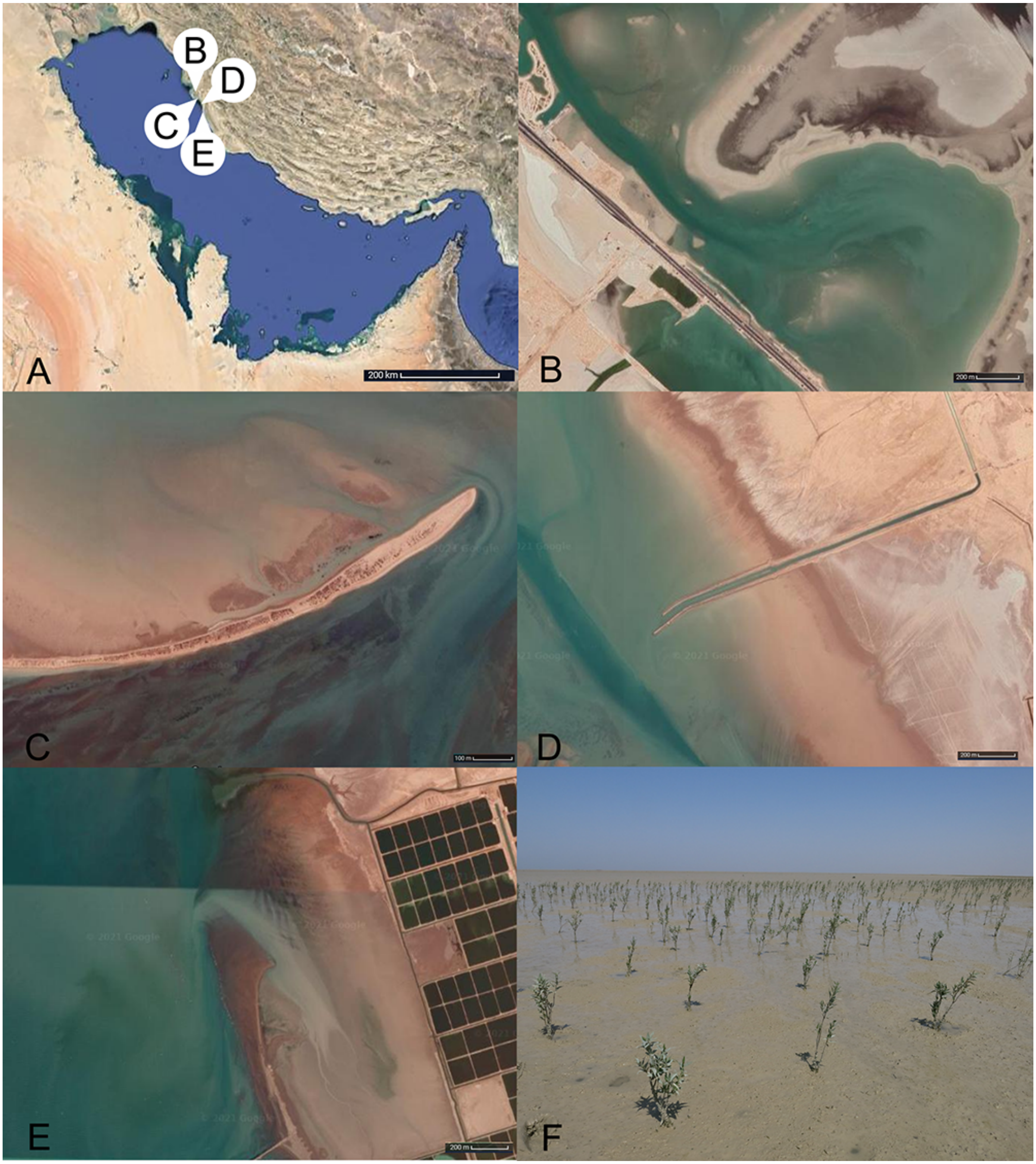

Figure 4

Locations of mangrove reforestation, northern part of the Persian Gulf (A, scale = 200 km). B, Khor-e-Soltani (scale = 200 m). C, Khor-e-Shekasteh (scale = 100 m). D, Jainak coast (scale = 200 m). E, Chah-Talkh coast (scale = 200 m). F, Reforestation of *Avicenna marina*in the Khor-e-Soltani after three years.

Figure 5

Avicenna marina seed preparation and planting. A, seeds size appropriate for propagation before peeling. B, Soaking the *Avicenna marina* seeds in fresh water for collecting the peeled seed. C, The correct seed direction on the cultivation media. D, Nursery are with water pond under shadow in green house E, Nursery area in daily watering system without water pound under direct sunlight.