Evaluation of Mangrove rehabilitation and afforestation in the southern coasts of Iran

Beytollah Mahmoudi[a], Davood Mafi-Gholami[b], Eric Ng[c]

[a] Department of Forest Sciences, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord, Iran. E-mail: Mahmoudi@sku.ac.ir
[b] Department of Forest Sciences, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord, Iran. E-mail: d.mafigholami@nres.sku.ac.ir
[c] School of Business, University of Southern Queensland, Toowoomba, QLD 4350, Australia; eric.ng@usq.edu.au

Abstract

The increasing multiple ecosystem services of mangrove forests, especially in the coastal regions have highlighted a need for conservation and afforestation of these forests. However, economic development and activities on the coasts have generated severe pollution issues that caused irreparable damages to the areas and quality of mangrove forests. As a result, rehabilitating the affected areas and forest planting are increasingly important, whereby some form of an assessment is needed to determine their sustainable performance and effectives. This study has used the indicators of forest resource sustainability, and the sustainability of planting sites to evaluate mangrove plantings in Iran's southern coast. Findings showed that there was a total of 47 mangrove planting sites on the coasts of the three provinces studied with an area of 9,584.5 hectares. There were 26 afforestation practice sites with an area of 5,724 hectares, and 21 combined rehabilitation and afforestation practice sites with an area of 3,860.5 hectares identified in this study. Approximately 76.6% of planting sites had been lost and the remaining areas had experienced an average density drop of 44%. Results of the stability class analysis revealed that 23 planting sites were in an extremely unsustainable state, 15 sites were considered as highly unsustainable, six sites were in a state of tendency to be unsustainable, whereas only three sites were regarded as sustainable. Findings from this study can assist managers and decision makers to review the site selection processes and pattern of successful planting sites, to facilitate better site selection and enhance the monitoring of mangrove rehabilitation or afforestation.

Keywords: Mangrove forest, rehabilitation, afforestation, sustainability, Iran.

1. Introduction

The increasing multiple ecosystem services of mangrove forests, including wildlife and aquatic habitat, timber production, livestock grazing, ecotourism, coastline protection, and educational and research values, have led to intensified conservation and afforestation of these forests (Sharma, 2018; Singh & Odaki, 2004). In many countries, coastal local communities are heavily dependent on mangrove forest structures, which have caused severe damages to the ecosystem (Gandhi & Jones, 2019). Furthermore, the increasing economic development and activities on the coasts have given rise to severe pollution issues that resulted in irreparable damages to the area and quality of these forests (Friess et al., 2019; Queiroz et al., 2020). Climate change has been regarded as a key underlying reason for many ecological pressures on these forests (Ellison, 2015). As such, mangrove forests are exposed to a significant number of natural and human disturbances globally. These disturbances have resulted in the reduction in the size and health of mangroves, global warming and other climate change, declining coastal water quality, biodiversity loss, degradation of coastal habitats, and the destruction of the resources needed by human communities in recent decades (Walters et al., 2008). In view of this phenomena and the associated threats, rehabilitating the affected areas and forest plantation are increasingly important (Thivakaran, 2017; Ward & de Lacerda, 2021).

Unlike other forest ecosystems, the process of forest regeneration and afforestation in mangrove habitats is often met with challenges due to its specific ecological conditions, and thus many of such efforts have failed (Lewis, 2005). One of the main reasons behind such failures is the lack of attention to ecological principles and incorrect assessment of the planting area (Balke & Friess, 2016; Bosire et al., 2008). Take for instance, despite two decades of efforts to rehabilitate mangrove forests at great expense in the Philippines, only 10% to 20% mangrove survival rates have been achieved due to unprincipled site selection and species inadequacy (Primavera & Esteban, 2008). Whereas in Bangladesh, the success rate of 9,050 hectares of mangroves was 1.52%, and in Vietnam, the survival rate of 580 hectares of mangrove forest between the years 1989 and 1993 is estimated to be approximately 40% (Marchand, 2008). A study by Kodikara et al. (2017) on the effectiveness of mangrove planting schemes in Sri Lanka reveal that only about 200 to 220 (out of approximately 1,000 to 1,200) hectares were successful.

According to Lewis et al. (2019), an understanding of the ecology of different mangrove species, hydrological patterns of species location and recognizing changes that have already occurred in the selected environment are important factors to the success of mangrove habitat. The unsuitability of the mangrove cultivation site is mainly caused by natural factors on the coasts that are not favorable to the establishment and long-term survival of mangrove species, and this has severely restricted forest creation. A lack of attention to the limiting natural processes (e.g. coastal microtopography, sedimentation, storms and drought) has also contributed to the failure of afforestation projects carried out on the coasts (Balke & Friess, 2016). In addition to natural factors, human factors (such as coastal exploitation and economic activities) and a lack of adequate monitoring mechanisms have also played a role in the destruction of afforested areas. Monitoring measures and replanting, along with efforts to reduce human destructive pressures are among the activities that can partially reduce failures after afforestation (Primavera & Esteban, 2008). Understanding these limitations requires on-going observations of the long-term trends about the coastal ecological factors (Lewis, 2005).

A critical success factor in mangrove forest rehabilitation and afforestation projects is the monitoring of hand-planted areas, which includes follow-up evaluation of sustainability indicators in these areas so that the performance and effectiveness of these projects can be assessed (Lewis, 2005; Primavera et al., 2004). While this is a very important aspect of planting and developing mangrove forests to achieve sustainability, however only a limited number of studies have been previously conducted, particularly in Iran (Andon Petrosians et al., 2013; Dehghani, 2014; Hajebi et al., 2019; Khayrandish et al., 2015).

Mangrove revitalization and afforestation activities first started in Iran in 1977, and to date there is inadequate information available about the success, effectiveness and monitoring of these activities. Due to the high administrative costs involve in the process of seedling production, transportation and planting of seedlings in the field, better target planning, and cost reduction, it is imperative to assess the sustainability of these planting areas. Such an assessment can provide provincial and national officials and planners a better understanding of the current status and help determines areas to be improved and strategies to be adopted, to strengthen the sustainability of Iran's mangrove rehabilitation and afforestation practices. Therefore, this study seeks to analyze the stability or instability of afforested sites by using a method of sustainability classification that includes indicators such as area decline, density decline, and regeneration rate and altitudinal growth.

2.Materials and methods

2.1. Study Area

In Iran, mangrove forests are located in the Gulf and Oman vegetation region at the coasts and islands of the Persian Gulf and the Sea of Oman in the three provinces of Bushehr, Hormozgan and Sistan, and Baluchestan (Zahed et al., 2010). All mangrove forests in Iran are regarded as important marine sensitive areas due to habitat importance (including for breeding of endangered and rare species), biodiversity, being on the ecological threshold of environmental conditions, and sensitivity to pollutants (Danehkar, 2012).

The study area is the coasts of the three provinces of Sistan and Baluchestan, Hormozgan, and Bushehr with a total coverage of 3,232 km. The coastlines of these three provinces account for the bulk of the natural distribution of mangrove forests in Iran (Figure 1). Although the habitat of the mangrove ecosystem in Iran is about 20,000 hectares, but the area of its forest habitat is estimated to be 10,692 hectares. There are two forest sites with an area of 560 hectares in the Sistan and Baluchestan province, 12 forest sites with an area of 10,026 hectares in the Hormozgan province, and three forest sites with an area of 106 hectares in the Bushehr province. In terms of the size of mangrove forests, Iran is ranked 43rd in the world and tenth in Asia, and among the countries bordering the Persian Gulf, Iran has the highest level of natural mangrove forests. Only two species of mangrove in Iran, namely *Avicennia marina* and *Rhizophora mucronata*. Ninety-five percent of Iranian mangrove forests harbor only *Avicennia marina* (Danehkar, 2012).

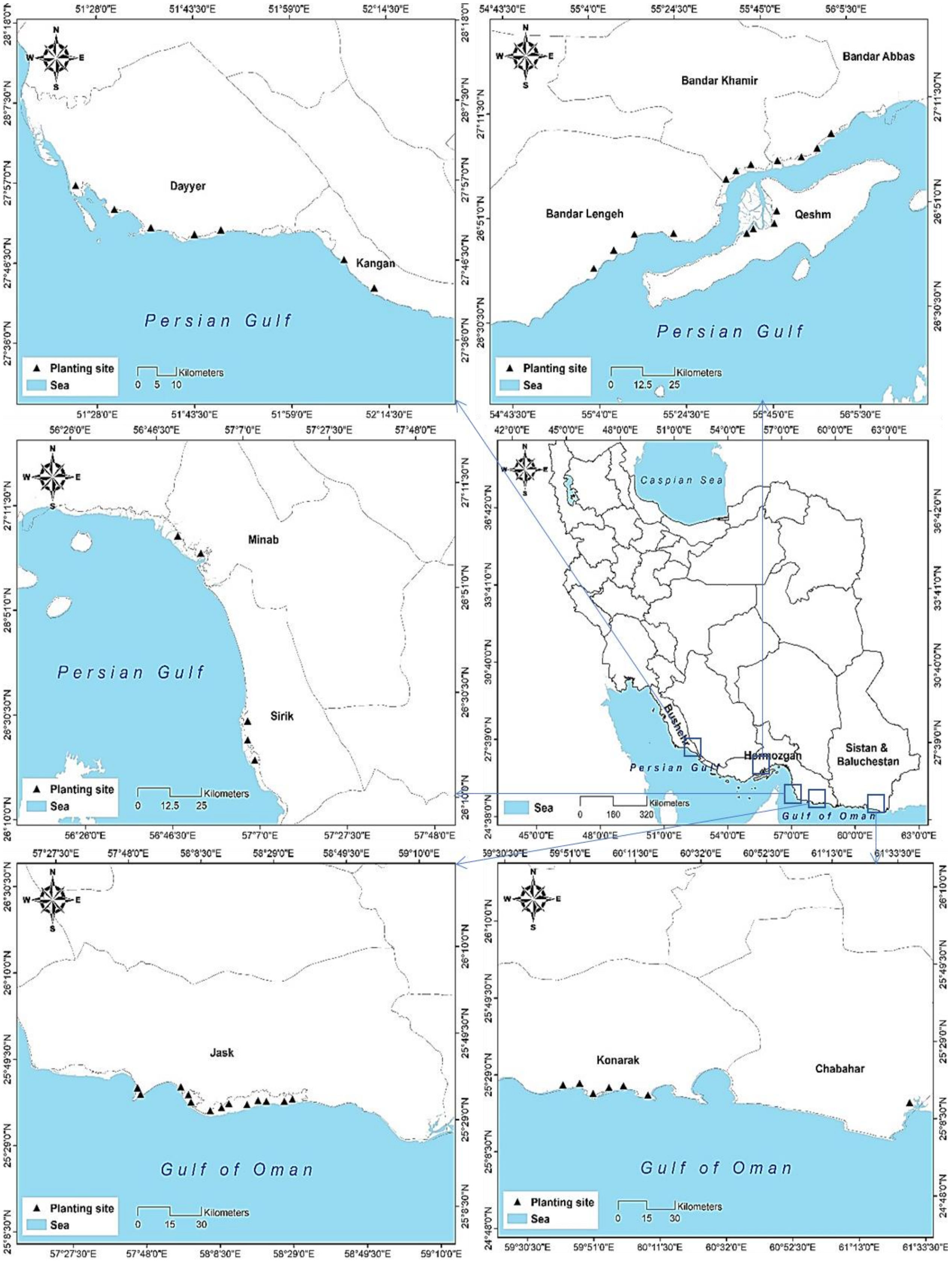

Fig. 1. Geographic location of the study area (Source: Current study)

2.2. Methodology framework

The research framework adopted in this study involves a multi-stage approach to evaluate the sustainability of afforested areas in the southern coast of Iran. Specifically, there were four stages, namely (1) Identification of forest restoration and afforestation sites, (2) Selection of criteria and indicators for measuring sustainability, (3) Measuring sustainability indicators, and (4) Scoring and classifying the sustainability of forest sites. Each of these stages will be further elaborated next.

2.3. Identification of rehabilitation and afforestation sites

During the first phase of the research, relevant reports and documents were reviewed, and preliminary information was obtained about the possibility of mangrove afforestation in the three studied provinces (i.e. Bushehr, Hormozgan and Sistan, and Baluchestan). These documents mainly included technical-administrative reports, articles and provincial studies, of which some might have provided statistics on tree planting on the southern coast of the country. To triangulate the information gathered, interviews were further conducted with experts and executives from the forest department of natural resources in the Bushehr, Hormozgan and Sistan, and Baluchestan provinces. In each province, an average of three experts and/or executives were interviewed, and this was followed by field visits to afforested areas (i.e. mangrove planting). As a result, the environmental characteristics of afforested areas such as geographical location, area of cultivation, year of cultivation, and number of seedlings planted, and planting distance were identified. In this study, only planting sites between the year 1977 (the beginning of forest rehabilitation and afforestation practices on the southern coast of the country) to 2011 were analyzed.

2.4. Selection of criteria and indicators for measuring sustainability

The second phase of the research investigated the sustainability of forest stands that had been used as criteria and indicators of forest sustainability (Raison et al., 2001). There were seven main criteria of sustainable forest management being considered, namely (1) Forest coverage, (2) Biological diversity, (3) Forest condition, (4) Productive functions of forest resources, (5) Protective functions of forest resources, (6) Socio-Economic-functions, and (7) Legal, policy and institutional framework. From these criteria, two (i.e. forest coverage, and forest condition) were selected based on the thematic relationship about the stability of afforestation stands, which is the key focus of this study. The indicators of these two criteria were subsequently determined by reviewing related studies (Boukherroub et al., 2017; Lewis et al., 2019; Luo et al., 2010; O'Connell et al., 2022; Trumbore et al., 2015). Table 1 shows the criteria and indicators used.

Table 1. Criteria and indicators for evaluation the sustainability of mangrove forest stands.

Criteria	Indicators
Forest coverage	Forest area changes (area reduction) Forest density changes (density reduction)
Forest condition	Average height growth Average forest regeneration

2.5. Measurement of sustainability indicators

In the third phase of the study, a purposeful sampling method was used to measure changes in forest density, average height growth and average regeneration (Badarna & Shimshoni, 2019; Ukpong, 1992). A total of 47 sites were sampled with the area of each site having a minimum of three and a maximum of 15 circular plots of 100 square meters. Visual interpretation of Google Earth images was used to examine changes in forest area and measure the current area of forest sites (Chen et al., 2021).

2.6. Scoring and classifying the sustainability of planting sites

The final phase of the study gathered the opinions and experiences of five experts (Lewis, 2005; Wodehouse & Rayment, 2019), to determine the importance of each indicator (Table 2) in the process of afforestation sustainability. In order to compare the status of indicators in planting zones and determine the sustainability status of each, the percentage of decline in density indices and habitat level was classified, and the score of each category was determined according to the mentioned method. Existing density was divided by the expected density, which was the number of seedlings planted per hectare. Based on the mean of minimum and maximum height growth and the rate of regeneration as lower and upper limit, the scores of these indicators are as shown in Tables 2. Then, by multiplying the score of each indicator (based on the results of the sample parts and estimating areas) in its weight score, a sustainability score was calculated for each indicator. Finally, by adding the stability scores of all indicators, the total sustainability score for each site was determined. The description of the sustainability status of the sites was considered based on the sustainability scores as presented in Table 3. The sustainability status of each habitat was calculated using Eq.1:

$$S = \sum_{I=4}^{I=1} X * Y \qquad (1)$$

S is sustainability score of each site, X is score of each indicator in each site, Y is weight score of each indicator, I is indicator 1 to 4.

Table2. Score of sustainability indicators

Indicators	Weight score	Percentage drop / Indicator range		Score
Forest area changes	5	Percentage drop	1-20	-1
			21-40	-2
Forest density changes	4		41-60	-3
			61-80	-4
			81-100	-5
Forest height growth	3	Indicator range	<1-1.5	1
			1.6-2	2
			2.1-2.5	3
			2.6-3	4
			3.1-3.5	5
Forest regeneration	2.5	Indicator range	1-50	1
			51-150	2
			151-300	3
			301-450	4
			451-600	5

Table 3. Description of the sustainability score of the indicators

Sustainability score	Sustainability status
1 to 10	Tendency to sustainability
10 to 20	High sustainability
Above 20	Extremely sustainability
-1 to -10	Tendency to unsustainability
-10 to -20	High unsustainability
Above -20	Extremely unsustainability

3. Results

3.1. Environmental characteristics of planting sites

A total of 47 sites have been planted on the coasts of the three provinces studied. As shown in Table 4, these sites were distributed on the coasts of two townships in the Sistan and Baluchestan province, seven townships in the Hormozgan province, and two coastal townships in the Bushehr province. The total area of mangrove planting sites was 9,584.5 hectares, of which approximately 15,503 thousand seedlings or seeds were used. Majority of the sites (70.2%) and their area (79%) were in the Hormozgan province. There were 26 afforestation practice sites with an area of 5,724 hectares, and 21 combined rehabilitation and afforestation practice sites with an area of 3,860.5 hectares carried out in this study. Seventy-six percent of the planting sites had a 3×3 meters planting distance with the remaining sites being 1×1.5 (15%) and 1×2 (9%) meters respectively (Figure 2). There were four sites in the Jask and Sirik township with an area of 417 hectares that had planted *Rhizophora mucronata*, whereas the rest of the afforestation sites were planted with *Avicennia marina*.

Table 4. Environmental characteristics of planted sites

Province	Township	Practice type	No. of Sites	Planted Area(ha)	No. of seedlings (thousand)
Sistan & Balouchestan	Chabahar	Afforestation	1	590	2475
	Konarak	Afforestation	6	1052	3000
Hormozgan	Jask	Afforestation	4	1147	1147
		Rehabilitation & Afforestation	9	2161	2161
	Sirik	Rehabilitation & Afforestation	1	648	648
	Minab	Afforestation	2	130	130
		Rehabilitation & Afforestation	2	270	270
	Qeshm	Afforestation	4	1641	1641
	Bandar Abbas	Afforestation	1	610	610
		Rehabilitation & Afforestation	3	600	600
	Bandar khamir	Afforestation	1	15	15
		Rehabilitation & Afforestation	2	17.5	17.5
	Bandar lengeh	Afforestation	3	188	188
		Rehabilitation & Afforestation	1	145	145
Bushehr	Kangan	Afforestation	1	8	53
		Rehabilitation & Afforestation	1	10	66.6
	Dayyer	Afforestation	3	343	2276.6
		Rehabilitation & Afforestation	2	9	59.6
Total			47	9584.5	15503.3

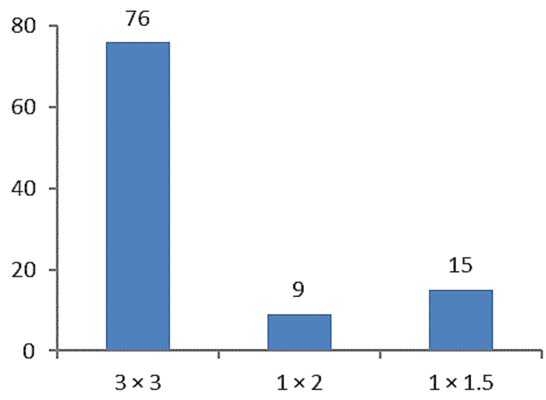

Fig. 2. Percentage of planting distance

3.2. Measuring sustainability indicators

As shown in Table 5, findings indicated that there was a total of 2,235.9 hectares of surviving planted area in the three provinces (i.e. Sistan and Baluchestan, Hormozgan, and Bushehr), of which the Qeshm township (in the Hormozgan province) had the largest area of 705.6 hectares, and the Kangan township (in the Bushehr province) had the smallest area of 7 hectares. The average forest density for the three provinces was approximately 1,498 per hectare, with the Chabahar (in the Sistan and Balouchestan province) and the Bandar khamir (in the Hormozgan province) townships having the highest and lowest average density of 4,460 and 390 per hectare respectively. Findings also revealed that the average generation per hectare in these three provinces was 206.5 per hectare, and the townships that had the highest and lowest average generation were Bandar Abbas (in the Hormozgan province) and Sirik (in the Sistan and Balouchestan province) respectively. The average tree height in the three provinces was estimated at 154 cm, with the tallest (215cm) in the Chabahar township (in the Sistan and Balouchestan province) and the shortest (121cm) in the Kangan township (in the Bushehr province). According to Figure 3, the largest area reduction was estimated to be 98% in the Konarak township, whereas the Qeshm township had the smallest reduction of 57%. In addition, the Konarak township had the highest density reduction of 79%, and the Qeshm township had the lowest density reduction of 16%. Overall, 76.7% of the area of planting sites were lost and the remaining areas had experienced a 44% decrease in density.

Table 5. Measuring sustainability indicators

Province	Township	Surviving Planted Area (ha)	Average density per hectare	Average of generation per hectare	Average tree height (cm)
Sistan & Balouchestan	Chabahar	20	4460	327.2	215
	Konarak	13.3	1580	230.7	198
Hormozgan	Jask	661.6	510	102	140
	Sirik	162	500	99.5	125
	Minab	92.5	389	105	122
	Qeshm	705.6	840	321	135
	Bandar Abbas	399.3	680	353.5	192
	Bandar khamir	11.4	390	102	150
	Bandar lengeh	99.8	690	169.2	150
Bushehr	Kangan	7	3800	345	121
	Dayyer	63.4	2640	116	142
	Total	2235.9	1498	206.5	154

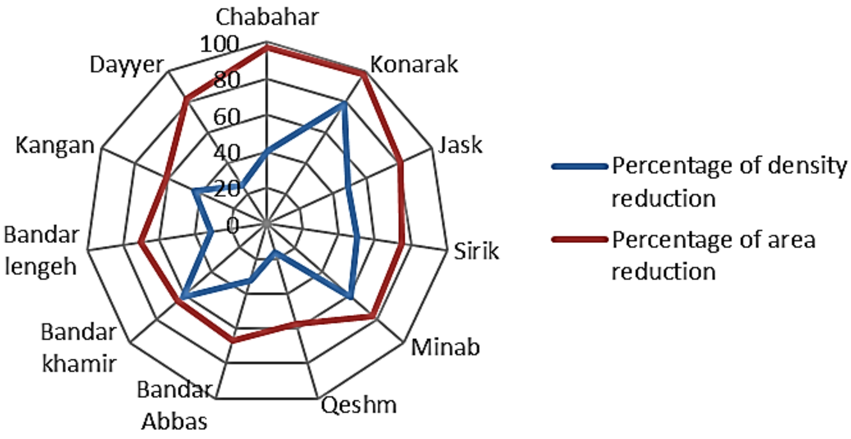

Fig. 3. Percentage of area and density reduction

3.3. Significant status of sustainability indicators

Although results showed that there was no significant difference between combined rehabilitation and afforestation practice and afforestation alone, however there was a significant difference between sites for all indicators. At the township level, findings indicated that there was a significant difference in survival planted area, average of density, percentage of area reduction, and percentage of density reduction. In contrast, only two indicators (i.e. surviving planted area, and percentage of area reduction) were significant at the province level. Table 6 shows the significant status of sustainability indicators at the scale of type of practice, sites, township and province.

Table 6. Significant status of sustainability indicators

Indicator	Practices (p-value)	Sites (p-value)	Township (p-value)	Province (p-value)
Surviving planted area	0.104	**0.004	**0.000	**0.000
Average of density	0.211	*0.063	*0.044	0.233
Average of generation	0.620	**0.000	0.199	0.928
Average of height trees	0.874	**0.009	0.380	0.733
Percentage of area reduction	0.112	**0.005	*0.025	*0.055
Percentage of density reduction	0.215	**0.000	*0.044	0.204

** Level of significance at 99% confidence interval
* Level of significance at 95% confidence interval

3.4. Sustainability of planting sites

According to Table 7, 93.7% (i.e. 44 out of 47) of the planting sites were regarded as unsustainable with majority (i.e. 31 out of 44) of them located in the Hormozgan province. In contrast, there were only three planting sites considered as sustainable and they were spread across two provinces (i.e. Sistan and Baluchestan, Hormozgan).

Table 7. Distribute the number of sites in each sustainability category

Province	Sustainability status					
	Tendency to be sustainable	Highly sustainable	Extremely sustainable	Tendency to be unsustainable	Highly unsustainable	Extremely unsustainable
Sistan & Balouchestan	0	0	1	2	2	2
Hormozgan	1	1	0	3	10	18
Bushehr	0	0	0	1	3	3
Total	1	1	1	6	15	23

4. Discussion

Monitoring and evaluating changes in sustainability indicators are important to the orientations and trends in the field of forestry, and they can reveal the degree of deviation or proximity to the ideal state or sustainable forestry. Through such monitoring and evaluating mechanisms, policy decision-makers, and planners in forestry could gain valuable insights to the status and develop appropriate strategies and actions to achieve sustainable forestry (Lewis et al., 2019). This study has identified and evaluated a series of indicators (e.g. changes in areas and density, regeneration rate and height growth rate) on forest resource sustainability, and the sustainability of planting sites on the southern coast of Iran, which have also been used in previous studies (e.g. (Lewis, 2005); (Luo et al., 2010).

In this study, the percentage change of planting area was considered the most important indicator since human interventions (e.g. economic developments, pollutions) have contributed to changes in these areas and impacted forest sustainability (Mafi-Golami et al, 2017). As shown in Table 4, there were two practice types (i.e. afforestation only, and rehabilitation and afforestation) of planting in the southern coast of Iran that covered an area of 9,584.5 hectares. This represents approximately 89.7% of the natural mangrove forests area in Iran, which is a significant coverage. The main purpose of mangrove planting in Iran has been to rebuild degraded sites as well as to expand the area of forests to benefit from ecological services and non-consumption uses (Danehkar, 2012). In fact, if appropriate sustainability measures and practices had been put in place, Iran's natural mangrove forests area could have been much greater. Instead, about 76.7% (equivalent to 7,348.6 hectares) of these planting areas have been destroyed and only 2,235.9 hectares remaining. Furthermore, results showed that the remaining area of planting sites had a 56% drop in density.

From the remaining 23.3% of the area, 93.7% were regarded as unsustainable (Table 7). This suggests that the remaining afforestation is unstainable and is highly exposed to area reduction. A detailed examination of the conditions of each site and the identification of degradation factors in each of them can help to apply management measures to support these sites. These measures can improve the sites' sustainability status from extremely unsustainable to highly unsustainable, or highly unsustainable to tendency to be unsustainable, by preventing controllable destruction factors.

Studies in other countries have confirmed that the success rate of mangrove rehabilitation and afforestation is low. For example, a study of mangrove plantations in Thailand and the Philippines found that 66% of rehabilitation had a survival rate of less than 20% (Wodehouse & Rayment, 2019). Another study by Marchand (2008) revealed that the success rate of mangrove afforestation was estimated at 1.52% in Bangladesh and 40% in Vietnam. Some of the key factors contributed to this relatively low rate of success included unfavorable ecological conditions in afforested sites, drastic reduction in the area and density of forests, which have obstructed the height growth of trees that prevented their regeneration.

Other factors such as inappropriate planting locations, storm events, coastal sediment, increasing droughts, lack of participation and supervision have also been regarded as the main causes of such a failure, and this is supported by previous studies (Balke & Friess, 2016; Bosire et al., 2008; Hai et al., 2020; Wodehouse & Rayment, 2019).

According to Table 6, there was no significant difference between combined rehabilitation and afforestation, and afforestation alone. This suggests that sites where planting was done for rehabilitation purposes were not significantly different from sites for afforestation purposes only. Areas that were once thought to have been deforested and reforested might have never been covered due to unfavorable ecological conditions. For this reason, the practice of rehabilitation could be less effective and practical, and afforestation practices should be considered instead. On average, the survival rate of planted area in western sites was higher than those in eastern sites, and this could be explained by the direct influence of the eastern sites on the sea currents of the Oman Sea. Furthermore, the Gono storm occurred in 2006 had caused extensive destruction of planting sites on the coasts of the Sistan and Baluchestan province and the eastern coasts of the Hormozgan province. This indicates that western sites are far less exposed to sea waves due to their location on the northern shores of the Persian Gulf.

One of the primary reasons for the unsustainable and failure of mangrove afforestation in the south coast of Iran was cultivation at inappropriate or unsuitable planting areas, which can be divided into two categories. The first category relates to areas that do not naturally have much capacity for mangrove growth, and therefore cultivation in them often result in failures. In these areas, factors such as sea hydrology, coastal geomorphology, lack of freshwater and erosion of the coasts will not provide mangroves a long-term establishment opportunity. The second category relates to areas that are affected by destructive social, economic, and environmental factors, which do not allow the dynamics and sustainability of forestry. In these areas, mangrove growth will face many challenges because of increasing pollutions, tourism, fishing, livestock grazing activities, and industrial, farming and environmental wastes. A key priority for the management is to not consider planting in areas that are naturally unsuitable for mangrove establishment, and to make essential adjustments and removal of destructive and limiting factors before starting any forestry activities. However, field investigations have shown that no control actions were taken before or after afforestation in these areas, to help improve the situation. Unsustainable sites located in the Bushehr province have been mainly affected by coastal erosion, oil pollution, and industrial and urban wastes. As for those unsustainable sites at the Hormozgan province, mangrove seedlings being out of the tidal range, shrimp farming, rural and urban wastes, tourism and fishing activities have the greatest effect on the sustainability of the areas. Whereas sea storms (Gono Storm) and livestock grazing are the main factors leading to the failure and unsustainable afforestation at the Sistan and Baluchistan province.

A lack of attention to the severity of occurrence and destructive effects of natural and human factors when selecting afforestation sites is deemed to be a critical concern. In fact, no study has been conducted on the vulnerability assessment of forestry areas in relation to multiple environmental hazards, and only criteria such as close access to the cultivation site, the allocation of provincial or city financial resources, and efforts to increase the extent of cultivation areas have been considered for the selection of sites. The actions taken before the start of cultivation activities in the sites were generally aimed at management coordination for cultivation. A greater level of involvement and participation from local institutions and communities will be beneficial to improving the site selection process.

With regards to the sustainability status, 48.9% of the planting sites were considered extremely unsustainable, 31.9% were highly unsustainable, and 12.8% had a tendency to be unsustainable. This outcome indicates that unless adequate support and remedial measures are put in place and undertaken, the planting sites will not be sustainable. Evidences show that actions that are based on continuous monitoring and evaluation over periods of time, and the use of adaptive management techniques can make positive changes (Laulikitnont, 2014; Lewis et al., 2019). Of the 47 sites studied, there was only one site in each of the category (i.e. extremely sustainable, highly sustainable, and tendency to be sustainable) to be considered as sustainable (Table 7). The ecological conditions in these three sites could be used as guiding principles for the subsequent forestation of mangrove forests on the southern coast of the country. Conducting climatological, sedimentological, geomorphological studies as well as social and economic surveys in these three sites can help to provide a better understanding when identifying new sites and improve the sustainability of existing sites.

It is also worth noting that in the process of revitalizing a forest ecosystem, attention should be paid to all components of the ecosystem, especially plant and animal biodiversity and even microorganisms. While the four indicators (i.e. area, density, height growth and natural regeneration of the forest) investigated in this study can serve as a basis for evaluating other forest restoration areas, but will more comprehensive if biodiversity indicators are included. Biological diversity is one of the seven criteria of forest sustainability that can be measured in a separate study, to better understand the extent of the restoration activity.

5. Conclusion

Findings from this study have provided the basis for proper management of sustainable mangrove forest areas, as well as a guide to select and prioritize the rehabilitation and afforestation of these forests. This is the first major study conducted in Iran, using the indicators of forest resource sustainability, the sustainability of planting sites on the southern coast to evaluate the sustainability of mangrove planting in the country. Specifically, changes in area, density, height growth, and generation rate were the key indicators evaluated. Results revealed that the total planting areas in 47 sites across seven cities in three provinces were 9,584.5 hectares with only 2,235.9 hectares remained in recent times, and only 6.3% of these sites were considered sustainable. Due to the various costs in the process of production, transfer, planting and maintenance of seedlings and cultivation areas, it is very important to choose the appropriate area for mangrove forestation and to consider the degree of coastal vulnerability. As such, it is necessary to review the southern coasts of the country by following the example of successful planting sites and locating forest restoration and afforestation in them. The results of this study will help managers and decision makers to review the site selection processes as well as regulatory and management measures, to assist them in their decision-making process towards achieving sustainable mangrove forests.

References

Andon Petrosians, H., Danehkar, A., Mahmoudi, B., Saeed Sabaei, M., Ghadirian, T,. Asadollahi, Z., Sharifi, N., & Petrosian, H., Ashrafis., & Feghhi. (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*(7), 37-. https://www.magiran.com/paper/1218888

Badarna, M., & Shimshoni, I. (2019). Selective sampling for trees and forests. *Neurocomputing*, *358*, 93-108.

Balke, T., & Friess, D. A. (2016). Geomorphic knowledge for mangrove restoration: a pan-tropical categorization. *Earth Surface Processes and Landforms*, *41*(2), 231-239.

Bosire, J. O., Dahdouh-Guebas, F., Walton, M., Crona, B. I., Lewis Iii, R., Field, C., Kairo, J. G., & Koedam, N. (2008). Functionality of restored mangroves: a review. *Aquatic Botany*, *89*(2), 251-259.

Boukherroub, T., LeBel, L., & Ruiz, A. (2017). A framework for sustainable forest resource allocation: A Canadian case study. *Omega*, *66*, 224-235.

Chen, S., Woodcock, C. E., Bullock, E. L., Arévalo, P., Torchinava, P., Peng, S., & Olofsson, P. (2021). Monitoring temperate forest degradation on Google Earth Engine using Landsat time series analysis. *Remote Sensing of Environment*, *265*, 112648.

Danehkar, A., Mahmoudi, B., Saeed Sabaei, M., Ghadirian, T,. Asadollahi, Z., Sharifi, N., & Petrosian, H. (2012). *National document of Iran mangrove forest sustainable management program*.

Dehghani, A., Pourhashemi, M., Shabanian, N. & Mirakhorlou, K. (2014). Identification of suitable sites for development of mangrove forests in Holor region, Qeshm Island. *Forest sustainable development*, *1*(2), 151-165. https://www.magiran.com/paper/1615981

Ellison, J. C. (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetlands Ecology and Management*, *23*(2), 115-137.

Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., Lucas, R., Primavera, J., Rajkaran, A., & Shi, S. (2019). The state of the world's mangrove forests: past, present, and future. *Annual Review of Environment and Resources*, *44*, 89-115.

Gandhi, S., & Jones, T. G. (2019). identifying mangrove deforestation hotspots in South Asia, Southeast Asia and Asia-Pacific. *Remote Sensing*, *11*(6), 728.

Hai, N., Dell, B., Phuong, V., & Harper, R. (2020). Towards a more robust approach for the restoration of mangroves in Vietnam. *Annals of Forest Science*, *77*(1), 1-18.

Hajebi, A., Moslehi, M., & Hassani, M. (2019). Effects of species, light, and irrigation regime on vegetative growth of grey mangrove (Avicennia marina and red mangrove (Rhizophora mucronata seedlings in the nursery. *Iranian Journal of Forest and Poplar Research*, *27*(1), 90-99. https://www.magiran.com/paper/1993206

Khayrandish, H., Esmaeilpour, Y., Kamali, A. R., & Zakeri, O. (2015). Locating suitable areas for mangrove afforestation in the Sirik habitat, Hormozgan Province. *Journal of Aquatic Ecology*, *5*(2), 112-123. https://www.magiran.com/paper/1634096

Kodikara, K. A. S., Mukherjee, N., Jayatissa, L. P., Dahdouh-Guebas, F., & Koedam, N. (2017). Have mangrove restoration projects worked? An in-depth study in Sri Lanka. *Restoration Ecology*, *25*(5), 705-716.

Laulikitnont, P. (2014). Evaluation of mangrove ecosystem restoration success in Southeast Asia.

Lewis, I., Roy R. (2005). Ecological engineering for successful management and restoration of mangrove forests. *Ecological engineering*, *24*(4), 403-418.

Lewis, R. R., Brown, B. M., & Flynn, L. L. (2019). Methods and criteria for successful mangrove forest rehabilitation. In *Coastal wetlands* (pp. 863-887). Elsevier.

Luo, Z., Sun, O. J., & Xu, H. (2010). A comparison of species composition and stand structure between planted and natural mangrove forests in Shenzhen Bay, South China. *Journal of Plant Ecology*, *3*(3), 165-174.

Marchand, M. (2008). Mangrove restoration in Vietnam: Key considerations and a practical guide.

O'Connell, D. P., Fusi, M., Djamaluddin, R., Rajagukguk, B. B., Bachmid, F., Kitson, J. J., Dunnett, Z., Trianto, A., Tjoa, A. B., & Diele, K. (2022). Assessing mangrove restoration practices using species-interaction networks. *Restoration Ecology*, *30*(4), e13546.

Primavera, J., Sadaba, R. B., Lebata, M., Hazel, J., & Altamirano, J. (2004). *Handbook of mangroves in the Philippines-Panay*. Aquaculture Department, Southeast Asian Fisheries Development Center.

Primavera, J. H., & Esteban, J. M. A. (2008). A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. *Wetlands Ecology and Management*, *16*(5), 345-358.

Queiroz, H. M., Ferreira, T. O., Taniguchi, C. A. K., Barcellos, D., do Nascimento, J. C., Nóbrega, G. N., Otero, X. L., & Artur, A. G. (2020). Nitrogen mineralization and eutrophication risks in mangroves receiving shrimp farming effluents. *Environmental Science and Pollution Research*, *27*(28), 34941-34950.

Raison, R. J., Brown, A. G., & Flinn, D. W. (2001). *Criteria and indicators for sustainable forest management* (Vol. 7). CABI.

Sharma, S. (2018). *Mangrove Ecosystem Ecology and Function*. BoD–Books on Demand.

Singh, V. P., & Odaki, K. (2004). *Mangrove ecosystem: structure and function*. Scientific Publishers.

Thivakaran, G. (2017). Mangrove restoration: an overview of coastal afforestation in India. *Wetland Science*, 501-512.

Trumbore, S., Brando, P., & Hartmann, H. (2015). Forest health and global change. *Science*, *349*(6250), 814-818.

Ukpong, I. (1992). Is there vegetation continuum in mangrove swamps. *Acta Botanica Hungarica*, *37*(1-4), 151-159.

Walters, B. B., Rönnbäck, P., Kovacs, J. M., Crona, B., Hussain, S. A., Badola, R., Primavera, J. H., Barbier, E., & Dahdouh-Guebas, F. (2008). Ethnobiology, socio-economics and management of mangrove forests: A review. *Aquatic Botany*, *89*(2), 220-236.

Ward, R. D., & de Lacerda, L. D. (2021). Responses of mangrove ecosystems to sea level change. In *Dynamic Sedimentary Environments of Mangrove Coasts* (pp. 235-253). Elsevier.

Wodehouse, D. C., & Rayment, M. B. (2019). Mangrove area and propagule number planting targets produce sub-optimal rehabilitation and afforestation outcomes. *Estuarine, Coastal and Shelf Science*, *222*, 91-102.

Zahed, M. A., 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 Ecologica Sinica*, *30*(4), 240-244.