J Arid Land (2024) 16(12): 1701–1713
doi: 10.1007/s40333-024-0111-2; CSTR: 32276.14.JAL.02401112

Science Press   Springer-Verlag

Impact of trimming intensity on the growth of mangrove in Iran

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Abstract: Mangrove forests in southern Iran are of high ecological and economic importance. These forests are being threatened because of uncontrolled harvesting to provide fodder for livestock. The objective of this study is to provide recommendations for appropriate harvesting intensities by quantifying the effect of different harvesting intensities on vegetative and vigor characteristics of mangrove trees. This study was conducted using a randomized complete block design comprising four treatments (10.00%, 20.00%, and 30.00% trimming, along with a control) replicated three times. Vegetative characteristics were measured before and after trimming (five-year period) and analyzed using generalized linear model statistical analysis. The growths of the average diameter of canopy, canopy area, canopy volume, canopy height, tree height, and collar diameter in the control treatment were all significantly higher than those in the trimming treatments. In addition, there was a decreasing trend in leaf fresh and dry mass, leaf area index, total area of canopy leaves, and health status of tree in the trimming treatments. For example, the percentage change in fresh and dry leaf mass in the control treatment was positive (29.87% and 38.31%, respectively), whereas the trimming treatments of 10.00%, 20.00% and 30.00% had negative effects (–7.01% and –4.79%, –11.32% and –14.30%, and –15.84% and –17.29%, respectively). In addition, the changes in leaf area index in the control (4.95%) and 30.00% trimming (–24.57%) treatments were the highest and lowest, respectively. The percentage change in soil organic matter in the control, 10.00%, 20.00%, and 30.00% treatments were 22.94%, –9.90%, –16.91%, and –18.68%, respectively. The study demonstrated that gray mangrove trees were highly sensitive to canopy trimming, with even minimal trimming intensities negatively affecting vegetative growth and soil organic matter. Therefore, it is recommended that cutting and trimming of mangrove trees should be prevented even at low intensity to preserve mangrove ecosystem health and resilience against environmental stressors.

Keywords: trimming; mangrove ecosystem; vegetative characteristic; harvest intensity; soil organic matter; Khamir Port

Citation: Maryam MOSLEHI, Akram AHMADI, Tom PYPKER. 2024. Impact of trimming intensity on the growth of mangrove in Iran. Journal of Arid Land, 16(12): 1701–1713. https://doi.org/10.1007/s40333-024-0111-2; https://cstr.cn/32276.14.JAL.02401112

1 Introduction

Mangrove forests in tropical and subtropical areas are vulnerable to human activities and climate change (Ghosh et al. 2015). From 1980 to 2005, 20.00% of the area covered by mangroves worldwide were lost because of coastal development, pollution, aquaculture, as well as logging and

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Received 2024-06-10; revised 2024-11-06; accepted 2024-11-30

exploitation for fuel supply (Spalding et al., 2014). Currently, mangrove habitats are decreasing with the rate of 1.00%–2.00% annually (FAO, 2003). It is predicted that the world may lose all the services provided by mangroves in the next 100 a (Duke et al., 2007).

Mangrove forests provide valuable environmental services. They are an important source of food and wood, and also provide valuable environmental services (e.g., timber and fuel wood, breeding and nursery habitats for fish species, protection from storms and floods, and erosion control) to coastal communities in the tropical areas. The services provided by mangrove forests can facilitate the attraction of capital for its protection in exchange for providing those services. Therefore, it is necessary for land managers to have sufficient information on the effects of human activities on mangroves so that they can properly manage and protect this valuable ecosystem (Akram et al., 2023).

Wood harvesting from mangrove is a common activity that can degrade the forest. Bosire et al. (2008) suggested that if raw material harvest is less than net production, the forest will remain sustainable. However, Walters et al. (2008) reported that the trimming of trees for wood products caused almost 90.00% of tree deaths in natural mangrove forests and plantations. In addition, van Oudenhoven et al. (2015) conducted a study on the effects of different management regimes on mangrove ecosystem services in Java Island, Indonesia. They applied five different management methods such as natural, low-intensity harvesting, high-intensity harvesting, and conversion of mangrove forests to irrigated croplands and abandoned croplands. Their results indicated that mangroves provide the best services when they are left in a natural state. Therefore, the proper management and preservation of mangrove forests require assessing if local harvesting methods can maintain healthy mangrove forests despite branch removal. Aheto et al. (2016) conducted a study on community-based mangrove forest management in which they examined people's livelihoods from coastal mangrove forests in Ghana. The results indicated that people's livelihoods and economic benefits are the primary factors that motivate participation in the restoration and management of mangrove forests. The unrestricted use of mangroves and the limited economic opportunities are among the reasons for harvesting from mangrove forests. The results showed that if local customary laws are established and basic rules are put in place to manage the harvesting and regeneration of mangroves, mangrove forest resources can be sustainably harvested, restored, and managed.

Mangrove forests are common in the southeastern portion of Iran, and the largest community is found near Khamir Port (Danehkar and Jalali, 2005). The mangrove forests in the south of the country are not immune from disturbance despite their high ecological and economic importance. The forests are heavily exploited and under threat due to indiscriminate harvesting to provide fodder for livestock. Due to the lack of proper management policies to supply fodder, people are inevitably forced to use mangrove forests to supply their needs (Danehkar and Jalali, 2005).

Past research demonstrated that mangrove forests in southern Iran are highly sensitive to human disturbance. Yaghoubzadeh et al. (2021b) investigated the effect of effluent from shrimp farms on vegetative and reproductive characteristics of Minab mangrove forests, and discovered that the freshness, average height, canopy height of *Avicennia marina* (Forssk.) Vierh trees, and the number of seedlings is significantly higher in the control treatment than in the shrimp farm affected regions. They also found that the vegetative and reproductive characteristics of mangrove trees in Hormozgan Province, Iran, are significantly poorer closer to port than those further away.

Khamir Port in southern Iran is an important habitat for mangrove forests, a sensitive ecosystem that requires careful management due to its vulnerability to human activities. Given the significant role mangrove forests play in the coastal protection and their ecological importance, it is essential to understand the impact of various human interventions, including trimming, on their health and productivity. The objective of this study is to provide recommendations for appropriate harvesting intensities by quantifying the effect of different trimming intensities on vegetative and vigor characteristics of mangrove trees in Khamir Port.

2 Materials and methods

2.1 Study area

Iran's mangrove forests range from 25°12′12″N to 27°50′25″N and from 51°57′37″E to 61°35′24″E. The mangrove forests in Khamir Port are the northernmost community of mangrove forests in Iran and in Southwest Asia (Fig. 1). The density of mangroves in Khamir Port is 1555 individuals/hm^2. The climate of Khamir Port, Hormozgan Province is characterized by a severe hot desert, with an average annual rainfall of 189.70 mm and an average annual temperature of 27.0°C. The average minimum and maximum temperatures are 18.0°C and 37.2°C, respectively, based on 27 a of statistical data (from 1975 to 2001) from the synoptic station at Bandar Abbas Airport. The average annual evapotranspiration is 2500.00 mm (Moslehi et al., 2023). Due to its proximity to the sea, the relative humidity in Bandar Khamir is high, especially in the summer months, reaching over 70.00%. The Persian Gulf is connected to the Indian Ocean through the Strait of Hormuz.

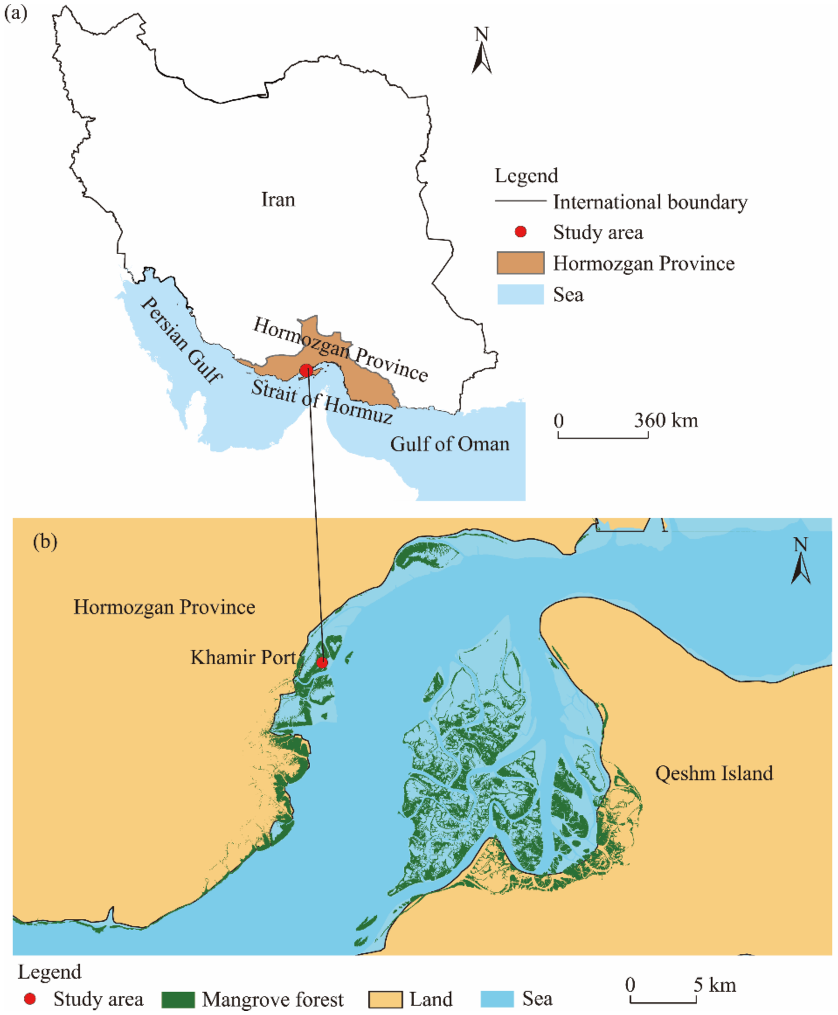

Fig. 1 Location of the study area (a) and the distribution range of mangrove forests (b) in Khamir Port, Iran

2.2 Research methods

2.2.1 Selection of sample tree

The sample site was located in the mangrove forests in Khamir Port. We selected the sample site based upon the distance and proximity of the forest to the coast and water depth. The length of sample site was 175.00 m and the width was based upon the highest and lowest tide levels. This design was implemented using a randomized complete block design with four treatments and three replications. The four treatments included: light trimming by removing 10.00% of branches; mild trimming by removing 20.00% of branches; medium trimming by removing 30.00% of branches; and a control treatment where no harvesting or trimming was done. The length and width of each treatment plot were 40.00 and 25.00 m, respectively, and the long edge of the treatment plot was parallel to the sea (Fig. 2). A hypothetical sample line of approximately 47.00 m length was laid and the trees whose trunk or canopy image hit this sample line were considered as the sample tree candidates in that plot. We randomly selected ten trees with a canopy diameter exceeding two meters as samples trees from the candidates along the sample line in each treatment plot.

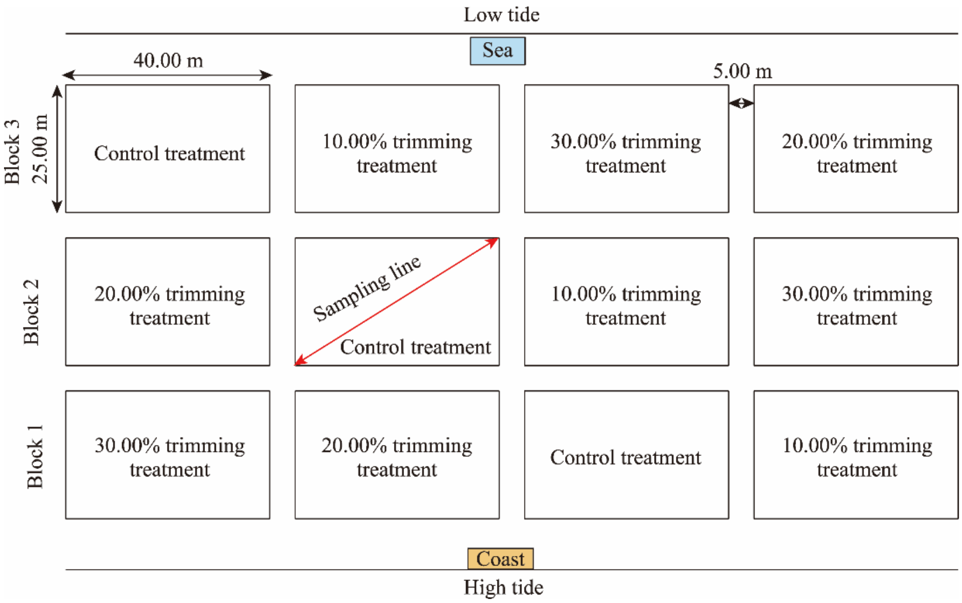

Fig. 2 Schematic layout of sampling

2.2.2 Measurement of vegetative characteristics

To investigate the effect of trimming on vegetative characteristics, including the small diameter of canopy, large diameter of canopy, average diameter of canopy, canopy area, canopy volume, canopy height, tree height, collar diameter, leaf fresh mass (LFM), leaf dry mass (LDM), leaf area index (LAI), total area of leaves (TAL), and health status of tree, we measured above mentioned indictors before trimming in spring 2016 and five years after trimming in spring 2021.

We employed a graduated scale pole (quickMOUNT pro, Chico, California, USA) to assess the tree height and canopy height, and a caliper (Weiler Company, Solingen, North Rhine-Westphalia, Germany) to measure collar diameter (Komiyama et al., 2008). To determine the average diameter of canopy, we measured two perpendicular diameters (i.e., large diameter and small diameter of canopy) by strip meter (SUNMAX 50 m, Shenzhen, Guangdong, China) and calculated their mean (±0.50 m) (Farnsworth and Ellison, 1996). The canopy area was calculated using Equation 1 and the canopy volume of broadleaf trees was calculated using Equation 2 (van Laar and Akça, 2007).

$$S = \frac{\pi}{4} \times \overline{D}^2 , \tag{1}$$

$$V = \frac{4}{3} \pi a^{\overline{D}^2} , \tag{2}$$

where S is the cross-sectional area of canopy (m^2); $\overline{D}$ is the average diameter of canopy, calculated by dividing the sum of small and large diameters of tree canopy by two (m); V is the volume of tree canopy (m^3); and a is the canopy height (m). To determine the total canopy area and canopy volume for each treatment, the individual value of canopy area and canopy volume of all trees in each treatment were summed to obtain the total canopy area and canopy volume of each treatment.

We divided the canopy of each of the 120 sample trees into eight sections to determine the leaf mass (Pourhashemi et al., 2011). The fresh weight of leaves collected from each tree was immediately determined using a digital scale and then, transferred to an oven for drying at a temperature of 70.0°C for 48 h and its weight was determined with an accuracy of 0.001 g (Bussotti et al., 1997). The leaf dry and fresh mass was estimated by multiplying the dry and fresh weight of the leaves from one section by eight to account for the entire canopy (Pourhashemi et al., 2011).

The TAL refers to the entire surface area of all the leaves of a tree; the LAI refers to a ratio of TAL to ground area. We randomly selected five leaves from each sample tree to calculate the TAL of each tree, and then averaged the TAL of each sample tree in one treatment to get the TAL of the treatment (Pourhashemi et al., 2011).

$$\mathrm{TAL} = \frac{M_t \times S_a}{M_a}, \tag{3}$$

$$\mathrm{LAI} = \frac{\mathrm{TAL}}{S_g}, \tag{4}$$

where M_t is the dry mass of total canopy leaves (g); S_a is the average area of five leaves (m^2); M_a is the average dry mass of five leaves (g); and S_g is the area of the shadow of canopy on the ground (m^2).

The health status of tree was visually assessed using qualitative characteristics, including color of leaf, shape of canopy, density of canopy, and number of dry microbranches. Based on the methods outlined in Moslehi and Hassanzadeh (2020), we graded the health status of the sample trees into three options: healthy, moderate, and weak (Table 1). Each indicator scored 5 points at healthy grade, 3 points at moderate grade, and 1 point at weak grade. The average score of all indicators could represent the health status of the tree; and the health status of tree of one treatment was the average score of each sample tree of that treatment.

Table 1 Rubric for assessing the grade of tree health

Grade	Score	Health indicator			
		Color of leaf	Shape of canopy	Density of canopy	Number of dry microbranches
Healthy	5	Bright green	Symmetrical and healthy	Dense	<10
Moderate	3	Pale green	Relatively symmetrical and average size	Semi-dense	10–30
Weak	1	Yellow or brown	Asymmetrical, small, or damaged	Very sparse	>30

2.2.3 Determination of soil organic matter (SOM)

To determine the SOM, we collected 120 soil samples at 10.00 cm depth below the canopy of each sample tree before trimming and five years later (Schrijvers et al., 1995; Middelburg et al., 1996) and calculated using the oxidation of organic matter method (Page et al., 1992). In this method, a 1.000 g soil sample was combined with 10 mL of potassium dichromate ($K_2Cr_2O_7$) solution, followed by the addition of 20 mL of sulfuric acid (H_2SO_4) to create an acidic environment that facilitates the complete oxidation of the organic matter. In this acidic setting, $K_2Cr_2O_7$ serves as a potent oxidizer, engaging with the organic carbon present in the soil. After the oxidation process, the amount of $K_2Cr_2O_7$ that has reacted was assessed through titration with ferrous ammonium sulfate ($Fe(NH_4)_2 \cdot (SO_4)_2$). The product provides an indirect estimation of the oxidized organic carbon within the soil sample.

2.2.4 Statistical analysis

Statistical analysis was done by SPSS software v. 26 (IBM, Chicago, Illinois, USA) and mean comparison was done by Duncan's multiple range test. The residuals of the linear model were checked by the Kolmogorov-Smirnov test for the normality of the data and the Levene test for the homogeneity of variance. We investigated the vegetative characteristics using generalized linear model (GLM) statistical analysis.

3 Results

3.1 Effect of trimming on canopy and tree growth

According to the results of Table 2 and Figure 3, in general, the greater the percent trimming, the lower the tree productivity. The large and small diameters of canopy in the control treatments increased 1.16 and 1.09 m through a five-year growth, respectively, whereas the growth of canopy diameter in the trimming treatments was significantly less than that in the control (Fig. 3a–c). Increasing trimming resulted in progressively less growth of small and large canopy diameters. The growth of average canopy diameter was the highest in the control treatment with 1.13 m; while the growth in the 10.00%, 20.00%, and 30.00% trimming treatments were 0.66, 0.46, and 0.40 m, respectively. Both the growth of canopy area and volume were the highest in the control treatment with 12.60 m^2 and 182.60 m^3, respectively. The 30.00% trimming treatment had the lowest growth of canopy area (4.09 m^2) and volume (76.43 m^3) (Fig. 3d and e). Changes in canopy height followed a similar pattern as the changes in canopy area and volume. The changes in average canopy height in the control (0.38 m) and 10.00% trimming (0.36 m) treatments were significantly greater than those in the 20.00% (0.26 m) and 30.00% (0.23 m) trimming treatments (Fig. 3f). The changes in tree height in the control (0.41 m) and 10.00% trimming (0.38 m) treatments were significantly greater than those in the 20.00% (0.26 m) and 30.00% (0.20 m) trimming treatments (Fig. 3g). Lastly, the growth of collar diameter in the control treatment (2.66 cm) was significantly greater than those in trimming treatments (Fig. 3h).

3.2 Effects of trimming on leaf characteristics and health status of tree

There was no significant difference in the leaf characteristics among different blocks (Table 3). In general, trimming negatively impacted leaf characteristics and health status of tree with the highest reduction in the 30.00% trimming treatment (Fig. 4). The percent change in leaf freshness (29.87%) and dry mass (38.31%) was significantly higher in the control treatment than in the 10.00% trimming treatment (–7.01% and –4.79%, respectively), 20.00% trimming treatment (–11.32% and –14.30%, respectively), and 30.00% trimming treatment (–15.84% and –17.29%, respectively) (Fig. 4a and b); the mass change in the control treatment was positive, while in any trimming treatments, it was negative. The LAI and TAL in the control treatment (4.95% and 43.74%, respectively) were significantly higher than those of the trimming treatments, as with the other measurements, only the control experienced positive changes (Fig. 4c and d). The percent change in health status of tree also showed a similar trend to that of leaf characteristics, and it had the highest and lowest values in the control (7.65%) and 30.00% trimming (–22.36%) treatments, respectively (Fig. 4e).

3.3 Effect of trimming on SOM

SOM significantly decreased with increasing trimming (Table 4). The percent change in SOM in the control treatment was positive (22.94%), which was significantly different from the 10.00%, 20.00%, and 30.00% trimming treatments with changes of –9.90%, –16.91%, and –18.68%, respectively (Fig. 5).

4 Discussion

4.1 Effect of trimming on growth

Mangrove forests have experienced contraction and expansion throughout history. However, in

Table 2 Analysis of variance for the growth of mangroves across various treatments

Variable	Source of variable	*df*	Mean square	Fisher coefficient
Small diameter of canopy	Block	2	0.085	6.23*
	Treatment	3	0.363	26.70**
	Error	6	0.014	
Large diameter of canopy	Block	2	0.267	12.40**
	Treatment	3	0.293	13.63**
	Error	6	0.022	
Average diameter of canopy	Block	2	0.160	10.57*
	Treatment	3	0.320	21.16**
	Error	6	0.010	
Canopy area	Block	2	25.670	28.71**
	Treatment	3	42.230	47.24**
	Error	6	0.890	
Canopy volume	Block	2	4415.840	12.73**
	Treatment	3	7207.430	20.77**
	Error	6	346.880	
Canopy height	Block	2	0.003	7.06*
	Treatment	3	0.017	38.37**
	Error	6	0.000	
Tree height	Block	2	0.004	7.21*
	Treatment	3	0.028	57.70**
	Error	6	0.000	
Collar diameter	Block	2	0.020	0.61ns
	Treatment	3	2.620	78.86**
	Error	6	0.033	

Note: *df*, degree of freedom; *, significant difference at P<0.05 level; **, significant difference at P<0.01 level; ns, no significant difference.

recent years, their global distribution is decreasing due to human activities (Friess et al., 2019). In our study, vegetative characteristics were reduced in all the trimming treatments compared with the control treatment. In addition, as the intensity of trimming increased, the growth of mangroves decreased. The findings of this study were consistent with past researches (Walter, 2005; Hosseinzadeh Monfared et al., 2008; Dehghanipour and Mashaikhi, 2015; Yaghoubzadeh et al., 2021a), which confirmed the negative effects of trimming mangroves. For example, Walter (2005) conducted experiments in mangrove forests located in the Philippines. In examining the effect of harvesting on the growth of mangrove at a very small scale, Walter (2005) reported that all the vegetative characteristics in the forests that were not harvested are more productive than in the harvested forests. In addition, Walter (2005) reported that clearing a small area (>2.60 m^2) can have a negative effect on the structure and other characteristics of mangrove forests. The negative effects of harvesting and human activities were also investigated by Simon and Raffaelli (2012) in Cameroon. Based on their results, small scale wood harvesting can be a threat to mangrove forest ecosystem health.

Medina-Irizarry and Andreu (2022) reported that high intensity trimming in mangrove forests leads to a reduction in leaf area. The stress induced by thinning reduces the tree's ability to be resilient as environmental conditions change. For example, sea level is rising, mangroves may be exposed to higher levels of salinity and longer periods of inundation, which is stressful for

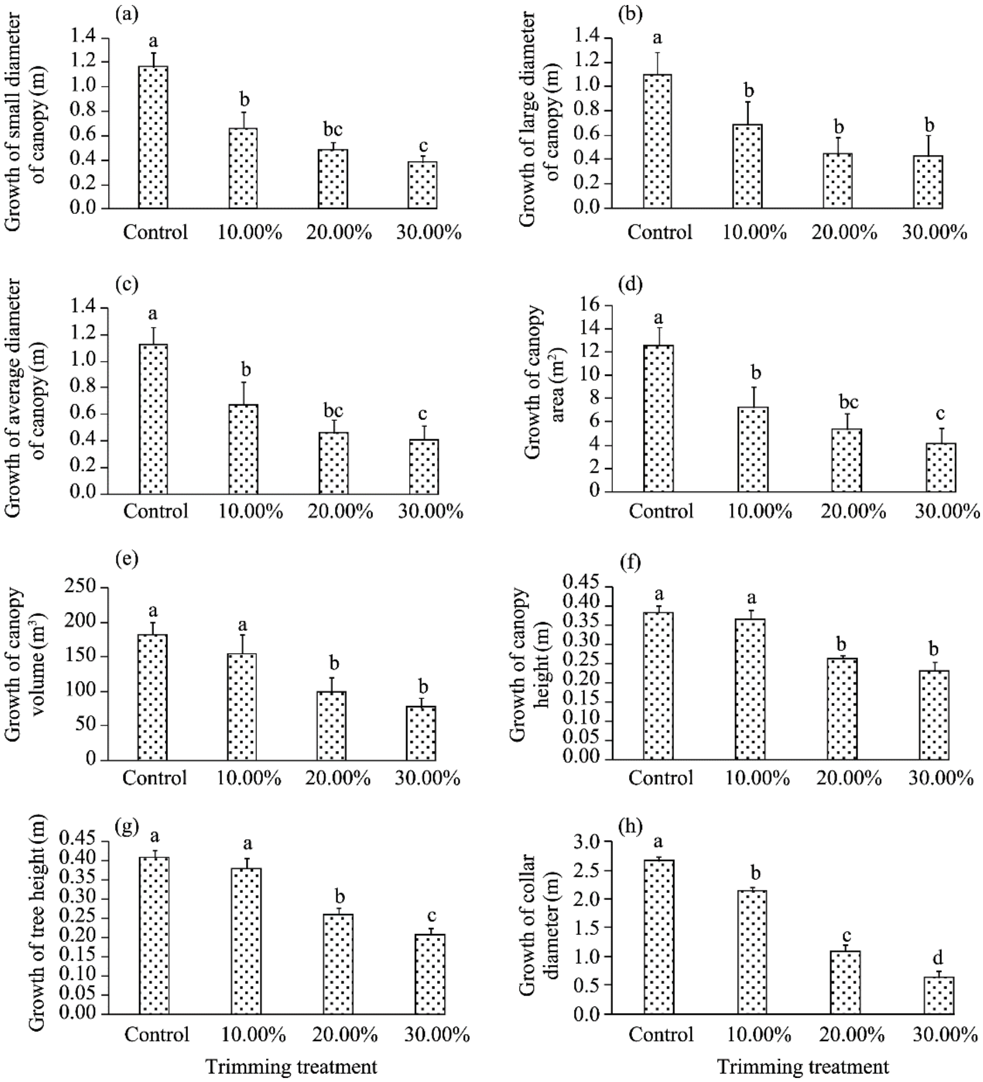

Fig. 3 Growth of mangroves across various treatments over a five-year period. (a), growth of small diameter of canopy; (b), growth of large diameter of canopy; (c), growth of average diameter of canopy; (d), growth of canopy area; (e), growth of canopy volume; (f), growth of canopy height; (g), growth of tree height; (i), growth of collar diameter. Different lowercase letters indicate significant differences among different treatments at P<0.05 level; and bar represents standard deviation.

mangroves. Additional stressors, such as wood harvesting, may make mangroves less resilient against the invasion of non-native species, cold stress, and mechanical alteration (Medina-Irizarry and Andreu, 2022).

Past research suggested that the timing of trimming affects how well the mangrove trees respond. Trimming in mangrove forests in winter leads to a decrease in leaf area and flowering of trees (Ellis and Bell, 2004). Carlton (1974) suggested that if trimming is done in spring, trimmed branches will recover faster and the reduction in production is not as severe as when trimming is done in winter. However, the gray mangrove trees in our study were trimmed in spring (from the end of April to the first half of May in 2016). The significant decline in vegetative characteristics suggested that gray mangrove trees in the south of Iran are very sensitive to trimming, even if done in spring. Decreasing the canopy density of gray mangrove trees because of trimming reduces the ability of mangrove trees to dissipate the stress brought by sea waves and wind (Othman, 1994; Medina-Irizarry and Andreu, 2022). The impacts of trimming may be exacerbated by climate change

Table 3 Analysis of variance for percentage changes in leaf characteristics and health status of tree across various treatments

Variable	Source of variable	*df*	Mean square	Fisher coefficient
Leaf fresh mass (LFM)	Block	2	22.190	0.64ns
	Treatment	3	1316.560	38.27**
	Error	6	34.390	
Leaf dry mass (LDM)	Block	2	20.450	0.58ns
	Treatment	3	1993.890	57.02**
	Error	6	34.960	
Leaf area index (LAI)	Block	2	40.250	2.56ns
	Treatment	3	570.640	69.70**
	Error	6	27.920	
Total area of canopy leaves (TAL)	Block	2	82.370	3.14ns
	Treatment	3	2251.250	64.56**
	Error	6	32.290	
Health status of tree	Block	2	167.990	1.44ns
	Treatment	3	530.640	20.43**
	Error	6	36.960	

Note: **, significant difference at $P<0.01$ level; ns, no significant difference.

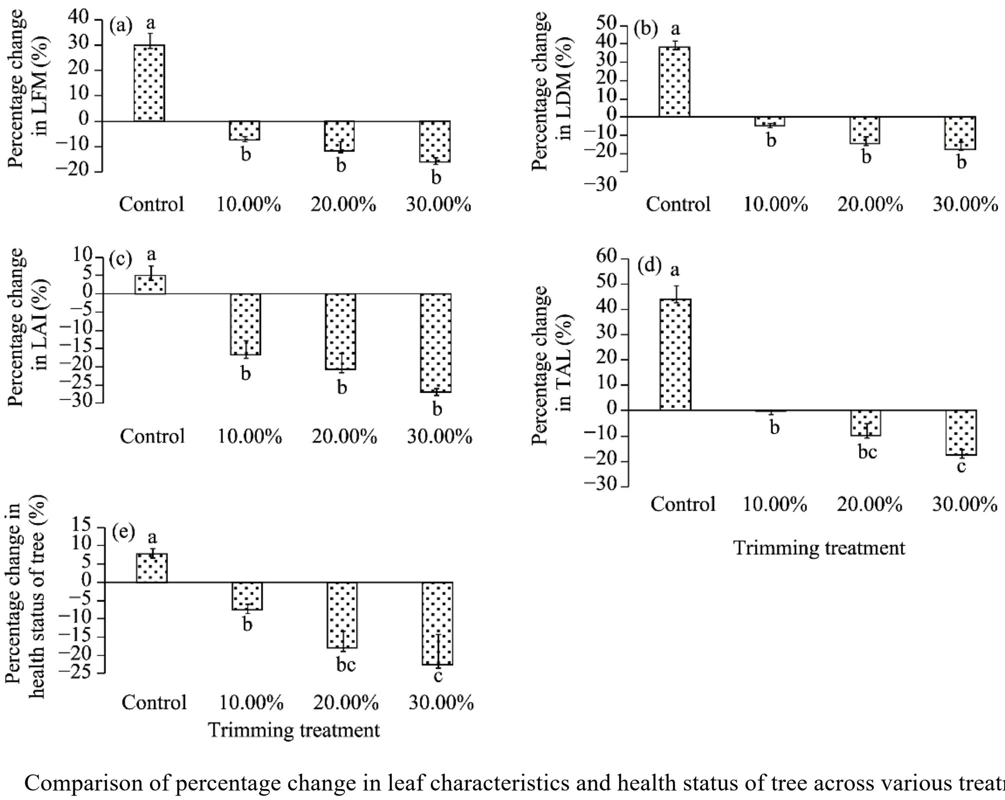

Fig. 4 Comparison of percentage change in leaf characteristics and health status of tree across various treatments over a five-year period using Duncan's multiple range test. (a), leaf fresh mass (LFM); (b), leaf dry mass (LDM); (c), leaf area index (LAI); (d), total area of canopy leaves (TAL); (e), health status of tree. Different lowercase letters indicate significant differences among different treatments at $P<0.05$ level; and bar represents standard deviation.

Table 4 Analysis of variance of the percentage change in soil organic matter (SOM) across various treatments

Variable	Source of variable	*df*	Mean square	Fisher coefficient
SOM	Block	2	22.960	1.32^{ns}
	Treatment	3	11.320	64.72**
	Error	6	17.490	

Note: **, significant difference at P<0.01 level; ^{ns}, no significant difference.

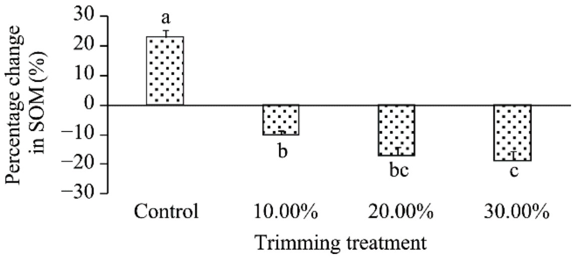

Fig. 5 Comparison of percentage change in soil organic matter (SOM) across various treatments over a five-year period using Duncan's multiple range test. Different lowercase letters indicate significant differences among different treatments at P<0.05 level; and bar represents standard deviation.

(Moslehi et al., 2017). Under the background of increasing intensity of storms, wave energy, sediment erosion, and rising sea levels (exposing gray mangroves to higher levels of salinity as well as longer tidal cycles), the mangrove forests have become very sensitive to modest levels of trimming (Medina-Irizarry and Andreu, 2022).

Trimmed trees exhibit either a decrease in leaf density on the trimmed branches or become weak and dry. This reduction in tree vitality due to trimming may lead to decreased disease resistance. Consequently, weakened trees may become more susceptible to diseases and pests. Goudarzi and Moslehi (2020) noted that the fungal agent *Neoscytalidium dimidiatum* is associated with mangroves under stress. This fungus is typically weak pathogenic agent, but the fungus can adversely affect stressed trees, while having little impact on healthy ones. The stress induced by trimming in this study makes the trees more vulnerable, potentially exacerbating the effects of this fungus on tree health. To mitigate these disease-causing factors, it is essential to eliminate stressors that hinder the tree's resilience against such pathogens (Hicks and Dugas, 1997).

It is critical for mangrove trees to continue to play their ecological role in coastal regions. The structural diversity and integrity of distinct ecosystems, such as mangrove forests, are necessary for coastal protection and carbon sequestration (Barbier et al., 2011). In addition, the mangrove forests are also crucial habitat for dozens of species of birds, fish, invertebrates, and mammals (Barbier et al., 2011). If adaptive management strategies are taken, selective harvest times would be seasonal and depend on vegetation cover and plant vigor. By doing so, we would effectively minimize the impacts of trimming on tree health by cutting when it is least impactful. This will be a challenge in the gray mangroves in this study because even very modest trimming affects tree growth. Hence, it is important that local communities should be involved in the management decisions so that the management activities balance human pressures and needs with the ecological health of mangrove ecosystem (Limbong et al., 2023).

4.2 Effect of trimming on SOM

The SOM decreased with increasing trimming intensity. Our finding aligned with that of Sigi Lang'at et al. (2014), who reported a decline in SOM following small-scale harvesting. Forest ecosystems are capable of rapidly absorbing and sequestering carbon dioxide from the atmosphere. However, human disturbance can diminish carbon levels and lead to significant alterations in the carbon balance of these ecosystems (Houghton et al., 2000a). Soil microorganisms play a crucial role in the decomposition of SOM, and their activity is influenced by changes in humidity and temperature. Harvesting activities modify canopy density (Abd Latif and Blackburn, 2008), resulting in increased light penetration. This enhanced light exposure may raise temperatures beneath the canopy (Swanson et al., 2010), potentially boosting microbial activity. An increase in the mineralization rate of organic materials can subsequently lead to a decline in SOM. Furthermore, this decline can be exacerbated by reduced above-ground carbon sequestration and the subsequent decrease in the production of SOM (Moslehi et al., 2017). The reduction in the inputs of SOM from the canopy may be attributed to vegetation removal through trimming or a reduction in photosynthetic capacity. The decrease in SOM associated with increased trimming intensity has broader implications for the functioning of mangrove ecosystems and their capacity for carbon sequestration. Mangrove forests are highly efficient at absorbing and storing atmospheric carbon dioxide, making them vital carbon sinks (Donato et al., 2011). However, human disturbances such as trimming can disrupt this natural carbon balance by diminishing the forests' capacity for carbon sequestration (Houghton et al., 2000b). The loss of SOM is critical as it is essential for maintaining soil fertility and structure (Moslehi et al., 2017). This loss can further amplify the negative impacts of trimming on mangrove health.

5 Conclusions

The results of our research demonstrated that gray mangrove trees are highly sensitive to any level of canopy trimming. Increasing levels of trimming were associated with declines in yield and production, and the drying of trimmed branches. The damage caused by trimming was significant enough that it not only failed to enhance tree vitality but also leaded to physiological weakness and the desiccation of upper branches. This study is crucial as it provides empirical evidence on the detrimental effects of even low-intensity harvesting on mangrove ecosystems. By quantifying the impacts of varying harvesting intensities, this research enhances our understanding of sustainable management practices for mangrove forests in southern Iran and underscores the need for effective conservation strategies. While this study offers valuable insights, it is limited because we focused on only three trimming intensities and a single species of mangrove. Additionally, the long-term ecological impacts beyond the five-year study period remain uncertain. Future research should consider a broader range of harvesting practices and environmental conditions to provide a more comprehensive understanding of mangrove resilience. Investigating the cumulative effects of multiple stressors on mangrove health—including climate change, pollution, and land-use changes—will also be beneficial. Moreover, exploring different species of mangroves and their responses to varying harvesting intensities could yield important insights. Implementing long-term monitoring programs could help assess recovery patterns and inform adaptive management strategies for sustainable mangrove forestry practices. In conclusion, we recommend eliminating even low levels of trimming to ensure the continued vitality and resilience of gray mangrove forests in southern Iran. This approach is essential for preserving sensitive mangroves for future generations.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors wish to express their sincere gratitude to the General Directorate of Natural Resources and Watershed Management of Hormozgan Province for their valuable support and collaboration.

Author contributions

Conceptualization: Maryam MOSLEHI; Acquisition data: Maryam MOSLEHI; Methodology: Maryam MOSLEHI;

Writing - original draft preparation: Maryam MOSLEHI, Akram AHMADI; Writing - review and editing: Tom PYPKER. All authors approved the manuscript.

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