Impact of trimming intensity on the growth of mangrove in Iran: Postprint

Authors: Maryam MOSLEHI

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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.

Full Text

Preamble

Impact of Trimming Intensity on the Growth of Mangrove in Iran

Maryam MOSLEHI[1]*, Akram AHMADI[2], Tom PYPKER[3]

[1] Research Division of Natural Resources, Hormozgan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Bandar Abbas 7915847669, Iran
[2] Research Division of Natural Resources, Golestan Agricultural and Natural Resources Research and Education Center, AREEO, Gorgan 4915677555, Iran
[3] Thompson Rivers University, Kamloops V2C 0C8, Canada

Abstract: Mangrove forests in southern Iran are of high ecological and economic importance, yet they are threatened by uncontrolled harvesting to provide fodder for livestock. This study quantifies the effects of different harvesting intensities on vegetative and vigor characteristics of mangrove trees to provide recommendations for appropriate harvesting practices. Using a randomized complete block design, we evaluated four treatments (10.00%, 20.00%, and 30.00% trimming, plus a control) with three replications over a five-year period. Vegetative characteristics were measured before and after trimming and analyzed using generalized linear model statistical analysis.

The control treatment exhibited significantly higher growth in average canopy diameter, canopy area, canopy volume, canopy height, tree height, and collar diameter compared to all trimming treatments. Additionally, trimming treatments showed decreasing trends in leaf fresh and dry mass, leaf area index, total canopy leaf area, and tree health status. For example, percentage changes in leaf fresh and dry mass were positive in the control treatment (29.87% and 38.31%, respectively), whereas 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). Leaf area index changes were highest in the control (4.95%) and lowest in the 30.00% trimming treatment (-24.57%). Percentage changes in soil organic matter were 22.94%, -9.90%, -16.91%, and -18.68% for the control, 10.00%, 20.00%, and 30.00% treatments, respectively. The study demonstrates that gray mangrove trees are highly sensitive to canopy trimming, with even minimal trimming intensities negatively affecting vegetative growth and soil organic matter. Therefore, we recommend preventing cutting and trimming of mangrove trees 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

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Introduction

Mangrove forests in tropical and subtropical regions are vulnerable to human activities and climate change (Ghosh et al. 2015). From 1980 to 2005, approximately 20.00% of global mangrove area was lost due to coastal development, pollution, aquaculture, logging, and exploitation for fuel supply (Spalding et al., 2014). Currently, mangrove habitats are decreasing at a rate of 1.00%-2.00% annually (FAO, 2003), and it is predicted that the world may lose all services provided by mangroves within the next 100 years (Duke et al., 2007).

Mangrove forests provide valuable environmental services, serving as important sources of food and wood while offering critical ecosystem services such as timber and fuelwood, breeding and nursery habitats for fish species, protection from storms and floods, and erosion control to coastal communities in tropical areas. These services can facilitate capital investment for mangrove protection. Therefore, land managers require sufficient information on the effects of human activities on mangroves to properly manage and protect this valuable ecosystem (Akram et al., 2023).

Wood harvesting from mangroves is a common activity that can degrade forests. 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 trimming trees for wood products caused nearly 90.00% of tree deaths in natural mangrove forests and plantations. Van Oudenhoven et al. (2015) studied the effects of different management regimes on mangrove ecosystem services in Java, Indonesia, applying five methods including natural, low-intensity harvesting, high-intensity harvesting, and conversion to irrigated and abandoned croplands. Their results indicated that mangroves provide optimal services when left in a natural state. Therefore, proper management and preservation of mangrove forests require assessing whether local harvesting methods can maintain healthy forests despite branch removal.

Aheto et al. (2016) conducted a study on community-based mangrove forest management, examining livelihoods derived from coastal mangrove forests in Ghana. Their results indicated that livelihoods and economic benefits are primary motivators for participation in restoration and management, while unrestricted use and limited economic opportunities drive harvesting. The study showed that establishing local customary laws and basic management rules could enable sustainable harvesting, restoration, and management of mangrove resources.

Mangrove forests are common in southeastern Iran, with the largest community found near Khamir Port (Danehkar and Jalali, 2005). Despite their high ecological and economic importance, these forests in southern Iran are heavily exploited and threatened by indiscriminate harvesting to provide fodder for livestock. Due to inadequate management policies for fodder supply, people are inevitably forced to use mangrove forests to meet their needs (Danehkar and Jalali, 2005).

Past research has demonstrated that mangrove forests in southern Iran are highly sensitive to human disturbance. Yaghoubzadeh et al. (2021b) investigated the effects of shrimp farm effluent on vegetative and reproductive characteristics of Minab mangrove forests, discovering that tree freshness, average height, canopy height of *Avicennia marina* (Forssk.) Vierh trees, and seedling numbers were significantly higher in control areas than in regions affected by shrimp farms. They also found that vegetative and reproductive characteristics of mangrove trees in Hormozgan Province, Iran, were significantly poorer near ports compared to those further away.

Khamir Port in southern Iran represents an important mangrove habitat—a sensitive ecosystem requiring careful management due to its vulnerability to human activities. Given the significant role mangrove forests play in coastal protection and their ecological importance, understanding the impact of various interventions, including trimming, on their health and productivity is essential. This study aims to provide recommendations for appropriate harvesting intensities by quantifying the effects of different trimming intensities on vegetative and vigor characteristics of mangrove trees in Khamir Port.

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 represent the northernmost mangrove community in Iran and Southwest Asia (Fig. 1 [Figure 1: see original paper]). Mangrove density in Khamir Port is 1,555 individuals/hm^2. The climate of Khamir Port, Hormozgan Province is characterized as a severe hot desert, with an average annual rainfall of 189.70 mm and average annual temperature of 27.0°C. Based on 27 years of statistical data (1975-2001) from the Bandar Abbas Airport synoptic station, average minimum and maximum temperatures are 18.0°C and 37.2°C, respectively. Average annual evapotranspiration is 2,500.00 mm (Moslehi et al., 2023). Due to its proximity to the sea, relative humidity in Bandar Khamir is high, especially in summer months, exceeding 70.00%. The Persian Gulf connects 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

2.2.1 Selection of Sample Trees

The sample site was located in mangrove forests of Khamir Port, selected based on distance and proximity to the coast and water depth. The sample site length was 175.00 m, with width determined by highest and lowest tide levels. We implemented a randomized complete block design with four treatments and three replications. The four treatments included: light trimming (removing 10.00% of branches), mild trimming (removing 20.00% of branches), medium trimming (removing 30.00% of branches), and a control treatment with no harvesting or trimming. Each treatment plot measured 40.00 m × 25.00 m, with the long edge parallel to the sea (Fig. 2 [Figure 2: see original paper]). We established a hypothetical sample line approximately 47.00 m long; trees whose trunk or canopy image intersected this line were considered sample tree candidates. We randomly selected ten trees with canopy diameters exceeding two meters as sample trees from candidates along the sample line in each treatment plot.

Fig. 2 Schematic layout of sampling

2.2.2 Measurement of Vegetative Characteristics

To investigate trimming effects on vegetative characteristics—including small canopy diameter, large canopy diameter, average canopy diameter, 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 tree health status—we measured these indicators 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 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 average canopy diameter, we measured two perpendicular diameters (large and small canopy diameters) using a strip meter (SUNMAX 50 m, Shenzhen, Guangdong, China) and calculated their mean ($±$0.50 m) (Farnsworth and Ellison, 1996). Canopy area was calculated using Equation 1 and canopy volume of broadleaf trees using Equation 2 (van Laar and Akça, 2007).

$$S = \pi \times \left(\frac{D}{2}\right)^2 \quad (1)$$

$$V = S \times a \quad (2)$$

where S is the cross-sectional area of canopy (m^2); D is the average canopy diameter, calculated by dividing the sum of small and large canopy diameters by two (m); V is canopy volume (m^3); and a is canopy height (m). To determine total canopy area and volume for each treatment, we summed individual values from all trees in each treatment.

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

TAL refers to the entire surface area of all leaves on a tree, while LAI is the ratio of TAL to ground area. We randomly selected five leaves from each sample tree to calculate TAL per tree, then averaged TAL across sample trees in each treatment to obtain treatment-level TAL.

$$\mathrm{TAL} = \frac{M_t \times S_a}{M_a} \quad (3)$$

$$\mathrm{LAI} = \frac{\mathrm{TAL}}{S_g} \quad (4)$$

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 canopy shadow on the ground (m^2).

Tree health status was visually assessed using qualitative characteristics including leaf color, canopy shape, canopy density, and number of dry microbranches. Based on methods outlined in Moslehi and Hassanzadeh (2020), we graded sample trees into three categories: healthy, moderate, and weak (Table 1). Each indicator scored 5 points for healthy, 3 points for moderate, and 1 point for weak. The average score across all indicators represented tree health status, and treatment-level health status was the average score across all sample trees in that treatment.

Table 1 Rubric for assessing tree health grade

Health indicator	Grade	Score
Color of leaf	Healthy	Bright green
	Moderate	Pale green
	Weak	Yellow or brown
Shape of canopy	Healthy	Symmetrical and healthy
	Moderate	Relatively symmetrical and average size
	Weak	Asymmetrical, small, or damaged
Density of canopy	Healthy	Dense
	Moderate	Semi-dense

Health indicator	Grade	Score
Number of dry microbranches	Weak	Very sparse

2.2.3 Determination of Soil Organic Matter (SOM)

To determine 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), analyzing them using the organic matter oxidation 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 addition of 20 mL of sulfuric acid (H_2SO_4) to create an acidic environment facilitating complete organic matter oxidation. In this acidic setting, $K_2Cr_2O_7$ serves as a potent oxidizer, reacting with organic carbon in the soil. After oxidation, the amount of $K_2Cr_2O_7$ that reacted was assessed through titration with ferrous ammonium sulfate ($Fe(NH_4)_2 \bullet (SO_4)_2$), providing an indirect estimation of oxidized organic carbon in the soil sample.

2.2.4 Statistical Analysis

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

3.1 Effect of Trimming on Canopy and Tree Growth

Results from Table 2 and Figure 3 [Figure 3: see original paper] demonstrate that, in general, greater trimming percentages corresponded to lower tree productivity. Large and small canopy diameters in control treatments increased by 1.16 m and 1.09 m over five years, respectively, whereas canopy diameter growth in trimming treatments was significantly less than in controls (Fig. 3a-c). Increasing trimming intensity resulted in progressively reduced growth of small and large canopy diameters. Average canopy diameter growth was highest in the control treatment (1.13 m), while growth in 10.00%, 20.00%, and 30.00% trimming treatments was 0.66 m, 0.46 m, and 0.40 m, respectively. Both canopy area and volume growth were highest in the control treatment (12.60 m^2 and 182.60 m^3, respectively). The 30.00% trimming treatment exhibited the lowest canopy area growth (4.09 m^2) and volume growth (76.43 m^3) (Fig. 3d and e). Canopy height changes followed similar patterns to area and volume changes. Average canopy height changes in control (0.38 m) and 10.00% trimming (0.36 m) treatments were significantly greater than in 20.00% (0.26 m) and 30.00% (0.23 m) trimming treatments (Fig. 3f). Tree height changes in control (0.41 m) and 10.00% trimming (0.38 m) treatments were significantly greater than in 20.00% (0.26 m) and 30.00% (0.20 m) trimming treatments (Fig. 3g). Finally, collar diameter growth in the control treatment (2.66 cm) was significantly greater than in all trimming treatments (Fig. 3h).

3.2 Effects of Trimming on Leaf Characteristics and Tree Health Status

No significant differences in leaf characteristics were observed among blocks (Table 3). In general, trimming negatively impacted leaf characteristics and tree health status, with the most severe reduction occurring in the 30.00% trimming treatment (Fig. 4 [Figure 4: see original paper]). Percentage changes in leaf fresh mass (29.87%) and dry mass (38.31%) were significantly higher in the control treatment than in 10.00% trimming (-7.01% and -4.79%, respectively), 20.00% trimming (-11.32% and -14.30%, respectively), and 30.00% trimming treatments (-15.84% and -17.29%, respectively) (Fig. 4a and b). Mass changes were positive in the control but negative in all trimming treatments. LAI and TAL in the control treatment (4.95% and 43.74%, respectively) were significantly higher than in trimming treatments, with only the control showing positive changes (Fig. 4c and d). Percentage change in tree health status showed a similar trend to leaf characteristics, with highest values in the control (7.65%) and lowest in the 30.00% trimming treatment (-22.36%) (Fig. 4e).

3.3 Effect of Trimming on SOM

SOM significantly decreased with increasing trimming intensity (Table 4). Percentage change in SOM was positive in the control treatment (22.94%), significantly different from 10.00%, 20.00%, and 30.00% trimming treatments, which showed changes of -9.90%, -16.91%, and -18.68%, respectively (Fig. 5 [Figure 5: see original paper]).

4.1 Effect of Trimming on Growth

Mangrove forests have experienced historical contraction and expansion; however, their global distribution is decreasing due to human activities (Friess et al., 2019). In our study, vegetative characteristics were reduced in all trimming treatments compared to controls, with growth decreasing as trimming intensity increased. These findings align with previous research (Walter, 2005; Hosseinzadeh Monfared et al., 2008; Dehghanipour and Mashaikhi, 2015; Yaghoubzadeh et al., 2021a), confirming the negative effects of mangrove trimming. For example, Walter (2005) conducted experiments in Philippine mangrove forests, reporting that all vegetative characteristics were more productive in unharvested forests than in harvested ones, and that clearing even small areas (>2.60 m^2) negatively affected mangrove structure and characteristics. Simon and Raffaelli (2012) also investigated negative harvesting effects in Cameroon, concluding that small-scale wood harvesting threatens mangrove ecosystem health.

Medina-Irizarry and Andreu (2022) reported that high-intensity trimming reduces leaf area in mangrove forests, with thinning-induced stress decreasing tree resilience as environmental conditions change. For example, rising sea levels expose mangroves to higher salinity and longer inundation periods, creating physiological stress. Additional stressors such as wood harvesting may further reduce resilience against non-native species invasion, cold stress, and mechanical alteration (Medina-Irizarry and Andreu, 2022).

Past research suggests trimming timing affects tree response. Winter trimming decreases leaf area and flowering (Ellis and Bell, 2004), while spring trimming allows faster branch recovery and less severe production reduction (Carlton, 1974). However, the gray mangrove trees in our study were trimmed in spring (late April to mid-May 2016), yet still showed significant declines in vegetative characteristics, suggesting that gray mangrove trees in southern Iran are very sensitive to trimming even when conducted in spring.

Reduced canopy density from trimming decreases mangrove trees' ability to dissipate stress from sea waves and wind (Othman, 1994; Medina-Irizarry and Andreu, 2022). These impacts may be exacerbated by climate change (Moslehi et al., 2017). Under scenarios of increasing storm intensity, wave energy, sediment erosion, and rising sea levels (exposing gray mangroves to higher salinity and longer tidal cycles), mangrove forests have become very sensitive to modest trimming levels (Medina-Irizarry and Andreu, 2022).

Trimmed trees exhibit decreased leaf density on trimmed branches or become weak and dry. This vitality reduction may decrease disease resistance, making weakened trees more susceptible to pests and pathogens. Goudarzi and Moslehi (2020) noted that the fungal agent *Neoscytalidium dimidiatum* is associated with stressed mangroves. Typically a weak pathogen, this fungus can adversely affect stressed trees while having minimal impact on healthy ones. Trimming-induced stress in this study likely increased vulnerability, potentially exacerbating fungal effects on tree health. Mitigating these disease factors requires eliminating stressors that hinder tree resilience against pathogens (Hicks and Dugas, 1997).

Mangrove trees must continue fulfilling their ecological role in coastal regions. Structural diversity and integrity of mangrove forests are necessary for coastal protection and carbon sequestration (Barbier et al., 2011), and these forests provide crucial habitat for numerous bird, fish, invertebrate, and mammal species (Barbier et al., 2011). Adaptive management strategies would require selective harvest timing to be seasonal and dependent on vegetation cover and plant vigor, minimizing impacts by cutting when least detrimental. This presents a challenge for gray mangroves in this study, as even modest trimming affects growth. Therefore, local community involvement in management decisions is essential to balance human pressures with ecological health of mangrove ecosystems (Limbong et al., 2023).

4.2 Effect of Trimming on SOM

SOM decreased with increasing trimming intensity, aligning with Sigi Lang' at et al. (2014), who reported SOM decline following small-scale harvesting. Forest ecosystems can rapidly absorb and sequester atmospheric carbon dioxide, but human disturbance diminishes carbon levels and significantly alters ecosystem carbon balance (Houghton et al., 2000a). Soil microorganisms crucially influence SOM decomposition, with their activity affected by humidity and temperature changes. Harvesting modifies canopy density (Abd Latif and Blackburn, 2008), increasing light penetration that may raise temperatures beneath the canopy (Swanson et al., 2010), potentially boosting microbial activity. Increased mineralization rates of organic materials can subsequently reduce SOM, a decline exacerbated by reduced above-ground carbon sequestration and decreased SOM production (Moslehi et al., 2017). Reduced SOM inputs from the canopy may result from vegetation removal through trimming or reduced photosynthetic capacity. The SOM decrease associated with increased trimming intensity has broader implications for mangrove ecosystem functioning and carbon sequestration capacity. Mangrove forests are highly efficient atmospheric carbon sinks (Donato et al., 2011), but human disturbances such as trimming disrupt this natural carbon balance by diminishing sequestration capacity (Houghton et al., 2000b). SOM loss is critical as it is essential for maintaining soil fertility and structure (Moslehi et al., 2017), further amplifying negative trimming impacts on mangrove health.

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5 Conclusions

Our research demonstrates that gray mangrove trees are highly sensitive to any level of canopy trimming. Increasing trimming levels were associated with declines in yield and production, plus drying of trimmed branches. Trimming damage was significant enough to not only fail enhancing tree vitality but also cause physiological weakness and upper branch desiccation. This study provides crucial empirical evidence on detrimental effects of even low-intensity harvesting on mangrove ecosystems. By quantifying impacts of varying harvesting intensities, this research enhances understanding of sustainable management practices for mangrove forests in southern Iran and underscores the need for effective conservation strategies.

While valuable, this study is limited by focusing on only three trimming intensities and a single mangrove species. Additionally, 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 more comprehensive understanding of mangrove resilience. Investigating cumulative effects of multiple stressors on mangrove health—including climate change, pollution, and land-use changes—would be beneficial. Exploring different mangrove species and their responses to varying harvesting intensities could yield important insights. Implementing long-term monitoring programs would help assess recovery patterns and inform adaptive management strategies for sustainable mangrove forestry practices.

In conclusion, we recommend eliminating even low-level trimming to ensure continued vitality and resilience of gray mangrove forests in southern Iran. This approach is essential for preserving these sensitive mangroves for future generations.

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References

Abd Latif Z, Blackburn G A. 2008. Forest microclimate modelling using gap and canopy properties derived from LiDAR and hyperspectral imagery. SilviLaser, 17: 151-158.

Aheto D W, Kankam S, Okyere I, et al. 2016. Community-based mangrove forest management: Implications for local livelihoods and coastal resource conservation along the Volta estuary catchment area of Ghana. Ocean & Coastal Management, 127: 43-54.

Akram H, Hussain S, Mazumdar P, et al. 2023. Mangrove health: A review of functions, threats, and challenges associated with mangrove management practices. Forests, 14(9): 1698, doi: 10.3390/f14091698.

Barbier E B, Hacker S D, Kennedy C, et al. 2011. The value of estuarine and coastal ecosystem services. Ecological Monographs, 81(2): 169–193.

Bosire J O, Dahdouh-Guebas F, Walton M, et al. 2008. Functionality of restored mangroves: a review. Aquatic Botany, 89(2): 251–259.

Bussotti F, Grossoni P, Bottacci A. 1997. Sclerophylly in beech (*Fagus sylvatica* L.) trees: its relationship with crown transparency, nutritional status and summer drought. Forestry, 70(3): 267–271.

Carlton J M. 1974. Land-building and stabilization by mangroves. Environmental Conservation, 1(4): 285–294.

Danehkar A, Jalali S G. 2005. Investigating the structure of gray mangrove forests in Khamir and Qeshm basins (Hormozgan Province) using transect statistics. Research and Construction in Natural Resources, 67: 18–24. (in Persian)

Dehghanipour M, Mashaikhizadeh A. 2015. Investigating the current situation and threats to the largest mangrove forest reserve in Iran. In: The Third National Conference of Student Scientific Associations of Agriculture and Natural Resources. Student Scientific Associations of Agriculture and Natural Resources. Karaj, Iran. (in Persian)

Donato D C, Kauffman J B, Murdiyarso D, et al. 2011. Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience, 4(5): 293–297.

Duke N C, Meynecke J O, Dittmann S, et al. 2007. A world without mangroves? Science, 317(5834): 41–42.

Ellis W L, Bell S S. 2004. Canopy gaps formed by mangrove trimming: An experimental test of impact on litter fall and standing litter stock in Southwest Florida (USA). Journal of Experimental Marine Biology and Ecology, 311(2): 201–222.

FAO (Food and Agricultural Organization). 2003. Status and Trends in Mangrove Area Extent World-wide. [2024-05-18]. http://www.fao.org/4/j1533e/J1533E01.htm.

Farnsworth E J, Ellison A M. 1996. Sun-shade adaptability of the red mangrove, *Rhizophora mangle* (Rhizophoraceae): changes through ontogeny at several levels of biological organization. American Journal of Botany, 83(9): 1131–1143.

Friess D A, Rogers K, Lovelock C E, et al. 2019. The state of the world’ s mangrove forests: past, present, and future. Annual Review of Environment and Resources, 44: 89–115.

Ghosh S, Bakshi M, Bhattacharyya S, et al. 2015. A review of threats and vulnerabilities to mangrove habitats: with special emphasis on East Coast of India. Journal of Earth Science & Climate Change, 6: 270, doi: 10.4172/2157-7617.100270.

Goudarzi A, Moslehi M. 2020. Distribution of a devastating fungal pathogen in mangrove forests of southern Iran. Crop Protection, 128: 104987, doi: 10.1016/j.cropro.2019.104987.

Hicks R A, Dugas W A. 1997. Estimating ashe juniper leaf area from tree and stem characteristics. Journal of Range Management, 51(6): 633-637.

Hosseinzadeh Monfared S, Tohidian Far Y, Ahmadnia Motlaq H, et al. 2008. Mangrove forests; its distribution, importance and threats in Iran, the first regional conference on inland aquatic ecosystems of Iran. Bushehr: Islamic Azad University, Bushehr branch, 1-6. (in Persian)

Houghton R A, Skole D L, Nobre C A, et al. 2000a. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature, 403: 301-304.

Houghton R A, Hackler J L, Lawrence K T. 2000b. Changes in terrestrial carbon storage in the United States. 2: The role of fire and fire management. Global Ecology and Biogeography, 9(2): 145-170.

Komiyama A, Ong J E, Poungparn S. 2008. Allometry, biomass, and productivity of mangrove forests: a review. Aquatic Botany, 89(2): 128-137.

Limbong C, Samsuri, Ahmad A G. 2023. Strategy to strengthening forest farming for sustainable mangrove forest management in the coastal area, Deli Serdang, Indonesia. Journal of Sylva Indonesiana, 6(1): 29-43.

Medina-Irizarry N D, Andreu M G. 2022. The Impacts of Trimming Mangroves. [2024-05-18]. https://edis.ifas.ufl.edu/publication/FR448.

Middelburg J J, Nieuwenhuize J, Slim F J, et al. 1996. Sediment biogeochemistry in an East African mangrove forest (Gazi Bay, Kenya). Biogeochemistry, 34(3): 133-155.

Moslehi M, Habashi H, Rahmani R. 2017. Seasonal changes of soil organic carbon storage in managed and unmanaged *Fagus orientalis-Carpinus betolus* stand. Scientific and Research Quarterly Journal of Forest and Poplar, 25(2): 286-297. (in Persian)

Moslehi M, Hassanzadeh H. 2020. The effect of different rainfall storage methods on soil moisture and vegetative characteristics of *Acacia oerfota* (Forssk.) Schweinf seedlings (case study: Dehgin watershed, Hormozgan Province). Desert Ecosystem Journal, 9(26): 72-61. (in Persian)

Moslehi M, Ahmadi A, Abadeh M, et al. 2023. The effect of different cutting intensities of mangrove grey trees (*Avicennia marina* (Forssk.) Vierh.) on the reproduction and the growth of stand. Journal of Wood and Forest Science and Technology, 30(1): 141-156. (in Persian)

Othman M A. 1994. Value of mangroves in coastal protection. Hydrobiologia, 285: 277-282.

Page A L, Miller R H, Keeney M. 1992. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties (2nd ed.). New York: John Wiley & Sons, Inc., 1159.

Pourhashemi M, Eskandari S, Dehghani M, et al. 2011. Biomass and leaf area index of Caucasian Hackberry (*Celtis caucasica* Willd.) in Taileh urban forest, Sanandaj, Iran. Iran Forest and Poplar Research Journal, 19(4): 609-620. (in Persian)

Schrijvers J, Gansbeke D, Vincx M. 1995. Macrobenthic infauna of mangroves and surrounding beaches at Gazi Bay, Kenya. Hydrobiologia, 306: 53-66.

Sigi Lang' at J K, Kairo G J, Mencuccini M, et al. 2014. Rapid losses of surface elevation following tree girdling and cutting in tropical mangroves. PLoS One, 9(9): e107868, doi: 10.1371/journal.pone.0107868.

Simon N L, Raffaelli D. 2012. Assessing ecosystem effects of small-scale cutting of Cameroon mangrove forests. Journal of Ecology and Natural Environment, 4(5): 126-134.

Spalding M, McIvor A, Tonneijck F H, et al. 2014. Mangroves for Coastal Defense. Guidelines for Coastal Managers and Policy Makers. Amsterdam: Wetlands International and the Nature Conservancy, 42.

Swanson M E, Franklin J F, Beschta R L, et al. 2010. The forgotten stage of forest succession: early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment, 9(2): 117-125.

van Laar A, Akça A. 2007. Forest Mensuration. Dordrecht: Springer, 383.

van Oudenhoven A P E, Siahainenia A J, Sualia I, et al. 2015. Effects of different management regimes on mangrove ecosystem services in Java, Indonesia. Ocean & Coastal Management, 116: 353-367.

Walters B B. 2005. Ecological effects of small-scale cutting of Philippine mangrove forests. Forest Ecology and Management, 206(1-3): 331-348.

Walters B B, Ronnback P, Kovacs J M, et al. 2008. Ethnobiology, socio-economics and management of mangrove forests: a review. Aquatic Botany, 89(2): 220-236.

Yaghoubzadeh M, Salman Mahiini R, Mikaili A, et al. 2021a. Prioritization of environmental hazards of mangrove forests in Hormozgan Province. Journal of Natural Environment Hazards, 30(10): 68-82. (in Persian)

Yaghoubzadeh M, Salman Mahiny R, Mikaeili Tabrizi A, et al. 2021b. Investigation of shrimp farming effluent effects on vegetative and reproductive characteristics of mangrove forests (*Avicennia marina* (Forssk.) Vierh.). Iranian Journal of Forest, 3(13): 271-284. (in Persian)

Note: Figure translations are in progress. See original paper for figures.

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