Assessment of Mangrove Health in Pancer Cengkrong, Trenggalek, East Java, Indonesia

Diana Arfiati[1]*, Umi Zakiyah[1], Endang Yuli Herawati[1], Titis Dwi Andhani[1,2], Pratama Diffi Samuel[1], Sri Sudaryanti[1], Michelle Sylvanya Ivanney Sundalangi[1], Firuliza Nurus Sofi[1]

[1]Aquatic Resources Management, Department of Fisheries and Marine Resources, Faculty of Fisheries and Marine Science, Brawijaya University
Jl. Veteran, Ketawanggede, Lowokwaru, Malang, East Java, 65145, Indonesia
[2]Doctoral Student, Faculty of Fisheries and Marine Science, Brawijaya University
Jl. Veteran, Ketawanggede, Lowokwaru, Malang, East Java, 65145, Indonesia
Email: d-arfiati@ub.ac.id

Abstract

Mangrove forests are highly sensitive to environmental disturbances, making them vulnerable to a decline in their condition and ecological functions. This study aims to assess the health of mangrove forests in Pancer Cengkrong, Trenggalek, using the mangrove health index method to support conservation and sustainable management efforts. The study was conducted from May to July 2025, using a survey method at six locations. The parameters studied were stem diameter (Sd), canopy cover (Sc), and sapling density (SNsp). This study identified 12 mangrove species, consisting of 11 true mangrove species, including Avicennia alba, Sonneratia alba, Avicennia marina, *Rhizophora mucronata, Rhizophora apiculata, Achantus ilicifolius, Ceriops decandra, Derris trifoliata, Nypa fruticans, Excoecaria agallocha*, as well as one associated mangrove species, Acrostichum speciosum. The highest species density was found in Rhizophora mucronata (6,075 ind.ha^{-1}), while the lowest was in Bruguiera gymnorrhiza (75 ind.ha^{-1}). SNsp values ranged from 4.10 to 4.12, Sd values ranged from 3.3 to 4.84, and Sc values ranged from 6.59 to 7.59. The health condition of the mangrove forest was categorized as "Moderate," with the highest MHI at Site 1 (54.41%) and the lowest at Site 5 (48.34%). The "Moderate" mangrove forest health category indicates the need to limit activities that could cause degradation and damage, and to increase mangrove forest rehabilitation efforts to preserve a sustainable ecosystem.

Keywords: Canopy Cover, Density, Mangrove Health, Stem Diameter

INTRODUCTION

Mangrove forests are coastal ecosystems with important ecological and economic functions, such as maintaining shoreline stability, protecting beaches from abrasion, supporting the food chain through detritus, and providing habitat for various aquatic and terrestrial biota (Taillardat *et al*., 2018). Their high carbon storage capacity contributes to global climate change mitigation (Alongi, 2018; Murdiyarso *et al*., 2015). In recent years, mangrove ecosystems have been damaged by human activities, coastal infrastructure development, fish farming, and natural factors such as sea level rise (Lovelock *et al*., 2024). Mangrove degradation results in decreased vegetation density and productivity, changes in community structure reflected in the Importance Value Index (IVI), and disruptions to the balance of fish communities. Important Value Index (IVI) analysis provides an overview of key species within a community and allows early detection of changes in vegetation structure due to environmental stress (Alimbon & Manseguiao, 2021; Cahyaningsih *et al*., 2022).

The general condition of a mangrove ecosystem can be assessed using an approach that evaluates mangrove health based on vegetation structure parameters, such as diameter at breast height (DBH), canopy cover, and stand density, which reflect ecosystem growth and stability. A healthy mangrove ecosystem demonstrates normal ecological functions, such as protecting the coast from abrasion and providing important habitat for biota, including fish, shrimp, birds, and crabs(Hariyanto *et al*., 2019; Haryati *et al*., 2024). Indicates ecological stress or suboptimal seedling regeneration. Previous research has shown that the use of mangrove health indices is effective in assessing ecosystem conditions in various coastal areas, including the formulation of basic policies for sustainable management (Jeffry *et al*., 2026; Schaduw, 2018).

Diterima/Received : 12-04-2026, Disetujui/Accepted : 19-05-2026
DOI: https://doi.org/10.14710/jkt.v29i2.32114

One of Indonesia's mangrove areas is the Mangrove Pancer Cengkrong (MPC) in Trenggalek, East Java, which is currently used as an ecotourism site. The condition of the mangrove ecosystem at MPC is not immune to the threat of degradation caused by human activities and environmental factors. Based on an interview with the mangrove area manager (Kejung Samudra), in 2010 this area experienced a 50% decline in mangrove cover at that time, due to mangrove logging and land conversion. In response to this degradation, the local community, together with relevant local agencies, has implemented mangrove conservation and restoration measures as a strategic step to restore the ecological functions of the mangrove ecosystem (Arifin *et al*., 2023; Yamamoto, 2023). Therefore, a comprehensive approach to mangrove health evaluation is needed to support sustainable mangrove management planning (Zhang *et al*., 2025).

The ecological impact of mangrove ecosystems can be seen in their health, which reflects the stability of their vegetation structure. Various studies at relevant sites have focused on zonation, vegetation structure, gastropod biodiversity (Arfiati *et al*., 2024), macrozoobenthos (Arfiati *et al*., 2025) and carbon storage (Zakiyah *et al*., 2025), and thus do not yet fully represent ecosystem health comprehensively. However, these studies tend to focus on individual components and have not yet fully integrated ecosystem level indicators to represent the overall health of mangroves. Quantitative approaches, such as a mangrove health index, integrated with vegetation structure parameters, can comprehensively assess ecosystem health. However, their application still requires support from analyses of the relationships among constituent parameters to identify the dominant factors influencing mangrove health. This understanding is crucial for a more in-depth explanation of the dynamics of mangrove forest conditions and serves as the foundation for coastal ecosystem management based on actual conditions. Therefore, this study aims to assess the health of mangrove ecosystems using the MHI approach and to analyze the relationships among its constituent parameters in the Mangrove Pancer Cengkrong area, Trenggalek.

MATERIAL AND METHODS

The research was conducted in the Mangrove Pancer Cengkrong (MPC), Trenggalek, East Java, Indonesia, in May – July 2025. The management of the Pancer Cengkrong mangrove area, known as Kejung Samudera, reported that the recorded area of the mangrove forest is ±135 ha. The average annual rainfall in this region is 3,094 mm, indicating a humid climate. The average daily temperature is 23℃, reflecting cool conditions due to the region's hilly topography (Karanggandu Village Government, 2026). Six locations were selected based on purposive sampling, representative of the study area (Fig. 1), based on predetermined criteria included mangrove zonation, salinity gradients, the presence of pollutants, and ease of access for data collection (Table 1) (Toknok *et al*., 2026).

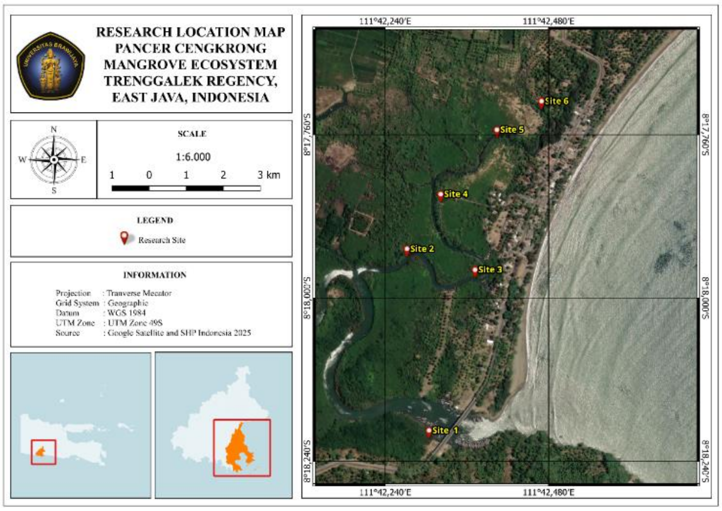

Figure 1. Map Location Research

Table 1. Description of the sampling sites

Site	Coordinat	Description
1	8°18'12.22" S, 111°42'18.31" E	Ship dock area, fishing activities, and natural mangrove area
2	8°17'56.21" S, 111°42'16.10" E	Natural mangrove areas and rehabilitation
3	8°17'58.08" S, 111°42'22.32" E	Natural mangrove areas
4	8°17'51.52" S, 111°42'19.01" E	Natural mangrove areas and ecotourism
5	8°17'45.99" S, 111°42'24.10" E	Natural mangrove areas and rehabilitation
6	8°17'43.50" S, 111°42'28.02" E	Community plantation activities such as coconut and natural mangrove areas

Mangrove sampling was conducted using line transect plots, drawn perpendicularly along 100 m from the coast towards the mainland. The observation transects measured 10 x 10 m to measure tree species with stem diameters ≥ 10 cm. For saplings with a stem diameters of ≤ 10 cm, plots measuring 5 m x 5 m were used. For seedlings with a height of <1.5 m, plots measuring 1 m x 1 m were used. The diameter at breast height was measured manually using a measuring tape to the nearest centimeter at a height of 1.3 vertical inches above the ground to the researcher's chest height (Liu *et al*., 2018). The number of species in each plot was recorded and identified based on morphological characteristics of leaves, roots, stems, and fruits, using an identification guide (Djamaluddin, 2018; Noor et al., 2006; Sidik et al., 2018), to analyze mangrove vegetation structure.

Density indicates the difference in the level of mangrove stand density between observation points. Formula calculation density and density relative mangrove (Tanjung *et al*., 2018), as following:

$$Di = \frac{ni}{A} \qquad RDi = \frac{ni}{\Sigma n} x\, 100\%$$

Where "Di" is density type, "Rdi" is density relative, "ni" is total number of individuals i-th, "A" is total area of the sampling area example, and " $\sum n$" is total number of all stands.

Species frequency and relative frequency reflect the heterogeneity of the mangrove community structure in the research area. Formula calculation frequency and frequency relatively, as following (Bengen *et al*., 2022):

$$Fi = \frac{Pi}{\Sigma f} \qquad RFi = \frac{Fi}{\Sigma f} x\, 100\%$$

Where "Pi" is the number of plots found of the i-th type, "Σf" is the total number of plots created, and "Fi" is the frequency of the i-th type.

Domination explained as wide closing type i-th in a unit of area. Formula calculation domination and domination relatively as following (Bengen *et al*., 2022):

$$Ci = \frac{\Sigma BA}{A} \quad BA = \frac{\pi DBH^2}{4} \quad RCi = \frac{Ci}{\Sigma C} x\, 100\%$$

Where "BA" is the basal area, "DBH" is the diameter of the mangrove tree at breast height, "Ci" is the total dominance of a given species, "ΣC" is the total dominance of all species, and "A" is the total area of the sampling plot.

The Importance Value Index (IVI) is used to measure the abundance of mangrove vegetation and describe the role of species within the mangrove ecosystem. The following is the formula for calculating the Importance Value Index (Kusmana & Susanti, 2015):

$$IVI = RDi + RFi + RCi$$

Where "IVI" is the importance value index, "RDi" is the relative density, "RFi" is the relative frequency, and "RCi" is the relative dominance.

Mangrove canopy cover was calculated using the hemispherical photography method, using the Monmang 2.0 application. The resulting photos were then processed using the image J application (Sugiana *et al*., 2022). The canopy cover photography technique was adapted to the designated plots in each research transect. The canopy cover percentage was calculated using the formula (Indrazora *et al*., 2024):

$$Canopy\ Cover\ (\%) = \frac{P255}{\sum P}\ x\ 100\%$$

Description: P255 is the number of pixels with a value of 255 as an interpretation of mangrove canopy cover, ∑P is the total number of pixels. Canopy cover criteria are based on the Decree of the Minister of Environment No. 201 of 2004, namely the dense category ≥ 75%, the moderate category 50 – 75%, and the sparse category <50%.

Parameters used in the MHI calculation include saplings and tree stands. The mangrove health index is calculated using the Mangrove Health Index (MHI) formula (Rizkiah *et al*., 2025):

$$\text{MHI}(\%) = \left[\frac{Sc\ +\ Sd\ +\ SNsp}{3}\right] x10$$
$$Sc\ =\ 0.25\ x\ C\ -\ 13.06$$
$$Sd\ =\ 0.45\ x\ D\ +\ 1.42$$
$$Snsp\ =\ 0.13\ x\ Nsp\ +\ 4{,}1$$

Description: MHI (Mangrove Health Index), C is the percentage of canopy cover (%), D is the stem diameter (saplings + trees), and Nsp is the number of saplings per area. Mangrove health conditions are determined based on the Mangrove Health Index value as follows: A value <33.33 = poor mangrove condition; A value of 33.33 ≤ MHI ≤ 66.67 = moderate; A value ≥ 66.67 = healthy mangrove condition.

Statistical analysis was performed using Minitab software version 22. Non-parametric tests were conducted using the Kruskal–Wallis test to evaluate differences among stations, while Spearman's correlation analysis was performed to assess the relationship between vegetation parameters and the mangrove health index (MHI) (Guglielmetti *et al*., 2022; Macunluoglu & Ocakoglu, 2023). The level of significance was set at $p < 0.05$.

RESULT AND DISCUSSION

Based on the research results, 12 species were found consisting of 11 true mangrove species, including *Avicennia alba, Sonneratia alba, Avincennia marina, Rhizophora mucronata, Rhizophora apiculata, Achantus ilicifolius, Ceriops decandra, Derris trifoliata, Nypa fruticans, Excoecaria agallocha, Bruguiera gymnorrhiza*, and one associated mangrove, namely *Acrostichum speciosum* (Table 2) (Gouda *et al*., 2015). At site 1, 5 species were found (*A. marina, A. alba*, *R. mucronata, R. apiculata*, and *S. alba*); at site 2, 4 species (*A. marina, A. alba, R. mucronata,* and *S. alba*); and at site 3, 7 species (A. *speciosum, A. ilicifolius, C. decandra, D. trifoliata, E. agallocha, N. fruticans, R. mucronata*), 3 species were found at site 4 (*A. alba, C. decandra,* and *S. alba*), 5 species were found at site 5 (*A. alba, A. speciosum, B. gyhmorrizha, C. decandra,* and *R. mucronata*), and 5 species were found at site 6 (*A. alba, C. decandra, E. agallocha, R. mucronata,* and *S. alba*). The high species richness at site 3 reflects habitat conditions that are relatively more ecologically stable. This high species diversity is thought to be related to variations in tidal influences, wave energy, and low levels of anthropogenic disturbance (Sugiana *et al*., 2022). The highest species density was found in the species *R. mucronata* (6075 $ind.ha^{-1}$), while the lowest was in *B. gymnorrhiza* (75 $ind.ha^{-1}$).

Table 2. Mangrove Vegetation. D (Density); RDi (Relative Density); F (Frequency); FR (Relative Frequency); BA (Bassal Area); C (Dominance); RCi (Relative Dominance); IVI (Importance Value Index)

Species	D (ind·ha^{-1})	Rdi (%)	F	RFi (%)	BA (m/ha)	C	RCi (%)	IVI (%)
Avicennia alba	2550	13.82	0.50	9.68	21.70	0.13	13.48	36.98
Sonneratia alba	1937.5	10.50	0.67	12.90	25.64	0.16	15.93	39.33
Avicennia marina	850	4.61	0.17	3.23	5.73	0.04	3.56	11.39
Rhizophora mucronata	6075	32.93	0.67	12.90	21.70	0.13	13.48	59.31
Rhizophora apiculata	750	4.07	0.17	3.23	16.40	0.10	10.18	17.47
Achantus ilicifolius	237.5	1.29	0.50	9.68	0.08	0.00	0.05	11.01
Acrostichum speciosum	762.5	4.13	0.67	12.90	0.08	0.00	0.05	17.09
Ceriops decandra	4137.5	22.43	0.67	12.90	10.12	0.06	6.28	41.61
Derris trifoliata	187.5	1.02	0.33	6.45	13.38	0.08	8.31	15.78
Nypa fruticans	362.5	1.96	0.17	3.23	20.12	0.12	12.50	17.69
Excoecaria agallocha	525	2.85	0.50	9.68	17.01	0.11	10.56	23.09
Bruguiera gymnorrhiza	75	0.41	0.17	3.23	9.06	0.06	5.63	9.26
Total		100	5.17	100	161.02	1	100	300

The most dominant species in a vegetation community will have a high IVI (Lelewa *et al*., 2023; Styaningsih & Binawati, 2023). The highest IVI value was recorded for *R. mucronata* at 59.31%, indicating its widespread distribution at the study site. This contrasts with previous studies that reported low IVI values for *R. mucronata* of 19% (Dharmawan *et al*., 2022), and 13.38% (Serosero *et al*., 2020). This difference suggests that each location has distinct habitat characteristics that influence the growth and distribution of mangrove stands (Soeprobowati *et al*., 2022).

The low IVI values for *A. marina* (11.39%), *A. ilicifolius* (11.01%), *D. trifoliata* (15.78%), and *B. gymnorrhiza* (9.26%) indicate that these species have a limited distribution and low stand density in the observed plots. The low IVI value for *B. gymnorrhiza* is likely related to the limited availability of suitable microhabitats to support its growth and distribution. Although vegetation distribution patterns generally follow ecological zoning, variations in microhabitats and local environmental conditions remain key factors in determining a species distribution and growth success within a given area. The species *A. ilicifolius* and *D. trifoliata* are shrubs or vines, so their contribution to community dominance is smaller. A low IVI value does not necessarily indicate that these species are unimportant, but rather suggests that their presence is not yet dominant in the mangrove vegetation structure of the study area.

The variability of observed mangrove vegetation types is thought to be influenced by differences in spatial characteristics at each observation location (Ahmed *et al*., 2022). These factors play a role in determining regeneration capacity, mortality rates, and interspecific competition. Although the mangrove community structure across stations is relatively similar, differences in environmental conditions still contribute to community heterogeneity, which ultimately affects the stability and function of the mangrove ecosystem (Harefa *et al*., 2024). The high abundance of *Rhizophora mucronata* stands may be influenced by the rehabilitation factors implemented at the MPC. This species has a strong taproot system that plays a crucial role in ecosystem ecology, making it suitable for rehabilitation programs (Wang *et al*., 2019). The low abundance of *Derris trifoliata* may be influenced by its absence in the seedling stands. Although classified as a native mangrove species, habitat unsuitability is a factor limiting stand growth (Y. Zhang *et al*., 2021).

The Mangrove Health Index (MHI) was developed to assess the health status of mangrove ecosystems, thus determining the quality of mangroves in the good or bad category (Matatula *et al*., 2019). The highest sapling density was at site 4 and 6 with a value of 0.19 ind·m^{-2}, respectively. The highest DBH value was at site 2 with a value of 7.59 cm and the lowest at site 5 with 4.18 cm. The highest canopy cover was at site 1 with a value of 82.62%, while the lowest was at site 6 with 78.58%. The highest Sc value was at site 1 with a value of 7.59, while the lowest was at site 6 with 6.59. The highest Sd value was at site 2 with a value of 4.84, while the lowest was at site 5 with a value of 3.30. The Snsp value at all stations had the same value, namely 4.12.

The health condition of mangroves at six observation points ranged from 48.35% to 54.46%, all of which were included in the moderate category according to the mangrove ecosystem health classification (Table 3). The moderate category reflects relatively stable conditions but indicates ecological stress, with moderate canopy cover and suboptimal sapling regeneration. This contrasts with the findings of (Wasil & Muhsoni, 2023), who reported that the MHI value for the mangroves in Tajungan Village, Bangkalan Regency, fell into the excellent category due to the nearly uniform tree height and very dense canopy cover.

The MHI value is strongly influenced by the structural parameters of vegetation, especially canopy density and cover. Site 1 showed the highest canopy cover, likely influenced by the dominance of Rhizophora sp., which has a relatively high density and dominance. This species is known for its broad and dense leaf morphology, enabling it to form a denser canopy. Furthermore, the complex branching structure of Rhizophora also contributes to the high level of cover (Rahim *et al*., 2017). Conversely, the lowest canopy cover percentage was found at site 6. This low value was influenced by the dominance of associated shrub-like mangrove vegetation, such as *Acrostichum speciosum* and *Acanthus ilicifolius*. Despite their relatively high density, their small leaf morphology and stem diameter do not contribute significantly to canopy formation.

The Kruskal–Wallis test results showed no significant differences between observation locations in all mangrove health parameters ($p > 0.05$). This indicates that the structure of the mangrove ecosystem throughout the study area is relatively homogeneous, which is thought to be influenced by similar environmental conditions between stations, such as tidal patterns and sediment characteristics (Latumahina *et al*., 2024; Maharani *et al*., 2025). Mangrove health is categorized as good if it is rarely exposed to strong waves and external disturbances such as animals and humans (Farid *et al*., 2024).

Spearman correlation analysis showed that MHI was strongly and positively correlated with DBH ($r = 0.886$) and canopy cover ($r = 0.829$), indicating that these structural attributes are key drivers of mangrove ecosystem health in the study area. Larger tree trunk diameters reflect better growing conditions and higher biomass accumulation, which contribute to ecosystem stability. Mangrove density had a weak correlation with MHI ($r = -0.383$). This finding suggests that vegetation density parameters cannot directly represent the health of mangrove forests in the study area. Ecologically, density values reflect the success of the mangrove stand regeneration process, not the structural condition of the developing ecosystem (Latumahina *et al*., 2024; Wiwiyani *et al*., 2025).

Table 3. Mangrove Health Index (MHI)

SP	Density (ind.m^{-2})	DBH (cm)	Canopy Cover (%)	Sc	Sd	Snsp	MHI (%)	Category
1	0.16	7.12	82.62	7.59	4.62	4.12	54.46	Moderate
2	0.13	7.59	81.74	7.38	4.84	4.12	54.42	Moderate
3	0.13	5.91	79.19	6.74	4.08	4.12	49.77	Moderate
4	0.19	5.88	81.26	7.25	4.07	4.12	51.48	Moderate
5	0.17	4.18	80.58	7.08	3.30	4.12	48.35	Moderate
6	0.19	5.5	78.58	6.59	3.90	4.12	48.68	Moderate

Variations in MHI values across research stations indicate that mangrove health is influenced not by a single parameter, but by the integration of several contributing factors. During the regeneration phase, high stand density does not always correlate with ecosystem quality, as the regeneration process depends on nutrient availability in the environment. High stand density can trigger increased intra- and inter-specific competition for nutrients, light, and space, which may limit optimal individual growth (Peng *et al*., 2022; Peters *et al*., 2020). Furthermore, the relatively uniform Sd values across observation stations may result in low data variability, thereby limiting their contribution to the MHI value. This indicates that mangrove density is not sufficiently sensitive to explain differences in mangrove health conditions.

Mangrove health at all locations was categorized as moderate, confirming that the mangrove ecosystems in the study area have not yet reached optimal conditions. The strong correlation between the MHI and the DBH and canopy cover parameters indicates that ecosystem stability in this area is supported by the presence of well-developed stands. This zone maintains a functional ecological structure but is beginning to show signs of degradation. Areas with moderate mangrove health are considered ecological transition zones and require proactive management. Priority zones—particularly those adjacent to anthropogenic activities—need to be designated to protect existing mangrove stands, thereby preventing physical disturbances to the vegetation. Rehabilitation efforts and adaptive management must continue, especially at sites with low index values, to improve the overall quality of the mangrove ecosystem. Furthermore, regulating access to mangrove areas and installing physical barriers in areas accessible to visitors are necessary to minimize potential ecosystem damage. Strengthening these measures is crucial for maintaining ecological stability and preserving the key ecosystem functions provided by mangroves in coastal protection, fisheries support, and biodiversity conservation.

The Mangrove Health Index (MHI), derived from vegetation structure parameters, effectively characterizes the condition of the mangrove ecosystem in the Mangrove Pancer Cengkrong area. Although this approach provides information on ecosystem condition, it needs to incorporate explicit spatial analysis, which can enhance the interpretation of spatial variability and facilitate the formulation of more effective management plans. Future research is recommended to integrate spatial approaches to capture patterns of mangrove health distribution across the landscape. Additionally, further research should include key ecological drivers, such as water quality parameters and sediment characteristics, to provide a more comprehensive understanding of the factors influencing the condition of mangrove ecosystems.

CONCLUSSION

The research results found 12 species consisting of *Avicennia alba, Sonneratia alba, Avincennia marina, Rhizophora mucronata, Rhizophora apiculata, Achantus ilicifolius, Acrostichum speciosum, Ceriops decandra, Derris trifoliata, Nypa fruticans*, and *Excoecaria agallocha*. The highest density was found in the *Rhizophora mucronata*, while the lowest was in the *Derris trifoliata*. The sapling density ranged from 0.13 – 0.19 ind·m^{-2}. DBH values ranged from 4.18 – 7.59 cm, canopy cover ranged from 78.58 – 82.62%. Sc values ranged from 6.59 – 7.59, Sd values ranged from 3.30 – 4.84, and Snsp values were the same at all stations, namely 4.12. The MHI value ranges from 48.35 – 54.46%, which means that all research site are classified in the moderate category. The mangrove vegetation in Pancer Cengkrong shows high density, but its health is still considered moderate. Therefore, monitoring, evaluation, and maintenance of the mangrove ecosystem are essential to optimize its health. Active involvement from management, the local community, and the local government is also crucial to ensure effective and sustainable monitoring.

ACKNOWLEDGMENTS

This research is part of a program funded by the Lecturer Research Grant Fund of the Faculty of Fisheries and Marine Sciences, Brawijaya University, Malang, for Fiscal Year 2025, contract number 1141/UN10.F06/KS/2025. This funding support provides an important contribution to the implementation of research activities.

REFERENCES

Ahmed, S., Kamruzzaman, Md., Rahman, Md. S., Sakib, N., Azad, Md. S., & Dey, T. (2022). Stand structure and carbon storage of a young mangrove plantation forest in coastal area of Bangladesh: The promise of a natural solution. *Nature-Based Solutions*, *2*, 100025. doi: 10.1016/j.nbsj.2022.100025

Alimbon, J. A., & Manseguiao, M. R. S. (2021). Species composition, stand characteristics, aboveground biomass, and carbon stock of mangroves in panabo mangrove park, philippines. *Biodiversitas*, *22*(6), 3130–3137. doi: 10.13057/biodiv/d220615

Alongi, D. M. (2018). Impact of global change on nutrient dynamics in Mangrove Forests. *Forests*, *9*(10), 1–13. doi: 10.3390/f9100596

Arfiati, D., Iranawati, F., Andhani, T. D., Orchida, K., & Aprilian, K. F. (2025). Macrozoobenthos community in Mangrove Pancer Cengkrong Area, Trenggalek Regency, East Java Province. *Journal of Maquares*, *12*(1), 65145.

Arfiati, D., Iranawati, F., Andhani, T. D., Orchida, K., Aprilian, K. F., Inayah, Z. N., & Pratiwi, R. K. (2024). Gastropod community structure in Mangrove Pancer Cengkrong Ecosystem. *International Journal of Innovative Science and Research Technology*, 9(11), 2815–2821. www.ijisrt.com

Arifin, Z., Yusapri, A., Rachman, A. B., & Sasmita Adi Putra, B. (2023). The impact of mangrove destruction on the economy and advocacy efforts for mangrove conservation in Indonesia. *Asian Journal of Management Entrepreneurship and Social Science*, *3*(4), 935–948.

Bengen, D. G., Yonvitner, & Rahman. (2022). Technical Guidelines for the Introduction and Management of Mangrove Ecosystem. (1st ed.). IPB Press.

Cahyaningsih, A. P., Deanova, A. K., Pristiawati, C. M., Ulumuddin, Y. I., Kusumawati, L., & Setyawan, A. D. (2022). Review: Causes and impacts of anthropogenic activities on mangrove deforestation and degradation in Indonesia. *International Journal of Bonorowo Wetlands*, *12*(1), 12-22. doi: 10.13057/bonorowo/w120102

Dharmawan, I. W. E., Renyaan, J., & Nurdiansah, D. (2022). Mangrove zonation, community structure and healthiness in Kei Islands, Maluku, Indonesia. *Biodiversitas*, *23*(9), 4918–4927. doi: 10.13057/biodiv/d230962

Djamaluddin, R. (2018). Mangrove Biology, Ecology, Rehabilitation, and Conservation. (1st ed.). Unsrat Press.

Gouda, S., Das, G., & Patra, J. K. (2015). Mangroves: A Rich Source of Natural Bioactive Compounds. Studium Press LLC.

Guglielmetti, L. C., Faber-Castell, F., Fink, L., & Vuille-dit-Bille, R. N. (2022). Statistics decrypted—a comprehensive review and smartphone-assisted five-step approach for good statistical practice. *Langenbeck's Archives of Surgery*, *407*(2), 529–540. doi: 10.1007/s00423-021-02360-0.

Harefa, M. S., Nasution, Z., Tuhono, E., & Susilowati, A. (2024). Floristic diversity of mangrove restoration area: a case study in Pasar Rawa, North Sumatra. *Jurnal Sylva Lestari*, *12*(1), 158–169. doi: 10.23960/jsl.v12i1.824.

Hariyanto, S., Fahmi, A. K., Soedarti, T., & Suwarni, E. E. (2019). Vegetation and community structure of mangrove in Bama Resort Baluran National Park Situbondo East Java. *Biosaintifika*, *11*(1), 132–138. doi: 10.15294/biosaintifika.v11i1.19111.

Haryati, A., Fikriyya, N., & Prihatingsih, I. (2024). Estimation of organic carbon stocks in the mangrove ecosystem in Mojo Village, Ulujami District, Pemalang. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *16*(1), 75–88. doi: 10.29244/jitkt.v16i1.5192.

Indrazora, T. H., Santoso, A., & Soenardjo, N. (2024). Mangrove health index in the Mangrove Area of Bedono Village, Sayung District, Demak Regency. *Journal of Marine Research*, *13*(4), 731–738. doi: 10.14710/jmr.v13i4.43270.

Jeffry, S., Zakaria, M. H., Ramaiya, S. D., Kamal, E., & Bujang, J. S. (2026). Mangrove diversity, stand structure, and distribution across four coastal ecosystem types in Peninsular Malaysia. *Regional Studies in Marine Science*, *98,* 1-15. doi: 10.1016/j.rsma.2026.105107

Kusmana, C., & Susanti, S. (2015). Composition and structure of natural forest stands in the Gunung Walat educational forest, Sukabumi. *Journal of Tropical Silviculture*, *05*(3), 210–217.

Latumahina, F., Susilawati, Antonius, & Tewoloipaky, W. (2024). Mangrove diversity as an indicator of ecosystem health on Ambon Island, Indonesia. *Agro Bali*, *7*(2), 295–306. doi: 10.37637/ab.v7i2.1637

Lelewa, B. R., Rumengan, A. P., Sondak, C. F. A., Paulus, J. J. H., Paruntu, C. P., & Sumilat, D. A. (2023). Index of the importance of mangrove communities in the Coastal Area of Minanga Dua Village, Pusomaen District, Southeast Minahasa Regency, North. *Jurnal Pesisir dan Laut Tropis*, *11*(3), 2023.

Liu, C., Xing, Y., Duanmu, J., & Tian, X. (2018). Evaluating different methods for estimating diameter at breast height from terrestrial laser scanning. *Remote Sensing*, *10*(4). doi: 10.3390/rs10040513

Lovelock, C. E., Bennion, V., de Oliveira, M., Hagger, V., Hill, J. W., Kwan, V., Pearse, A. L., Rossini, R. A., & Twomey, A. J. (2024). Mangrove ecology guiding the use of mangroves as nature-based solutions. *Journal of Ecology*. John Wiley and Sons Inc. doi: 10.1111/1365-2745.14383

Macunluoglu, A. C., & Ocakoglu, G. (2023). Comparison of the performances of non-parametric k-sample test procedures as an alternative to one-way analysis of variance. *The European Research Journal*, 9(4), 687–696. doi: 10.18621/eurj.1037546

Maharani, M., Irham, M., & Rusdi, M. (2025). The analysis of density and types of mangroves on the coast of Aceh Tamiang district. *Depik*, *14*(1), 52–60. doi: 10.13170/depik.14.1.38567

Matatula, J., Poedjirahajoe, E., Pudyatmoko, S., & Sadono, R. (2019). The Spatial spread of the mangrove forest environmental condition at Kupang Seashore. *Jurnal Pengelolaan Sumberdaya Alam Dan Lingkungan*, *9*(2), 467–482. doi: 10.29244/jpsl.9.2.467-482

Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., Manuri, S., Krisnawati, H., Taberima, S., & Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. *Nature Climate Change*, *5*(12), 1089–1092. doi: 10.1038/nclimate2734

Noor, Y. R., Khazali, M., & Suryadiputra, I. N. N. (2006). An Introduction to Mangroves in Indonesia. (2nd ed.). PHKA/WI-IP.

Peng, D., Guo, H., Armitage, A. R., & Pennings, S. C. (2022). Competition and abiotic stress affect the size of mangroves near their geographic range limit. *Journal of Plant Ecology*, *15*(1), 129–140. doi: 10.1093/jpe/rtab079

Peters, R., Walther, M., Lovelock, C., Jiang, J., & Berger, U. (2020). The interplay between vegetation and water in mangroves: new perspectives for mangrove stand modelling and ecological research. *Wetlands Ecology and Management*, *28*(4), 697–712. doi: 10.1007/s11273-020-09733-0

Rahim, S., Baderan, D. W. K., & Hamidun, M. S. (2017). The density, composition and mangrove forest habitat in coastal areas of Torosiaje Jaya Village, Gorontalo, Indonesia. *Bonorowo Wetlands*, *7*(1), 38–42. doi: 10.13057/bonorowo/w070108

Rizkiah, R., Wardono, S., Rosalina, D., Handayani, E., Yusuf, M., Moh Ismail, R., Sulistiyo, B., Amdani, & Romauli, A. Y. (2025). Mangrove health indeks in Segarajaya Village Tarumajaya District Bekasi Regency, West Java. *Jurnal Segara*, *20*(2), 151–162. doi: 10.15578/segara.v20i2.17723

Schaduw, J. N. (2018). Distribusi dan karakteristik kualitas perairan Ekosistem Mangrove Pulau Kecil Taman Nasional Bunaken. *Majalah Geografi Indonesia*, *32*(1), 40. doi: 10.22146/mgi.32204

Serosero, R. H., Abubakar, S., & Hasan, S. (2020). Distribution and community structure of mangrove in Donrotu, Guratu And Manomadehe Islands, West Halmahera District, North Maluku. *Jurnal Ilmu Dan Teknologi Kelautan Tropis*, *12*(1), 151–166. doi: 10.29244/jitkt.v12i1.26929

Sidik, F., Wigati, N., Zaky, A. R., Hidayat, J. J., Kadarisman, H. P., & Islamy, F. (2018). Buku Panduan Mangrove Estuari Perancak (1st ed.). Balai Riset dan Observasi Laut.

Soeprobowati, T. R., Anggoro, S., Puryono, S., Purnaweni, H., Sularto, R. B., & Mersyah, R. (2022). Species composition and distribution in the mangrove ecosystem in the City of Bengkulu, Indonesia. *Water (Switzerland)*, *14*(21, 1-19. doi: 10.3390/w14213516

Styaningsih, K., & Binawati, D. K. (2023). Diversity and important value index of mangrove In Gresik, Kebomas and Manyar District, Gresik Regerency. *Stigma*, *16*(2), 60–67.

Sugiana, I. P., Andiani, A. A. E., Pradnyandari Dewi, I. G. A. I., Astawa Karang, I. W. G., As-Syakur, A. R., & Dharmawan, I. W. E. (2022). Spatial distribution of mangrove health index on three genera dominated zones in Benoa Bay, Bali, Indonesia. *Biodiversitas*, *23*(7), 3407–3418. doi: 10.13057/biodiv/d230713

Taillardat, P., Friess, D. A., & Lupascu, M. (2018). Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. *Biology Letters*, *14*(10), 1-6. doi: 10.1098/rsbl.2018.0251

Tanjung, R. H. R., Kabelen, A., & Antoh, A. (2018). Analysis of Mangrove Vegetation on Liki Island, Sarmi District, Sarmi City, Papuan. *Journal of Biology*, *7*(1), 22–28. doi: 10.31957/jbp.428

Toknok, B., Eltriman Hulu, A., Purnama, R., Panuntun, M. D., Shariati Zamani, I., & Hasibuan, D. K. A. (2026). Assessing mangrove health index as a basis for degradation mitigation planning. *Journal of Degraded and Mining Lands Management*, *13*(2), 9953–9962. doi: 10.15243/jdmlm.2026.132.9953

Wang, W., Li, X., & Wang, M. (2019). Propagule dispersal determines mangrove zonation at intertidal and Estuarine scales. *Forests*, *10*(3). doi: 10.3390/f10030245

Wasil, M., & Muhsoni, F. F. (2023). Mangrove Health Index (MHI) in Tajungan Mangrove Tourism, Kamal District, Bangkalan Regency. Juvenil: Scientific Journal of Marine Affairs and Fisheries, *4*(4), 366–375. doi: 10.21107/juvenil.v4i4.19287

Wiwiyani, Werorilangi, S., & Saru, A. (2025). The impact of mangrove forest density on marine debris accumulation: implications for ecosystem health and sustainable coastal management. *Jurnal Bisnis Kehutanan Dan Lingkungan*, *2*(2), 105-121. doi: 10.61511/jbkl.v2i2.2025.1629

Yamamoto, Y. (2023). Living under ecosystem degradation: Evidence from the mangrove–fishery linkage in Indonesia. *Journal of Environmental Economics and Management*, *118*, 1-23. doi: 10.1016/j.jeem.2023.102788

Zakiyah, U., Andhani, T. D., Siregar, U. J., Erintika, D., Rizki, M., Kinanti, A. S., Pramudia, Z., Misbakudin, I., & Zamzami, A. (2025). The relationship of tree stand structure parameters with aboveground carbon as an estimation carbon storage in Pancer Cengkrong Mangrove, Trenggalek, East Java. *Egyptian Journal of Aquatic Biology & Fisheries*, *29*(4), 1657–1676.

Zhang, S., Huang, H., Peng, D., Zhu, Y., Dong, D., Huang, H., & Chu, J. (2025). Potential distribution projections of mangrove forests and invasive plants under climate change: case insights from mangrove management in Guangdong Province, China. *Marine Pollution Bulletin*, *218*, 1–13. doi: 10.1016/j.marpolbul.2025.118131

Zhang, Y., Xin, K., Liao, B., Sheng, N., & Ai, X. (2021). The characteristics of pods and seeds of liana species Derris trifoliata and their relationship with environmental factors in Guangdong, China. *Ecological Indicators*, *129*, 1-8. doi: 10.1016/j.ecolind.2021.107930