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Mangrove Canopy Cover Analysis Using Hemispherical Photography in Gonenggati Mangrove Area, Donggala Regency, Central Sulawesi

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Abstract

Mangrove forests play a vital role in mitigating the impacts of global climate change by protecting coastal areas from natural disasters such as tsunamis and by storing significant amounts of carbon. Their capacity to sequester carbon is reported to be substantially higher than that of many tropical forest ecosystems, making mangroves important components of climate change mitigation strategies. This study aimed to assess the percentage of mangrove canopy cover in the Gonenggati Mangrove Ecotourism Area, Donggala Regency, Central Sulawesi Province, Indonesia. Canopy cover was evaluated using the Hemispherical Photography method, which involves taking upward-facing photographs beneath the canopy using a smartphone camera. The images were subsequently analyzed with ImageJ software and Microsoft Excel to estimate canopy density. Sampling stations were determined using a purposive sampling approach at three observation sites. The study recorded 15 mangrove species belonging to 8 families, indicating relatively high species richness within the area. The dominant species were *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, and *Ceriops tagal*. The average canopy cover across all stations was 75.21%, classified as moderate (healthy). The highest canopy cover was observed at Station 2 (78.49%), while the lowest was recorded at Station 3 (71.06%). Overall, the results indicate that the mangrove ecosystem in the Gonenggati Mangrove Ecotourism Area is in a healthy condition and possesses strong potential to support biodiversity conservation, coastal protection, and climate change mitigation efforts.

Keywords: Mangrove forest; canopy cover; hemispherical photography; ecotourism; Gonenggati; Central Sulawesi.

INTRODUCTION

Mangrove forests play a significant role in mitigating the impacts of global climate change due to their ability to reduce coastal damage caused by natural disasters, particularly tsunamis, and their exceptional capacity for carbon sequestration (Kumari, & Rathore, 2021). According to Alongi (2020), mangrove ecosystems can absorb and store carbon emissions up to 400% more effectively than tropical forests, making them one of the most efficient natural carbon sinks in the world. In addition to their role in climate regulation, mangroves provide numerous ecological services, including shoreline stabilization, erosion control, nutrient cycling, and habitat provision for a wide variety of terrestrial and aquatic organisms. One of the most important parameters used to assess the health and ecological condition of mangrove ecosystems is canopy density or canopy cover. The canopy, often referred to as the tree crown layer, is formed by the overlapping arrangement of branches, twigs, and leaves that collectively create a continuous vegetative cover above the forest floor (Sarun & Hun, 2026). A dense canopy generally indicates healthy vegetation structure and high primary productivity because it allows for efficient photosynthetic activity and carbon assimilation. Furthermore, canopy cover functions as a regulator of microclimatic conditions within the ecosystem by influencing light intensity, air temperature, humidity, and wind movement. Conversely, the loss or degradation of canopy cover can negatively affect habitat quality, reduce biodiversity, alter nutrient dynamics, and disrupt the chemical and biological processes occurring within mangrove substrates. Therefore, monitoring canopy cover is essential for evaluating ecosystem health and supporting sustainable mangrove management and conservation programs (Chow, 2018).

One of the most widely used approaches for measuring canopy characteristics within forest ecosystems is the hemispherical photography method (Sunkur et al., 2023). Hemispherical photography is a non-destructive and cost-effective technique that estimates canopy density and canopy cover by capturing upward-facing photographs from beneath the forest canopy. The resulting images provide detailed information regarding the proportion of sky visible through the canopy, which can then be analyzed using specialized image-processing software to quantify

canopy openness and vegetation cover. This method has become increasingly popular because it is relatively simple to implement in the field while producing reliable and accurate results (Segaran et al., 2023). According to Sidik et al. (2018), the mangrove canopy plays a crucial role in the photosynthetic process by intercepting and regulating incoming solar radiation. The denser the canopy cover, the more difficult it becomes for sunlight to penetrate through the upper vegetation layers and reach the forest floor. Although dense canopy cover is often associated with healthy and mature mangrove stands, excessive shading may limit the availability of sunlight for younger mangrove growth stages, such as seedlings and saplings, which depend heavily on adequate light exposure to support photosynthesis and growth. Consequently, understanding canopy structure is important not only for assessing ecosystem health but also for evaluating regeneration potential and vegetation dynamics within mangrove forests (Jennerjahn et al., 2017).

Mangrove forests possess extensive canopy structures that provide shade and create favorable environmental conditions for numerous organisms inhabiting coastal ecosystems. The percentage of mangrove canopy cover is widely recognized as an important ecological indicator for determining the health status and structural integrity of mangrove ecosystems (Taillardat et al., 2018). Healthy mangrove stands generally exhibit relatively high canopy cover values, reflecting good vegetation growth, sufficient regeneration, and stable ecological functioning. Conversely, low canopy cover may indicate ecosystem degradation caused by natural disturbances or anthropogenic activities such as land conversion, logging, coastal development, pollution, and aquaculture expansion. Mangrove ecosystems are particularly vulnerable to environmental changes because they occupy transitional zones between terrestrial and marine environments. Damage to mangrove ecosystems can significantly reduce their ecological functions and adversely affect the overall quality of coastal environments (Schaeffer-Novelli et al., 2016). According to Godoy & Lacerda (2015), the degradation of mangrove ecosystems can have serious environmental and socio-economic consequences, including increased coastal erosion, declining fisheries productivity, reduced biodiversity, and diminished protection against extreme weather events. Furthermore, communities living in coastal areas often rely on mangrove ecosystems for food resources, livelihoods, and ecosystem services. Therefore, regular monitoring of canopy cover is necessary to detect early signs of ecosystem degradation and to support effective conservation and restoration efforts aimed at maintaining the long-term sustainability of mangrove resources and the well-being of surrounding communities (Fusi et al., 2015).

Donggala Regency is one of the administrative regions located in Central Sulawesi Province, Indonesia, with a total area of approximately 5,275.69 km (Djirimu et al., 2024). The regency consists of sixteen districts, several of which are situated along extensive coastal zones characterized by diverse marine and coastal ecosystems. These coastal areas support a variety of natural resources, including coral reefs, seagrass beds, and mangrove forests that contribute significantly to local biodiversity and economic activities. One of the coastal districts within Donggala Regency is Banawa District, which possesses extensive mangrove habitats distributed across several villages and urban wards. The coastal region of Banawa District is known for supporting a diverse assemblage of true mangrove species and associated mangrove vegetation that form important ecological habitats along the shoreline. These mangrove communities provide critical ecosystem services such as shoreline protection, sediment trapping, nutrient retention, carbon sequestration, and habitat provision for fish, crustaceans, mollusks, birds, and other wildlife (Umar, 2023). Despite their ecological importance, many mangrove areas face increasing pressure from human activities and environmental changes, highlighting the need for continuous ecological assessment and monitoring. Evaluating canopy cover within these mangrove ecosystems is therefore essential for understanding their current ecological condition and for developing appropriate management strategies to ensure their long-term conservation and sustainability ² (Pratiwi et al., 2021). This study aimed to assess the percentage of mangrove canopy cover in the Gonenggati Mangrove Ecotourism Area, Donggala Regency, Central Sulawesi Province, Indonesia.

MATERIALS AND METHODS

Study Area

The study was conducted in the Gonenggati Mangrove Ecotourism Area, located in Kabonga Besar Village, Banawa District, Donggala Regency, Central Sulawesi Province, Indonesia. This area represents one of the important coastal ecosystems in Donggala Regency and serves both ecological and socio-economic functions for local communities. The mangrove ecosystem in Gonenggati provides a variety of ecosystem services, including shoreline protection from coastal erosion, carbon sequestration, habitat provision for numerous aquatic and terrestrial species, and support for ecotourism activities. In recent years, the area has gained increasing attention as an ecotourism destination due to its relatively well-preserved mangrove vegetation and its potential for environmental education and conservation-based tourism. These characteristics make the Gonenggati Mangrove Ecotourism Area a suitable location for studying mangrove canopy structure and ecosystem health. Field data collection was carried out in 2025 through direct observations and canopy

photography measurements at designated sampling stations within the study area. The selected sites were considered representative of the existing mangrove vegetation conditions and were expected to provide comprehensive information regarding canopy cover characteristics. The results of this study are expected to contribute valuable scientific information for mangrove ecosystem management, conservation planning, and the sustainable development of ecotourism activities in the Gonenggati coastal region.

Procedures

Sampling Technique

The selection of research stations was carried out using a purposive sampling technique, whereby sampling locations were intentionally chosen based on their ability to represent the overall characteristics of the mangrove ecosystem within the study area. Three observation stations were established in different sections of the Gonenggati Mangrove Ecotourism Area to capture variations in vegetation structure and environmental conditions. This approach ensured that the collected data adequately reflected the spatial distribution and ecological characteristics of the mangrove community. At each observation station, a sampling plot measuring 10 m × 10 m was established using the transect method. The plots served as standardized units for collecting vegetation and canopy cover data, allowing for consistent comparisons among stations. The transect-based sampling design is commonly employed in mangrove ecological studies because it facilitates systematic observations of vegetation composition, stand structure, and environmental parameters within a defined area. Furthermore, the use of multiple observation stations enabled a more comprehensive assessment of canopy cover conditions across the mangrove ecosystem, thereby improving the reliability and representativeness of the study results.

Data Collection Technique

Data collection was conducted through field observations and direct measurements at each sampling station. The field measurement stage included the assessment of several environmental physicochemical parameters that influence mangrove growth and ecosystem dynamics, namely temperature, pH, and salinity. These environmental variables were measured to characterize site conditions and to provide supporting information for interpreting canopy cover patterns within the study area. In addition, all mangrove species encountered within the observation plots were identified to determine species composition and vegetation characteristics. Species identification was performed based on observable morphological characteristics such as leaf shape, bark texture, root structure, flowers, and propagules. Mangrove canopy cover was measured using the hemispherical photography method, which involves taking upward-facing photographs from beneath the canopy using a smartphone camera. This technique captures the arrangement of leaves, branches, and canopy gaps, allowing researchers to estimate vegetation cover and canopy density accurately. The collected photographic data were subsequently processed and analyzed to quantify canopy cover percentages and evaluate the condition of the mangrove ecosystem at each observation station.

Data Analysis

Mangrove canopy cover was analyzed by calculating the percentage of vegetation pixels obtained from binary image analysis. The analysis followed the method described by Nucci and Andrea (2012), which estimates canopy cover based on the proportion of pixels representing vegetation relative to the total number of pixels in a hemispherical photograph. The percentage of mangrove canopy cover was calculated using the following equation:

$$\%\text{Mangrove Canopy Cover} = \sum P_{255} \times 100\%$$

Where:

$P_{(255)}$ = Number of pixels classified as mangrove canopy cover (vegetation pixels).

ΣP = Total number of pixels in the analyzed image.

The hemispherical photographs were processed using ImageJ software to convert the images into binary format and classify canopy and non-canopy areas. Subsequently, Microsoft Excel was used to calculate the canopy cover percentage and summarize the results for each observation station. This analytical approach provides an efficient and reliable means of estimating canopy cover, which is an important indicator of mangrove ecosystem health and vegetation structure. The resulting canopy cover percentages were then categorized according to the Mangrove Forest Damage Criteria established by the Indonesian Ministry of Environment Decree No. 201 of 2004 (*Keputusan Menteri Negara Lingkungan Hidup Nomor 201 Tahun 2004*). The classification system was used to determine the condition of the mangrove ecosystem based on canopy cover values. The classification categories are presented in Table 1.

Table 1. Mangrove forest damage criteria based on Ministerial Decree No. 201 of 2004.

Condition Category	Canopy Cover (%)	Density (Individual ha-1)
Dense	≥ 75%	≥ 1,500
Moderate	50–75%	1,000–1,500
Sparse	≤ 50%	≤ 1,000

RESULTS AND DISCUSSION

Environmental Physicochemical Conditions

The physicochemical characteristics of the environment are important factors influencing the growth, distribution, productivity, and ecological stability of mangrove ecosystems. Environmental parameters such as temperature, pH, salinity, and substrate type directly affect physiological processes in mangrove plants, including photosynthesis, nutrient uptake, respiration, and seedling establishment. Therefore, the measurement of these environmental variables is essential for understanding the habitat conditions that support mangrove vegetation within the study area. In this study, physicochemical measurements were conducted at three observation stations in the Gonenggati Mangrove Ecotourism Area to characterize the environmental conditions associated with mangrove canopy cover. The measured parameters included water temperature, pH, salinity, and substrate type. These variables were selected because they represent key ecological factors influencing mangrove growth and ecosystem functioning. The results of the environmental measurements showed relatively similar conditions among the three observation stations, indicating that the study area provides a generally suitable habitat for mangrove development. Detailed results of the physicochemical measurements are presented in Table 2.

Table 2. Environmental physicochemical conditions at the observation stations.

Physicochemical Parameter	Station I	Station II	Station III	Average
Temperature (°C)	30	30	30	30
pH	7.6	7.5	7.6	7.5
Salinity (ppt)	30	30	35	31
Substrate Type	Soil	Muddy	Muddy	-

Mangrove Canopy Cover Images in Gonenggati Mangrove Area

A total of 45 canopy photographs were obtained from the three observation stations established in the Gonenggati Mangrove Ecotourism Area, Donggala. The photographs were collected using the hemispherical photography method, which captures upward-facing images from beneath the mangrove canopy to document the distribution of leaves, branches, and canopy gaps. These images served as the primary data source for estimating mangrove canopy cover and evaluating vegetation structure within the study area. Following image acquisition, each photograph was processed using ImageJ software to convert the original images into binary images that distinguish vegetation-covered areas from open sky. This image-processing procedure facilitates the quantification of canopy cover by calculating the proportion of vegetation pixels relative to the total number of pixels in each photograph. The resulting binary images provide a clearer representation of canopy density and improve the accuracy of canopy cover estimation. Differences in canopy structure among the observation stations can be visually identified through variations in the proportion of vegetation and canopy openings visible in the processed images. The original hemispherical photographs and the corresponding binary images generated using ImageJ are presented in Figures 1, 2, 3, 4, 5, and 6.



Figure 1. Mangrove canopy cover at Station 1.

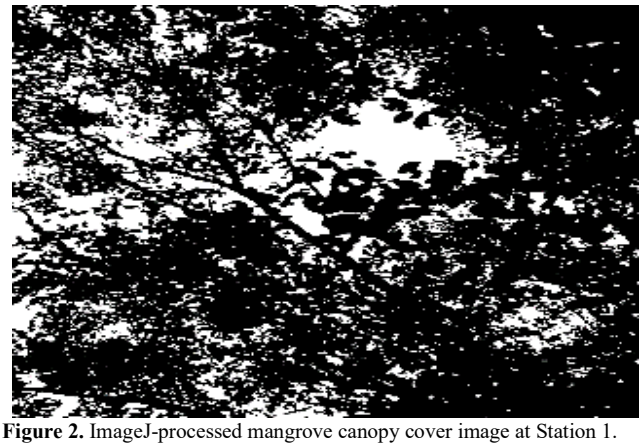


Figure 2. ImageJ-processed mangrove canopy cover image at Station 1.



Figure 3. Mangrove canopy cover at Station 1.



Figure 4. ImageJ-processed mangrove canopy cover image at Station 2.



Figure 5. Mangrove canopy cover at Station 3.



Figure 6. Image-J processed mangrove canopy cover image at Station 3.

Mangrove Species Recorded in Gonenggati Mangrove Area

A total of 15 mangrove species belonging to 8 families were identified within the Gonenggati Mangrove Ecotourism Area during the study period. The relatively high number of species recorded indicates considerable mangrove diversity and reflects the ecological importance of the study area as a coastal habitat. Species composition is an important indicator of ecosystem condition because diverse mangrove communities generally exhibit greater ecological stability, productivity, and resilience to environmental disturbances. The mangrove vegetation in the study area was dominated by members of the family Rhizophoraceae, which are commonly recognized as the principal structural components of tropical mangrove forests. Four species were classified as dominant or major species, namely *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lam., *Rhizophora stylosa* Griff., and *Ceriops tagal* (Perr.) C.B.Rob. These species were widely distributed across the observation stations and contributed substantially to the overall canopy structure. The remaining species were categorized as minor species because of their relatively lower abundance and more limited distribution within the study area. The complete list of mangrove species recorded during the survey is presented in Table 3.

Table 3. Environmental physicochemical conditions at the observation stations.

Family	Species	Category
Rhizophoraceae	*Rhizophora apiculata* Blume	Major
Rhizophoraceae	*Rhizophora mucronata* Lam.	Major
Rhizophoraceae	*Rhizophora stylosa* Griff.	Major
Rhizophoraceae	*Ceriops tagal* (Perr.) C.B.Rob.	Major
Rhizophoraceae	*Bruguiera gymnorhiza* (L.) Lam.	Minor
Acanthaceae	*Avicennia marina* (Forssk.) Vierh.	Minor
Acanthaceae	*Avicennia lanata* Ridley	Minor
Acanthaceae	*Avicennia alba* Blume	Minor
Acanthaceae	*Acanthus ilicifolius* L.	Minor
Meliaceae	*Xylocarpus granatum* J.Koenig	Minor
Meliaceae	*Xylocarpus moluccensis* Lam.	Minor
Lythraceae	*Sonneratia alba* Sm.	Minor
Primulaceae	*Aegiceras corniculatum* (L.) Blanco	Minor
Euphorbiaceae	*Excoecaria agallocha* L.	Minor
Arecaceae	*Nypa fruticans* Wurmb	Minor

Mangrove Canopy Cover Percentage

The percentage of mangrove canopy cover was analyzed using ImageJ software based on images obtained through the Hemispherical Photography method. This approach enabled the quantification of canopy cover by calculating the proportion of vegetation pixels relative to the total number of pixels in each hemispherical image. The results revealed that the average mangrove canopy cover was 75.21%, indicating that the mangrove forest within the Gonenggati Mangrove Ecotourism Area is in a moderately dense to healthy condition. According to the criteria established in the Indonesian Ministry of Environment Decree No. 201 of 2004, mangrove forests with canopy cover values greater than 75% are classified as dense (good condition), while canopy cover values between 50% and 75% are categorized as moderate (healthy condition). The average canopy cover recorded in this study therefore reflects a well-developed mangrove stand with a relatively dense canopy structure. Such canopy conditions are ecologically important because they enhance the capacity of mangrove forests to function as effective carbon sinks, improve sediment retention, regulate microclimatic conditions, and protect coastal areas from erosion and wave action. Dense canopy cover also contributes to habitat availability for numerous terrestrial and aquatic organisms, thereby supporting biodiversity conservation and ecosystem stability (Figure 7).

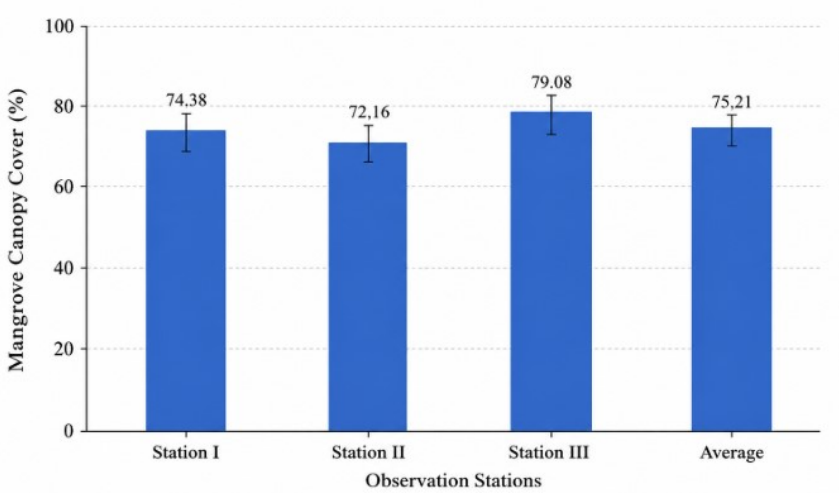


Figure 7. Percentage of mangrove canopy cover across the three observation stations in the Gonenggati Mangrove Ecotourism Area.

Discussion

The physicochemical characteristics measured in the Gonenggati Mangrove Ecotourism Area indicate that the environmental conditions are highly favorable for mangrove establishment and long-term ecosystem development. The uniform temperature of 30°C recorded at all observation stations suggests a stable thermal environment that supports optimal physiological activity in mangrove plants. Temperature influences a wide range of biological processes, including enzyme activity,

photosynthetic efficiency, respiration rates, and nutrient assimilation. Under suitable thermal conditions, mangrove trees can allocate more energy to growth and biomass accumulation, resulting in improved structural development and ecosystem productivity (Engku et al., 2021). In addition, the measured pH values ranging from 7.5 to 7.6 indicate neutral to slightly alkaline conditions that facilitate nutrient availability and root absorption processes. Such pH conditions are particularly advantageous for the decomposition of organic matter and microbial activity, both of which contribute to nutrient recycling within mangrove sediments. Salinity values between 30 and 35 ppt also reflect the natural influence of seawater in coastal habitats and fall within the tolerance range of most true mangrove species. The combination of these environmental variables demonstrates that the Gonenggati mangrove ecosystem possesses environmental stability that promotes healthy vegetation growth and minimizes physiological stress, thereby creating suitable conditions for the maintenance of a productive coastal ecosystem (Numbere, 2020).

Substrate characteristics observed in the study area provide further evidence of environmental suitability for mangrove development. Stations II and III were dominated by muddy substrates, whereas Station I consisted primarily of soil substrate. Substrate composition is one of the principal factors influencing mangrove zonation patterns, seedling establishment, nutrient dynamics, and root system development. Muddy sediments generally contain higher concentrations of organic matter and possess greater water-holding capacity than sandy substrates, allowing them to support more vigorous mangrove growth. These fine sediments also facilitate the accumulation of nutrients transported by tidal currents and terrestrial runoff, thereby increasing ecosystem fertility (Li et al., 2022). The prevalence of muddy substrate in the study area may explain the successful establishment of numerous mangrove species, particularly those belonging to the family Rhizophoraceae, which are well adapted to soft sediment environments. Moreover, muddy substrates contribute to coastal stabilization by trapping suspended particles and reducing sediment erosion. Through this process, mangrove root systems and sediment dynamics interact to create a positive feedback mechanism that enhances habitat stability and promotes forest expansion. Consequently, the substrate conditions identified in the Gonenggati mangrove ecosystem not only support vegetation growth but also contribute significantly to ecosystem resilience and long-term ecological sustainability (Rodda et al., 2016).

The presence of 15 mangrove species belonging to eight families highlights the ecological significance of the Gonenggati Mangrove Ecotourism Area as a center of coastal biodiversity. Species richness is often used as an indicator of ecosystem quality because diverse communities are generally more resistant to environmental disturbances and capable of maintaining ecological functions under changing conditions (Naseef et al., 2024). The recorded assemblage includes representatives from several major mangrove families, reflecting the availability of diverse ecological niches and habitat conditions within the study area. High species diversity contributes to ecosystem functioning by promoting complementary resource utilization, reducing interspecific competition, and enhancing ecological stability. Different mangrove species exhibit distinct adaptations related to salinity tolerance, rooting systems, reproductive strategies, and nutrient acquisition. As a result, species diversity enables mangrove ecosystems to occupy a broader range of environmental conditions and maintain ecosystem processes even when particular species experience environmental stress (Fusi et al., 2015). Furthermore, diverse mangrove communities support a greater abundance of associated fauna, including fish, crustaceans, mollusks, insects, and birds, which depend on mangrove habitats for feeding, breeding, and shelter. Therefore, the relatively high diversity recorded in this study not only reflects favorable habitat conditions but also emphasizes the importance of conserving the area as a reservoir of coastal biodiversity and ecological resources (Naskar & Palit, 2015).

The dominance of *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, and *Ceriops tagal* provides valuable insight into the structural characteristics and ecological dynamics of the mangrove forest. These species are widely recognized as key structural components of Indo-Pacific mangrove ecosystems due to their ability to thrive in intertidal environments characterized by fluctuating salinity and prolonged inundation. Their dominance suggests that environmental conditions within the study area favor species possessing specialized adaptations such as prop roots, aerial roots, and viviparous propagules (Islam et al., 2024). These adaptations enhance stability in soft sediments, improve oxygen acquisition in waterlogged substrates, and increase seedling survival rates in dynamic coastal environments. The prevalence of these species also has important ecological implications because they contribute significantly to canopy formation, carbon storage, and sediment retention. Dense root networks generated by *Rhizophora* and *Ceriops* species effectively trap sediments and organic matter, facilitating land accretion and shoreline stabilization. In addition, these species provide structurally complex habitats that support diverse assemblages of marine organisms. Their ecological importance extends beyond the forest itself, as they contribute to fisheries productivity and coastal protection. Consequently, the dominance of these species can be interpreted as an indicator of a relatively intact and functional mangrove ecosystem (Ray & Jana, 2017).

The canopy cover analysis revealed an average value of 75.21%, indicating that the mangrove forest in the Gonenggati area falls within the healthy category

according to national mangrove assessment standards. Canopy cover is a particularly important indicator because it integrates multiple aspects of vegetation condition, including tree density, crown development, leaf biomass, and overall forest maturity (Mi et al., 2019). A canopy cover value exceeding 75% reflects a well-developed forest structure capable of supporting a wide range of ecological processes. Dense canopies enhance photosynthetic productivity by increasing total leaf area and maximizing carbon assimilation. They also regulate microclimatic conditions by reducing temperature fluctuations, maintaining humidity, and controlling light penetration to the forest floor (Arshad et al., 2020). These functions create favorable environmental conditions for understory organisms and contribute to the maintenance of ecosystem stability. Furthermore, dense canopy cover is closely associated with increased aboveground biomass and carbon storage potential, reinforcing the role of mangrove forests as important natural solutions for climate change mitigation. The canopy values observed in this study therefore indicate that the Gonenggati mangrove ecosystem remains structurally intact and capable of delivering critical ecosystem services that benefit both biodiversity and surrounding human communities (Kühnhold et al., 2017).

The successful use of hemispherical photography combined with ImageJ analysis demonstrates the value of modern image-based approaches for mangrove monitoring and ecological assessment. Traditional methods of evaluating canopy structure often require extensive field measurements that can be time-consuming, labor-intensive, and subject to observer bias. In contrast, hemispherical photography provides a rapid and non-destructive means of quantifying canopy characteristics while maintaining high levels of accuracy and repeatability (Friess et al., 2022). The conversion of photographs into binary images through ImageJ software enables objective measurement of vegetation cover by distinguishing canopy elements from visible sky. This analytical approach facilitates standardized comparisons among sampling locations and allows researchers to detect subtle differences in canopy structure that may not be evident through visual observation alone (Abdelsalam et al., 2024). Additionally, digital image archives can be stored and reanalyzed in future studies, supporting long-term monitoring programs and temporal assessments of ecosystem change. The effectiveness of this method in the present study suggests that it represents a practical tool for evaluating mangrove condition, particularly in regions where financial resources and technical infrastructure may be limited. Its application can therefore contribute to evidence-based conservation planning and the sustainable management of mangrove ecosystems (Han et al., 2016).

CONCLUSIONS

The Gonenggati Mangrove Ecotourism Area possesses favorable environmental conditions for mangrove growth, characterized by stable temperature, suitable pH, salinity levels, and predominantly muddy substrates. A total of 15 mangrove species belonging to 8 families were recorded, with *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, and *Ceriops tagal* identified as the dominant species. The average mangrove canopy cover was 75.21%, indicating a healthy ecosystem condition according to the Indonesian Ministry of Environment Decree No. 201 of 2004. These findings suggest that the mangrove ecosystem in the Gonenggati area remains well preserved and continues to provide important ecological functions, including coastal protection, biodiversity conservation, and climate change mitigation. The Hemispherical Photography method combined with ImageJ analysis proved to be an effective and reliable approach for assessing mangrove canopy cover and ecosystem health.

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