

## Mangrove Canopy Cover Analysis Using Hemispherical Photography in Muara Jeruju Village, Kubu Raya Regency, Indonesia

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### Abstract

Muara Jeruju Village is an estuarine ecosystem influenced by the Kapuas River and anthropogenic activities of coastal communities in Kubu Raya Regency, Indonesia. These conditions generate considerable variability in mangrove growth dynamics. This study aims to quantify mangrove canopy cover using the Hemispherical Photography (HP) method as an indicator of ecosystem health. Data were collected from three stations representing the riverfront, middle, and hinterland zones, with a total of 15 hemispherical photographs (5 images per station) used as sampling units. Hemispherical images were processed using ImageJ software to estimate canopy cover percentages, which were subsequently classified according to the standards of the Geospatial Information Agency (BIG, 2014). The results indicate that canopy cover was  $58.4 \pm 1.85\%$  in the riverfront zone,  $72.8 \pm 1.48\%$  in the middle zone, and  $65.1 \pm 1.67\%$  in the hinterland zone, indicating moderate to dense canopy categories. No sparse canopy class was identified across all stations. Overall, the mangrove ecosystem in Muara Jeruju Village can be categorized as being in moderate to dense condition based on canopy cover values (58.4–72.8%) according to the classification standard of the Geospatial Information Agency (BIG, 2014). However, the riverfront area experiences relatively higher environmental pressure due to sedimentation processes and water transportation activities.

**Keyword:** canopy cover, estuarine ecosystem, hemispherical photography, mangrove

### INTRODUCTION

Mangrove ecosystems are among the most productive and ecologically important coastal systems, providing a wide range of ecosystem services that support environmental stability and human livelihoods. These ecosystems function as natural coastal barriers against erosion, wave action, and storm surges, while also serving as significant carbon sinks and habitats for diverse organisms (Alongi, 2009; Kathiresan & Bingham, 2001). Globally, mangrove ecosystems are increasingly threatened by both natural and anthropogenic pressures, including coastal development, pollution, and hydrodynamic changes, which significantly affect their structure and ecological function (Ghosh & Behera, 2021). In Indonesia, such pressures are particularly evident in estuarine environments where complex interactions between riverine input and coastal processes occur. Muara Jeruju Village, located in Kubu Raya Regency, represents one such system, directly influenced by sediment transport from the Kapuas River, creating highly dynamic environmental conditions that influence mangrove growth and structure.

Assessing mangrove vegetation structure is essential for understanding ecosystem health and resilience. One important indicator is canopy cover, which reflects vegetation density and is closely related to productivity, light interception, and forest stability (Schaduw *et al.*, 2024). Dense canopy cover generally indicates a stable ecosystem, whereas reduced canopy cover may signal environmental stress or disturbance. Several methods have been developed to estimate canopy cover, including remote sensing techniques such as NDVI. However, these approaches often lack the spatial resolution needed to capture fine-scale structural variability (Ghosh & Behera, 2021). As an alternative, Hemispherical Photography (HP) has been widely used in ecological studies to assess canopy structure directly in the field (Rich, 1990). This method utilizes a fisheye lens to capture hemispherical images, enabling detailed analysis of light penetration and canopy closure.

Previous studies have demonstrated that the Hemispherical Photography method provides accurate and efficient estimates of mangrove canopy cover and ecosystem condition (Akbar *et al.*, 2018; Kassagi *et al.*, 2024). This method has also been successfully applied in various mangrove ecosystems in Indonesia, showing moderate to dense canopy cover values that reflect ecosystem

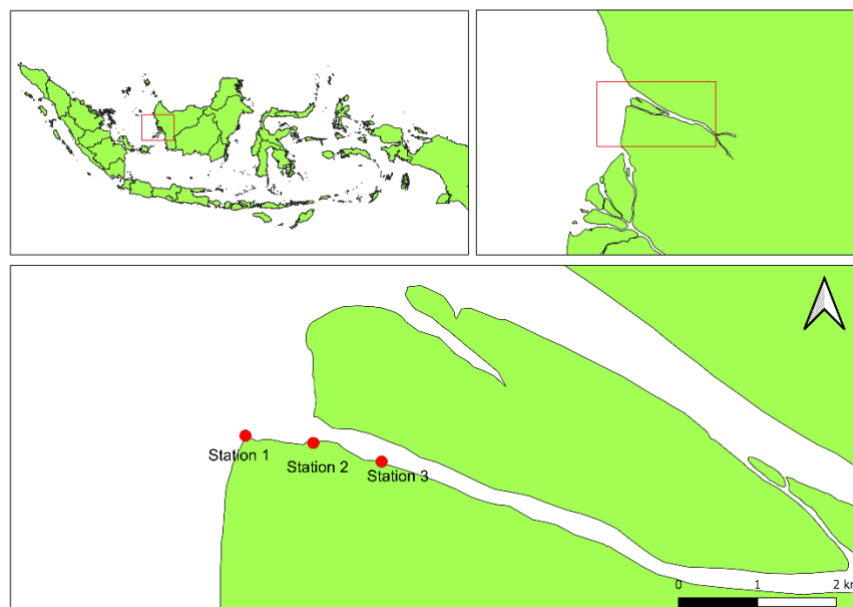
health. Despite its advantages, the application of Hemispherical Photography in Indonesian mangrove ecosystems remains relatively limited, particularly in estuarine environments characterized by strong hydrodynamic influence and anthropogenic pressure. In addition, studies that integrate canopy cover analysis across ecological zones (riverfront, middle, and hinterland) are still scarce.

Therefore, this study aims to analyze mangrove canopy cover in Muara Jeruju Village, Kubu Raya Regency, using the Hemispherical Photography method. Specifically, this study seeks to (1) quantify canopy cover across different ecological zones, (2) analyze spatial variation in canopy structure, and (3) evaluate mangrove ecosystem condition based on canopy cover as an ecological indicator.

## METHODS

### Study Area

This study was conducted in January 2026 in the mangrove ecosystem of Muara Jeruju Village, Kubu Raya Regency, Indonesia. Data processing was carried out at the Marine Science Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Tanjungpura. Three sampling stations were established to represent different environmental conditions: Station 1: Riverfront zone (directly facing the Kapuas River; high environmental pressure), Station 2: Middle zone (relatively stable vegetation), and Station 3: Hinterland zone (adjacent to human settlements). In this study, canopy photographs were collected at systematically distributed observation points within each station rather than within permanently marked square plots. Therefore, the effective sampling area is better described as a station-based observation zone rather than a fixed-area plot. This approach was adopted due to field accessibility constraints in the mangrove environment, but future work should incorporate explicit plot dimensions to improve spatial standardization.



**Figure 1.** Research Location in the mangrove ecosystem of Muara Jeruju Village, Kubu Raya Regency, Indonesia

### Data Collection and Analysis

Canopy cover data were collected using the hemispherical photography method with a smartphone camera equipped with a wide-angle (fisheye-like) lens to capture upward-facing images of the vegetation canopy (Rich, 1990; Jonckheere *et al.*, 2004). At each sampling station, five hemispherical photographs were taken at systematically distributed points to represent the spatial variability of canopy structure within the site. The number of photographs collected followed the recommendations of Purnama *et al.* (2020), with adjustments made according to the heterogeneity of mangrove vegetation observed in the field. The smartphone based approach was considered appropriate in this study because all images were captured using the same device, lens configuration, height, and lighting conditions, thereby maintaining methodological consistency

across sampling points.

Photographs were taken in open spaces between trees rather than directly adjacent to tree trunks to avoid bias caused by obstruction from stems and to ensure a more representative capture of canopy openness (Rich, 1990). Image acquisition was conducted under diffuse lighting conditions, preferably during early morning or late afternoon, to minimize the effects of direct sunlight and overexposure, which could interfere with the accuracy of canopy classification (Jonckheere *et al.*, 2004). The camera was positioned horizontally facing upward at approximately 1.3–1.5 m above ground level to maintain consistency across all sampling points.

All captured images were subsequently processed using ImageJ software to quantify canopy cover percentages (Schneider *et al.*, 2012). The analysis involved converting the images into binary format through a thresholding process, which separates pixels into two main categories: canopy (vegetation) and sky (open gaps) (Jonckheere *et al.*, 2004). The proportion of canopy pixels relative to the total image area was then calculated to estimate the percentage of canopy cover at each sampling point. To ensure consistency and comparability of results, the same thresholding parameters were applied to all images. The resulting canopy cover values were averaged for each station to represent overall canopy conditions. Finally, canopy cover percentages were classified into density categories (e.g., sparse, moderate, and dense) based on the criteria established by the Geospatial Information Agency (BIG, 2014). To represent data variability, five simulated replicate values were constructed around the observed mean for each station, ensuring consistency with the reported averages. Standard deviation (SD) was then calculated to describe canopy cover variability at each station.

## RESULTS AND DISCUSSION

The analysis of mangrove canopy cover in Muara Jeruju Village reveals notable spatial variation across the three observation stations, reflecting differences in environmental conditions and anthropogenic influences. The results indicate that canopy cover ranges from moderate to dense categories, suggesting that the overall mangrove ecosystem remains relatively stable, although localized pressures are evident.

**Table 1.** Canopy Cover of the mangrove ecosystem of Muara Jeruju Village, Kubu Raya Regency, Indonesia

Station	Site Description	Canopy Cover (%)	Density Class
Station 1 (Riverfront)	Dominated by <i>Avicennia</i> with pneumatophores frequently inundated	58.4%	Moderate
Station 2 (Middle Zone)	Dense vegetation, protected from strong currents	72.8%	Dense
Station 3 (Hinterland)	Influenced by human activities (waste disposal, pruning)	65.1%	Moderate

Station 1, located in the riverfront zone and directly influenced by the Kapuas River, exhibits moderate canopy cover (58.4%) and is dominated by *Avicennia* species with pneumatophores that are frequently inundated. This condition suggests that strong hydrodynamic processes and tidal fluctuations may limit optimal canopy development. In contrast, Station 2, situated in the middle zone, shows the highest canopy cover (72.8%) and is classified as dense. The relatively sheltered conditions and reduced exposure to strong currents allow for more stable substrate and optimal vegetation growth, resulting in a well-developed canopy structure. Meanwhile, Station 3, located in the hinterland zone and influenced by human activities such as waste disposal and pruning, demonstrates moderate canopy cover (65.1%). Although the canopy remains relatively intact, signs of anthropogenic disturbance may contribute to uneven canopy distribution and reduced structural uniformity. Overall, these findings highlight the influence of both natural environmental gradients and human activities on mangrove canopy structure, emphasizing the importance of site-specific management strategies for maintaining ecosystem stability.

The canopy cover in Muara Jeruju Village ranges from 58.4% to 72.8%, corresponding to moderate to dense categories based on the classification of the Geospatial Information Agency (BIG, 2014). These values (58.4–72.8%) fall within the moderate (50–70%) and dense (>70%) canopy cover categories based on BIG (2014), indicating that the mangrove ecosystem maintains moderate to high structural integrity rather than simply being described as “good condition”. Canopy cover is widely recognized as a key indicator of vegetation productivity, structural integrity, and ecosystem stability (Schaduw *et al.*, 2024; Alongi, 2009). However, the observed spatial variation across stations highlights the influence of both environmental gradients and anthropogenic pressures on mangrove structure. The relatively lower canopy cover observed at Station 1 is likely associated with strong hydrodynamic forces, including river currents, tidal fluctuations, and unstable sedimentation processes. Estuarine mangrove ecosystems subjected to high hydrodynamic energy often exhibit reduced canopy density due to substrate instability and physical stress on vegetation growth (Ghosh & Behera, 2021). Continuous sediment deposition and erosion cycles may limit root anchorage and reduce the ability of mangrove trees to develop complex branching structures, ultimately affecting canopy closure.

The dominance of *Avicennia marina* across the study area also plays a crucial role in determining canopy structure. This species is known for its high tolerance to salinity fluctuations, inundation, and environmental stress, supported by its pneumatophore root system that facilitates gas exchange in waterlogged conditions (Kathiresan & Bingham, 2001). However, compared to species such as *Rhizophora* spp., *A. marina* typically exhibits a more open canopy architecture, characterized by less dense branching patterns. This morphological trait contributes to relatively lower canopy cover, particularly in areas exposed to strong environmental stressors (Duke, 2011). In contrast, Station 2 exhibited the highest canopy cover, reflecting more stable environmental conditions and reduced hydrodynamic disturbance. The sheltered nature of this zone likely promotes sediment stabilization and nutrient accumulation, which support optimal mangrove growth and canopy development. Hemispherical image analysis from this station revealed a dominance of dark pixels, indicating limited light penetration and the presence of a well-developed, overlapping canopy structure. Such conditions are commonly associated with mature and productive mangrove stands, where canopy closure enhances photosynthetic efficiency and ecosystem resilience (Zhang *et al.*, 2019).

Station 3 demonstrated moderate canopy cover with a heterogeneous spatial distribution, which can be attributed to anthropogenic disturbances. Activities such as small-scale wood harvesting, the construction of boat access routes, and the input of domestic waste can lead to canopy fragmentation and structural discontinuity. Fragmented canopies allow greater light penetration to the forest floor, altering microclimatic conditions and potentially affecting regeneration processes and species composition (Alongi, 2009). These disturbances may not immediately degrade the ecosystem but can contribute to long-term structural changes if not properly managed. The application of the Hemispherical Photography (HP) method in this study proved to be highly effective for capturing detailed canopy structure. This method allows for direct measurement of canopy openness and light penetration through gap fraction analysis, providing a more accurate representation of canopy architecture at the plot scale compared to satellite-based approaches (Rich, 1990; Jonckheere *et al.*, 2004). While remote sensing techniques such as NDVI are useful for large-scale monitoring, they often fail to detect fine-scale variability in heterogeneous ecosystems such as mangroves. Therefore, HP serves as a complementary tool that enhances the accuracy of canopy assessment in field-based studies.

From an ecological perspective, the relatively high canopy cover observed in Muara Jeruju Village suggests that the mangrove ecosystem retains its functional capacity to regulate microclimate, support nutrient cycling, and provide habitat for diverse biota. Dense canopy cover reduces solar radiation reaching the forest floor, maintains humidity, and facilitates organic matter decomposition, which are essential processes for sustaining ecosystem productivity (Alongi, 2009). However, the variability observed among stations indicates that certain areas are subject to environmental stress and anthropogenic pressure, which may influence long-term ecosystem resilience. Overall, these findings underscore the importance of integrating field-based canopy assessment methods with an understanding of local environmental conditions and human activities. Such an approach is essential for developing adaptive and site-specific mangrove management strategies that can effectively maintain ecosystem stability in estuarine environments.

Beyond the structural interpretation of canopy cover, the observed variation across stations also reflects underlying ecological processes related to energy flow and resource allocation within mangrove ecosystems. Canopy structure is closely linked to leaf area index (LAI), which governs

photosynthetic capacity and carbon assimilation (Jonckheere *et al.*, 2004). Higher canopy density, as observed in Station 2, suggests a more efficient interception of solar radiation, leading to increased primary productivity and biomass accumulation (Alongi, 2009). This condition is particularly important in mangrove ecosystems, where productivity supports complex food webs and detritus-based energy pathways. In contrast, the relatively lower canopy cover in Station 1 may indicate a trade-off between survival and growth under stressful environmental conditions. Mangrove species exposed to strong hydrodynamic forces often allocate more energy toward root development and structural stability rather than canopy expansion. This adaptive strategy allows species such as *A. marina* to withstand physical stress but may result in reduced canopy density and lower aboveground biomass (Kathiresan & Bingham, 2001). Consequently, canopy cover not only reflects vegetation density but also represents an ecological response to environmental constraints.

Another important aspect to consider is the role of sediment dynamics in shaping mangrove canopy structure. In estuarine systems like Muara Jeruju Village, sediment deposition plays a dual role: it can enhance nutrient availability and support vegetation growth, but excessive or unstable sedimentation may disrupt root systems and inhibit canopy development (Ghosh & Behera, 2021). Studies have shown that optimal sediment conditions promote mangrove expansion, whereas highly dynamic sediment environments can limit canopy closure due to reduced substrate stability. Anthropogenic influence, as observed in Station 3, introduces additional complexity to canopy structure dynamics. Human activities such as selective cutting and land-use modification can alter forest structure by creating gaps that affect light distribution, temperature, and soil moisture. These microenvironmental changes can influence seedling recruitment and species composition, potentially leading to shifts in ecosystem structure over time (Alongi, 2009). Although the canopy cover in Station 3 remains within the moderate category, continued disturbance may gradually reduce ecosystem resilience if not properly managed.

Furthermore, canopy cover is strongly associated with ecosystem services provided by mangrove forests. Dense canopies enhance carbon sequestration capacity by increasing biomass accumulation and reducing carbon loss through decomposition processes. Mangroves are recognized as one of the most efficient carbon-storing ecosystems, often referred to as “blue carbon” systems (Alongi, 2012). Therefore, maintaining high canopy density is not only important for local ecological stability but also contributes to global climate regulation. The findings of this study also highlight the importance of spatial heterogeneity in mangrove ecosystems. The gradient observed from riverfront to hinterland zones demonstrates how environmental factors such as hydrodynamics, sedimentation, and human activities interact to shape vegetation structure. This spatial variability emphasizes the need for zonation-based management approaches, where conservation strategies are tailored according to specific environmental conditions and levels of disturbance (Zhang *et al.*, 2019).

In addition, the successful application of the Hemispherical Photography method in this study reinforces its potential as a practical and cost-effective tool for monitoring mangrove ecosystems. Compared to advanced remote sensing technologies, this method requires minimal equipment while still providing high-resolution data at the plot scale (Rich, 1990). This makes it particularly suitable for long-term monitoring programs in developing regions, where access to high-cost technologies may be limited. Integrating HP with remote sensing approaches could further enhance monitoring accuracy by combining fine-scale and large-scale observations (Jonckheere *et al.*, 2004). Finally, the overall findings suggest that while the mangrove ecosystem in Muara Jeruju Village remains in relatively good condition, it is not entirely free from environmental stress. The presence of moderate canopy cover in certain areas indicates early signs of disturbance that may not yet be critical but could become significant over time. Therefore, continuous monitoring and adaptive management are essential to ensure the sustainability of mangrove ecosystems in this region.

## CONCLUSION

The results of this study indicate that mangrove canopy cover in Muara Jeruju Village ranges from moderate to dense categories, reflecting a generally good ecological condition of the mangrove ecosystem. Despite being dominated by *A. marina*, canopy cover varies significantly across ecological zones, highlighting the influence of environmental gradients and anthropogenic pressures on vegetation structure. The riverfront zone (Station 1) exhibits moderate canopy cover due to strong hydrodynamic forces, tidal fluctuations, and unstable sedimentation processes associated with the Kapuas River, which limit optimal canopy development. In contrast, the middle

zone (Station 2) shows the highest canopy cover, supported by relatively stable environmental conditions, reduced disturbance, and favorable substrate characteristics that promote dense and well-developed canopy formation. Meanwhile, the hinterland zone (Station 3) also falls within the moderate category but displays a more heterogeneous canopy structure, likely influenced by human activities such as waste disposal, pruning, and small-scale resource utilization.

The application of the Hemispherical Photography method proved effective in capturing detailed canopy structure through analysis of light penetration and canopy openness at the plot scale. This method provides reliable and high-resolution data, making it suitable for assessing mangrove ecosystems, particularly in heterogeneous and dynamic estuarine environments. Ecologically, the relatively high canopy cover observed in Muara Jeruju Village indicates that the mangrove ecosystem still maintains its functional role in supporting microclimate regulation, nutrient cycling, and habitat provision. However, the presence of moderate canopy cover in certain areas suggests early signs of environmental stress, emphasizing the need for continuous monitoring and sustainable management. Future studies integrating canopy analysis with other ecological indicators are recommended to provide a more comprehensive understanding of mangrove ecosystem health and resilience.

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