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Article

Comparison of Mangrove Biomass in Three Different Mangrove Ecosystem Locations in Maros Regency

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Abstract. This study aims to analyze the variation in mangrove biomass across three locations in Maros Regency, South Sulawesi, namely Borongkalukua, Bonto Bahari, and Ampekale. Data collection was conducted using purposive sampling design, 27 observation plots (10×10 m; n=9 per location) were established to estimate biomass through Diameter at Breast Height (DBH) and species-specific allometric equations. Five mangrove species were identified, namely *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia alba*, *Avicennia marina*, and *Sonneratia alba*. The two-way ANOVA results showed that species ($p = 0.0003$), location ($p = 0.0266$), and their interaction ($p = 0.0065$) had significant effects on biomass. The Kruskal–Wallis test also confirmed differences in median biomass among locations ($p = 0.0104$). Borongkalukua exhibited the highest biomass (302.57 Mg/ha) dominated by *R. mucronata* and *R. apiculata*, followed by Ampekale (223.20 Mg/ha) dominated by *R. apiculata* and *S. alba*, while the lowest biomass was recorded in Bonto Bahari (129.44 Mg/ha), dominated by *A. marina*. These variations in biomass reflect differences in species' adaptive capacity to local environmental conditions. Overall, the findings emphasize that the interaction between species and location is a key determinant of mangrove biomass productivity. This study highlights the need for management and conservation strategies based on species characteristics and habitat conditions to ensure the sustainability of mangrove ecosystems in Maros Regency.

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1. Introduction

Mangrove ecosystems are tropical biological resources that play a crucial role in maintaining coastal equilibrium. They provide essential ecological functions, serving as feeding, spawning, and nursery habitats for various aquatic organisms, while simultaneously protecting shorelines from abrasion and erosion. In addition to their ecological functions, mangrove ecosystems also possess economic value through their utilization as sources of timber, construction materials, and pharmaceutical raw ingredients. Given these ecological and economic roles, mangrove conservation efforts are fundamental to ensuring environmental sustainability and supporting the well-being of coastal communities[1-2].

Climate change, driven by increasing concentrations of greenhouse gases, has resulted in global warming, which is characterized by rising average temperatures of the Earth's surface and oceans. This condition affects various ecosystems, including mangrove forests that are highly sensitive to environmental changes in coastal areas [3-4]. Mangroves are tropical–subtropical coastal ecosystems located within intertidal zones and serve essential ecological functions, including shoreline protection, habitat provision for biota, and support for aquatic productivity [5]. In addition, mangroves play a significant role in the global carbon cycle through their capacity to store carbon within both biomass and sediments, making them a strategic component in climate change mitigation. One of the primary aspects of mangroves' contribution to carbon storage is their biomass, which serves as a key indicator of the carbon sequestration potential within this ecosystem [6-7].

Biomass is defined as the total mass or weight of all living organisms within a given area at a specific point in time [8]. Variations in biomass are influenced by differences in tree diameter classes at each growth stage [9]. Mangrove forests are known to possess a substantially higher carbon sequestration capacity compared to terrestrial forests and tropical rainforests [10]. Within this ecosystem, biomass serves as a critical indicator for estimating carbon stocks, where its magnitude is largely determined by tree dimensions particularly Diameter at Breast Height (DBH) and wood density [11]. The greater the DBH value and wood density, the higher the carbon storage potential, reflecting the accumulation of plant cellular components [12]. However, the distribution of this biomass is not uniform and is strongly influenced by the variability of environmental factors (temperature, salinity, and nutrients) as well as anthropogenic pressures [13].

Although numerous studies on mangrove biomass have been conducted globally, understanding of carbon stock variation at a micro-scale under specific environmental conditions such as those in the coastal region of Maros remains highly limited [14]. This study offers novelty by comparing mangrove biomass across three distinct ecosystems in Maros Regency and examining the simultaneous influence of species and location on biomass variation using a Two-way ANOVA approach. This aligns with the findings of Razzaq (2025), whose study emphasizes that mangrove biomass variation is strongly influenced by species characteristics and environmental factors, demonstrating significant differences in stem biomass among the evaluated species [15].

In contrast to previous studies that generally focused on a single location or a single species, this study demonstrates that the interaction between species and location is the most decisive factor influencing biomass productivity. An approach that integrates linear variation in species-related biological factors with spatial variation across locations strengthens the argument that mangrove biomass is not merely a function of a single factor, but rather the result of complex interactions between species' genetic characteristics and the physical and chemical conditions of the environment in which they grow [16]. In contrast to previous studies that generally focused on a single location or a single species, this study demonstrates that the interaction between species and location is the most decisive factor influencing biomass productivity. An approach that integrates linear variation in species-related biological factors with spatial variation across locations strengthens the argument that mangrove biomass is not merely a function of a single factor, but rather the result of complex interactions between species' genetic characteristics and the physical and chemical conditions of the environment in which they grow [17].

The mangrove area in South Sulawesi is estimated to cover approximately 104,030 ha. This estimate is based on a baseline study conducted in 2010 across four regencies in South Sulawesi, namely Barru Regency (96,92 ha), Maros Regency (43.05 ha), Pangkep Regency (60.7 ha), and Takalar Regency (1.083,8 ha). Accordingly, the total mangrove forest area within these four regencies is approximately 1,284.92 ha, representing about 1.23% of the total mangrove area in South Sulawesi. The mangrove species composition commonly found in Bontoa District includes *Avicennia* spp., *Rhizophora* spp., *Bruguiera* spp., and *Sonneratia* spp [18]. The coastal zone of Maros Regency extends for approximately 31 km and encompasses several coastal districts. Specifically, Bontoa District has a coastline length of about 8,2 km, with an estimated mangrove area of approximately 45.89 ha. This area comprises several coastal villages with varying mangrove extents, including Bonto Bahari Village (15.71 ha), Borongkalukua Village (15.12 ha), and Ampekale Village (15.07 ha) (Department of Fisheries, Marine Affairs, and Livestock of Maros Regency, 2010). Nevertheless, information regarding biomass variation and the environmental factors influencing it in the coastal areas of Maros Regency remains limited. Each site exhibits distinct ecological characteristics, such as substrate type, salinity levels, and vegetation density, which may substantially influence mangrove biomass accumulation.

Therefore, this study is crucial for addressing local data gaps related to mangrove biomass potential and carbon stocks in Maros Regency. This research aims to analyze and compare mangrove biomass across three distinct mangrove ecosystem locations in Maros Regency, namely Borongkalukua Village, Bonto Bahari Village, and Ampekale Village. In addition, the study seeks to identify the dominant mangrove species at each site and to elucidate differences in their characteristics. Environmental factors contributing to variations in mangrove biomass at the study sites also constitute a primary focus of this research. From a practical perspective, the findings of this study provide baseline data that can be utilized for species- and habitat-based conservation planning, as well as serving as an initial reference for estimating blue carbon stocks to support climate change mitigation policies and mangrove rehabilitation efforts at the local level.

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2. Experimental Section

2.1. Study Site

This study was conducted within the coastal mangrove ecosystems of Borongkalukua Village, Bonto Bahari Village, and Ampekale Village, located in Bontoa Sub-district, Maros Regency.These locations were selected due to their relatively well-preserved mangrove ecosystems. In addition, these areas play an important role in maintaining coastal ecological balance, providing habitat for diverse marine biota, and functioning as natural buffers that mitigate the impacts of coastal abrasion. The research locations are presented in Figure 1.

Figure 1. Research Location in Maros Regency, South Sulawesi

2.2. Materials

The research employed a range of tools and materials. An identification guidebook was used as the primary reference for determining mangrove species in the field, while a measuring tape was utilized to measure tree diameter at breast height (DBH), and raffia rope was used to measure plot dimensions and to establish physical boundaries within the observation area. All research activities and objects were documented using a camera, and writing instruments were prepared specifically for recording observational data. For technical plot arrangement within the 10 m × 10 m plots, measuring tapes and wooden stakes played a crucial role in accurately delineating and marking sampling points.

2.3. Sampling Procedure

The selection of study sites was conducted using a purposive sampling approach, focusing on mangrove ecosystem conditions along the coastal areas of Borongkalukua, Bonto Bahari, and Ampekale. These sites were chosen because they represent relatively well-preserved mangrove ecosystems with varying levels of vegetation density. At each site, a single observation area was established consisting of nine plots (N = 9), each measuring 10 × 10 m, which were used for sampling and assessing mangrove vegetation parameters.

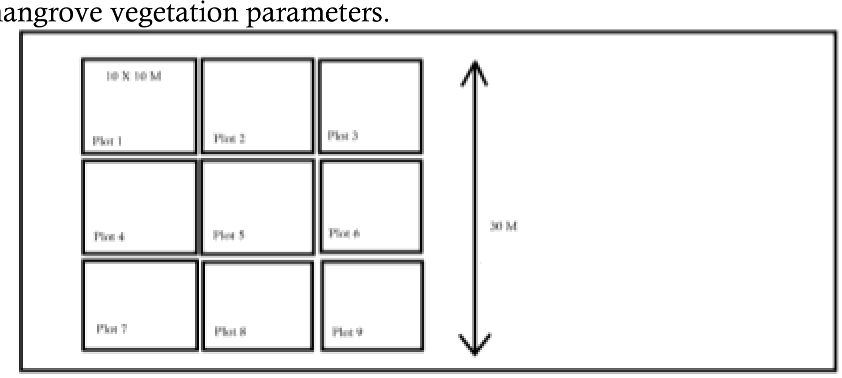

Figure 2. Observation plot design measuring

2.4. Data Collection

Mangrove species identification was conducted *in situ* through direct observation of morphological characteristics that serve as the primary diagnostic features for each species. The observed characteristics included root type, leaf shape and arrangement, flower and fruit morphology and arrangement, as well as bark texture and color, without accounting for propagules. The identification process was carried out by referring to relevant literature and standardized mangrove identification guidebooks. Meanwhile, biomass data collection involved measuring the Diameter at Breast Height (DBH) of each mangrove tree individual within the observation plots. Measurements were restricted to trees with a diameter ≥ 4 cm [19-20]. The recorded DBH values were subsequently used to estimate biomass using allometric equations specifically developed for mangrove ecosystems.

2.5. Data Analysis

Biomass data were analyzed to evaluate variations among species and study sites. Prior to statistical analysis, individual biomass values (kg) derived from allometric equations were converted into Megagrams (Mg), where 1 Mg=1.000 kg (equivalent to one metric ton). These values were then standardized to Mg/ha by scaling the total biomass within each plot to the sampling area. Subsequently, the data were subjected to assumption testing; normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was evaluated using Levene's test.

For data meeting these assumptions, a Two-way Analysis of Variance (ANOVA) was employed to determine the effects of species, location, and their interaction on biomass values, with the significance level set at $p<0.05$. In cases where data did not satisfy the assumptions of normality or homogeneity, the Kruskal-Wallis test was utilized as a non-parametric alternative to evaluate differences in median values across locations. All statistical analyses and data visualizations were performed using GraphPad Prism version 8.0. The results are presented as graphs representing the mean ± standard error ($\bar{x}$±SE) to facilitate the comparative interpretation of biomass and carbon potential within the mangrove ecosystems.

Table 1. Allometric equations for mangrove stands

No	Spesies Name	Allometrik Equations	Sumber
1	*Rhizophora mucronata*	$W = 0.1466*DBH^{2.3136}$	Komiyama et al. (2005)
2	*Rhizophora apiculata*	$W = 0.235*DBH*^{2.42}$	Komiyama et al. (2008)
3	*Avicenia alba*	$W = 0.251* \rho *DBH^{2.46}$	Komiyama et al (2005)
4	*Avicenia marina*	$W = 0.308*DBH^{2.11}$	Komiyama et al. (2008)
5	*Sonnertaia alba*	$W = 0.251*DBH^{2.46}$	Komiyama et al. (2005)

Keterangan : W = Biomassa (kg), DBH = Diameter at Breast Height (cm)

3. Results and Discussion

The observations in the mangrove ecosystems of Bontobahari, Borongkalukua, and Ampekale Villages, Maros Regency, South Sulawesi, identified 5 mangrove species (Table 2).

Table 2. Mangrove Species Identified

No	Famili	Genus	Spesies
1	Acanthaceae	*Avicennia*	*Avicennia alba*
2	Rhizophoraceae	*Rhizophora*	*Rhizophora apiculata*
3	Rhizophoraceae	*Rhizophora*	*Rhizophora mucronata*
4	Lythraceae	*Sonneratia*	*Sonneratia alba*
5	Acanthaceae	*Avicennia*	*Avicennia marina*

Based on observations conducted at the three study sites along the coastal area of Bontoa District, the mangrove species recorded belonged to three mangrove families and comprised five species, namely *Avicennia marina*, *Avicennia alba*, *Rhizophora apiculata*, *Rhizophora mucronata*, and *Sonneratia alba*.

This species composition is dominance of *Avicennia* spp., *Rhizophora* spp., *Bruguiera* spp., and *Sonneratia* spp. in coastal areas of Bontoa District, although the present study did not record *Bruguiera* spp. or associated mangrove species such as *Acanthus ilicifolius* and *Nypa fruticans* [18] who identified seven true mangrove species across six different sites in Maros Regency, including *A. alba*, *A. marina*, *R. apiculata*, *R. mucronata*, and *S. alba* species that were likewise dominant in the present study indicating a consistent core mangrove species composition along the coastal areas of Sulawesi [21].

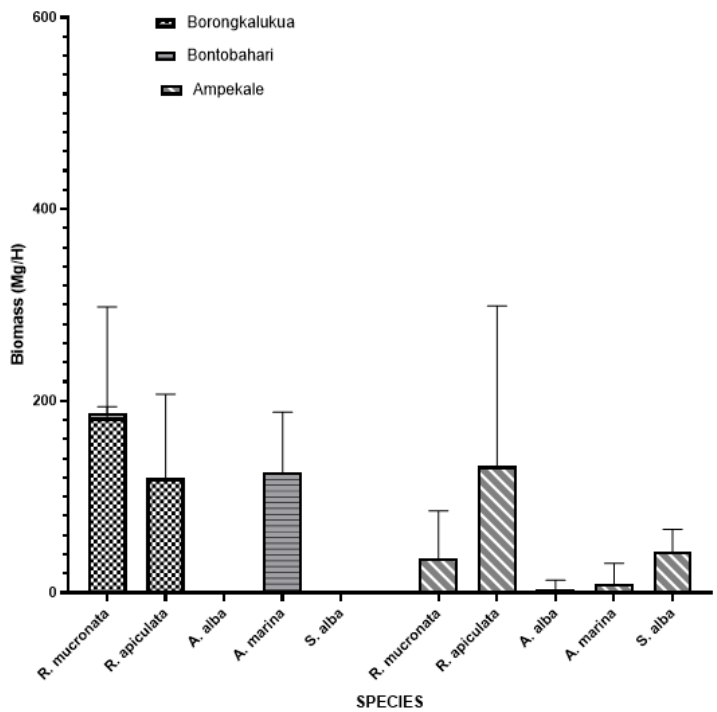

Figure 3. Graph of Mangrove Biomass based on Speciesx±S∈, based on nine plots per location (N=9)

Community structure analysis across the three study sites revealed contrasting zonation patterns. Borongkalukua was dominated by *Rhizophora mucronata* (182.77 Mg/ha) and *Rhizophora apiculata* (119.37 Mg/ha), whereas Bonto Bahari was dominated by the pioneer species *Avicennia marina* (125.26 Mg/ha). In contrast, Ampekale exhibited a heterogeneous transitional zone characterized by the co-dominance of *Rhizophora apiculata* (131.93 Mg/ha) and *Sonneratia alba* (42.86 Mg/ha).The dominance of the genus *Rhizophora* in Borongkalukua and Ampekale confirms the role of these species as structural components of climax mangrove forests, characterized by high efficiency in carbon dioxide uptake associated with their relatively high wood density [16].

This zonation pattern reflects the process of mangrove ecological succession, in which pioneer species are gradually replaced by species that are more tolerant of increasingly stable environmental conditions, while simultaneously indicating ecosystem recovery and the enrichment of mangrove community structure and function [22].

Table 3. Summary of Two-way Repeated Measures ANOVA on mangrove biomass across different species and locations.

Source of Variation	% of Total Variation	DF	MS	F (DFn,DFd)	P-value
Species	14.74%	4	35048	F(1.97,15.73)=14.44	0.0003***
Location	2.84%	2	13521	F(1.09,8.72)=6.89	0.0266*
Interaction (Species x Location)	34.78%	8	41350	F(1.58,12.66)=8.54	0.0065**
Residual (Error)	-	64	4840	-	-

The results of the two-way ANOVA indicated that species, location, and their interaction had significant effects on mangrove biomass. The species factor accounted for 14.74% of the total variance, with a p-value of 0.0003, indicating a highly significant effect. These findings confirm the presence of substantial differences in biomass production among mangrove species. Interspecific variations in stem biomass and carbon content among mangrove species are statistically significant and are influenced not only by local environmental conditions but also by species-specific physiological and structural characteristics, such as wood density and growth patterns. Such differences have direct implications for the carbon sequestration and storage capacity of different mangrove species [23].

The location factor, despite contributing a smaller portion of 2.84%, remains statistically significant (p=0.0266), indicating that environmental variations across sites are not stochastic. Spatial and temporal salinity variations driven by site-specific differences and tidal dynamics significantly influence the structure and characteristics of mangrove vegetation [24].

The interaction between species and location emerged as the most influential factor, accounting for 34.78% of the total variance with a p-value of 0.0065, indicating a significant effect. This result suggests that the biomass response of each species varies depending on its growth location. Mangrove dynamics and biomass are governed by the interaction between species-specific physiological tolerance and site conditions, particularly soil salinity gradients [25]. Salinity acts as a key factor influencing mangrove growth responses and biomass in a species-specific manner, whereby certain species may exhibit higher productivity at sites with environmental conditions that closely match their ecological requirements [26]. The occurrence of particular species is closely associated with the distinct environmental conditions at each site, underscoring the critical role of species location interactions in shaping community structure and ecosystem productivity in mangrove ecosystems [27]. These results indicate that the biomass potential of mangrove species is not uniform, but is strongly influenced by the specific environmental conditions at each study site.

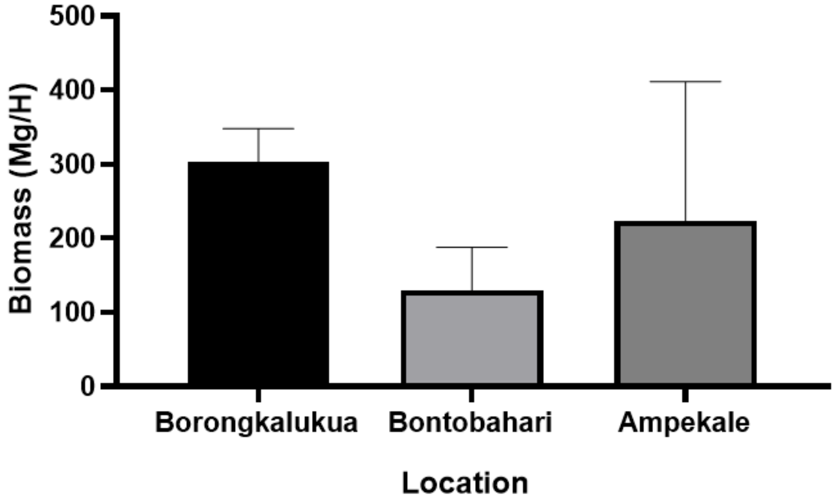

Figure 4. Total Mangrove Biomass at Research Locations ($x \pm S \in, N = 9$)

Figure 4 presents the biomass estimates from the three study sites, revealing significant variation among locations. Borongkalukua exhibited the highest biomass, reaching 302.57 Mg/ha, substantially exceeding that of the other two sites, which were also dominated by *Rhizophora* species. The high level of biomass accumulation was not solely attributable to individual tree density. This dominance indicates the resilience of the genus *Rhizophora*, which, both physiologically and allometrically, generally possesses higher wood density than pioneer species such as *Avicennia*. Consequently, for an equivalent stem volume, *Rhizophora* stores a considerably greater amount of carbon mass [23]. This dominance is facilitated by the deep muddy substrate conditions in Borongkalukua, which experience minimal wave disturbance, allowing the stilt root systems of *Rhizophora* to effectively support tree structure and attain maximum diameter at breast height (DBH) without a high risk of uprooting. Under these conditions, *Rhizophora* is able to optimize its growth rate through enhanced biomass accumulation [28], thereby making it the most efficient carbon sink in this area.

In contrast, Bonto Bahari recorded the lowest biomass, amounting to 129.44 Mg/ha, and was predominantly dominated by *Avicennia marina* (125.26 Mg/ha). This site exhibited comparatively lower biomass levels under the dominance of *A. marina*. The reduced biomass at this location is not solely attributable to species differences, but rather reflects vegetation adaptive responses to environmental stressors. Bonto Bahari is characterized by high salinity levels and moderately textured sediment substrates, conditions that may substantially constrain mangrove stem diameter growth [29]. *Avicennia marina* is known as a species with high salinity tolerance; however, a consequence of this adaptation is often a greater allocation of energy toward survival rather than toward the accumulation of woody biomass [30]. Consequently, the community structure in Bonto Bahari more closely reflects a stressed mangrove forest rather than a high-productivity mangrove forest [29].

Meanwhile, Ampekale recorded a biomass of 223.20 Mg/ha, representing a transitional zone with a mixed community structure dominated by *Rhizophora apiculata*, followed by *Sonneratia alba*. The presence of *S. alba* indicates a nutrient-rich habitat with relatively higher oxygen availability. The occurrence of *S. alba* also reflects adaptation to substrate conditions and more variable tidal dynamics at this site [31]. Such environmental conditions support the mixed growth of several species with a relatively high level of biomass. This biomass is higher than that observed at Bonto Bahari, but remains lower than that of the denser mangrove forest in Borongkalukua.

The results of the Kruskal–Wallis test revealed a significant difference in the median total biomass among the three study sites ($p = 0.0104$). With a Kruskal–Wallis statistic of 9.125 and three groups tested, these findings indicate that biomass distribution is not uniform across the study locations. This result further confirms that heterogeneity in environmental conditions among the three observation stations exerts a significant influence on vegetation productivity and biomass accumulation [24]. This variation is primarily driven by differences in local environmental characteristics, such as salinity fluctuations, tidal dynamics, and the physical properties and composition of sediments [26]. Comparatively, the highest biomass value recorded in this study, particularly in Borongkalukua (302.57 Mg/ha), is considered high when compared with the average mangrove biomass in Indonesia, which ranges from 240-303 Mg/ha [32-33]. These findings position the Borongkalukua ecosystem as a High Conservation Value area at the regional level, playing a crucial role in local carbon mitigation due to its biomass levels exceeding the average productivity of mangrove ecosystems.

Overall, a clear pattern of biomass zonation was observed: sites with relatively stable environmental conditions (Borongkalukua) were dominated by the climax species *Rhizophora*, which exhibited high biomass, whereas sites subjected to higher physical stress (Bonto Bahari) were primarily occupied by the pioneer species *Avicennia*, characterized by lower biomass. The pronounced contrast between 302.57 Mg/ha and 129.44 Mg/ha underscores that conservation strategies cannot be uniformly applied across sites. Areas dominated by *Rhizophora* should be prioritized for strict protection as major carbon reservoirs, while *Avicennia*-dominated areas require a stronger focus on rehabilitation efforts to enhance coastal resilience. Effective climate mitigation strategies must account for spatial variation in carbon stocks driven by local environmental gradients and geomorphological settings [34].

4. Conclusion

Five mangrove species were identified across the three study sites, namely *Avicennia marina*, *Avicennia alba*, *Rhizophora apiculata*, *Rhizophora mucronata*, and *Sonneratia alba*. It can be concluded that mangrove biomass productivity in Maros Regency is highly heterogeneous and is primarily determined by the interaction between species-specific characteristics and local environmental conditions. Borongkalukua recorded the highest biomass, at 302.57 Mg/ha, dominated by the climax genus *Rhizophora*, reflecting stable and mature habitat conditions. In contrast, Ampekale exhibited an intermediate biomass value of 223.20 Mg/ha, representing a mixed transitional zone, while Bonto Bahari recorded the lowest biomass, at 129.44 Mg/ha, due to the dominance of the pioneer species *Avicennia marina*, which is adapted to environments experiencing high physical stress.

These findings underscore that conservation strategies cannot be uniformly applied; areas with high biomass such as Borongkalukua should be prioritized as primary blue carbon sink protection zones, whereas lower-biomass areas such as Bonto Bahari should focus on enhancing ecosystem resilience and coastal protection functions. Overall, these results contribute valuable insights to the literature by emphasizing the importance of site-specific management approaches in ecosystem-based climate change mitigation efforts involving mangrove ecosystems in South Sulawesi.

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