International Journal of Agriculture and Biosciences 2026, 15(1): 69-76.
https://doi.org/10.47278/journal.ijab/2025.142

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Assessing the Carrying Capacity of Mangrove Ecosystems for Sustainable Ecotourism Development in Pangandaran, Indonesia

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ABSTRACT

The sustainability of mangrove ecotourism is greatly influenced by an area's physical, real, and practical carrying capacity (ECC). Therefore, this study aims to evaluate and compare the physical carrying capacity (PCC), real carrying capacity (RCC), and adequate carrying capacity (ECC) in Bojongsalawe, Bulaksetra, and Batukaras. The study procedures were conducted using a mixed quantitative and qualitative method with direct observation in the field. Assessment was performed by integrating biophysical parameters, ecological constraints, and management capacity. The results showed that although the 3 locations had high PCC, the ECC value was lower due to limited management personnel and ecosystem sensitivity. In Batukaras, the actual visits exceeded all calculated thresholds, showing overcapacity conditions and threats to environmental sustainability. The current study emphasized the importance of zoning strategies, visit restriction policies, increasing management capacity, and community-based conservation. Further studies are recommended to use a GIS-based spatial approach and more comprehensive socio-ecological indicators.

Keywords: Mangrove ecotourism, Carrying capacity, Pangandaran, Sustainability tourism, Ecosystems management.

Article History
Article # 25-292
Received: 22-May-25
Revised: 09-Jul-25
Accepted: 18-Aug-25
Online First: 31-Aug-25

INTRODUCTION

Mangrove ecosystems are important coastal habitats in tropical and subtropical regions, and they function as an important link between land and sea. These habitats provide various ecological services important for environmental health and human well-being (Rizal et al., 2024), such as a natural barrier against storm waves, tsunamis, and coastal erosion. The root system can dissipate wave energy, which protects inland areas from flooding and land loss. Mangrove ecosystems also support a variety of species, including fish, crustaceans, birds, and mammals. The complex root structures provide bursary habitats for many marine organisms, contributing to rich biodiversity. In addition to ecological functions, these habitats provide resources, including timber, firewood, and medicinal plants, and support ecotourism and cultural practices, contributing to coastal communities' socio-economic development (Wardhani, 2011; Bimrah, 2022; Suhardi et al., 2024). In the context of tourism, mangrove ecotourism offers an educational and sustainable experience. Activities such as interpretive trails, wildlife observation, and participation in planting can increase tourist environmental awareness. Wahyuningsih (2021) stated that several mangrove areas in Indonesia had the potential to be developed for ecotourism, but their management still needed to be improved.

Developing ecotourism can benefit coastal communities economically through job creation and increased income. Utomo and Pulungan (2023) emphasized that activities that involved local communities in management and decision-making could simultaneously improve welfare and environmental conservation. One of the most significant benefits of mangrove ecotourism is its contribution to environmental conservation. The increasing

Cite this Article as: Zallesa S, Ihsan YN, Pribadi TDK, Qiang YX, Iskandar, Syamsudin ML and Irawan B, 2026. Assessing the carrying capacity of mangrove ecosystems for sustainable ecotourism development in Pangandaran, Indonesia. International Journal of Agriculture and Biosciences 2026, 15(1): 69-76. https://doi.org/10.47278/journal.ijab/2025.142

A Publication of Unique Scientific Publishers

interest of tourists in sustainable nature tourism helps raise public awareness of the importance of maintaining ecosystems. In addition, it provides new sources of income for coastal communities (Nelly et al., 2020; Pratama et al., 2020). Local people can feel its direct economic benefits by becoming guides, artisans, or transportation service providers. Despite the potential, the increase in tourism activities has created new environmental challenges, placing ecological pressure on ecosystems, specifically when such activities exceed the environment's carrying capacity due to poor management or excessive development.

Mangrove ecosystems play an important role in supporting environmental sustainability and the welfare of coastal communities. The main functions include protecting the coast from abrasion, providing habitat for marine biota, storing blue carbon, and filtering waste from land (Alongi, 2002). The uniqueness of ecosystems attracts tourists, specifically in activities such as tracking, environmental education, planting, bird watching, and nature photography. In addition to providing a nature-based tourism experience, mangrove ecotourism also contributes to improving the economy of local communities (Sukuryadi et al., 2020).

Increased tourism activities that exceed environmental carrying capacity can cause soil erosion, air pollution, and disturbance to wildlife, specifically in rural areas with inadequate waste management systems. Although economic and cultural benefits exist, the activities negatively impact the environment, such as increased waste and pollution (Towoliu et al., 2020; Kurniawansyah et al., 2021; Askar et al., 2021). Overcapacity tourism activities significantly impact and can even worsen environmental degradation, specifically in areas with low energy efficiency and high urbanization (Ahmad & Jabben, 2023). This emphasizes the importance of policies tailored to local conditions to minimize environmental negative impacts. Carrying capacity is very relevant in planning and managing marine ecotourism. The carrying capacity of the mangrove ecosystem in the context of ecotourism refers to the ability of the ecosystem to receive tourist visits without causing significant environmental damage (Apdillah et al, 2023; Minata et al., 2024). That is one of the crucial aspects of ecotourism management and planning, especially in areas with high conservation value, such as mangroves. The assessment of the carrying capacity not only looks at the number of visitors that the area can accommodate but also considers ecological factors that support the long-term sustainability of the area, such as water quality, habitat damage, and the impact of human activities on the ecosystem (Hidayat et al., 2024; Faubiany et al., 2024). Assessment of the carrying capacity of the mangrove ecosystem for sustainable ecotourism development requires a holistic approach involving various aspects, including visitor capacity, area management capabilities, and ecological impacts of tourism activities. Several previous studies have shown that ecotourism development that does not consider carrying capacity can risk causing ecosystem damage, such as mangrove habitat degradation, pollution, and changes in biodiversity (Chauhan et al., 2017; Hernandez et al., 2020). Therefore, analysis of the carrying capacity of mangrove areas in Pangandaran is important to maintain a balance between economic development through ecotourism and environmental protection. Ahmad and Jabeen (2023) showed that uncontrolled growth of marine tourism could result in environmental degradation, such as damage to coral reefs, seawater pollution, and loss of biodiversity. Carrying capacity calculation must be the basis for determining tourism capacity, visiting schedules, and forms of permitted activities. This factor is a sustainability measurement tool that integrates ecological, social, and economic dimensions (Sofiyudin, 2024; Rasidi et al, 2024). Ecotourism management that fails to consider carrying capacity risks typically damages the environment and reduces the quality of the tourism experience. Marine ecotourism destination managers can create adaptive, participatory, and long-term management systems by considering the factors.

This study aims to assess the carrying capacity of the mangrove ecosystem in Pangandaran and provide recommendations for sustainable ecotourism development. This study will examine various factors that influence the carrying capacity of the mangrove ecosystem, including the number of visitors that can be accommodated, supporting infrastructure, and potential damage caused by tourism activities. In this context, the concept of carrying capacity will be the primary focus, considering the interaction between visitor capacity and the ability of the ecosystem to maintain its function in the long term. Therefore, this study aims to measure the environmental carrying capacity of mangrove ecosystems for the management and development of sustainable ecotourism in Pangandaran. The results are expected to help minimize the impact of tourism activities, considering that ecosystems are vital for ecological balance, climate regulation, and supporting human livelihoods. This shows that conservation is essential to ensure the health of coastal environments and the well-being of the dependent communities. In addition, this research is expected to provide a better understanding of the carrying capacity of the mangrove area in Pangandaran and inform more sustainable ecotourism management by maintaining a balance between economic benefits and preservation of the mangrove environment.

MATERIALS & METHODS

The current study was carried out in the Pangandaran district at three locations: Bulaksetra, located in the Pangandaran subdistrict; Bojongsalawe, in the Parigi subdistrict and Batukaras, in the Cijulang district (Fig. 1). The locations were located along the southern coastline of Java Island and were known for their ecological significance, specifically mangrove ecosystems. These areas were also known for potential ecotourism development and could be used to assess the region's carrying capacity and sustainability of mangrove-based ecotourism.

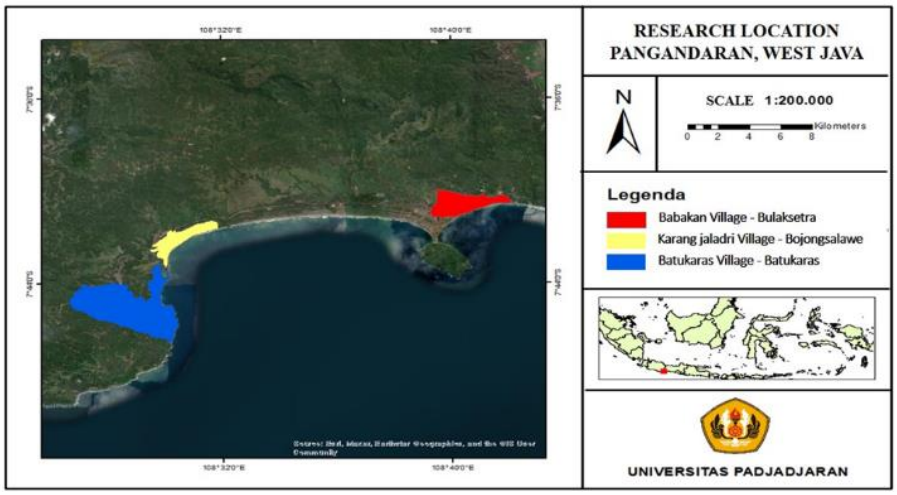

Fig. 1: Research Location Map.

This study used a mixed-method approach, combining quantitative and qualitative methods. Data collection was performed using observation methods at three locations: Bulaksetra, Bojongsalawe, and Batukaras. The process comprised visual observation of the physical condition of the environment, land use, tourism activities, and tourism support facilities.

Data Analysis

Data analysis was carried out using various methods, including;

The area of carrying capacity was assessed using a formula adopted from Yulianda (2007).

$$DDK = K\ x\ \left(\frac{Lp}{Lt}\right) x\ (\frac{Wt}{Wp})$$

DDK = Carrying capacity of the area, K = Ecological potential of tourists per unit area (person), Lp = Length or area of utilizable area (m or m^2), Lt = Unit area for a specific category (m or m^2), Wt = time provided by the area for tourism activities in one day (hours/day), Wp = Time spent by tourists for each specific activity (hours/ day).

Physical Carrying Capacity (PCC)

PCC = A x V/a x Rf

A = Available area for tourism utilization, V = Tourist, a = area needed by Tourists according to Douglas (Sasmita, 2014) (swimming activities 302 feet, boating 544 feet, picnicking 2725- 2726 feet), Rf = Rotation factor is the number of daily visits allowed to one location.

RCC

RCC = $PCC\ x$ F1 x f2 x ... ... x fn

RCC = Real carrying capacity, PCC= Physical carrying capacity, Fn = Correction factor (n data).

ECC

ECC = RCC x MC

ECC = effective carrying capacity, RCC = real carrying capacity, MC = Management area capacity. Management capacity is calculated using the formula:

MC = Rn / Rt x 100%

Rn = number of active staff workers, Rt = total staff number.

Next, compare PCC, RCC, and ECC with the number of tourist visits per day, with the following provisions:

PCC> RCC and RCC ≥ ECC

If the PCC > RCC and RCC ≥ ECC, the carrying capacity is significant; if the ECC > RCC > PCC, the number of Tourists has exceeded the limit of carrying capacity; if the PCC = RCC = ECC, the carrying capacity is optimal.

RESULTS

Area of Carrying Capacity

Table 1 shows that the value of carrying capacity at Bulaksetra for educational tourism activities was 100 people/day, while mangrove planting activities had 200 people/day. Based on the results, the activities possible with the current conditions in Bulaksetra were educational tourism and mangrove planting. This was in line with the limited supporting facilities and infrastructure for other tourism activities.

Table 1: Carrying Capacity of Bulaksetra Mangrove Tourism Area

Parameters	Tourism Activity	
	Education	Mangrove planting
Ecological Potential (K)	20 people	50 people
Unit Area (Lt)	40m^2	40.000m^2
Tracking area (Lp)	4m x 10m = 40m^2	50m x 800m = 40.000m^2
Travel time (Wt)	10	4
Time 1 Day (Wp)	2	2
Regional Carrying Capacity (DDK)	100	200

Based on Table 2, Bojong Salawe had a mangrove area that could be used for tourism activities, covering an area of 3Ha. The location was divided into several activities, including mangrove track exploration with an area of 300m, a carrying capacity of 30 people/day, an estimated operational time of 10 hours, and a visit time of 2 hours per person. For photography tourism activities, the available area was 50m^2, with a visit time of 2 hours per person and a carrying capacity of 5 people/ day. Planting mangroves had a value of 100 people/day. According to Yunita et al. (2023), the mangrove area of Bojongsalawe had a carrying capacity of 40 tourists/day, but utilization was suboptimal due to the lack of supporting facilities. Therefore, the development of supporting facilities was needed to increase tourist attractions. Compared to the results of Yunita et al. (2023), the current

Table 2: Carrying Capacity of Bojongsalawe Mangrove Tourism Area

Parameters	Tourism Activity				
	Walking Track	Photography	Education	Sit back	Mangrove Planting
Ecological Potential (K)	1people	1people	10people	1people	50people
Unit Area (Lt)	50m^2	50m^2	50m^2	5m^2	20.000m^2
Tracking area (Lp)	300m^2	50m^2	50m^2	5m^2	20.000m^2
Travel time (Wt)	10	10	10	10	4
Time 1 Day (Wp)	2	2	2	2	2
Regional Carrying Capacity (DDK)	30	5	50	5	100

Table 3: Carrying Capacity of Batukaras Mangrove Tourism Area

Parameters	Tourism Activity
	Mangrove planting
Ecological Potential (K)	100people
Unit Area (Lt)	60.000m^2
Tracking area (Lp)	60.000m^2
Travel time (Wt)	4
Time 1 Day (Wp)	2
Regional Carrying Capacity (DDK)	200

study showed an increase in tourist capacity in the Bojongsalawe. Improvements could influence infrastructure and recreational facilities, affecting carrying and tourist capacity.

The results of the analysis at Batukaras are in Table 3. They show that the most possible activity in Location 3 Batukaras was mangrove planting, with a carrying capacity of 200 people/day. The availability of supporting facilities and infrastructure in Batukaras affected other activities. In 2018, there were other tourist activities, such as walking tracks, educational tours, and relaxing. However, after the COVID-19 pandemic, the existing facilities were damaged due to a lack of maintenance, and were not revitalized.

PCC, RCC

Table 4 shows the value of each limiting factor in the 3 locations. Batukaras had a very low Cf5 value, requiring special attention because it has a high potential for ecosystem degradation. This was in line with Gunawan and Kurniawan (2020), who stated that low mangrove vegetation was a critical indicator in managing ecosystem-based tourism carrying capacity. Based on the results of the PCC, the average duration was 2 hours of visit, with 4 four changes (rotation) of tourists per day. The value of PCC in Bulaksetra was 1230 people /day, Bojongsalawe 1923 people/day, and Batukaras 1846 people/day. This showed the maximum capacity of tourists that could be accommodated without considering other limiting factors, such as environmental conditions, tourists' comfort, and conservation aspects. However, due to tourism activities, the PCC did not consider the ecosystem degradation factor. The highest RCC was in Bojongsalawe, valued at 82 people/day, followed by Bulaksetra at 60 People/day and Batukaras at 32 people/day. This significant difference was caused by the low correction factor (Cfn) for PCC. The results showed that the dominant limiting factor of each location was different. In Bojongsalawe and Batukaras, the lowest Cfn value was from vegetation conditions (0.16 and 0.07), indicating the area's vulnerability to disturbances from tourism activities. In Bulaksetra, the main limiting factor was soil erosion (0.33), showing soil sensitivity to weathering and damage due to visitor loads. According to Cifuentes (1992), although the area accommodated a relatively large number of tourists, the RCC value obtained was lower after considering ecological limiting factors.

The low RCC value showed the need for strict visitor management based on carrying capacity. Bojongsalawe and Baulaksetra still had the potential to be developed as limited ecotourism destinations, provided that area zoning and vegetation restoration were considered. Batukaras were more suitable for development as a conservation area or educational tourism with limited access to prevent further damage to mangrove ecosystems (Zallesa et al., 2025).

Table 4: Value of PCC, RCC and Limiting Factors

Location	Value of Cfn					PCC	RCC
	Rainfall (Cf1)	Slope (Cf2)	Soil erosivity (Cf3)	Biota (Cf4)	Vegetation (Cf5)		
Bojongsalawe	0.851	0.8	0.4	0.980	0.16	1923	82
Bulaksetra	0.851	0.8	0.33	0.986	0.22	1230	60
Batukaras	0.851	0.8	0.37	0.978	0.07	1846	32

ECC

Table 5 shows the results of the ECC at 3 locations. Bojong Salawe had the highest value of ECC at 49 people/day, followed by Bulaksetra at 17 people/day and Batukaras at seven people/day. The number of active staff greatly affected the area management capacity. According to Laori et al. (2024), ECC was calculated by considering the proportion of active staff to total staff and area management capacity, which reflected the actual ability of a destination to manage tourist visits sustainably. Differences in ECC values between locations showed the importance of strengthening management capacity and optimizing human resources in managing tourist destinations. A study by Yan (2022) emphasized that the evaluation of tourism carrying capacity must consider managerial factors to ensure the sustainability and quality of the tourist experience.

Table 5: Value of ECC

Location	Active Employee staff (Rn)	Total Number of Staff (Rt)	Area Management Capacity (MC)	ECC
Bojongsalawe	12	20	0.6	49
Bulaksetra	4	14	0.2	17
Batukaras	7	30	0.2	7

Analysis of Carrying Capacity and Pressure of Tourist Visits

Table 6 compares the values of PCC, RCC, ECC, and average tourist visits per day at 3 locations in Pangandaran. The results showed that all locations experienced several visits that exceeded their respective ECC values. Bojongsalawe had an actual number of visits of 60 tourists/day, which exceeded the ECC but was still below the RCC. Bulaksetra recorded an ECC of 17 tourists /day, far below its PCC and RCC, with actual visits of around 40 tourists/day. Batukaras had the lowest ECC, only 7 tourists/day, compared to actual visits reaching 25

tourists/day. Based on the comparison between PCC, RCC, ECC, and the average actual daily visits, the 3 locations experienced visit pressure that exceeded their ECC. Consistently exceeding the ECC limit can harm mangrove ecosystems by causing vegetation damage, disturbance to local biota, and decreased tourist attractions. This was in line with Navarro-Radén et al. (2022), who stated that tourism management based on carrying capacity must be the primary foundation in planning sustainable tourism areas.

Table 6: Comparison of values PCC, RCC, ECC, and Actual visit

Location	PCC People/day	RCC People/day	ECC People/day	Actual visit People/day
Bojongsalawe	1.923	82	49	60
Bulaksetra	1.230	60	17	40
Batukaras	1.846	32	7	25

DISCUSSION

The analysis showed that all 3 mangrove tourism sites experienced tourist visits that exceeded their respective ECC. For example, in Batukaras, actual visits reached almost 4 times the set ECC. This imbalance reflected the mismatch between physical and managerial capacity and visitor numbers, which could lead to a decline in the quality of the tourist experience. Ewaldo et al. (2023) showed the importance of carrying capacity evaluation in mangrove tourism management. The results showed that although the PCC was high, the ECC value could be significantly lower after considering factors such as management capacity and ecosystem conditions. Therefore, tourism management must be based on ECC to ensure environmental and social sustainability. Regarding policy implications, local governments and tourism managers must integrate carrying capacity evaluation into planning and decision-making. This included setting daily visit limits, developing environmentally friendly infrastructure, and promoting conservation awareness among tourists and local communities (Wopa et al., 2022; Efani, 2024).

Environmental carrying capacity limits an area's ability to accommodate human activities without causing ecological, social, and economic damage. In the context of tourism, this concept was crucial for determining the maximum number of tourists a destination could accommodate without compromising the quality of its environmental carrying capacity (Abdillah et al., 2020). This included PCC, the maximum number of tourists a space and its facilities could support; ecological carrying capacity, the environment's ability to absorb the negative impacts of tourism, such as pollution and habitat degradation; and social carrying capacity, the local community's tolerance for social and cultural pressures caused by tourism, as well as the degree of comfort tourist experienced while visiting the destination. Understanding carrying capacity in a multidimensional way allowed tourism managers to develop adaptive and participatory strategies for maintaining the sustainability of destinations (Utami et al., 2022; Rifanjani et al, 2024).

Ghasemi and Hamidi (2022) reported that neglecting ECC led to ecosystem degradation, such as reduced mangrove biodiversity and physical damage to root systems. Similarly, Navarro-Radén et al. (2022) noted that inappropriate tourist loads in protected areas reduced habitat quality and satisfaction over time. The mismatch between RCC and ECC across all sites was primarily attributed to inadequate staffing and insufficient management capacity. According to Ewaldo et al. (2023), human resources were key limiting factors in managing sensitive ecotourism zones, regardless of the physical space available.

These results showed the need for policy interventions, including establishing clear daily visitor limits, mandatory ecotourism guidelines, and enforcing zoning regulations to manage ecological pressure. As supported by Ardila and Galeano (2023), Zonation strategies have proven effective in reducing stress on highly sensitive mangrove regions by spatially distributing tourist activities. It is reality, not all mangrove areas can be used for tourism activities, considering the need to maintain the area's ecological integrity, such as core conservation areas, rehabilitation areas, and fauna habitat protection zones. In addition, aspects of tourist comfort and safety were also considered. Sustainable tourism standards recommend reducing PCC by 30-50% to maintain the quality of the tourist experience and avoid ecosystem damage.

Sustainable ecotourism development in the mangrove ecosystem of the Pangandaran district requires a holistic approach and is based on a deep understanding of the ecosystem's carrying capacity. Based on the results of this study, various ecological, social, and economic factors greatly influence the carrying capacity. Assessment of this carrying capacity is important to ensure that ecotourism management is economically profitable and ecologically sustainable. A well-maintained mangrove ecosystem can provide many benefits for the sustainability of ecotourism, from providing habitat for local fauna to protecting the coast from erosion. However, it should be noted that the pressure caused by excessive numbers of tourists can damage the structure of the mangrove itself, reduce its ecological function, and even affect the quality of the surrounding water and soil (Purnomo et al., 2023). For example, visitors who do not comply with management rules can damage mangrove vegetation, which will reduce the ecosystem's carrying capacity. As explained by Teguh et al. (2021), mangrove damage can occur if there are no clear restrictions on tourist access and adequate supervision of their activities. Therefore, the government and managers need to determine the maximum capacity of visitors and apply sustainable ecotourism principles in managing mangrove areas. Wang et al. (2022) explained that community-based approaches not only increase local income but also strengthen community commitment to preserving the environment. In Bali, a successful example of implementing community-based management shows that educated and empowered communities can act as supervisors and implementers of existing regulations. Therefore, training programs for local communities on the importance of mangrove conservation and ecotourism governance should be an integral part of ecotourism development in Pangandaran.

Considering its natural wealth, Pangandaran has excellent potential to become a sustainable mangrove

ecotourism destination. However, the biggest challenge in developing ecotourism in the mangrove area is maintaining a balance between environmental conservation and economic interest. As explained by Purnomo et al. (2023), the success of sustainable ecotourism management is highly dependent on careful planning and the involvement of various parties, including local communities, government, and the private sector. Without good coordination, ecotourism development risks causing greater damage to the mangrove ecosystem.

The implications of this study in terms of suboptimal management of carrying capacity could accelerate the destruction of mangrove habitats and disrupt their ecological functions, such as coastal protection, carbon absorption, and habitats for aquatic biota. Weakness in area management, specifically regarding the number and competence of human resources, required policy intervention to increase capacity and improve institutional management. Local governments and tourism managers must use ECC results to determine visit limits, tourism spatial planning, and ecotourism activity permits. With a capacity-based management approach, the economic benefits of tourism could be maintained sustainably without sacrificing the sustainability of natural resources and the involvement of local communities (Islam, 2025). In addition, policies supporting local community empowerment and monitoring technology development must be a top priority in mangrove ecotourism planning in this area. Local communities' involvement in managing mangrove ecotourism in Pangandaran is crucial to creating fair and sustainable management.

Conclusion

In conclusion, although the 3 locations had relatively high PCC, the RCC and ECC were significantly lower due to biotic and managerial limitations. The imbalance between carrying capacity and the actual number of visits posed a serious risk to the sustainability of mangrove ecosystems and tourist comfort. Batukaras had the lowest ECC of 7 people/day but received actual visits up to 25 people/day, showing the most severe overcapacity condition. Meanwhile, Bojongsalawe and Bulaksetra each also showed visitor pressure exceeding the ECC threshold. This mismatch between capacity and the actual number of visits could cause degradation, a decline in the quality of tourism services, and long-term space utilization conflicts. Therefore, the management of mangrove ecotourism in this area needed to be directed at strengthening managerial capacity, controlling the number of tourist visits, and implementing conservation-based tourism strategies and community participation to ensure the socio-ecological sustainability of the area. These results showed the importance of carrying capacity-based management for ecotourism planning and development. Overcapacity posed a risk of environmental degradation and impacted tourism's educational and economic value.

Recommendations

1. Implementing a zoning system by dividing mangrove areas into conservation, buffer, and tourism zones to balance ecological protection with tourism activities. This strategy is important to maintain sustainable ecosystems, reduce visitor pressure on sensitive areas, and strengthen managerial capacity by increasing the number and competence of field staff in mangrove tourism management, including training on conservation, tourism interpretation, and environmental risk management.
2. Limiting the number of daily visits by implementing a ticket or online reservation system based on daily quotas according to the ECC value ensures that the number of visits does not exceed the management and ecosystem capacity.
3. Involving the community in managing, supervising, and providing tourism services (local guides, mangrove education, and local products). This is expected to strengthen the community-based approach and improve socio-economic sustainability.
4. Conduct periodic monitoring of tourism carrying capacity through biophysical and social indicators, including visitor perceptions and ecosystem impacts.
5 Further studies: Integrating GIS-based spatial analysis and long-term ecological monitoring to develop predictive carrying capacity models

DECLARATIONS

Funding: This research is funded by Universitas Padjadjaran with the lecturer's dissertation grant scheme.

Acknowledgement: The authors are grateful to Universitas Padjadjaran for funding the internal grant scheme for Universitas Padjadjaran lecturers' dissertation study and to all parties involved in the study and writing of the manuscript.

Conflict of Interest: The authors declare no conflicts of interest related to this study.

Data Availability: All the data is available in the article.

Ethics Statement: The authors declare that no Gen AI/ Deepseek was used in the writing/creation of this manuscript.

Author's Contribution: SZ, YNI, TDKP, YXQ, Is, MLS, and BG designed the study. They supervised and coordinated field observations and drafted the manuscript. All authors critically revised it and approved the final version.

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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