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Spatial Assessment of Coastal Carrying Capacity and Current Coastal Utilization for Sustainable Coastal Management of Jepara Region, Indonesia

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RESEARCH ARTICLE

Spatial Assessment of Coastal Carrying Capacity and Current Coastal Utilization for Sustainable Coastal Management of Jepara Region, Indonesia

Abstract. Balancing coastal resource utilization with environmental conservation is a fundamental challenge for achieving sustainable coastal development. This study assessed the spatial suitability between coastal carrying capacity and current coastal utilization in Ujung Piring, Jepara Region, Indonesia, to support sustainable coastal management. A spatial carrying capacity assessment was conducted following the framework of the Indonesian Minister of Environment Regulation No. 17 of 2009, complemented by key oceanographic parameters including bathymetry, seabed morphology, coral reef condition, and current patterns. Geographic Information System (GIS)-based overlay analysis was applied to integrate multiple spatial datasets and evaluate the compatibility between environmental carrying capacity and existing coastal utilization.

The assessment classified the study area into four carrying-capacity classes. Classes I and II, covering 1,254.71 ha, exhibited high suitability for capture fisheries, aquaculture, and coastal tourism, whereas Classes III and IV, totaling 574.21 ha, demonstrated more limited carrying capacity, particularly for fisheries activities. Current coastal utilization was dominated by capture fisheries (1,335.11 ha; 73%), followed by aquaculture (419.38 ha; 23%), tourism (54.09 ha; 3%), and mangrove ecosystems (20.34 ha; 1%), which continue to provide essential ecological functions for shoreline protection and habitat conservation. Suitability analysis revealed that approximately 96% of existing coastal utilization was consistent with the environmental carrying capacity of the area, while only 4% represented unsuitable utilization requiring improved management interventions to reduce potential environmental risks.

These findings demonstrate that the current pattern of coastal utilization in Ujung Piring is generally compatible with the environmental capacity of the coastal ecosystem, providing a strong foundation for sustainable coastal development. The proposed spatial assessment framework offers a practical decision-support approach for coastal zoning, ecosystem conservation, and adaptive resource management, enabling policymakers to balance economic development with long-term environmental sustainability in tropical coastal regions.

Keywords: carrying capacity suitability; coastal; conservation areas

INTRODUCTION

Coastal regions are highly vulnerable to hazards arising from land–sea interactions, including

erosion, flooding, and storm surges, necessitating multi-faceted protection strategies that combine civil engineering with ecological approaches. Recent syntheses emphasize that nature-based solutions (NbS), particularly mangrove belts, can attenuate wave energy, trap sediments, and stabilize shorelines, while also delivering co-benefits for biodiversity and livelihoods when hydrological and sediment dynamics are properly addressed (Aiken et al., 2021; Barnett et al., 2022; Gerona-Daga & Salmo, 2022). In high-energy or degraded settings, hybrid designs pairing soft NbS with engineered structures and supportive measures (e.g., hydrological restoration, sediment management) have shown promise for enhancing resilience and reducing erosion, albeit with site-specific boundary conditions and longer time horizons to observe benefits (Aiken et al., 2021; Schmitt & Albers, 2023; Suroso et al., 2025). Evidence from Southeast Asia, Africa, and other tropical coastal systems highlights the importance of site-specific installation methods, such as protected seedling establishment and sediment-promoting enclosures, to improve mangrove restoration success under wave exposure (Kinya et al., 2024; Phan & Stive, 2022; Schmitt & Albers, 2023).

Governance and planning frameworks are critical to translating NbS and hybrid protection into durable coastal resilience. In Indonesia, Marine Conservation Areas (KKP) provide a zoning-based paradigm for protecting mangrove, seagrass, and coral ecosystems, aligning protection with four principal zones and emphasizing integrated management of coastal resources and habitats (Hernández-Delgado, 2024). Contemporary literature also underscores the need to integrate NbS within broader coastal risk management through “Working with Nature” approaches, ecosystem-based adaptation, and cross-sector governance to ensure that ecological restoration is linked to disaster risk reduction and climate resilience objectives (Aiken et al., 2021; Barnett et al., 2022; Janna et al., 2026). Riverine and deltaic systems, such as the Mekong Delta, illustrate how restoration of tidal flats can be a precursor to mangrove rehabilitation, highlighting the synergies

between hydrological restoration, sediment dynamics, and ecosystem protection within governance structures that engage local communities and stakeholders (Elliott et al., 2016; Phan & Stive, 2022; Schmitt & Albers, 2023). International policy instruments, including SDG-driven sustainability frameworks and climate-resilient ICZM governance indicators, provide complementary lenses to track progress and align local actions with global resilience objectives (Schipper et al., 2021; Walling et al., 2024).

A holistic strategy for Indonesia should harmonize civil technical safeguards with NbS and robust governance under KKP zoning, while incorporating ecosystem-based disaster risk reduction and climate resilience indicators. Mangroves and related habitats contribute to coastal protection and sediment stabilization, but their protective capacity depends on hydrological connectivity, sediment supply, and protection from further anthropogenic damage; therefore, restoration should be coupled with hydrological rehabilitation and community co-management to sustain benefits over time (Aiken et al., 2021; Gerona-Daga & Salmo, 2022; Janna et al., 2026; Kinya et al., 2024; Schmitt & Albers, 2023). To evaluate and improve interventions, monitoring should extend beyond tree survival to functional indicators such as sediment accretion, carbon stocks, and ecosystem services; and governance should integrate NbS into coastal planning, disaster risk reduction, and climate adaptation policies, guided by zoning frameworks like KKP and supported by resilience indicators for coastal communities (French et al., 2020; Janna et al., 2026; Mahmoudi et al., 2022; Walling et al., 2024). Together, these components can foster climate-resilient coastal development that safeguards both people and ecosystems in Indonesia's littoral zone (Aiken et al., 2021; Barnett et al., 2022; Hernández-Delgado, 2024; Suroso et al., 2025).

The management of Marine Conservation Areas (KKP) in Indonesia has increasingly embraced integrated and ecosystem-based approaches, including ecosystem-based fisheries management (EBFM), to address the complex social-ecological dynamics of coastal and marine systems. The

shift from conventional, government-centric methods toward governance that emphasizes ecosystem resilience and multi-stakeholder engagement is reflected in recent literature on MPA/KKP governance, which highlights the value of co-management, participatory planning, and bottom-up and adaptive strategies as more effective alternatives in addressing fisheries, coastal zone, and marine challenges within KKP networks (Amkieltiela et al., 2022; Nelson et al., 2019; Purwanto et al., 2021). At the same time, scholars acknowledge that these governance innovations do not automatically resolve all dynamics of fisheries management or coastal processes, indicating ongoing tensions between top-down authority and local-scale co-management in practice (Amkieltiela et al., 2022; Nelson et al., 2019; Purwanto et al., 2021). This body of work aligns with Indonesia's diverse MPA typologies and governance arrangements, which increasingly integrate local knowledge, customary institutions, and stakeholder participation into management plans and zoning frameworks (Iswara & Afriansyah, 2022; Purwanto et al., 2021; Safrina, 2020; Tarigan & Tirtamulia, 2023).

Promoting good governance in KKP requires moving beyond purely managerial approaches toward normative and institutional reforms that embed participatory decision-making, accountability, transparency, and capacity-building within coastal and marine planning. National and regional regulations—such as spatial planning instruments and sectoral laws—support these governance objectives by defining zoning-based management and enabling multi-level governance arrangements that involve provincial and district authorities, local communities, and civil society in decision-making processes (e.g., zoning in KKPD/KKP structures; regional legal instruments) (Atmodjo, n.d.; Natassa & Setiyono, 2023; Salminah & Alviya, 2019; Tarigan & Tirtamulia, 2023). Empirical studies of Indonesian MPAs and coastal governance emphasize the importance of local participation, customary law, and social-ecological integration in achieving sustainable outcomes, while also documenting challenges such as governance fragmentation,

conflicting jurisdictions, and variable enforcement (Iswara & Afriansyah, 2022; Khania et al., 2022; Pramoda et al., 2022; Soselisa & Ellen, 2024; Tarigan & Tirtamulia, 2023). The literature also underscores the role of capacity-building and networked learning across MPA networks to improve management effectiveness and social legitimacy, drawing on cross-site experiences in Indonesia and beyond (Nelson et al., 2019).

Sustainable development within Indonesia's coastal and island regions depends on balancing development pace with ecological capacity, and aligning MPA governance with broader policy instruments and spatial planning: for example, Regional Regulation No. 13 of 2018 governing Central Java's RZWP3K planning for coastal and small islands; and the general principle that conservation areas are designated as special protected areas to support sustainable management of coastal resources (including mangroves, seagrass, and coral ecosystems) (Iswara & Afriansyah, 2022; Natassa & Setiyono, 2023). A holistic governance framework for KKP integrates ecosystem-based protection, NbS (notably mangroves), and participatory governance, coupled with monitoring of functional indicators (e.g., ecosystem services, carbon stocks, habitat integrity) to track progress toward sustainable coastal development that benefits both communities and biodiversity (Amkieltiela et al., 2022; Basori et al., 2023; Djumanto et al., 2022; Iswara & Afriansyah, 2022). Taken together, these strands point toward a governance architecture for KKPs that couples legal-enabling instruments with participatory, co-managed, and adaptive practices to advance resilience and equitable outcomes across Indonesia's coastal and offshore regions (Natassa & Setiyono, 2023; Tarigan & Tirtamulia, 2023).

Regional Regulation of Central Java Province No. 13 of 2018 regulates the Spatial Plan for Coastal and Small Islands (RZWP3K) for the period 2018-2038, designating conservation areas as special protected areas for sustainable management of coastal and small island regions, as shoen in Fig.1.

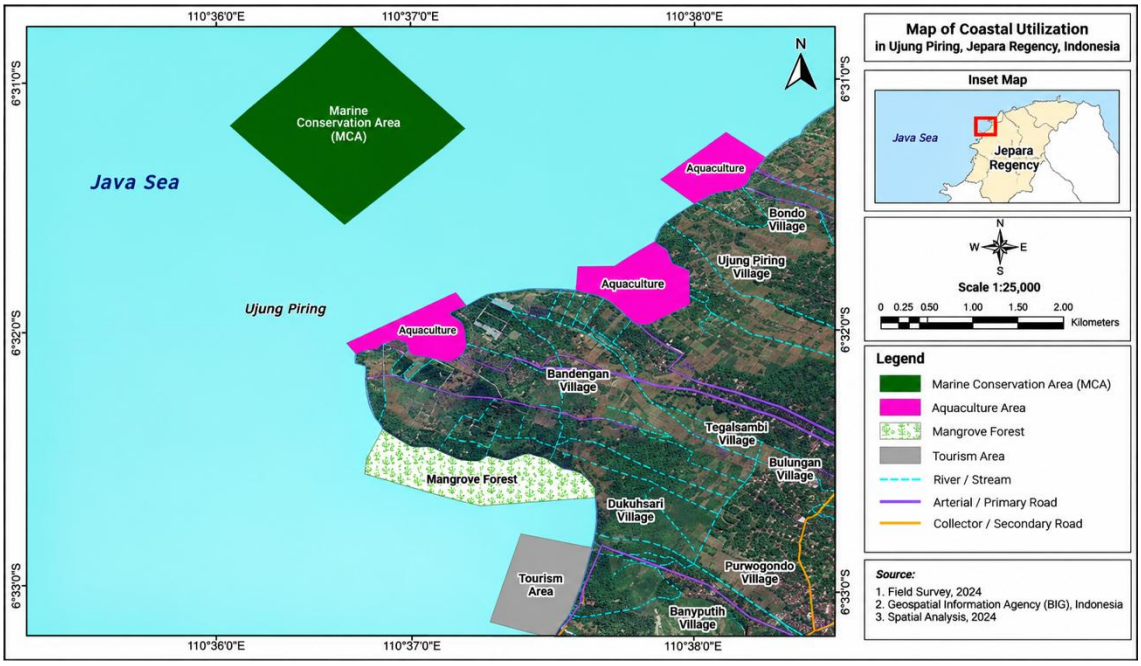


Fig. 1 Location Map of KP-25 in Relation to Perda RZWP3-K of Central Java Province 2018-2038.

Sustainable management of marine resources and fisheries is inseparable from their conservation function. Conservation of marine resources and fisheries can be understood through ecological and socio-economic perspectives. Conservation is recognized as a crucial effort to ensure sustainable availability of resources, contributing to prosperous livelihoods. Effectively managing marine and coastal conservation areas in line with principles of blue economy can guarantee efficient use of natural resources, supporting environmentally friendly utilization and fostering economic benefits for local communities. Conservation has become a necessity to harmonize economic needs ith the desire to preserve existing resources for the future. The definition of environmental carrying capacity, as per Government Regulation No. 46 of 2016 on Procedures for Strategic Environmental Assessment, refers to the ability of the environment to support human life, other living organisms, and the balance between them. Meanwhile, environmental absorptive capacity is the ability of the environment to absorb substances, energy, and/or other components that enter or are introduced into it (Towoliu et al. 2020). These concepts of environmental carrying capacity and absorptive

capacity are crucial for the ability and sustainability of the environment in the face of increasing development pressures (Nuzula et al. 2017).

Coastal ecosystems are increasingly subjected to multiple anthropogenic and environmental pressures, including climate change, sea-level rise, and the intensification of coastal resource exploitation, which collectively threaten ecosystem integrity and long-term sustainability. In many developing coastal regions, rapid expansion of fisheries, aquaculture, tourism, and coastal settlements often occurs without adequate consideration of the ecological carrying capacity of the environment, resulting in spatial conflicts, habitat degradation, and declining ecosystem services. These challenges highlight the need for integrated coastal management supported by scientifically robust assessments of carrying capacity that can guide sustainable spatial planning and evidence-based decision-making. Although the concept of carrying capacity has been widely recognized as a fundamental principle of sustainable coastal management, spatially explicit assessments that evaluate the compatibility between existing coastal utilization and the ecological capacity of coastal ecosystems remain limited, particularly in tropical coastal environments. Furthermore, the integration of carrying-capacity assessment with ecosystem-based management, stakeholder engagement, and locally adaptive governance frameworks has received comparatively little attention, despite its importance for improving management effectiveness and enhancing socio-ecological resilience. Therefore, this study aims to assess the spatial carrying capacity of coastal ecosystems in Ujung Piring Beach, Mlonggo District, Jepara Regency, Indonesia, evaluate the degree of compatibility between current coastal utilization and ecosystem carrying capacity, and develop a spatially informed framework to support sustainable coastal management and long-term conservation of coastal ecosystem services.

DATA AND METHODS

Sudy Area

The research location is along the coastal areas of Blebak and Ujung Piring in Mlonggo District, Jepara Regency, covering an area of 1828.916 hectares (Fig.2).

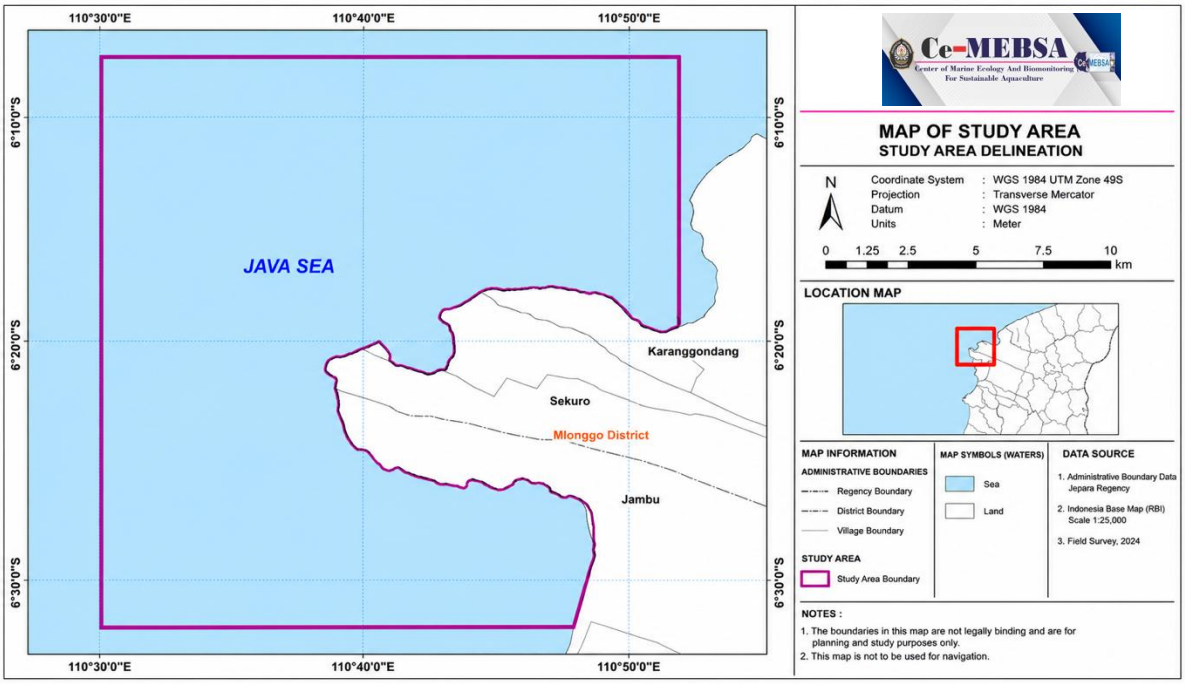


Fig. 2 Map Delimitation of Research Area, Source: Mapping by the Research Team, 2024

Data acquisition

This study did not involve any experimental procedures on live animals that could cause pain, suffering, or distress. No experimental manipulation, testing, or harm was inflicted on the organisms beyond their collection. Field sampling was conducted in the coastal areas of Blebak and Ujung Piring, Mlonggo District, Jepara Regency, in accordance with applicable local regulations governing coastal resource utilization and environmental monitoring. Sampling

activities were carried out with the knowledge and permission of the relevant local authorities and did not involve access to strictly protected core conservation zones. All procedures complied with the prevailing national and regional regulations on coastal and marine resource research, including adherence to the coastal management framework referenced in this study (Minister of Environment Regulation No. 17 of 2009 and Central Java Province Spatial Plan No. 8 of 2024, which incorporates the zoning plan for coastal areas and small islands (RZWP3K).

The initial stage of this article involves referencing the methodology using the concept of assessing carrying capacity as per Minister of Environment Regulation No. 17 of 2009 on Guidelines for Determining Environmental Carrying Capacity in Spatial Planning, adjusted for oceanographic or marine parameters such as Bathymetry, Seabed Contours, Coral Reef Conditions, Ocean Currents, etc. The coastal carrying capacity was classified into four suitability classes based on the criteria outlined in the Indonesian Minister of Environment Regulation No. 17 of 2009, incorporating key environmental characteristics including water depth, coral reef distribution, seagrass occurrence, and wave conditions. Each class represents different levels of environmental suitability and management constraints for coastal utilization. Class I indicates areas with minimal limitations that are suitable for multiple uses, including aquaculture, capture fisheries, tourism, and water conservation. Class II comprises areas with moderate limitations, particularly for tourism, but remains suitable for aquaculture and conservation. Class III includes environmentally sensitive areas characterized by the presence of coral reefs and seagrass beds, where utilization is more restricted and conservation becomes a higher priority. Class IV represents areas with the greatest ecological constraints, designated primarily for water conservation because of their high ecological value and limited suitability for intensive human activities. In the analysis of carrying capacity, this includes determining land capability class parameters as shown in the Table 1.

228 **Table 1** Carrying capacity for coastal zone classes

No	Class	Coastal Criteria	Utilization
1	1st Class	No significant or few barriers restricting its use. Suitable for various uses such as tourism, capture fisheries activities, aquaculture, etc. Region Characteristics. Water Characteristics: - Depth between 0-1.5 meters - No Coral Reefs Present - No Seagrass in the Surrounding Area - Low to Medium Wave Heights	Cultivation Zone - Tourism Activities - Aquaculture Activities - Capture Fisheries Activities Protection Zone - Water Conservation
2	2nd Class	Has barriers for tourism activities. Water Characteristics: - Depth between 1.5-3 meters - No Coral Reefs Present - No Seagrass in the Surrounding Area - - Low to Medium-High Wave Heights	Cultivation Zone - Tourism Activities - Aquaculture Activities Protection Zone - Water Conservation
3	3rd Class	Has barriers for tourism activities. Water Characteristics: - Depth between 1.5-3 meters - Presence of Coral Reefs - Presence of Seagrass in the Surrounding Area - Low to Medium-High Wave Heights	Cultivation Zone - Tourism Activities Protection Zone - Water Conservation
4	4th Class	Has many management barriers and serves many conservation functions. Water Characteristics: - Depth greater than 3 meters - Presence of Coral Reefs - Presence of Seagrass in the Surrounding Area - Low to Medium-High Wave Heights	Protection Zone - Water Conservation

Source: Analyst's Analysis, 2024, and Comparison of the Minister of Environment Regulation Number 17 of 2009 Regarding Guidelines for Determining Environmental Carrying Capacity in Spatial Planning and Marine Conservation.

The carrying-capacity classification was subsequently integrated with existing coastal utilization to evaluate the compatibility between environmental suitability and current resource use. This assessment established a decision matrix indicating whether specific activities, including marine conservation, capture fisheries, aquaculture, and tourism, were appropriate within each carrying-capacity class. Marine conservation was considered compatible across all classes because of its role in maintaining ecosystem integrity, whereas extractive and development-related activities became progressively more restricted with decreasing carrying capacity. Capture fisheries, aquaculture, and tourism were permitted only in areas where environmental conditions could sustainably support these activities, while locations with greater ecological sensitivity were designated primarily for conservation purposes. This framework provided the basis for identifying suitable and unsuitable utilization patterns and for evaluating the consistency of existing coastal use with the environmental carrying capacity of the study area, as shown in the Table 2.

Table 2 Relationship between coastal water carrying capacity classes and existing water utilization

Class	**Conservation Zone**	**Cultivation Zone**		
	Marine Conservation	**Capture Fisheries Activities**	**Aquaculture Activities**	**Tourism Activities**
1st Class	*V*	*V*	*V*	*V*
2nd Class	*V*	*V*	*V*	*X*
3rd Class	*V*	*V*	*X*	*X*
4th Class	*V*	*X*	*X*	*X*

Source: Analyst's Analysis, 2024
Legend:
V = Activities can be carried out with restrictions and capacity.
X = Activities are not allowed

RESULT

Analysis of Bathymetry and Wave Current Conditions

Bathymetric conditions determine the sea depth contours in the study area, providing insights into the marine conditions. The sea depth in the research study area varies significantly, with the largest area (493.17 hectares or 27%) having depths between 10-15 meters located in the central part. Areas with depths greater than 15 meters are the smallest, covering 81.04 hectares or 4%. For a detailed breakdown, refer to the table below. The bathymetric map depicting the sea depths along the coastal areas of Blebak and Ujung Piring, Mlonggo District, Jepara Regency, as shown in Table 3 and Fig. 3.

Table 3 Area of sea depths along the coastal areas of Blebak and Ujung Piring, Mlonggo District, Jepara Regency.

No	Water Depths	Area Size	%
1	0-1,5	179,66	10%
2	1,5-3	325,03	18%
3	3-6	325,41	18%
4	6-10	424,61	23%
5	10-15	493,17	27%
6	> 15	81,04	4%
	Total	1828,92	100%

Source: Calculation by the Mapping Team, 202

The depth stratification reported shows a clear shift in area between shallow and deeper zones, with 0-1.5 m occupying 179.66 ha (10%), 1.5-3 m at 325.03 ha (18%), 3-6 m at 325.41 ha (18%), 6-10 m at 424.61 ha (23%), and 10-15 m at 493.17 ha (27%), while depths >15 m account for 81.04 ha (4%). This pattern indicates that nearly half of the study area lies between 6 and 15 m, suggesting a substantial mid-depth zone that may support a distinct assemblage of benthic and pelagic habitats compared with the very shallow and very deep limits. The distribution implies that habitat provisioning, such as seagrass beds or coral-associated communities, may be concentrated

in the 6-15 m range, while shallow 0-3 m zones could favor mangrove edge systems or intertidal flats, consistent with NbS and ecosystem-based management approaches that emphasize habitat connectivity across depth-stratified zones (Dolatowski et al., 2024; Nagy et al., 2019; Palinkas et al., 2022; Salim et al., 2020).

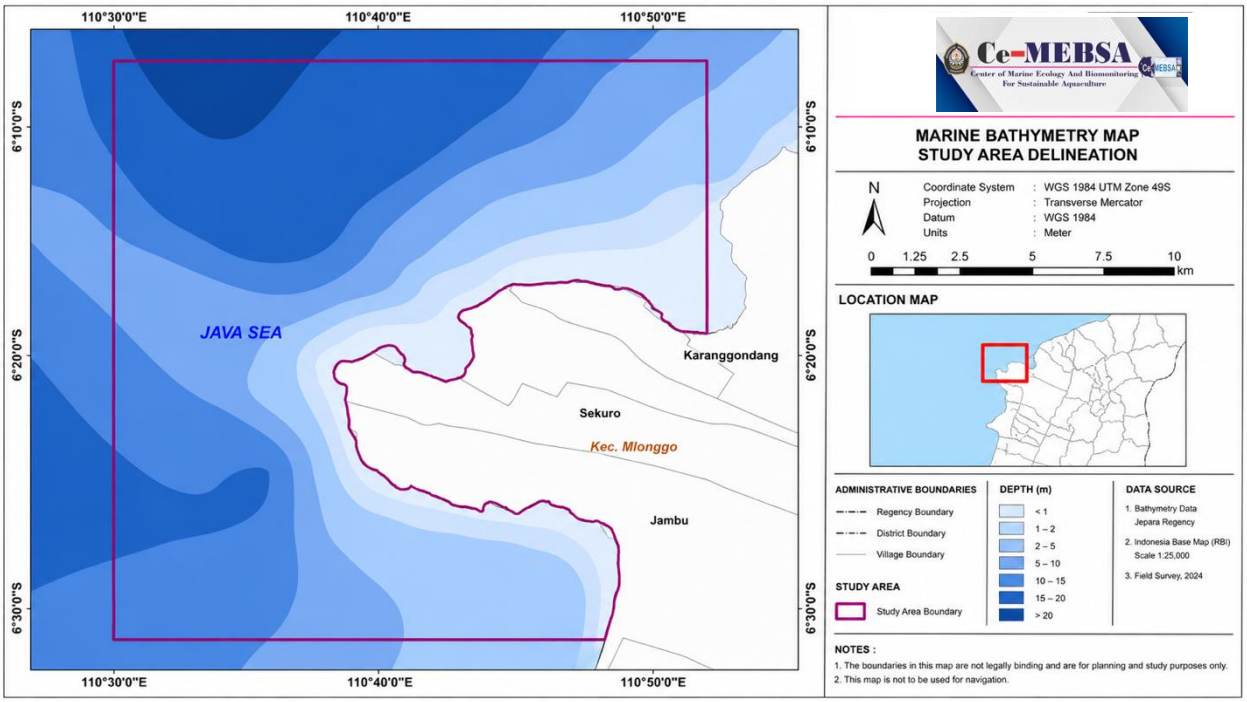


Fig. 3 Map of depth area of study site, with the range of depth (m).

This interpretation aligns with NbS scholarship that highlights the importance of integrating habitat types across depth gradients to enhance coastal resilience and ecosystem services (e.g., shoreline protection, sediment binding, and nursery habitats) within an integrated planning framework (Dolatowski et al., 2024; Hain & Sutton, 2023; Petzold & Scheffran, 2024).

The pronounced presence of mid-depth habitats (6-15 m) alongside substantial deeper zones (>10 m) reinforces the need for integrated spatial planning that spans multiple depth contours, consistent with ecosystem-based management and Marine Spatial Planning (MSP) principles. Governance literature stresses that effective protection and exploitation decisions for Marine Conservation

296 Areas (KKP) should consider depth-structured habitat distributions to optimize ecosystem
297 resilience, biodiversity conservation, and service provisioning within zoning regimes (e.g., core,
298 sustainable fisheries, utilization zones) (Natassa & Setiyono, 2023; Oktaviani & Masjud, 2024;
299 Well et al., 2022). The depth structure also implies that monitoring programs should be depth-
300 stratified, capturing changes in habitat extent, species composition, and carbon stocks across depth
301 bands to evaluate NbS performance and EB-MSP outcomes under climate and anthropogenic
302 pressures (Bai & Li, 2023; Ribbe et al., 2024). Additionally, alignment with regional planning
303 instruments (e.g., Central Java's RZWP3K) supports integrating depth-informed habitat zoning
304 into legally designated protected area frameworks (Iswara & Afriansyah, 2022; Lausche, 2019).
305 Given the depth distribution, management actions should prioritize depth bands with high area
306 share (6-10 m and 10-15 m) for targeted habitat restoration and protection, while ensuring
307 connectivity to shallower edge habitats where feasible. This approach supports ecosystem
308 resilience and the maintenance of sediment dynamics, wave attenuation, and biodiversity across
309 depth gradients, in line with NbS-guided strategies that advocate for ecosystem-based protections
310 and hybrid approaches that combine natural habitats with conventional management tools
311 (Dolatowski et al., 2024; Hain & Sutton, 2023; Petzold & Scheffran, 2024). To enhance decision
312 support, practitioners should adopt depth-aware indicators (e.g., habitat extent by depth band,
313 sediment accretion rates, biodiversity indices, and carbon stock changes) and integrate them into
314 the monitoring frameworks accompanying KKP zoning and ICZM-aligned governance, as
315 recommended in the literature on EB-MSP and NbS governance (Hernández-Delgado, 2024;
316 Ngwenya, 2024; Oktaviani & Masjud, 2024). Finally, incorporating community and stakeholder
317 participation in depth-stratified planning—consistent with co-management and participatory
318 governance themes for KKP—will improve legitimacy and adaptive capacity in the face of shifting

coastal dynamics (Nelson et al., 2019; Pramoda et al., 2022; Purwanto et al., 2021; Tarigan & Tirtamulia, 2023).

Overall, the total area along the coastal areas of Blebak and Ujung Piring, Mlonggo District, Jepara Regency, is 1828.92 hectares. This distribution reflects how each depth contributes to the overall area. These percentages provide insights into the marine topography characteristics at the study location and can serve as a basis for various management and utilization activities of marine resources. Wave conditions based on location are categorized into 3 types: Very Low, Low, and Medium. Very Low waves are found along the coastline, while Medium waves are towards the open sea, as shown in Table 4.

Table 4 Area of wave height conditions at the study location

No	Wave	Area	%
1	Low Wave Height	813,31	44%
2	Very Low Wave Height	365,46	20%
3	Medium Wave Height	650,14	36%
	Total	1828,92	100%

Source: Calculation by the Mapping Team, 2024

The distribution of area based on wave height shows significant variation. Areas with low wave heights cover 813.31 hectares, which is 44% of the total area. Areas with very low wave heights encompass 365.46 hectares, or 20% of the total area. Meanwhile, areas with medium wave heights cover 650.14 hectares, equivalent to 36% of the entire study area. The total overall area is 1828.92 hectares. The distribution of wave height areas at the study location indicates that nearly half of the area (44%) experiences low waves. This suggests that most of the area is likely calmer and more stable, suitable for activities such as fisheries cultivation or tourism that require calm sea conditions. In contrast, 20% of the area has very low wave heights. These areas may be the most

stable and calmest parts of the entire study area, ideal for activities requiring very calm sea conditions, such as cultivating sensitive aquatic species.

Areas with medium wave heights, covering 36% of the total area, show more dynamic variations in wave height. These areas may be more suitable for activities that can accommodate more variable sea conditions, such as some forms of fishing or recreational activities that require a bit more challenge from sea conditions. Understanding this distribution of wave heights allows managers to plan optimal use of marine land, placing activities according to the wave characteristics in each area. This is crucial to ensure the safety, efficiency, and sustainability of various activities along the coastal areas of Blebak and Ujung Piring, Mlonggo District, Jepara Regency.

The substantial coverage of low-wave areas implies opportunities for operations that require calmer seas, such as certain forms of aquaculture, coastal tourism, or nursery habitats, provided that other factors (sediment supply, exposure to storms, and anthropogenic stressors) are favorable (Doong et al., 2021; Piscopo et al., 2022). Conversely, the sizeable mid-range (6-10 m) and high-range (10-15 m) zones signal regions where management must consider higher risk of wave-driven processes, sediment resuspension, and potential habitat disturbance, reinforcing the case for integrated protection approaches that combine NbS with engineering features where appropriate (hybrid solutions) and depth- or distance-informed zoning strategies (Figueroa-Alfaro et al., 2022; Liu et al., 2010; Rosa et al., 2021). Given the total area and its wave-state partitioning, a depth- and location-aware Marine Spatial Planning (MSP) approach can allocate activities according to wave exposure, supporting EB-MSP objectives and zoning within protected area networks such as KKP frameworks or regional spatial plans (Moradi, 2021; Ribbe et al., 2024; Swail et al., 2019). Monitoring should therefore adopt a stratified design that tracks changes in wave-driven habitat metrics (e.g., sedimentation rates, biotic indicators) across wave-height bands to evaluate NbS

362 performance under climate- and human-driven pressures (Figueroa-Alfaro et al., 2022; Liu et al.,
363 2010; Moradi, 2021).

364 To operationalize these insights, management should prioritize ensuring connectivity
365 between high- and low-wave zones, enabling spillover of ecological services and maintaining
366 sediment dynamics necessary for NbS efficacy (e.g., mangrove sediment stabilization and nursery
367 habitats in protected nearshore belts) (Figueroa-Alfaro et al., 2022; Li et al., 2020; Liu et al., 2010).
368 Depth- or wave-height-stratified indicators (area by wave class, changes in habitat extent by band,
369 carbon stock dynamics, and biodiversity metrics) should be integrated into KKP monitoring and
370 reporting, enabling adaptive governance and decision-making under an EB-MSP framework
371 (Figueroa-Alfaro et al., 2022; Oktaviani & Masjud, 2024; Salim et al., 2020). Finally, stakeholder
372 engagement and co-management should be foregrounded to align wave-climate-informed
373 planning with local livelihoods, ensuring that planning for fisheries, tourism, and conservation
374 reflects both ecological thresholds and community needs in Jepara Regency's coastal context
375 (Lorente et al., 2022; Venolia et al., 2024; Βάρλας, n.d.). Ongoing collaboration with regional
376 modeling efforts and sensor networks (e.g., HF radar, buoy-based wind-wave observations) can
377 enhance the resolution and temporal responsiveness of wave height maps used for management
378 decisions (Lorente et al., 2022; Rosa et al., 2021).

379 **Analysis of Surrounding Ecosystem Conditions**

380 The conditions of the surrounding ecosystem, including coral reefs and seagrass conditions around
381 the location, indicate the absence of coral reefs, while there is potential for seagrass presence
382 (Table 5).

383

384

385 **Table 5** Characteristics of Surrounding Ecosystem

No	Surrounding Ecosystem	Assessment	Remarks
1	Coral Reef	Types	Moderate Potential Coral Reefs
		percentage of mangrove cover.	Moderate
		very dense (≥75)	
		moderate (≥50-<75)	
		rare (<50)	
		area	-
2	Seagrass	Types	Potential Seagrass
		Seagrass cover percentage	Fair Condition
		rich/healthy (≥60)	
		less rich/less healthy (30-59.9	
		poor (≤29,9)	
		area	1828,92

Source: Calculated by the Research Team, 2024

The results indicate a moderate potential for coral reefs along the Blebak and Ujung Piring coast in Jepara Regency, with reported coverage within 50% to less than 75%. While this reflects a substantial presence of coral habitat, the exact extent is not specified, suggesting a need for more precise mapping to quantify spatially explicit conservation needs and to track changes over time (Muhtadi et al., 2020; Wijaya et al., 2021). The moderate classification aligns with patterns observed in Indonesia where patchy and stressed coral systems often require targeted protection and restoration to achieve healthier cover levels, particularly in contexts facing pollution, sedimentation, and human disturbance (Aulia et al., 2024; Muhtadi et al., 2020; Wijaya et al., 2021). This framing supports integrating coral reef conservation within an ecosystem-based planning approach that couples protection with restoration actions such as targeted outplanting,

reduced local stressors, and connectivity to adjacent habitats (seagrass and mangrove) that support reef resilience (Hidayah et al., 2023; Rifai et al., 2023; Siburian et al., 2023).

Seagrass ecosystems show moderate potential but with relatively broad coverage (30% to 59.9%), totaling 1,828.92 hectares, underscoring their ecological importance for coastal protection, habitat provisioning, and water filtration within the study area. Although not in optimal condition, the substantial extent indicates strong capacity for maintaining ecosystem services if threats are mitigated and restoration is prioritized where appropriate (Alfazali et al., 2021; Dewi et al., 2024; Rahmadi et al., 2024; Rifai et al., 2023). Seagrass health is closely linked to water quality and turbidity, so monitoring should couple habitat extent with water-column indicators and sediment dynamics to guide NbS integration and EB-MSP planning for Jepara's coast (Dewi et al., 2024; Ningwuri et al., 2026; Rifai et al., 2023). Given the overlap with coral habitats, coordinated management that preserves hydrodynamic regimes and sediment transport will enhance overall ecosystem resilience and service delivery (Muryani et al., 2026; Sabila et al., 2025; Tarigan et al., 2024).

The overall assessment suggests a favorable but not optimal scenario for both coral and seagrass, advocating for integrated governance that combines ecosystem-based management, nature-based solutions, and precautionary planning within spatial frameworks such as KKP zoning and regional plans. Management actions should emphasize strengthening protection of existing habitats, mitigating pollution and erosion pressures, and advancing connectivity among coral reefs, seagrass beds, and adjacent mangrove systems to sustain services and resilience under climate and development pressures (Ariyani & Kismartini, 2018; Manea et al., 2023; Mulyasari et al., 2019; Siburian et al., 2023). Monitoring should employ depth- and habitat-specific indicators (habitat extent by ecosystem type, carbon stocks, biodiversity indices, water quality proxies) and incorporate participatory governance to reflect local knowledge and community needs, enabling

adaptive management as conditions evolve (Mujiyanto et al., 2022; Pratiwi & Elfidasari, 2020; Siburian et al., 2023). Aligning these ecological priorities with regional planning instruments and potential certifications or ecosystem service valuation can further incentivize sustainable stewardship and ecosystem recovery in Jepara's coastal zone (Kunarso et al., 2019; Ondara, 2026; Wahyudin, 2020).

Analysis of Bathymetry and Wave Current Conditions

Based on aerial photo identification and field observations, the coastal area of Ujung Piring is identified with four existing utilization zones, including Tourism, Mangrove, Cage Aquaculture, and Capture Fisheries (Table 6).

Table 6 Area of Existing Utilization

No	Existing Utilization	Area	%
1	Mangrove	20,34	1%
2	Tourism	54,09	3%
3	Cage Fisheries	419,38	23%
4	Capture Fisheries	1335,11	73%
	Jumlah	1828,92	100%

Source: Calculated by the Mapping Team, 2024

As shown in the Table 6, with a total coastal area of 1,828.92 hectares for utilizing zone, capture fisheries occupies the largest share at 1,335.11 ha, equivalent to 73% of the total area, indicating heavy use of nearshore waters for fishing activities and suggesting potential cumulative pressure on habitat quality and biodiversity within the zone allocated for capture fisheries (Hernández-Delgado, 2024). The cage fisheries zone accounts for 419.38 ha, representing 23% of the area, highlighting a substantial multi-trophic or polyculture use that may interact with other users through nutrient loading, habitat modification, or spatial competition for space and access

(Gerona-Daga & Salmo, 2022). Mangrove and Tourism are comparatively small in area, with mangroves covering 20.34 ha (1%) and tourism covering 54.09 ha (3%), reflecting significant but relatively limited spatial footprints for these uses within the study location. This concentration pattern implies that management priorities may need to focus on sustaining the dominant capture fisheries while mitigating potential adverse interactions with cage aquaculture and ensuring that mangrove conservation and tourism development are integrated into planning to maintain ecosystem services such as shoreline protection and recreational value (Aiken et al., 2021; Dutta & Hossain, 2020; Kinya et al., 2024).

The prevalence of capture fisheries within the existing utilization framework underscores the necessity for EB-MSP (ecosystem-based marine spatial planning) that explicitly accounts for depth, habitat connectivity, and species movements, as well as potential trade-offs with other uses such as aquaculture and mangrove protection. Integrating these zones under a cohesive governance framework—aligned with existing zoning concepts like KKP and regional spatial plans—can help balance exploitation with conservation objectives, while enabling ecosystem resilience through connectivity among nearshore habitats and protective mangrove belts where present (Barnett et al., 2022; Phan & Stive, 2022; Schmitt & Albers, 2023). Monitoring should be depth- and habitat-aware, capturing changes in habitat extent, fishery pressure indicators, and potential water quality impacts from cage culture that could influence coral, seagrass, or mangrove health indirectly through nutrient inputs or turbidity shifts (Elliott et al., 2016; Suroso et al., 2025; Zimmer et al., 2022). The relatively small mangrove and tourism shares suggest opportunities to strengthen these sectors without displacing the dominant fishing uses, provided that safeguards are built into permitting and enforcement regimes (Janna et al. 2026; Lacerda et al. 2024).

Land Carrying Capacity Analysis and Suitability Matrix

Based on the overlay map results, capability classes were determined in terms of area at the study location, as shown in Table 7.

Table 7 Area of Land Carrying Capacity Classes

No	Land Carrying Capacity Classes	Area	%
1	1st Class	504,70	28%
2	2nd Class	750,01	41%
3	3rd Class	493,17	27%
4	4th Class	81,04	4%
	Total	1828,92	100%

Source: Calculated by the Mapping Team, 2024

At the study location, the existing utilization of the area shows that capture fisheries are the dominant activity, covering 1335.11 hectares or 73% of the total area. Cage aquaculture also plays a significant role, occupying 419.38 hectares or 23% of the area. The tourism sector, although utilizing only 54.09 hectares or 3% of the total area, holds substantial potential for further development, especially through ecotourism approaches that support nature conservation and enhance the local economy. The mangrove ecosystem covers a very small area, only 20.34 hectares or 1% of the total area, yet it is crucial for coastal protection, habitat provision, and carbon sequestration. With utilization largely dominated by fishing activities, sustainable management is crucial to prevent overfishing and maintain the balance of the marine ecosystem. This utilization needs to be balanced with sustainable conservation and management efforts to ensure that natural resources can support economic activities without harming the environment.

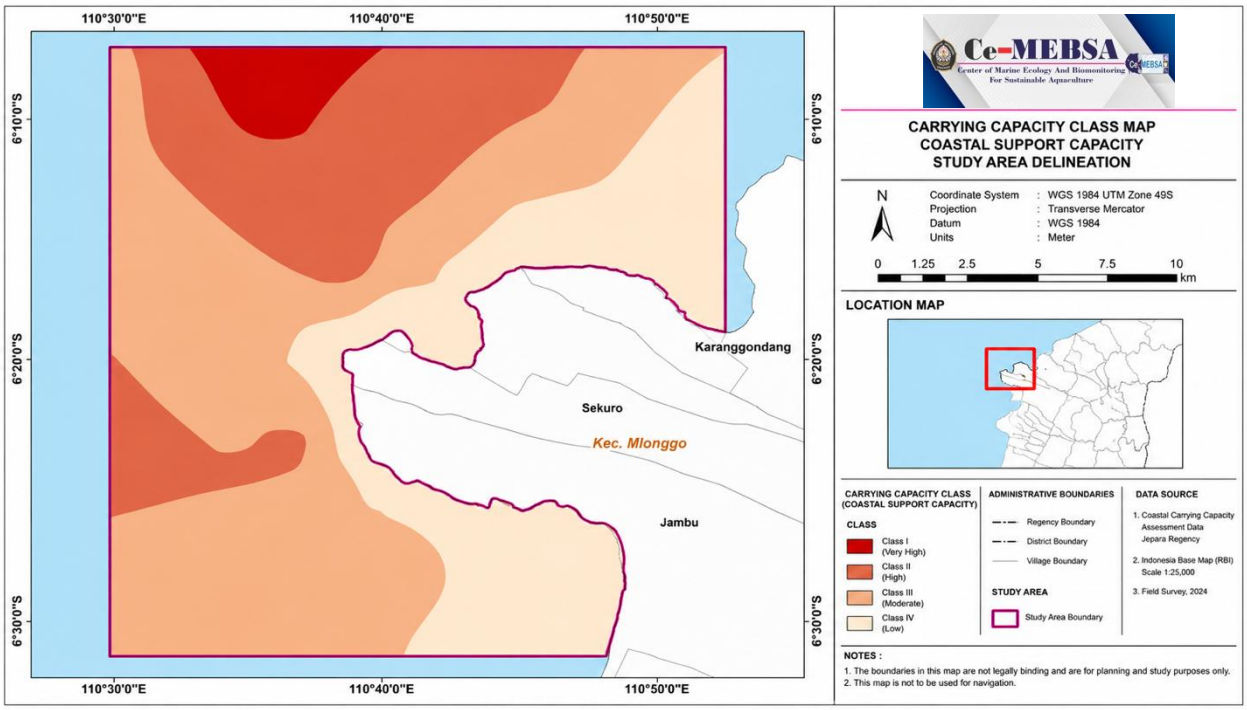


Fig. 7 Map of marine carrying capacity area.

After obtaining the marine carrying capacity map (Fig.7), it was overlaid with the map of existing utilization to assess its suitability. For further clarity, please refer to Fig 8.

Based on the distribution of area according to carrying capacity and existing utilization, the analysis reveals distinct categories: the largest area, Class I, covers 504.70 hectares and boasts the highest carrying capacity, accommodating diverse activities such as mangroves (20.34 hectares), tourism (54.09 hectares), cage aquaculture (211.09 hectares), and capture fisheries (219.18 hectares). Class II, spanning 750.01 hectares, is predominantly used for cage aquaculture (184.01 hectares) and capture fisheries (566.00 hectares). Class III, covering 493.17 hectares, supports smaller-scale cage aquaculture (24.28 hectares) and capture fisheries (468.89 hectares). Meanwhile, Class IV, comprising only 81.04 hectares, has the lowest carrying capacity, suitable solely for capture fisheries.

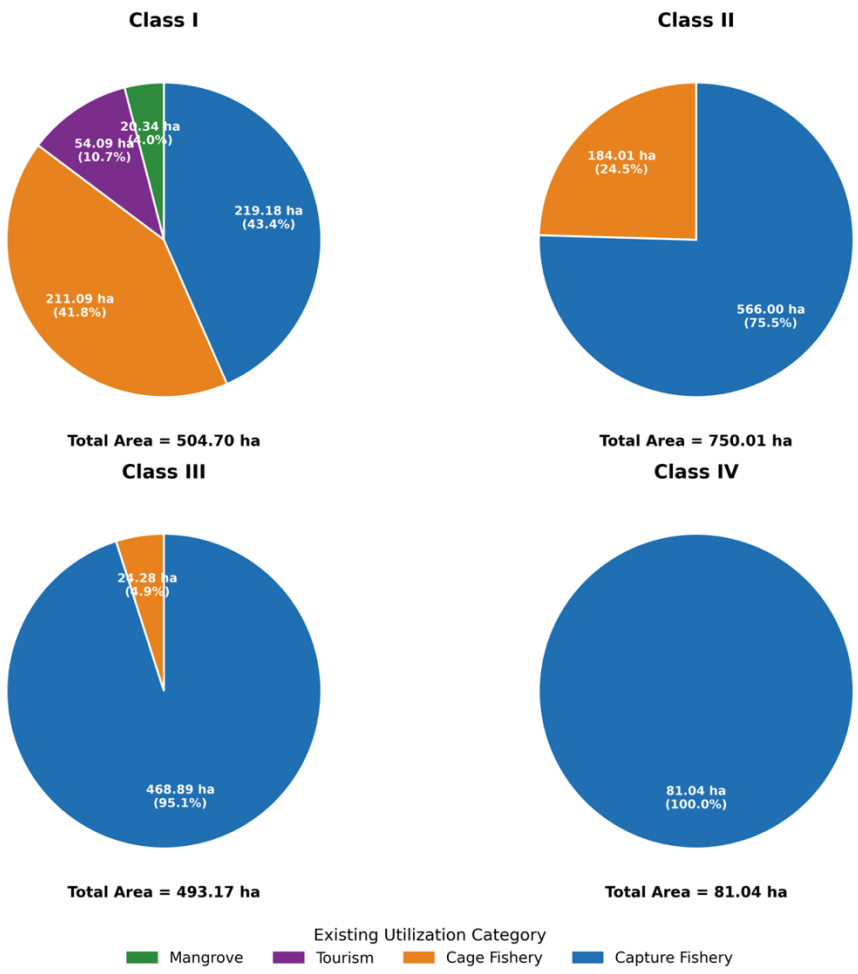


Fig.8 Pie diagram of the distribution of area according to carrying capacity and existing utilization.

Among the total 1828.92 hectares, the predominant existing utilization is capture fisheries (73%), followed by cage aquaculture (23%), tourism (3%), and mangroves (1%). The majority of the area falls within Classes I and II, accommodating various uses, particularly fisheries. Conversely, Classes III and IV have more constrained capacities, primarily for capture fisheries. This analysis underscores the importance of balancing environmental carrying capacity with current utilization to sustain economic activities and preserve the environment. Effective conservation and management strategies are essential to maximize benefits from each carrying capacity class while safeguarding the ecosystem.

Table 8 Area distribution based on carrying capacity suitability illustration.

No	Suitability	Area	Percentage
1	In accordance carrying capacity	1747,88	96%
2	It is not in accordance with carrying capacity	81,04	4%
	Total area	1828,92	100%

The distribution of area based on carrying capacity suitability indicates that the majority, comprising 1747.88 hectares or 96% of the total area of 1828.92 hectares, is considered suitable for existing carrying capacities (Table 8). This reflects conditions where the area can support various economic activities such as fisheries, tourism, and other marine resource management activities without jeopardizing marine environmental sustainability.

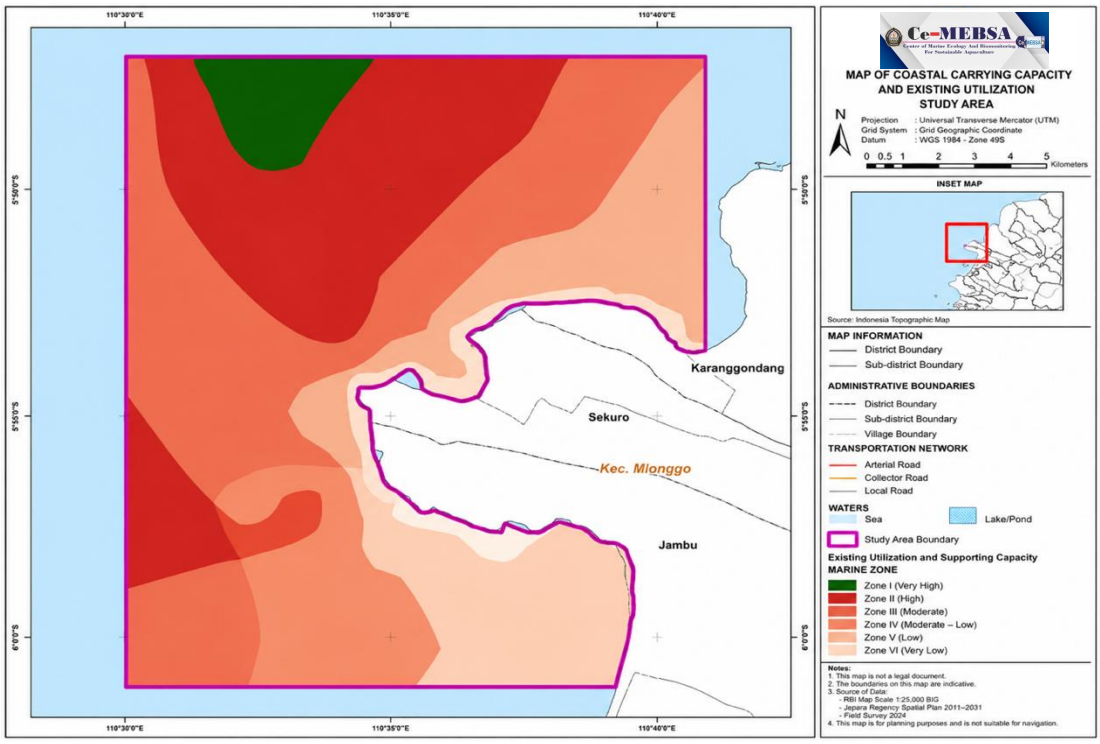


Fig. 9 Map of classes and existing marine use.

In contrast, only 81.04 hectares or 4% of the total area are deemed unsuitable based on existing carrying capacities. This suggests the presence of areas that may have more vulnerable environmental conditions or do not optimally support certain economic activities. Utilization and management of these areas require special attention to mitigate negative impacts on marine ecosystems while ensuring the sustainability of resource utilization (Fig. 9).

Discussion

Based on the analysis of the matrix map of classes and existing marine use, as well as the suitability of carrying capacity with existing conditions, a clear picture emerges of the distribution and interaction between utilization and environmental potential in the coastal areas of Blebak and Ujung Piring, Mlonggo District, Jepara Regency. Areas classified as Class I and II, which have a high carrying capacity, dominate the utilization for cage aquaculture, capture fisheries, and tourism. The significant area covered by these classes indicates diverse usage of marine resources that strategically contribute to economic development. Classes III and IV, with more limited carrying capacities, show constraints on economic activities, with a primary focus on capture fisheries in Class III and particularly in Class IV.

The existing distribution, such as the dominance of capture fisheries in certain areas, reflects established use of marine resources, especially in Class II and III areas. Nevertheless, the 4% of unsuitable areas in terms of carrying capacity indicate potential challenges or risks in developing economic activities in those areas. Integrating this information is crucial in designing sustainable management policies that support economic growth while preserving marine biodiversity and minimizing negative impacts on sensitive marine ecosystems. Based on the provided data on suitability of carrying capacity with existing conditions, the suitable areas (96% of total area) has

574 the potential to support economic activities such as fisheries, tourism, and cage aquaculture
575 without compromising marine environmental sustainability, whilst dominant existing use captures
576 fisheries (covering 73% of total area) reflect established utilization of marine resources in the
577 region. Furthermore, high carrying capacity classes (Class I and II) that support various economic
578 activities significantly, including cage aquaculture and tourism, indicating effective integration
579 between economic development and environmental conservation. Meanwhile, unsuitable areas
580 (4% of total area) indicate limitations or potential risks in developing economic activities,
581 necessitating special attention in management and risk mitigation.
582 The analysis indicates a relatively good balance between the use of marine resources for economic
583 activities and environmental conservation in the coastal areas of Blebak and Ujung Piring,
584 Mlonggo District, Jepara Regency. However, sustainable management is essential to ensure the
585 continued use of natural resources in the future.
586 The carrying capacity of marine land and the current utilization conditions in the study
587 area can be described as follows. The area is classified into four classes based on its potential to
588 support economic activities such as capture fisheries, aquaculture, and tourism. Classes I and II,
589 totaling 1254.71 hectares, indicate high carrying capacity suitable for various marine economic
590 activities. Conversely, Classes III and IV cover a total area of 574.21 hectares, primarily suitable
591 for capture fisheries. Regarding current utilization, capture fisheries dominate with an area of
592 1335.11 hectares (73% of the total area). Aquaculture and tourism contribute significantly with
593 419.38 hectares (23%) and 54.09 hectares (3%) respectively. Although small in area (20.34
594 hectares or 1%), mangrove areas remain crucial for coastal protection and mangrove ecosystem
595 preservation.
596 This analysis highlights the importance of maintaining a balance between economic development
597 and marine environmental conservation. Areas with higher carrying capacity can sustain various

598 marine economic activities sustainably, while areas with limited carrying capacity require careful
599 management to ensure the sustainability of natural resources. Understanding these conditions
600 enables directed marine management to support natural resource sustainability and enhance the
601 well-being of local communities dependent on marine ecosystems. The analysis of suitability of
602 current marine land utilization with land carrying capacity indicates that the majority of the area,
603 96% of the total study area, aligns with existing carrying capacity potentials. This high suitability
604 reflects that economic activities such as capture fisheries, aquaculture, and tourism can proceed
605 relatively well without threatening marine environmental sustainability.
606 Practically, management could prioritize maintaining and enhancing habitat connectivity between
607 the dominant capture fisheries area and adjacent zones (cage aquaculture and mangrove stands) to
608 support fish recruitment, shelter, and trophic flows, while limiting negative externalities from cage
609 structures (e.g., potential nutrient loading or shading). Given the substantial area under capture
610 fisheries, implementing spatially explicit license controls, gear restrictions, and seasonal closures
611 in collaboration with local communities may help reduce overfishing pressure and sustain
612 livelihoods. Augmenting monitoring with community-based reporting, remote sensing for habitat
613 changes, and water quality indicators will support adaptive management under an EB-MSP
614 framework and help track progress toward maintaining or improving ecological services in
615 Jepara's Ujung Piring coast (Doelle & Puthucherril, 2021; Mahmoudi et al., 2022; Schipper et al.,
616 2021). Finally, integrating this spatial allocation with regional policy instruments (e.g., RZWP3K
617 and KKP zoning) can reinforce governance coherence and provide a pathway for sustainable
618 development that aligns fisheries livelihoods with coral, seagrass, and mangrove conservation
619 goals (French et al., 2020; Walling et al., 2024).

620 # CONCLUSION

This study demonstrates the effectiveness of a GIS-based carrying capacity assessment for evaluating the compatibility between environmental capacity and existing coastal utilization in the K-25 Conservation Reserve, Ujung Piring, Indonesia. The results indicate that 96% of current coastal activities are consistent with environmental carrying capacity, with only 4% requiring management intervention, suggesting that existing spatial utilization generally supports sustainable coastal development. These findings provide a scientific basis for ecosystem-based coastal zoning and adaptive management by identifying suitable areas for fisheries, aquaculture, tourism, and conservation while protecting environmentally sensitive zones. Although the assessment is constrained by the quality and temporal resolution of spatial datasets, the proposed framework offers a practical and transferable decision-support tool for sustainable coastal planning in tropical regions. Future studies should integrate higher-resolution spatial data, long-term monitoring, and ecosystem health indicators to improve assessment accuracy under changing environmental conditions.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgment (hiden information)

Author contributions (hiden information)

Data availability All data supporting the findings of this study are available within the paper.

References

Aiken, C. M., Mulloy, R. P., Dwane, G., & Jackson, E. L. (2021). Working With Nature Approaches for the Creation of Soft Intertidal Habitats. Frontiers in Ecology and Evolution, 9. https://doi.org/10.3389/fevo.2021.682349

Alfazali, M. F., Hanafi, Y., & Ma'rifah, D. R. (2021). Literature Study: Diversity level of coastal echinoidea as a source of biology learning materials for biodiversity. Edubiotik Jurnal Pendidikan Biologi Dan Terapan, 6(02). https://doi.org/10.33503/ebio.v6i02.1234

Amkieltiela, Handayani, C. N. N., Andradi-Brown, D. A., ESTRADIVARI, E., Ford, A. K., Beger, M., Hakim, A., Muenzel, D., Carter, E., Agung, F., Veverka, L., Iqbal, M., Lazuardi, M. E., Fauzi, M. N., Tranter, S. N., & Ahmadia, G. N. (2022). The rapid expansion of Indonesia's marine protected area requires improvement in management effectiveness. Marine Policy, 146, 105257. https://doi.org/10.1016/j.marpol.2022.105257

Ariyani, N. A. E., & Kismartini, . (2018). Implementation Of Conservation Policy Through The Protection Of Life Support System In The Karimunjawa National Park. E3s Web of Conferences, 31, 08014. https://doi.org/10.1051/e3sconf/20183108014

Atmodjo, E. (n.d.). Marine conservation tourism and local communities : The case of Raja Ampat, Indonesia. https://doi.org/10.18174/532851

Aulia, E. D., Park, J., Lee, S., & Khim, J. S. (2024). Revealing macrozoobenthos diversity of Java coral reefs, Indonesia: a review on research trends and species assemblages. Frontiers in Marine Science, 11. https://doi.org/10.3389/fmars.2024.1387984

Bai, J., & Li, X. (2023). The evolution of China's policies on marine and coastal ecosystems in climate change adaptation. Frontiers in Marine Science, 10. https://doi.org/10.3389/fmars.2023.1190132

Barnett, J., Jarillo, S., Swearer, S. E., Lovelock, C. E., Pomeroy, A., Konlechner, T. M., Waters, E., Morris, R. L., & Lowe, R. (2022). Nature-based solutions for atoll habitability. Philosophical Transactions of the Royal Society B Biological Sciences, 377(1854). https://doi.org/10.1098/rstb.2021.0124

Basori, M. H., Triyono, A., Hidayat, M. N., Sensato, S. T., & Dewi, U. (2023). Metaverse in Tourism as a Medium for Conservation of Maritime Area in Karimunjawa National Park. Jurnal Audiens, 4(2), 220–230. https://doi.org/10.18196/jas.v4i2.19

Beger, M., Hakim, A., Muenzel, D., Carter, E., Agung, F., Veverka, L., Iqbal, M., Lazuardi, M. E., Fauzi, M. N., Tranter, S. N., & Ahmadia, G. N. (2022). The rapid expansion of Indonesia's marine protected area requires improvement in management effectiveness. Marine Policy, 146, 105257. https://doi.org/10.1016/j.marpol.2022.105257

Cianelli, D., Ciraolo, G., Corgnati, L., Dadić, V., Doronzo, B., Drago, A., Dumas, D., Falco, P., Fattorini, M., Gauci, A., Gómez, R., Griffa, A., … Cardín, V. (2022). Coastal high-frequency radars in the Mediterranean – Part 1: Status of operations and a framework for future development. Ocean Science, 18(3), 761–795. https://doi.org/10.5194/os-18-761-2022

Dewi, C. S. U., Wahyudi, S., Widodo, W., Tarno, H., Ciptadi, G., & Wiadnya, D. G. R. (2024). Analyzing seagrass species and distribution for sustainable management of coastal areas and small islands: A case study of Java Island, Indonesia. Bio Web of Conferences, 106, 02003. https://doi.org/10.1051/bioconf/202410602003

Djumanto, D., Lazuardi, M. E., Zainudin, I. M., & Ridarwati, S. (2022). The Role of Marine-Protected Areas as A Life Support for Fishery Communities: Indonesian Perspective. https://doi.org/10.5772/intechopen.100214

689 Doelle, M., & Puthucherril, T. G. (2021). Nature-based solutions to sea level rise and other climate
690 change impacts on oceanic and coastal environments: a law and policy perspective.
691 Nordic Journal of Botany, 2023(1). https://doi.org/10.1111/njb.03051
692 Dolatowski, E., Suedel, B., Calabria, J., Bilskie, M. V., Byers, J. E., Broich, K., McKay, S. K.,
693 Tritinger, A., & Woodson, C. (2024). Embracing biodiversity on engineered coastal
694 infrastructure through structured decision-making and Engineering With Nature®.
695 https://doi.org/10.21079/11681/48395
696 Doong, D.-J., Fan, Y.-M., Chen, J. Y., & Kao, C. C. (2021). Analysis of Long-Period Hazardous
697 Waves in the Taiwan Marine Environment Monitoring Service. Frontiers in Marine
698 Science, 8. https://doi.org/10.3389/fmars.2021.657569
699 Dutta, S., & Hossain, M. K. (2020). Bringing back the Chakaria Sundarbans mangrove forest of
700 South-east Bangladesh through sustainable management approach. Asian Journal of
701 Forestry, 4(2). https://doi.org/10.13057/asianjfor/r040204
702 Estradivari, Agung, M. F., Adhuri, D. S., Ferse, S. C. A., Sualia, I., Andradi-Brown, D. A.,
703 Campbell, S. J., Iqbal, M., Jonas, H. D., Lazuardi, M. E., Nanlohy, H., Pakiding, F.,
704 Pusparini, N. K. S., Ramadhana, H. C., Ruchimat, T., Santiadji, I. W. V., Timisela, N.
705 R., Veverka, L., & Ahmadia, G. N. (2022). Marine conservation beyond MPAs:
706 Towards the recognition of other effective area-based conservation measures (OECMs)
707 in Indonesia. *Marine Policy*, *137*. https://doi.org/10.1016/j.marpol.2021.104939
708 Ferraz, D., Falguera, F. P. S., Mariano, E. B., & Hartmann, D. (2021). Linking economic
709 complexity, diversification, and industrial policy with sustainable development: A
710 structured literature review. *Sustainability (Switzerland)*, *13*(3), 1–29.
711 https://doi.org/10.3390/su13031265
712 Figueroa-Alfaro, R. W., Rooijen, A. van, Garzón, J. L., Evans, M., & Harris, A. (2022). Modelling
713 wave attenuation by saltmarsh using satellite-derived vegetation properties. Ecological
714 Engineering, 176, 106528. https://doi.org/10.1016/j.ecoleng.2021.106528
715 French, M., Trundle, A., Korte, I., & Koto, C. (2020). Climate Resilience in Urban Informal
716 Settlements: Towards a Transformative Upgrading Agenda. 129–153.
717 https://doi.org/10.1007/978-3-030-57537-3_7
718 Gerona-Daga, M. E., & Salmo, S. G. (2022). A systematic review of mangrove restoration studies
719 in Southeast Asia: Challenges and opportunities for the United Nation's Decade on
720 Ecosystem Restoration. Frontiers in Marine Science, 9.
721 https://doi.org/10.3389/fmars.2022.987737
722 Hain, H., & Sutton, G. M. (2023). The Impact of Climate Change on Biodiversity in Coastal
723 Ecosystems. Jurnal Ilmu Pendidikan Dan Humaniora, 12(3), 167–182.
724 https://doi.org/10.35335/jiph.v12i3.9
725 Hernández-Delgado, E. A. (2024). Coastal Restoration Challenges and Strategies for Small Island
726 Developing States in the Face of Sea Level Rise and Climate Change. Coasts, 4(2), 235–
727 286. https://doi.org/10.3390/coasts4020014
728 Hidayah, A., Ilmawan, K. F., & Yudhanto, W. (2023). Contribution of Community-Based Festival
729 to the Development of Sustainable Tourism on Karimunjawa Island.
730 https://doi.org/10.4108/eai.9-8-2022.2338589
731 Iswara, R., & Afriansyah, A. (2022). Arrangement of Submarine Cables and Pipelines as Part of
732 Marine Spatial Planning in Indonesia. Jambe Law Journal, 5(1), 1–38.
733 https://doi.org/10.22437/jlj.5.1.1-38

Janna, R., Yulianda, F., & Kurniawan, F. (2026). Mapping Functional Indicators for Evaluating Mangrove Rehabilitation Effectiveness: A Systematic Literature Review. New Zealand Journal of Marine and Freshwater Research, 60(2). https://doi.org/10.1002/nzm2.70038

Khania, A. R., Satria, A., & Purwandari, H. (2022). Stakeholder dan Pengaruh Insentif dalam Pengelolaan Kolaboratif Kawasan Konservasi Perairan. Jurnal Sains Komunikasi Dan Pengembangan Masyarakat [Jskpm], 6(3), 346–362. https://doi.org/10.29244/jskpm.v6i3.994

Kinya, G., Kairo, J. G., Nyoike, R. N., Nguu, J. G., Githinji, B. K., & Githaiga, M. N. (2024). Eco-Engineering Mangrove Restoration at Gazi Bay, Kenya. Diversity, 16(3), 135. https://doi.org/10.3390/d16030135

Kunarso, K., Zainuri, M., Sugianto, D. N., Marwoto, J., Hariyadi, H., & Muslim, M. (2019). Prediction of Demersal Fishing Ground Associated with Coral Reefs in the Coastal Jepara Regency, Central Java, Indonesia Based on Sentinel 2a Imagery. Advances in Science Technology and Engineering Systems Journal, 4(6), 263–269. https://doi.org/10.25046/aj040633

Lacerda, L. D. de, Ferreira, A. C., Borges, R., & Ward, R. D. (2024). Challenges to mangroves of the Semiarid Equatorial Coast of Brazil in the Anthropocene. Cambridge Prisms Coastal Futures, 2. https://doi.org/10.1017/cft.2024.16

Lausche, B. J. (2019). Integrated planning: policy and law tools for biodiversity conservation and climate change. https://doi.org/10.2305/iucn.ch.2019.eplp.88.en

Li, Y., Dong, Y., & Zhu, D. (2020). Copula-Based Vulnerability Analysis of Civil Infrastructure Subjected to Hurricanes. Frontiers in Built Environment, 6. https://doi.org/10.3389/fbuil.2020.571911

Mahmoudi, B., Mafi-Gholami, D., & Ng, E. (2022). Evaluation of mangrove rehabilitation and afforestation in the southern coasts of Iran. Estuarine Coastal and Shelf Science, 277, 108086. https://doi.org/10.1016/j.ecss.2022.108086

Li, Y., Dong, Y., & Zhu, D. (2020). Copula-Based Vulnerability Analysis of Civil Infrastructure Subjected to Hurricanes. Frontiers in Built Environment, 6. https://doi.org/10.3389/fbuil.2020.571911

Liu, R., Pu, L., Zhu, M., Huang, S., & Jiang, Y. (2020). Coastal resource-environmental carrying capacity assessment: A comprehensive and trade-off analysis of the case study in Jiangsu coastal zone, eastern China. *Ocean and Coastal Management*, *186*. https://doi.org/10.1016/j.ocecoaman.2020.105092

Lorente, P., Aguiar, E., Bendoni, M., Berta, M., Brandini, C., Cáceres-Euse, A., Capodici, F., Cianelli, D., Ciraolo, G., Corgnati, L., Dadić, V., Doronzo, B., Drago, A., Dumas, D., Falco, P., Fattorini, M., Gauci, A., Gómez, R., Griffa, A., … Cardín, V. (2022). Coastal high-frequency radars in the Mediterranean – Part 1: Status of operations and a framework for future development. Ocean Science, 18(3), 761–795. https://doi.org/10.5194/os-18-761-2022

Mahmoudi, B., Mafi-Gholami, D., & Ng, E. (2022). Evaluation of mangrove rehabilitation and afforestation in the southern coasts of Iran. Estuarine Coastal and Shelf Science, 277, 108086. https://doi.org/10.1016/j.ecss.2022.108086

Manea, E., Agardy, T., & Bongiorni, L. (2023). Link marine restoration to marine spatial planning through ecosystem-based management to maximize ocean regeneration. Aquatic Conservation Marine and Freshwater Ecosystems, 33(11), 1387–1399. https://doi.org/10.1002/aqc.3999

Moradi, M. (2021). Integration of geographical information system and Wave Hindcast model - case study: Persian Gulf. International Journal of Coastal and Offshore Engineering, 5(2), 47–55. https://doi.org/10.52547/ijcoe.5.2.47

Muhtadi, Ahmad, Leidonald, R., Triwibowo, K., & Azmi, N. (2020). Flora Fauna Biodiversity and CSR Implementation in the Mangrove Ecosystem of Bagan Serdang Village, North Sumatra Province. Jurnal Ilmiah Perikanan Dan Kelautan, 12(1), 59–72. https://doi.org/10.20473/jipk.v12i1.17120

Mujiyanto, M., Syam, A. R., Suharti, S., Sugianti, Y., & Sharma, S. (2022). Reef Fish Biodiversity at Different Depths in Tunda Island, Banten Province, Indonesia. Hayati Journal of Biosciences, 30(2), 256–270. https://doi.org/10.4308/hjb.30.2.256-270

Nagy, G. J., Gutiérrez, O., Brugnoli, E., Verocai, J. E., Gómez-Erache, M., Villamizar, A., Olivares, I., Azeiteiro, U. M., Filho, W. L., & Amaro, N. (2019). Climate vulnerability, impacts and adaptation in Central and South America coastal areas. Regional Studies in Marine Science, 29, 100683. https://doi.org/10.1016/j.rsma.2019.100683

Natassa, A. T. G. H. U., & Setiyono, J. (2023). Juridical Review of the Authority of Local Governments in Management of Coastal Areas and Small Islands. International Journal of Law and Politics Studies, 5(2), 65–79. https://doi.org/10.32996/ijlps.2023.5.2.7

Nelson, A., Johnson, G. L., Wenzel, L., Antoine, A. E., Avilla, L., & Manubag, Ma. L. (2019). Integrating social network development into marine protected area management capacity building and institutionalization in the Philippines and Indonesia. Aquatic Conservation Marine and Freshwater Ecosystems, 29(S2), 233–244. https://doi.org/10.1002/aqc.3050

Ngwenya, F. (2024). Biodiversity Conservation Strategies and their Impact on Ecosystem Health in Mozambique. International Journal of Natural Sciences, 4(1), 32–45. https://doi.org/10.47604/ijns.2660

Ningwuri, A. A., Nugroho, B. D. K., & Tasriva, Y. K. (2026). Assessment of Spatio-Temporal Variability of Turbidity using the Normalized Difference Turbidity Index (NDTI) in Jepara Coastal Waters (Sentinel-2). Iop Conference Series Earth and Environmental Science, 1611(1), 012024. https://doi.org/10.1088/1755-1315/1611/1/012024

Nurhayati, A., Aisah, I., & Supriatna, A. K. (2019). Model Development of a synergistic sustainable marine ecotourism—a case study in Pangandaran region, west java province, Indonesia. *Sustainability*, *11*(4), 1103–1114. www.ijcs.ro

Nuzula, N. I., Armono, H. D., & Rosyid, D. M. (2017). Management of Baluran National Park Resources for Coastal Ecotourism Based on Suitability and Carrying Capacity. *Applied Mechanics and Materials*, *862*, 161–167. https://doi.org/10.4028/www.scientific.net/amm.862.161

Oktaviani, A., & Masjud, Y. I. (2024). Nature based solution to climate change: Ecosystem based adaptation: How effective for climate change strategies? Journal of Earth Kingdom, 1(2). https://doi.org/10.61511/jek.v1i2.2024.576

Ondara, K. (2026). Enhancing Coastal Resilience Through Seagrass Ecosystem Engineering: Physical and Ecological Functions of Enhalus acoroides. Environmental Quality Management, 35(4). https://doi.org/10.1002/tqem.70387

Palinkas, C. M., Orton, P., Hummel, M. A., Nardin, W., Sutton-Grier, A. E., Harris, L. A., Gray, M. W., Li, M., Ball, D. L., Burks-Copes, K. A., Davlasheridze, M., Schipper, M. A. de, George, D. A., Halsing, D., Maglio, C., Marrone, J. F., McKay, S. K., Nutters, H., Orff, K., … Williams, T. D. (2022). Innovations in Coastline Management With Natural and

Nature-Based Features (NNBF): Lessons Learned From Three Case Studies. Frontiers in Built Environment, 8. https://doi.org/10.3389/fbuil.2022.814180
Petzold, J., & Scheffran, J. (2024). Climate change and human security in coastal regions. Cambridge Prisms Coastal Futures, 2. https://doi.org/10.1017/cft.2024.2
Phan, M. H., & Stive, M. J. F. (2022). Managing mangroves and coastal land cover in the Mekong Delta. Ocean & Coastal Management, 219, 106013. https://doi.org/10.1016/j.ocecoaman.2021.106013
Phan, M. H., & Stive, M. J. F. (2022). Managing mangroves and coastal land cover in the Mekong Delta. Ocean & Coastal Management, 219, 106013. https://doi.org/10.1016/j.ocecoaman.2021.106013
Piscopo, V., Rossi, G. B., Crenna, F., Gaglione, S., Scamardella, A., Uttieri, M., & Zambianchi, E. (2022). Measurement of Sea Waves. 157–179. https://doi.org/10.1007/978-3-030-82024-4_7
Piscopo, V., Rossi, G. B., Crenna, F., Gaglione, S., Scamardella, A., Uttieri, M., & Zambianchi, E. (2022). Measurement of Sea Waves. 157–179. https://doi.org/10.1007/978-3-030-82024-4_7
Pramoda, R., Apriliani, T., Zulham, A., Triyanti, R., & Nurlaili, N. (2022). Pendekatan Kebijakan Keadilan Biru Untuk Pengelolaan Perikanan Skala Kecil di Kabupaten Natuna. Jurnal Kebijakan Sosial Ekonomi Kelautan Dan Perikanan, 12(2), 159. https://doi.org/10.15578/jksekp.v12i2.11468
Pratiwi, R., & Elfidasari, D. (2020). Short communication: The crustaceans fauna from Natuna Islands (Indonesia) using three different sampling methods. Biodiversitas Journal of Biological Diversity, 21(3). https://doi.org/10.13057/biodiv/d210349
Purnomo, A. R., Patria, M. P., Takarina, N. D., & Karuniasa, M. (2022). Environmental Impact of the Intensive System of Vannamei Shrimp (Litopenaeus vannamei) Farming on the Karimunjawa-Jepara-Muria Biosphere Reserve, Indonesia. International Journal on Advanced Science Engineering and Information Technology, 12(3), 873. https://doi.org/10.18517/ijaseit.12.3.14181
Purwanto, P., Andradi-Brown, D. A., Matualage, D., Rumengan, I., Awaludinnoer, Pada, D. N., Hidayat, N. I., Amkieltiela, Fox, H., Fox, M., Mangubhai, S., Hamid, L., Lazuardi, M. E., Mambrasar, R., Maulana, N., Mulyadi, M., Tuharea, S., Pakiding, F., & Ahmadia, G. N. (2021). The Bird's Head Seascape Marine Protected Area network—Preventing biodiversity and ecosystem service loss amidst rapid change in Papua, Indonesia. Conservation Science and Practice, 3(6). https://doi.org/10.1111/csp2.393
Qian, W., Zhao, Y., & Li, X. (2023). Construction of ecological security pattern in coastal urban areas: A case study in Qingdao, China. *Ecological Indicators*, *154*. https://doi.org/10.1016/j.ecolind.2023.110754
Rahmadi, M. T., Lubis, D. P., Rohani, Yuniastuti, E., & Suciani, A. (2024). Utilization of SPOT 6 Image Remote Sensing for Mapping Coral Reef and Seagrass. Journal of Physics Conference Series, 2908(1), 012020. https://doi.org/10.1088/1742-6596/2908/1/012020
Ribbe, L., Dekker, G., & Thapak, G. (2024). Urban wetlands and water bodies. 91–107. https://doi.org/10.1016/b978-0-323-85703-1.00007-9
Rengganing Suci, D., Yurianto, M., & Djoko Said, B. (2021). Manajemen Tata Kelola Maritim Kepulauan Seribu sebagai Kawasan Strategis Nasional dalam Perspektif Keamanan Maritim. *Jurnal Maritim Indonesia (Indonesian Maritime Journal), 9*(3), 281–298.
Ribbe, L., Dekker, G., & Thapak, G. (2024). Urban wetlands and water bodies. 91–107. https://doi.org/10.1016/b978-0-323-85703-1.00007-9

Safrina, S. (2020). PARTISIPASI MASYARAKAT DALAM PENGELOLAAN WILAYAH PESISIR DI ACEH. Jurnal Hukum Lingkungan Indonesia, 2(1), 30–49. https://doi.org/10.38011/jhli.v2i1.19

Rifai, H., Quevedo, J. M. D., Lukman, K. M., Hernawan, U. E., Alifatri, L., Risandi, J., Kuswadi, Kristiawan, Uchiyama, Y., & Kohsaka, R. (2023). Understanding community awareness of seagrass ecosystem services for their blue carbon conservation in marine protected areas: A case study of Karimunjawa National Park. Ecological Research, 38(4), 541–556. https://doi.org/10.1111/1440-1703.12391

Rizal, A., Wirawan, C. A., Pratiwy, M., & Pratiwi, D. Y. (2022). Integrated Development of Marine and Fisheries of Sangihe Islands District, North Sulawesi, Indonesia. *The Institute of Biopaleogeography Named under Charles R. Darwin*, *12*, 1–63. http://www.institutebiopaleogeography-darwin.com/

Roni Bawole, I., Ir Fredinan Yulianda, Ms., Ir Dietriech Bengen, Ms. G., Ir Achmad Fahrudin, D., Ir Mudjirahayu, Ms., & Ir Unstain NWJ Rembet, Ms. (2018). *TATA KELOLA KAWASAN KONSERVASI PERAIRAN: Sistem Tata Kelola, Sistem yang Dikelola dan Tata Kelola Interaktif (Teori dan Aplikasi)*. www.cvalfabeta.com

Rosa, T. L., Santos, A. M. P., Vettor, R., & Soares, C. G. (2021). Review and Prospects for Autonomous Observing Systems in Vessels of Opportunity. Journal of Marine Science and Engineering, 9(4), 366. https://doi.org/10.3390/jmse9040366

Rosa, T. L., Santos, A. M. P., Vettor, R., & Soares, C. G. (2021). Review and Prospects for Autonomous Observing Systems in Vessels of Opportunity. Journal of Marine Science and Engineering, 9(4), 366. https://doi.org/10.3390/jmse9040366

Rusandi, A., Hakim, A., Wiryawan, B., & Yulianto, I. (2021). *INDONESIA Development of Marine Protected Area to Supporting Sustainable Fisheries Management in Indonesia Oleh*. *12*(2).

Sabila, A. Y., Wirasatriya, A., Maslukah, L., & Widada, S. (2025). Pollution Index Mapping Based on Total Suspended Solids Concentration Extracted From Sentinel-2 MSI Imagery in Teluk Awur Coastal Waters, Jepara Indonesia. Environmental Quality Management, 35(1). https://doi.org/10.1002/tqem.70154

Salim, J. M., Radzi, M. A., Razali, S. M., & Cooke, F. M. (2020). Coastal Landscapes of Peninsular Malaysia: The Changes and Implications for Their Resilience and Ecosystem Services. https://doi.org/10.5772/intechopen.82155

Schipper, C. A., Dekker, G. G. J., Visser, B. de, Bolman, B. C., & Lodder, Q. (2021). Characterization of SDGs towards Coastal Management: Sustainability Performance and Cross-Linking Consequences. Sustainability, 13(3), 1560. https://doi.org/10.3390/su13031560

Schmitt, K., & Albers, T. (2023). Mangroves and Ecosystem-Based Coastal Protection in the Mekong River Delta, Vietnam. https://doi.org/10.5772/intechopen.110820

Soselisa, H. L., & Ellen, R. (2024). Multivocal responses to conservation in Maluku province, Indonesia: Biocultural diversity, protest and management in a zone of ecological transition. Singapore Journal of Tropical Geography, 45(3), 515–532. https://doi.org/10.1111/sjtg.12554

Schmitt, K., & Albers, T. (2023). Mangroves and Ecosystem-Based Coastal Protection in the Mekong River Delta, Vietnam. https://doi.org/10.5772/intechopen.110820

Siburian, R. H., Tapilatu, J. R., & Tapilatu, M. E. (2023). Discovery of habitat preferences and community structure of Echinoderms in Kri, Raja Ampat, Indonesia. Biodiversitas Journal of Biological Diversity, 24(7). https://doi.org/10.13057/biodiv/d240735

Soselisa, H. L., & Ellen, R. (2024). Multivocal responses to conservation in Maluku province, Indonesia: Biocultural diversity, protest and management in a zone of ecological transition. Singapore Journal of Tropical Geography, 45(3), 515–532. https://doi.org/10.1111/sjtg.12554

Sumarmi, S., Arinta B, D., Suprianto C, A., & Aliman, M. (2021). THE DEVELOPMENT OF ECOTOURISM WITH COMMUNITY-BASED TOURISM (CBT) IN CLUNGUP MANGROVE CONSERVATION (CMC) OF TIGA WARNA BEACH FOR SUSTAINABLE CONSERVATION. *Folia Geographica*, *63*(1), 123. https://orcid.org/0000-0003-1416-1668

Suroso, D. S. A., Suroso, M. S. P. A., Maureen, N. K., Pratiwi, D., Puspitasari, N., & Kurniawan, Y. (2025). Sustainable Restoration Strategies of a Major Degraded Mangrove Ecosystem Using Social-Ecological System Framework: A Case Study of Pondok Bali, North Coast of Java, Indonesia. https://doi.org/10.21203/rs.3.rs-7721961/v1

Tarigan, M. I., & Tirtamulia, T. (2023). Legal Recognition of Coastal Communities in Marine Protected Areas: An Imperative for Indonesia. https://doi.org/10.4108/eai.27-7-2022.2342421

Walling, L. J., Collie, C., Taylor, A., Cartwright, R., Brown, A., & Hori, T. (2024). Climate Resilient Integrated Coastal Zone Management (ICZM) Governance and Performance Indicators. https://doi.org/10.18235/0013010

Tarigan, S. A., Munasik, M., Wijayanti, D. P., MUHIDIN, M., ROHMAN, E. A., & Pardede, S. (2024). Dynamic of coral recruits in the Karimunjawa National Park, Central Java, Indonesia. Biodiversitas Journal of Biological Diversity, 25(2). https://doi.org/10.13057/biodiv/d250247

Towoliu, B. I., Runtuwene, T., Permana, E., Lumettu, A., Alelo, M., & Sangari, F. (2020). *Coastal Carrying Capacity for Mangrove Ecotourism Development, Case Study in Budo Village, North Minahasa Regency*.

Venolia, M., Marsooli, R., & Portilla-Yandún, J. (2024). Historical change and variability of spectral wind wave climate in the New York Bight. International Journal of Climatology, 44(5), 1739–1757. https://doi.org/10.1002/joc.8408

Wahyudin, Y. (2020). Study Of Claims For Compensation Of Damage To Coral Reef Ecosystem Due To Vessel Grounded In The Waters Area Of Cilik Island, Karimunjawa Subdistrict, Jepara Regency, Central Java Province. Indonesian Journal of Social Research (Ijsr), 2(1), 111–118. https://doi.org/10.30997/ijsr.v2i1.27

Walling, L. J., Collie, C., Taylor, A., Cartwright, R., Brown, A., & Hori, T. (2024). Climate Resilient Integrated Coastal Zone Management (ICZM) Governance and Performance Indicators. https://doi.org/10.18235/0013010

Well, L. V., Isayeva, A., Olsson, P. A., & Hollander, J. (2022). Public perceptions of cultural ecosystem services provided by beach nourishment and eelgrass restoration in southern Sweden. Nordic Journal of Botany, 2023(1). https://doi.org/10.1111/njb.03654

Wijaya, A., Pramono, S. E., Melati, I. S., Zamzuri, N. H., Hanafiah, M. H., & Ghazali, A. R. (2021). Toward the Community-based Sustainable Marine Tourism: Identifying the Impact of Tourism Development in Karimunjawa Island. International Journal of Academic Research in Business and Social Sciences, 11(5). https://doi.org/10.6007/ijarbss/v11-i5/9924

Zamzami, L., Ermayanti, E., Hendrawati, H., & Miko, A. (2020). Socio-Cultural Impacts of Marine Conservation Areas in Indonesian Fishing Communities. *IOP Conference Series: Earth and Environmental Science*, *430*(1). https://doi.org/10.1088/1755-1315/430/1/012016

967 Zimmer, M., Ajonina, G. N., Amir, A. A., Cragg, S. M., Crooks, S., Dahdouh-Guebas, F., Duke, N.
968 C., Fratini, S., Friess, D. A., Helfer, V., Huxham, M., Kathiresan, K., Kodikara, K. A.
969 S., Koedam, N., Lee, S. Y., Mangora, M. M., Primavera, J. H., Satyanarayana, B., Yong,
970 J. W. H., & Wodehouse, D. (2022). When nature needs a helping hand: Different levels
971 of human intervention for mangrove (re-)establishment. Frontiers in Forests and Global
972 Change, 5. https://doi.org/10.3389/ffgc.2022.784322
973