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DETERMINATION OF MARINE ECOTOURISM ZONES ON PISANG ISLAND – PESISIR BARAT, INDONESIA USING MARXAN ZONING

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Abstract: Pisang Island on Pesisir Barat has great potential to be developed as a marine ecotourism destination, particularly due to its coral reef ecosystem, seagrass beds, and beautiful, picturesque beaches. However, when developing this tourism, it is important to consider the balance between ecosystem protection and the economic needs of coastal communities, so that the ecosystem remains sustainable. This study aims to determine sustainable marine ecotourism zones using Marxan. We integrated ecological variables—bathymetry, brightness, current velocity, coral reefs and seagrass cover beds—with social layers: jetties, boat sailing lanes, traditional fishing areas, and surfing spots. The integrated ecological data includes bathymetric maps from BATNAS, water brightness indices from Sentinel-2A image processing, surface current velocities from Copernicus Marine Service, and maps of coral reefs and seagrass bed distribution from Allen Coral Atlas. Socio-economic data was obtained by identifying jetties locations, boat sailing lanes, traditional fishing areas, and established tourist sites around Pisang Island. Three habitat protection targets (30%, 40%, 50%) were tested through Marxan Zoning on hexagonal planning units. The model results are displayed using the summed-solution frequency approach to see how often a unit is selected. After that, the zones are divided into four categories: core zone, buffer zone, marine ecotourism zone, and other zone. The results of the study indicate that Scenario A, with a protection target of 30%, is the most optimal choice, with an allocation of 120,670 ha (5.30%) for the ecotourism zone and 26,199 ha (1.15%) for the core zone. Scenario A is the most balanced approach in supporting marine ecosystem conservation and coastal community empowerment through tourism activities. This approach is considered the most balanced as it preserves marine ecosystems while providing space for tourism that supports local community economic benefits. These findings highlight the important role of Marxan as a data-driven spatial planning tool to support sustainable marine ecotourism management policies in Pisang Island.

Keywords: coral reefs, marine ecotourism, Marxan, Pisang Island, sustainable management, spatial planning

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INTRODUCTION

Indonesia is the largest archipelago in the world, with a water area of 6,315,222 km² and a coastline of 99,093 km. About two-thirds of Indonesia's territory is ocean, with abundant natural resources consisting of 17,504 islands (Mafruhah et al., 2020). Various coastal resources can provide tourism opportunities, especially marine ecotourism (Prihadi et al., 2018). Ecotourism is an alternative to the sustainable use of natural resources that can be financed relatively cheaply (Rahman & Haque, 2024). Marine ecotourism is growing rapidly as part of the tourism industry, providing various recreational activities in coastal areas and marine waters (Sukran et al., 2025). Marine ecotourism utilizes natural potential such as coral reefs, seagrass beds, and mangrove forests scattered in Indonesia's coastal and marine areas (Tuwo et al.,

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2017). It is one of the fastest-growing types of tourism in the world, with activities both on the surface and under the sea (Jonas et al., 2019). However, despite the diverse characteristics of the islands, the development of various marine tourism trend destinations is still not optimal (Rizki et al., 2018). Ecologically-based integrated management that considers physical and social aspects is needed to provide ecological, aesthetic, and economic benefits in a sustainable manner (Muflih et al., 2015). Marine ecotourism is an alternative to environmentally friendly tourism that utilizes coastal potential responsibly, while supporting nature conservation and community welfare (Yulianda et al., 2007; Tiyasmono et al., 2019).

Marine resources in marine ecotourism have a significant role in improving the welfare of coastal communities through sustainable economic opportunities, while contributing to the Indonesian economy (Umar, 2022; Amanda et al., 2024). Despite these financial benefits, marine ecotourism in Indonesia still faces challenges that hinder sustainability and often overlook its role in global marine conservation (Reniel et al., 2025). Coral reefs, with their high ecological, aesthetic, and biodiversity values, are the main attraction for marine tourism development (Achmad et al., 2023; Intyas et al., 2023). Coral reefs, tough corals, support tourism activities such as diving and snorkeling (Nurhayati et al., 2019).

Therefore, the sustainable development of marine ecotourism is significant in ensuring economic, social, cultural, and environmental sustainability and strengthening national economic resilience in the future (Arismayanti, 2019; Reszi et al., 2019). Pisang Island, located in West Pesisir Regency, Lampung, has marine tourism potential thanks to its underwater natural beauty, charming beaches, and marine biodiversity (Amanda et al., 2024). Visitors can enjoy activities such as boating, walking on the beach, swimming, snorkeling, diving, sunbathing, surfing, and fishing (Riyani & Tamjuddin, 2017; Yusuf et al., 2015). Pisang Island also has a coral reef ecosystem, an essential asset for developing the marine and fisheries sector. Research by Lazuardi et al. (2013) showed that there are areas that are very suitable for snorkeling and diving at a depth of 1-5 meters, with 71.3-81.2% coral cover, 11 types of life forms, more than 50 reef fish, a brightness of about 3 meters, and a current of 15 cm/second, which supports safety and comfort factors.

However, some locations are considered unsuitable due to the impact of anthropogenic activities.

Coastal communities play an essential role in developing marine ecotourism because this sector is part of a cultural industry that requires the involvement of various parties (Mafruhah et al., 2020). Ecotourism development must apply conservation principles to preserve the environment and tourist comfort, including zoning that protects natural resources and facilitates management. Activities such as snorkeling and diving are highly dependent on the condition of the coral reef ecosystem (Johan, 2016). Therefore, integrated planning, including proper zoning, is needed to avoid conflicts over the use of the area (Yulianda et al., 2018). This research supports data-driven decision-making so stakeholders can develop sustainable tourism areas, preserve resources, and promote local development (Sukandar et al., 2017; Rudolph, 2014). Based on Lampung Province Regional Regulation No. 1/2018, Pisang Island is located in the Capture Fisheries Zone.

This research aims to determine the sustainable and environmentally friendly zone of marine ecotourism areas on Pisang Island using a geospatial information approach with the Marxan method. The resulting geospatial information is essential for optimal marine ecotourism development (Yulius et al., 2013). Multicriteria-based spatial analysis approaches have often been utilized in ecotourism development planning (Pathmanandakumar & Chenoli, 2023). Marxan is a spatial-based planning tool that is very useful in managing and conserving natural resources, including in the context of marine ecotourism. Marxan can be used to determine conservation zones, which will be used to determine conservation-based marine ecotourism zones. Marxan is a target-based spatial planning tool that works within the framework of systematic conservation planning, utilizing the spatial distribution of conservation features to determine optimal priority locations (Baker et al., 2025).

MATERIALS AND METHODS

Research Study

The research area is located on Pisang Island, West Pesisir Regency, Lampung Province, Indonesia, at the geographical coordinates of 5°21'52"–5°29'02" South Latitude and 105°48'20"–105°48'24" East Longitude. The research location can be seen in Figure 1. Pisang Island Sub-district, located in West Pesisir Regency, Lampung, has an area of 313 hectares with a population of 1,971 and is directly adjacent to the Indian Ocean. The area consists of six pekon (villages) and is a leading tourist destination thanks to its island character. Located in the middle of the Indian Ocean waters, the area has a plains and hills topography, with plantations and beaches. The climate is cool and humid due to the influence of the sea, although temperatures can be very hot during the day. With a vision of "Realizing Pisang Island as a Tourism Destination of West Pesisir Regency", the sub-district continues to develop its natural tourism potential.

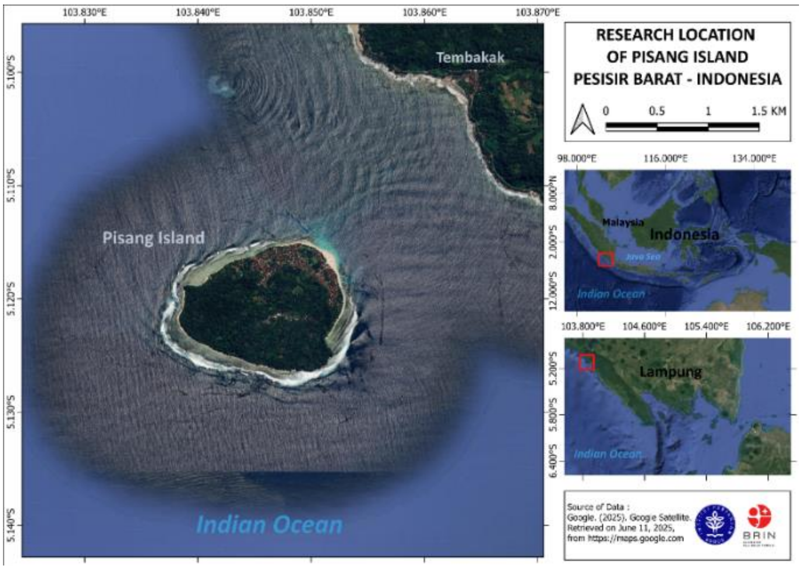

Figure 1. Map of the research location

Tools and Materials

The tools used for data processing rely on software to support data analysis. The overall tools used are listed in Table 1.

The materials needed are secondary data and images that will be input into the Marxan software. The materials used are obtained from various sources listed in Table 2. This study used Sentinel-2A satellite images in 2025 to detect water brightness data on Pisang Island. Sentinel-2A imagery was employed in a spectral ratio-based empirical optical approach for estimating water brightness. Sentinel-2A provides spectral data from 13 bands, covering visible, near-infrared, red edge, and shortwave spectra (Huang et al., 2018). Sentinel-2A imagery in this study was chosen due to its spatial resolution of 10 meters, better than the 30-meter resolution of Landsat imagery, and its temporal resolution of 10 days.

Table 1. Tools used

Name	Function
QGIS 3.34.3	Import the results of the Marxan scenario processing, brightness image processing
QMarxan	Data processing plugins
Zonae Cogito, R 4.3, C-Plan	Marxan scenario simulation
Surfer	Processing and visualization of depth, brightness, and current velocity data

Table 2. Materials and data sources

Data Type	Source	Time
Sentinel-2A Image	https://dataspace.copernicus.eu/	2025
Coral Reef and Seagrass Cover	https://www.allencoralatlas.org/	2022
Bathymetry	https://sibatnas.big.go.id/	2025
Current Velocity	https://marine.copernicus.eu/	2025
Traditional Fishing Areas	Field Observation	2025
	Document of Zoning Plan for Coastal Areas and Small Islands of Lampung	2018
Boat Sailing Lanes	Field Observation	2025
	Document of Zoning Plan for Coastal Areas and Small Islands of Lampung	2018
Surfing Spot	Field Observation	2025
Jetties	https://earth.google.com	2025
Indonesia Topographic Map	https://tanahair.indonesia.go.id/	2019

Work Procedure

Data processing began with collecting all the data required to identify conservation areas. Secondary data and spatial data were then input into the Marxan software. Creating planning units within the research area was the first step in the Marxan analysis, as shown in Figure 2. Planning units are the basic elements in establishing the conservation area system and are the focal point for evaluation and selection by Marxan to generate solutions.

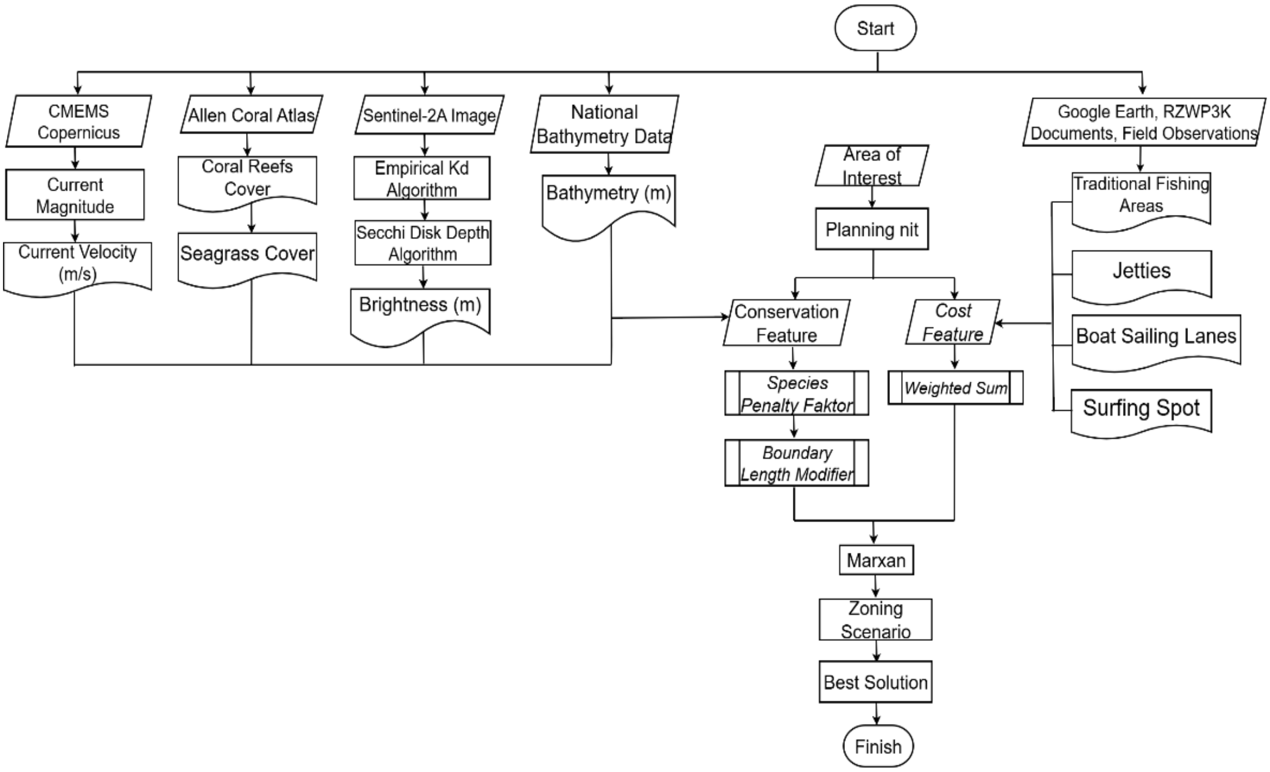

Figure 2. Research flow chart

Data Analysis

Bathymetry: The depth data for the waters around Pisang Island were sourced from the National Bathymetry (BATNAS) of the Geospatial Information Agency (BIG), obtained from https://tanahair.indonesia.go.id/portal-web/unduh/batnas. Data processing and visualization were conducted using Surfer software. The processed data were adjusted to match the Area of Interest (AOI) location.

Brightness: Water brightness data were obtained from Sentinel-2A image processing, which requires pre-processing steps such as atmospheric correction to ensure the accuracy of surface spectral reflectance (RS) values. This method applies the algorithm of Lee et al. (2005) to calculate the light attenuation coefficient (Kd) and the approach of Lee et al. (2015a) for Secchi disk depth estimation, processed using QGIS software. The use of Sentinel-2A to detect Kd both temporally and spatially has been demonstrated by Rodrigues et al. (2020) in the Alqueva Reservoir, Southern Portugal. The shallower the depth of the visible Secchi disk, the higher the light attenuation in water (Kd), which aligns with recent theories on visibility and underwater light (Lee et al., 2015a). The calculations in this method utilize the ratio of remote sensing reflectance (Rrs) values at specific wavelengths to quantitatively estimate water depth.

Coral Reef and Seagrass Cover: Data on coral reef and seagrass cover in the waters of Pisang Island were obtained from the Allen Coral Atlas (2022), which provides high-resolution satellite imagery accessible via https://www.allencoralatlas.org/ (Li et al., 2019). The Allen Coral Atlas uses a 3.125-meter resolution PlanetScope image mosaic, consisting of three visual bands (red, green, blue) and four analytical bands (blue, green, red, near-infrared). This PlanetScope data is utilized for benthic habitat mapping through image processing that produces benthic habitat cover classifications (Kennedy et al., 2020). This information serves as both a monitoring and observation tool (Misiuk & Brown, 2024) and provides high-resolution maps that display detailed coral reef composition and structure on a global scale (Wen et al., 2021).

Current Velocity: This research employs resultant vector analysis of surface currents by utilizing ocean current velocity data along two main components: u (horizontal) and v (vertical). These components are combined to calculate the resultant current velocity (current magnitude). The current data are then interpolated using the kriging method to generate a new grid (re-grid), allowing integration with other datasets or use in models of different resolutions. Kriging is a geostatistics-based interpolation method that estimates values at specific locations by considering the spatial correlation among data points (Purnomo & Sumarjono, 2015) and is capable of revealing patterns or trends in the data (Nirwansyah, 2015). Processing and visualization of current velocity data were conducted using surfer software.

Data and Zoning Scenario: Conservation features are coastal resources and aquatic conditions that are protected and utilized for marine ecotourism. These features include specific elements such as species, habitats, or ecosystems that serve as the basis for spatial planning (Watts et al., 2009; Schmiing et al., 2015). Based on the Minister of Marine Affairs and Fisheries Regulation No. 31 of 2020, the maintenance and rehabilitation of coral reefs and seagrasses aim to preserve ecosystems from the impacts of natural changes and human activities, one of which is through the establishment of conservation areas. This research establishes conservation areas that support the development of marine ecotourism based on the principle of sustainability for coral reef ecosystems. Three scenarios were analyzed using Marxan, with 30%, 40%, and 50% protection of critical habitats (coral reefs and seagrasses), respectively (Figure. 3).

These protection percentages align with statutory requirements and recommendations by Green et al. (2014), who suggest that ideally, 20–40% of each critical habitat should be included in conservation areas. In addition, oceanographic parameters such as brightness, current velocity, and water depth, adapted from Yulianda et al. (2018), were also used as supporting factors for marine ecotourism activities such as snorkeling and diving.

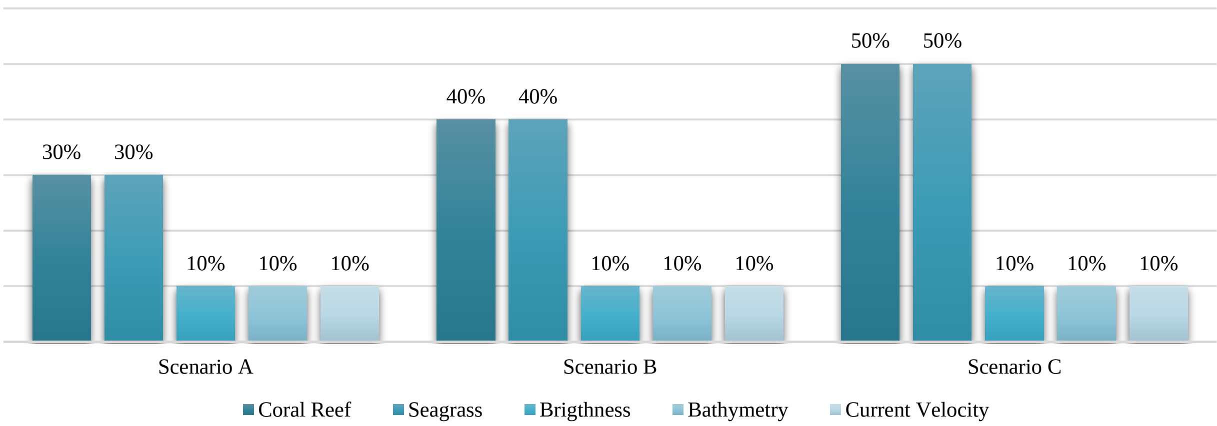

Figure 3. Determination of the penalty factor (SPF) value of conservation features

Cost features are defined as constraints that serve as key factors in the results of Marxan analysis. The input for cost features includes social data related to resource utilization patterns and area usage. In all scenarios, cost weights are set consistently to determine priorities in the spatial outcomes, where the higher the weight, the more difficult it is for an area to be designated as a maximum protection zone (Henriques et al., 2017).

In the waters of Pisang Island, cost features include four elements: jetties, traditional fishing areas, boat sailing lanes, and surfing spots. Planning unit costs are calculated based on the intensity of resource utilization, influencing the total overall cost. Table 3 presents the prioritization order of area utilization in the waters of Pisang Island.

Table 3. Determination of cost weight values

No	Cost Feature	Level of Importance	Penalty Factor
1	Jetties	High	5
2	Traditional Fishing Grounds	High	3
3	Boat Sailing Lanes	High	5
4	Surfing Spot	Low	1

Marxan: The Marxan method runs with an algorithm system that uses simulated annealing to achieve optimal results quickly through algorithm optimization (Anggraeni et al., 2017). The Marxan optimal result will show the lowest overall cost if four conditions are met (Watts et al., 2017:12-13):

$$\text{Total Cost} = \sum_{i=1}^{n} \text{Cost} + (\text{BLM} \times \sum \text{Boundary}) + \sum_{i=1}^{n} (\text{SPF} \times \text{Penalty}) \qquad (1)$$

Where:

Cost = Combination of socio-economic values at each planning unit in the solution selected

BLM = A value is set by the user and is related to the level of connectivity between planning units. The higher the Boundary Length value, the denser the solution area.

Boundary = A value set by the user and related to the level of connectivity between planning units. The higher the Boundary Length value, the denser the solution area.

SPF = A value set by the user and relates to the importance of the biodiversity target objective. The higher the SPF assigned to a feature, the more priority Marxan will give the target feature.

Penalty = The value of the penalty given if the biodiversity protection target is not achieved (optional).

i = Shapefile unit id; n = Last shapefile unit id

RESULTS AND DISCUSSION

Bathymetry

Bathymetry measures the seabed's height and describes the waters' topography (Febrianto et al., 2015). Depth mapping is essential for coastal management (Zhang & Shehhi, 2025) regarding tourist safety and comfort.

Bathymetry maps show that the waters around Pisang Island are dominated by shallow depths of 1-5 meters, typical of fringing coral reef areas, shown in Figure 4. These depths are ideal for beginner snorkeling and diving due to high visibility and lower safety risks (Spalding et al., 2017).

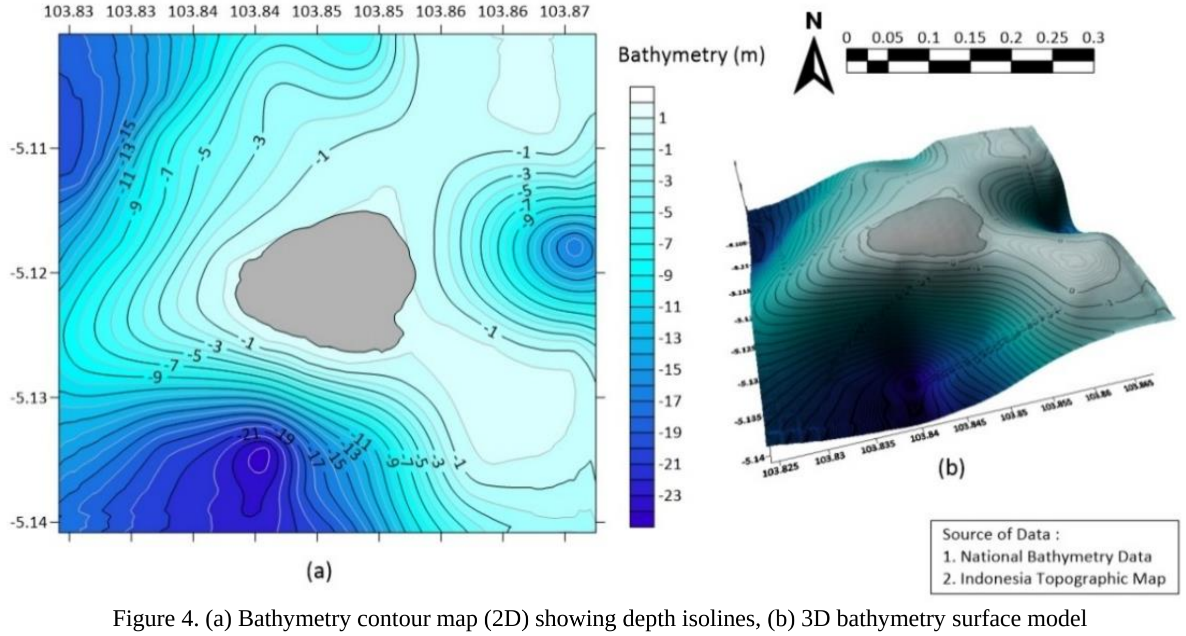

Figure 4. (a) Bathymetry contour map (2D) showing depth isolines, (b) 3D bathymetry surface model

The shallow waters (<5 m) around Pisang Island are suitable for water tourism such as snorkeling, kayaking, and coral reef education, especially for general tourists and families. Sloping depths allow easy access for tour boats and local fishermen. However, areas with tight contours must be watched as they could indicate strong currents or sudden topographic changes. The bathymetry of Pisang Island shows high potential for developing conservation-based marine ecotourism, which aligns with sustainability principles that maintain the safety of tourists and the preservation of marine ecosystems.

Brightness

Water brightness plays an essential role in determining the suitability of snorkeling and diving tourism sites, as it affects visibility, safety, and tourist satisfaction in enjoying the beauty of the underwater ecosystem (Panra et al., 2016; Yulianda, 2019). The brightness map from Sentinel-2A image processing shows the distribution of seawater visibility around Pisang Island, displayed in brightness units (m) in Figure 5.

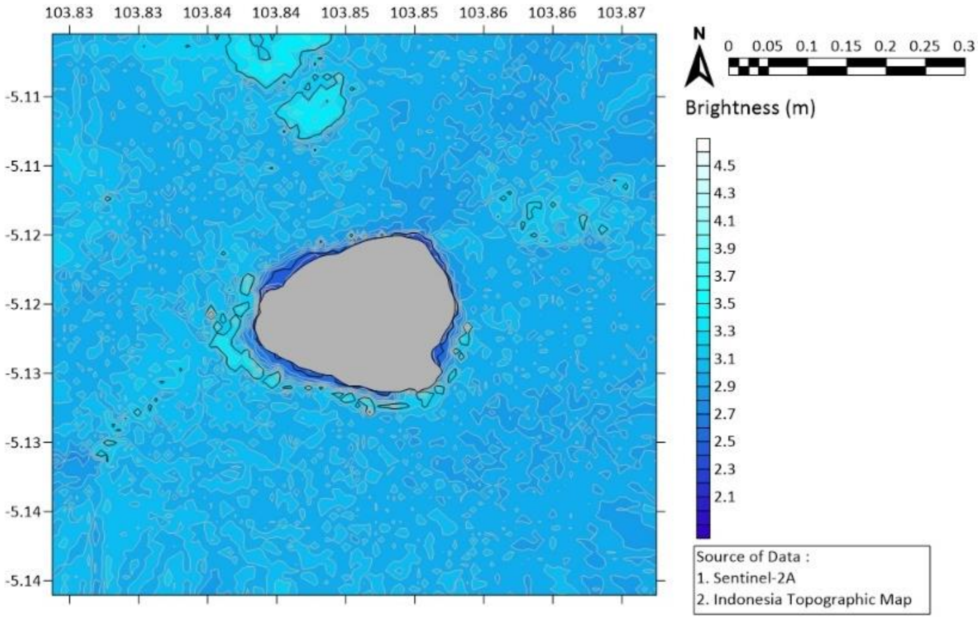

Figure 5. Water brightness map

Brightness maps of Pisang Island's waters show high brightness (4-5 m) in the north and northeast, indicating good water clarity for snorkelling and diving. In contrast, the southwest area has lower brightness (2-3 m), possibly due to waves, sediment, or island shadows. Brightness in the reef area remained good (Figure 5), indicating high potential for marine tourism, as high visibility is essential for tourists' comfort and safety (Yulianda, 2019; Spalding et al., 2017).

Current Velocity

The current velocity map of Pisang Island shows the variation in ocean currents, which is influenced by the geographical location and orientation of the island towards the Indian Ocean. The western and southern parts experience stronger currents due to direct exposure to open ocean currents, as shown in Figure 6.

Current velocity is essential in determining the feasibility of snorkeling sites, where low currents (0-15 cm/sec) are considered ideal for tourists' comfort and safety (Yulianda, 2010).

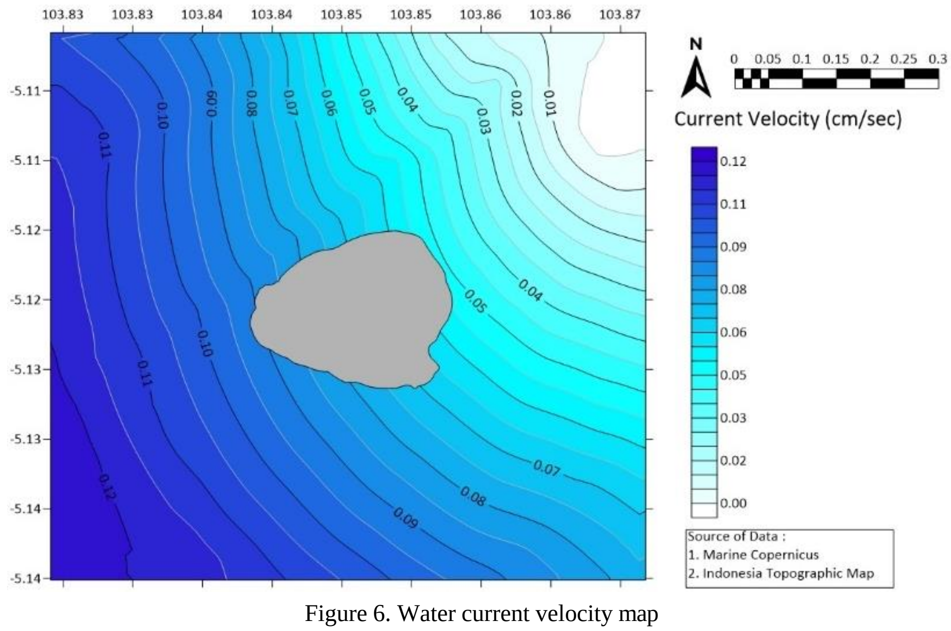

Figure 6. Water current velocity map

Coral Reefs and Seagrass Cover

The underwater habitat cover map shows that coral reefs are distributed almost all around Pisang Island, especially on the east, south, and southwest sides. Seagrasses are more limited in distribution in shallow water, especially in the west and southeast. The pattern of coral reefs surrounding the island indicates the presence of a fringing reef system, which is a reef that grows directly from the shoreline to the sea, generally at a depth of less than 5 meters, making it ideal for beginner snorkeling and diving (Muis et al., 2016).

The coral reef and seagrass cover of Pisang Island is shown in Figure 7. The coral reefs surrounding Pisang Island in shallow waters show great potential for marine ecotourism development. The wide and even distribution of reefs is a visual and ecological attraction, especially in areas with clear water and suitable depth. Besides being attractive for snorkeling, seagrass ecosystems also play an essential role in maintaining water quality and supporting biodiversity.

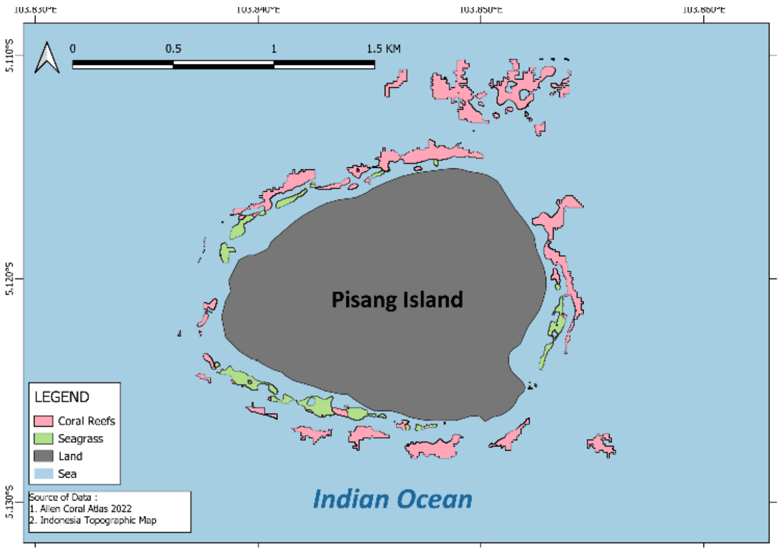

Figure 7. Coral reef and seagrass cover map

Jetties, Traditional Fishing Areas, Boat Sailing Lanes, and Surfing Spots

This data was obtained through indirect observation, documents Zoning Plan for Coastal Areas and Small Islands Regional Regulation of Lampung Province No. 1 of 2018, and Google Earth. The following are the locations in the cost feature, which can be seen in Figure 8. Maps of marine infrastructure and activity around Pisang Island show the island has only one local jetty in the north as the main access to the mainland, with transportation relying on small boats in the absence of a large port, a condition common on small islands and potentially supportive of local character-based ecotourism (Trianasari et al., 2019). Two main shipping channels from Krui and Tembakak connect the island with mainland Lampung, essential for logistics and tourist visits. Traditional fishing areas are located in the south and east, where fishers use simple, environmentally friendly fishing gear, which aligns with the findings of Hoshino et al. (2017) on the non-destructive fishing methods of small island fishers.

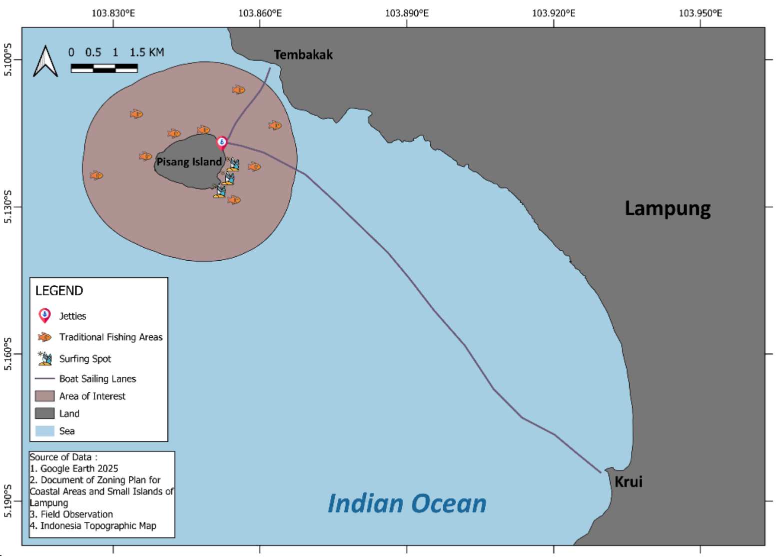

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Figure 8. Map of jetties, traditional fishing areas, boat sailing lanes, and surfing spots

In addition, the surf spot in the southwest of Pisang Island has high waves that attract foreign tourists, but as in the Mentawai Islands, surf development needs to involve local communities to achieve economic benefits and environmental sustainability (Towner & Davies, 2018).

Establishment of Area of Interest (AOI) and Planning Unit

Determining the area of interest (AOI) and planning unit is essential in Marxan analysis. According to Law No. 32/2004, districts/cities are authorized to manage the sea up to 4 miles. Still, this study only uses a 1-mile buffer from the shoreline because coastal resources and fishing activities are generally near land and coral reefs. The planning unit is the smallest division of the study area, which in this study is hexagon-shaped because it is considered efficient and produces a more refined analysis (Geselbracht et al., 2005; Miller, 2003; Warman, 2001). The size of the planning unit was adjusted according to the size of the study area. For the small area of Pisang Island, hexagons with an area of 40 m² were used, with a total of 5,400 units, for a more detailed Marxan analysis.

Marine Ecotourism Target Analysis

Marxan analysis produces two main outputs: the best solution and the summed solution (ssoln). This study used the summed solution because it has a higher convergence rate and lower total cost, area boundary length, and number of clusters than the best solution (Zhang et al., 2019). The frequency of area selection in the summed solution is grouped into four categories based on the quartile distribution. The number of planning units per category is shown in Table 4.

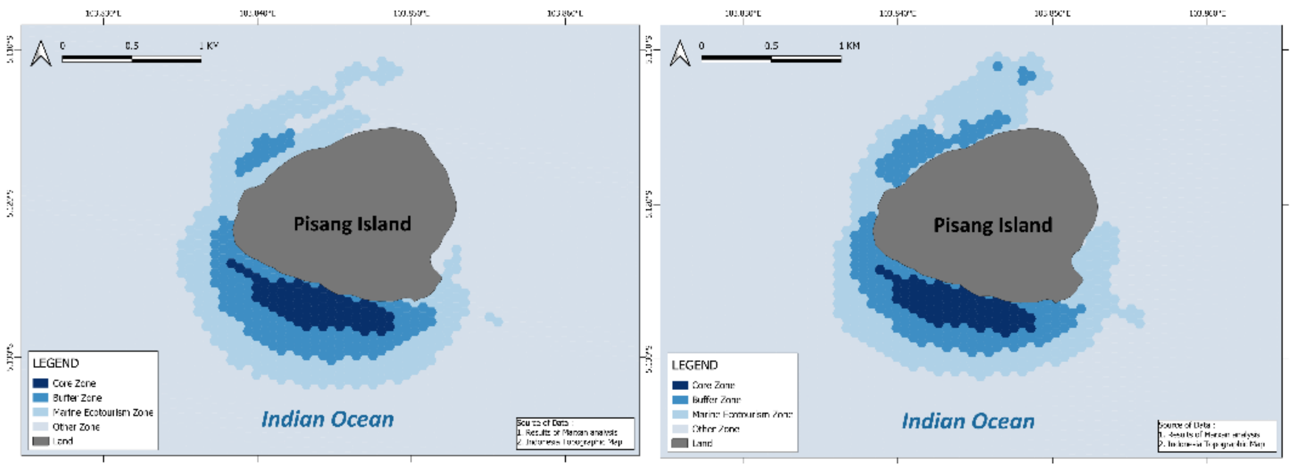
Table 4. Number of planning units based on summed simulation

Summed Solution	Jumlah Unit Perencanaan		
	Scenario A	Scenario B	Scenario C
0-250	4667	4669	4683
251 - 500	292	278	229
501 - 750	142	156	187
751 - 1000	65	63	71
Total	5166	5166	5170

Marine Ecotourism Zone Scenario Results

The study divided the conservation area into four zones. The core zone includes areas with high biodiversity, with a frequency of >750 selections in the Marxan analysis. The buffer zone considers the socio-economic aspects of surrounding communities, with a frequency of 501-750 (Anggraeni et al., 2017).

The sustainable marine/fisheries ecotourism zone is at a frequency of 251-500 times, allowing utilization for tourism activities that benefit the community economically. Other zones, with the lowest frequency (0-250 times), include rehabilitation areas, shipping lanes, or modern fishing. The results of the Marxan scenario are shown in Figure 9.

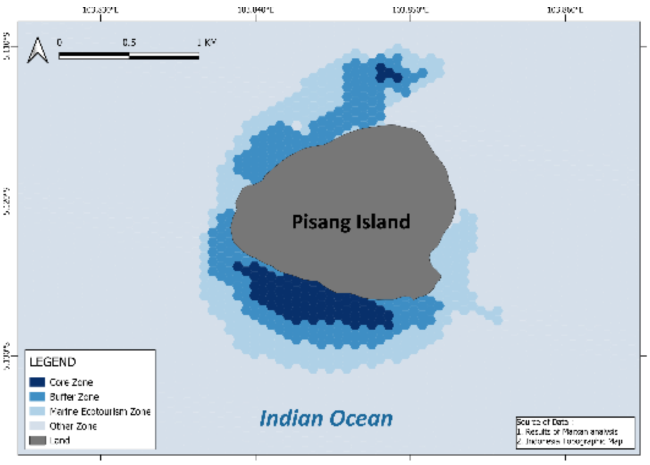


(a) Scenario A (b) Scenario B

Figure 9(a) & (b). Marxan scenario map results - (a) Scenario A & (b) Scenario B

Scenario A shows the largest allocation for the marine ecotourism zone of 120,670 ha (5.30%) and the core zone of 26,199 ha (1.15%), reflecting management based on ecotourism utilization while maintaining conservation. The 30% habitat protection in this scenario aims to preserve the ecosystem while supporting fisheries benefits for the surrounding community (Firmansyah et al., 2018; IUCN, 2008). The core zone is essential as a biodiversity buffer, provided it is managed with adaptive management (Giakoumi et al., 2018). The extent of the ecotourism zone supports the development of snorkeling, diving, and environmental education, while providing economic benefits to the community (Spalding et al., 2017). Thus, Scenario A is considered to be balanced between ecological protection and improving the welfare of coastal communities.

Scenario B increases coral reef and mangrove protection to 40%, with a marine ecotourism zone of 46,261 ha (2.03%) and a core zone of 26,861 ha (1.18%). Compared to scenario A, the ecotourism zone is smaller, emphasizing ecosystem protection but limiting the use of space. This approach is appropriate for vulnerable ecosystems, but could hamper tourism-based socio-economic opportunities (Sala et al., 2021). While conservation is maintained, the benefits of tourism to the community are more limited, making this scenario less optimal for overall sustainable ecotourism development.



(c) Scenario C

Figure 9(c). Marxan scenario map results - (c) Scenario C

Scenario C was designed with optimal protection (50%) of coral reefs and seagrass ecosystems. Marxan analysis results in scenario C having the largest core zone (33,732 ha / 1.48%) but the smallest marine ecotourism zone (40,583 ha / 1.48%). This strategy emphasizes a maximal conservation approach, which is essential for maintaining marine ecosystems in the long term. According to Gurney et al. (2019), expanding conservation zones without integrated utilization can lead to social trade-offs, especially for communities that depend on marine resources. An ecotourism zone that is too small can also limit the space for tourist interaction and environmental education. Therefore, while this scenario is ecologically robust, it is not ideal for implementing inclusive and socio-economically productive ecotourism.

Table 5. Zoning area of the marine ecotourism area for each scenario

Scenario	Zoning	Area (ha)	Percentage of Total Area (%)
Scenario A	Core Zone	26.199	1.15%
	Buffer Zone	44.928	1.97%
	Marine Ecotourism Zone	120.670	5.30%
	Other Zone	2.084.295	91.58%
	Total By Area	2.276.092	100%
Scenario B	Core Zone	26.861	1.18%
	Buffer Zone	43.300	1.90%
	Marine Ecotourism Zone	46.261	2.03%
	Other Zone	2.150.670	94.89%
	Total By Area	2.276.092	100%
Scenario C	Core Zone	33.732	1.48%
	Buffer Zone	49.723	2.19%
	Marine Ecotourism Zone	40.583	1.48%
	Other Zone	2.152.054	94.55%
	Total By Area	2.276.092	100%

Scenario A is the best option for developing sustainable marine ecotourism areas of the three scenarios analyzed. With a large proportion of ecotourism zones and core conservation zones, this approach aligns with the principles of marine protected area management integrated with community empowerment (UNEP-WCMC et al., 2018).

The success of ecotourism is determined not only by ecological protection but also by the ability of the area to provide educational and productive activity spaces for local communities and tourists. Therefore, this scenario has great potential to simultaneously support conservation and community welfare.

CONCLUSION

This research produced zoning for marine ecotourism areas on Pisang Island using a Marxan-based spatial approach. The analysis considered ecological parameters (depth, brightness, ocean currents, coral reefs, and seagrasses) and social aspects (docks, shipping lanes, fishing areas, and surfing locations).

Scenario A, which sets habitat protection at 30%, is the best alternative of the three scenarios analyzed. This scenario allocates a large marine ecotourism zone (5.30%) while leaving a core conservation zone.

This makes Scenario A the most balanced approach in supporting marine ecosystem conservation and empowering coastal communities through tourism activities. The zoning produced in this study can be an essential reference in making spatial data-based and sustainable marine ecotourism management policies on Pisang Island.

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