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Marine Functional Zoning in Hoat Sorbay Bay, Southeast Mollucas Regency

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ABSTRACT

Hoat Sorbay Bay, located in Southeast Maluku Regency, is a complex coastal area with significant yet underutilized potential for seaweed farming, mud crab aquaculture, and mangrove-based ecotourism. This study aimed to develop a Marine Functional Zoning (MFZ) model that integrates ecological suitability with stakeholder participation. Using spatial analysis (GIS), suitability assessments were conducted for seaweed cultivation, mud crab farming, and mangrove ecotourism, while MARXAN was employed to identify conservation priority areas. The results delineate seven functional zones: mud crab fishing (530.90 ha), mangrove protection (135.65 ha), ecofishery tourism (120.12 ha), mangrove rehabilitation (60.62 ha), general fishing (331.84 ha), marine transportation (211.46 ha), and seaweed aquaculture (129.10 ha). A total of 266.19 ha is recommended for conservation and ecofishery tourism development. The zoning plan seeks to balance ecological sustainability with local socio-economic needs, particularly those of the Ohoi Evu community, which relies on traditional crab fisheries. By optimizing the use of marine space, the proposed MFZ model supports integrated coastal zone management and promotes ecosystem-based governance. This research aligns with Indonesia's commitment to the Sustainable Development Goals (SDGs), particularly SDG 14 (Life Below Water) and SDG 8 (Decent Work and Economic Growth).

INTRODUCTION

Marine and coastal ecosystems are vital to the economic, social, and ecological wellbeing of many nations, particularly those with extensive coastlines like Indonesia.

Sectors such as fisheries, aquaculture, transportation, tourism, and even pharmaceuticals rely heavily on the sustainable use of marine resources. As population growth, urbanization, and technological development accelerate, so does the pressure on these natural resources, often leading to degradation, overexploitation, and spatial conflicts among users **(Ansong *et al.*, 2019; Mattos *et al.*, 2021)**.

Hoat Sorbay Bay, located in Southeast Maluku Regency, is one of the coastal regions that reflects this complexity. The bay covers approximately 668.82 hectares of marine area and extends 14.92km in length. Its waters are utilized for various purposes, including seaweed aquaculture, artisanal fishing, and local sea transportation. Additionally, the bay hosts a substantial mangrove ecosystem estimated at 941.78 hectares, which is ecologically significant and economically valuable, particularly as a mud crab (*Scylla* spp.) fishing ground for communities like Ohoi Evu **(Abrahamsz *et al.*, 2018; 2024)**.

Several prior studies have been conducted in Hoat Sorbay Bay, but they remain fragmented in scope. For instance, **Saga (2018)** explored the relationship between mud crab populations and mangrove species; **Abrahamsz *et al.* (2018)** examined institutional arrangements for crab fisheries; **Renjaan (2020)** analyzed the potential for mangrove ecotourism in Letvuan village; **Abrahamsz *et al.* (2024)** examined the status resources of the mud crabs; and **Soselisa and Ingratubun (2024)** examined the traditional management for crab fisheries. However, these studies did not integrate spatial planning tools, ecological suitability, or stakeholder participation into a holistic zoning framework, leaving a gap in strategic and inclusive marine resource management.

Marine Spatial Planning (MSP) and Marine Functional Zoning (MFZ) are evolving approaches developed to tackle spatial challenges by directing how marine areas are allocated, with careful consideration of ecological, social, and economic factors. MSP has been widely recognized as a tool for harmonizing human activities with marine conservation and sustainable development goals. MFZ, in particular, offers more specific zoning designations that can help manage competing uses such as fishing, aquaculture, tourism, and conservation within the same coastal area **(Ehler & Douvere, 2009; Lu *et al.*, 2015)**.

Despite the relevance of MSP and MFZ, their application in Eastern Indonesia remains limited, especially in small-scale and community-based fisheries settings. There is currently no integrated marine zoning framework that addresses the combined challenges of fisheries productivity, habitat conservation, and socio-economic development in Hoat Sorbay Bay. This lack of comprehensive planning represents a critical gap in both policy and practice, particularly in areas where marine resources are central to local livelihoods.

This study seeked to design a Marine Functional Zoning model for Hoat Sorbay Bay that integrates ecological suitability assessments for seaweed aquaculture, mud crab cultivation, and mangrove-based ecofishery tourism. The model integrates biophysical analysis, conservation priorities, and stakeholder perspectives to produce a spatial plan that supports both environmental sustainability and socio-economic resilience. The findings are expected to offer valuable contributions to coastal zone management in Southeast Maluku and support Indonesia's commitment to the Sustainable Development Goals (SDGs), especially SDG 14 (Life Below Water) and SDG 8 (Decent Work and Economic Growth).

MATERIALS AND METHODS

Study site

From February to November 2022, this study was carried out in Hoat Sorbay Bay, Southeast Maluku Regency. Administratively, the region is a part of Hoat Sorbay District, which is a sub-district inside the Southeast Maluku Regency's administrative territory. Dian Darat, Tetoat, Letvuan, Arso, Ohoira, and Warwut are the six villages (ohoi) that make up the Hoat Sorbay Bay area (Fig. 1).

Hoat Sorbay Bay is 14.92km long and 668.82 acres in size. The water area of Hoat Sorbay Bay is mostly utilized for local shipping, fishing, and seaweed cultivation. In addition, these waterways contain a sizable mangrove ecosystem, covering 941.78 hectares which is utilized by the locals, especially Ohoi Evu fishermen, as a crab fishing area **(Abrahamsz *et al*., 2018, 2024)**.

In addition, under the Ministry of Maritime Affairs and Fisheries Regulation No. 6 of 2016, Hoat Sorbay Bay is officially recognized as part of the TPK Kei Kecil marine conservation area. This conservation area is classified as a sustainable fisheries zone, aquaculture subzone, and other zones, as well as a marine tourist subzone with an emphasis on mangrove ecotourism operations, according to the zoning management plan.

Data collection

Data for this study were gathered in a number of ways, including: (1) Direct surveys and observation of Hoat Sorbay Bay's waters using fifteen observation stations; (2) Interpretation of satellite images used to gather information on potential and environmental mangroves conditions; (3) Surveys and interviews used to gather information on economic and sociocultural aspects, and (4) Information from associated agencies and literature reviews used to gather further relevant data.

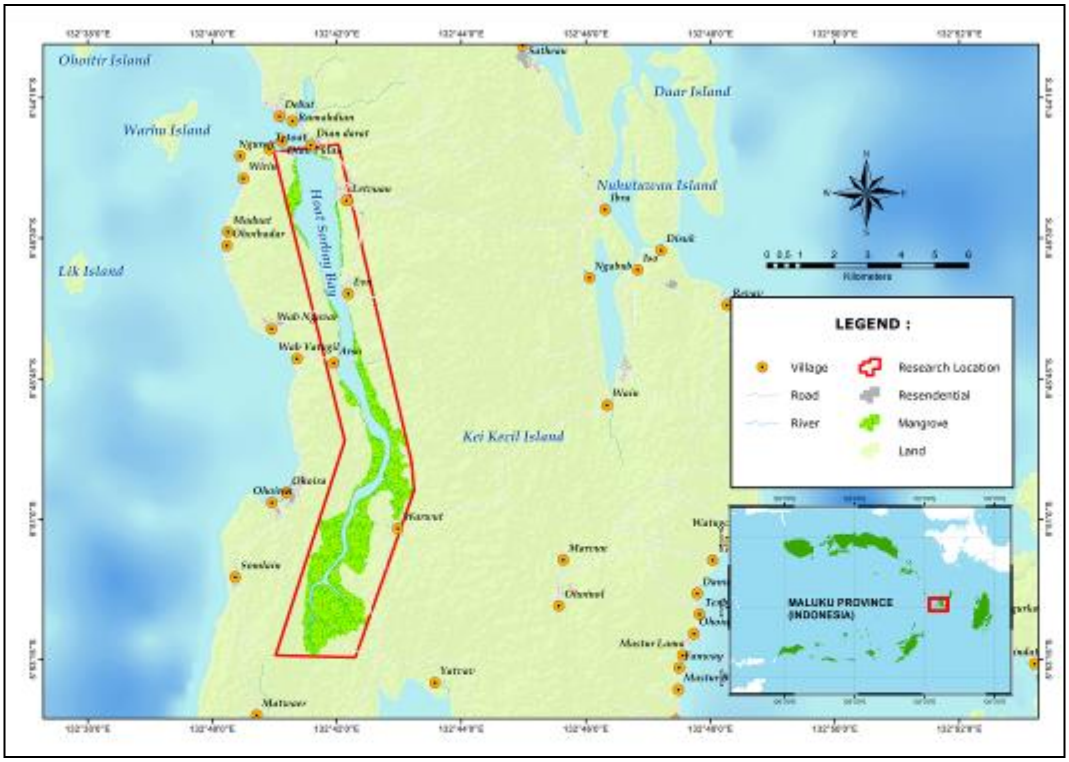

Fig. 1. Map of research location

Data analysis

This study's data analysis is based on a geographic information system (GIS) and involves multiple steps, such as:

Seaweed aquaculture suitability analysis

The suitability parameters listed in Table (1) are used to analyze the appropriateness of seaweed aquaculture **(Wijaya, 2007; Modification of SNI, 2011; Agustina, 2017)**.

Table 1. Criteria for seaweed aquaculture suitability

Parameter	Weight	Suitability Class (Score)		
		S1(3)	**S2(2)**	**N(1)**
Substrate	2	Sandy Coral	Muddy Sand	Mud
Wave (m)	2	0.2–0.3	>0.1-<0.2 or >0.3-<0.4	<0.1 or >0.4
Current (m/s)	2	0.25-0.40	>0.10-<0.25 or >0.40-<0.60	<0.10 or >0.60
Brigthness (m)	2	>5	>1.5-<5	<1.5
Depth (m)	2	4-6	>3-<4 or >6-<10	<2 or >10
Temperature (^{0}C)	1	26-32	>22-<24 or >32-<36	<22 or >36
Salinity (ppt)	1	28-34	>25-<28 or >33-<37	<25 or >37
pH	1	7.5-8.5	>6-<7 or >8.5-<9	<5 or >9
Nitrate (mg/l)	1	0.04-0.1	>0.01-<0.04 or >0.1-<0.5	<0.01 or >0.5
Phospate (mg/l)	1	0.1-0.2	>0.01-<0.1 or >0.2-<1	<0.01 or >1

*S1 = Very Suitable; S2 = Conditionally Appropriate; N = Not suitable

Ecofisherytourism suitability analysis

There are three forms of GIS (Geographical Information System) analysis used to assess ecofishery tourism. The following is an explanation of the three analyses.

- The suitability criteria employed by **Setiawan and Triyanto, (2012)** in Table (2) are consulted in the analysis of the suitability of mud crab cultivation.
- The appropriate criteria which are adapted from **Yulianda (2007)** and **Nugroho *et al*. (2019)** and are displayed in Table (3), are applied in the assesment of the suitability of mangrove ecotourism.

Table 2. Criteria for mud crab cultivation suitability

Parameter	Weight	Suitability Class (Score)		
		S1(3)	S2(2)	N(1)
Soil texture	15	Fine	Medium	Kasar
Soil type	15	Aluvial	Mediteran, regosol, latosol	Grumosol
Rainfall (mm/yr)	5	<1500	1500-3000	>3000
Topography	10	Flat	Wavy	Hily
Land slope (%)	10	0-2	>2-8	>8
Land use	10	Bushes, reeds, swamps, ponds	Port development, rice fields, mixed gardens	Residential areas, protected forests
Distance from river (m)	5	<500	500 - 2000	>2000
Distance from sea (m)	5	<2000	2000-4000	>4000
Coastal vegetation	15	Mangroves	Nipah, nipah and coconut	Tidal forest
Salinity (ppt)	15	15-25	25-30	<15

*S1 = Very Suitable; S2 = Conditionally Appropriate; N = Not suitable

Table 3. Criteria for mangrove ecotourism suitability

Parameter	Weight	Suitability Class (Score)			
		S1(4)	S2(3)	S3(2)	N(1)
Mangrove thickness (m)	0.35	>500	>200-500	50-200	<50
Mangrove density (100m^2)	0.25	>15-25	>10-15	5-10	<5
Mangrove type	0.17	>5	>3-5	1-2	0
Biota association	0.13	Fish, shrimp, crabs, reptiles, molluscs, birds	Fish, shrimp, crab, molluscs	Fish, molluscs	One of aquatic biota
Tides (m)	0.10	0-1	>1-2	>2-5	>5

*S1 = Very Suitable; S2 = Conditionally Appropriate; S3 = Less suitable; N = Not suitable

The suitability criteria for ecofisherytourism are a combination of the suitability criteria for mud crab cultivation and the suitability criteria for mangrove ecotourism where the total score results of both suitability analysis results are then combined with an additional operation and then classified into three classes of suitability for ecofisherytourism, namely very suitable (S1), with a total score of >215; conditionally appropriate (S2), with a total score >185-<214; and not suitable (N), with a total score <184.

Marxan analysis

In this study, priority locations for ecofisherytourism and mangrove conservation areas were determined using Marxan analysis. MARXAN analysis uses the simulated annealing process to determine the optimal solution, which is the one with the lowest cost of using conservation space **(Ball & Posingham, 2000)**. This analysis uses the following equation:

$$\text{Total } Cost = \sum_{n=1}^{n} cost + (BLM * Boundary) + \sum_{n=1}^{n} (SPF * Penalty)$$

Cost	=	The chosen, quantifiable cost value in the planning unit
BLM	=	Boundary Length Modifier, is a crucial control of the planning unit's chosen relative cost limit. Since BLM is 0 (zero), the boundary length is excluded from the objective function.
Boundary	=	The chosen area's boundary
SPF	=	The species penalty factor, determines how much of a penalty value will be assessed if each species' aim is not reached.
Penalty	=	Each target that is not fulfilled results in a penalty of value added to the objective function; this penalty is optional and may not be included in the objective function.

With a total of 1.329 PU units, the planning unit (PU) that is utilized is hexagon-shaped and is 100 ha. One hundred literations of a Marxan running process is the BLM value utilized. The height and lowness of the BLM will influence the area that emerges in the solution, whereas the PU hexagon form is more natural and has a low edge ratio, according to **Loos (2006)**.

Using three approach scenarios, prioritize sites for mangrove conservation and ecofisherytourism development (Table 4). Marxan makes use of cost (Table 6) and conservation (Table 5) aspects. Target percentages for a number of conservation characteristics vary throughout the three scenarios. The target percentage is the proportion of targets in the study area's planning unit.

Marine functional zonation (MFZ)

Marine Functional Zoning (MFZ) involves dividing marine and island areas into specific functional zones, each designated for particular uses and environmental standards. This approach considers the condition of marine resources, the region’s current level of economic development, and ecological characteristics, with the overall goal of supporting balanced and sustainable economic and social growth **(Fang *et al*., 2011; Fang & Ma, 2018)**.

Table 4. Scenario for determining priority of ecofisherytourism and mangrove conservation areas

Parameters	Scenario 1	Scenario 2	Scenario 3
	Target	Target	Target
Mud crab cultivation's as a ecofisherytourism in very suitable category (S1).	30%	20%	30%
Mud crab cultivation's as a ecofisherytourism in conditionally appropriate category (S2)	-	10%	10%
Mud crab cultivation in very suitable category (S1).	30%	20%	30%
Mud crab cultivation in conditionally appropriate category (S2).	-	10%	10%
Mangrove ecotourism in very suitable category (S1).	30%	20%	30%
Mangrove ecotourism in conditionally appropriate category (S2).	-	10%	10%

Table 5. Conservation feature

Parameter	Weight
Mud crab cultivation's as a ecofisherytourism in very suitable category (S1).	20 - 30%
Mud crab cultivation's as a ecofisherytourism in conditionally appropriate category (S2)	10%
Mud crab cultivation in very suitable category (S1).	20 - 30%
Mud crab cultivation in conditionally appropriate category (S2).	10%
Mangrove ecotourism in a very suitable category (S1).	20 - 30%
Mangrove ecotourism in a conditionally appropriate category (S2).	10%

Table 6. Cost feature

Parameter	Weight
Mud crab fishing ground	High
Residential area	High

RESULTS AND DISSCUSSION

1. Seaweed aquaculture suitability

According to the suitability criteria for seaweed aquaculture suitability, the overall state of the waters in Hoat Sorbay Bay is as follows: (1) Muddy sand bottom substrate makes up 60% of the bay's waters, while mud bottom substrate makes up 40.0%; (2) The average wave height in this area is 1.17m; (3) Current speed ranges from 0.03 to 0.09m/ sec; (4) Water brightness ranges from 2.6 to 3.5m; (5) Water depth ranges from 2.6 to 9.7m; (6) The average water temperature in these waters is 23.98ºC; (7) The salinity content ranges from 28.0-30.0ppt; (8) Waters have a pH between 6.79 and 7.37; (9) A nitrate content between 0.04 and 0.10mg/ l, and (10) A phosphate content between 0.02 and 0.08 mg/l. The suitable area for seaweed aquaculture in Hoat Sorbay Bay is depicted in Fig. (2) based on the analysis's findings using these criteria.

The suitability of seaweed aquaculture areas demonstrates that the level of suitability of aquaculture in Hoat Sorbay Bay is divided into three levels of suitability with different areas (Fig. 2), respectively: Very suitable is 127.10 ha; Conditionally appropriate is 331.84 ha; and not suitable is 211.46 ha. Based on these findings, only a small portion of the area has been utilized by local fishers, primarily through simple *long-line* seaweed farming systems. However, this utilization remains limited and does not yet cover the full extent of both the very suitable and conditionally appropriate zones, which still offer considerable undeveloped potential. With adequate support in terms of infrastructure, access to high-quality seedlings, and technical training for the community, these areas hold great promise for development into a productive and sustainable seaweed farming center. Expanding cultivation in this zone would not only increase the income of coastal communities but also strengthen local economic resilience and support livelihood diversification in Hoat Sorbay Bay.

Establishing seaweed cultivation zones is crucial for maximizing output since it considers environmental elements like water quality **(Nabila *et al*., 2022)**. Marine Spasial Planning encourages sustainable resource use by regulating marine space, making sure that commercial operations don't jeopardize ecological integrity **(Zekic *et al*., 2023)**.

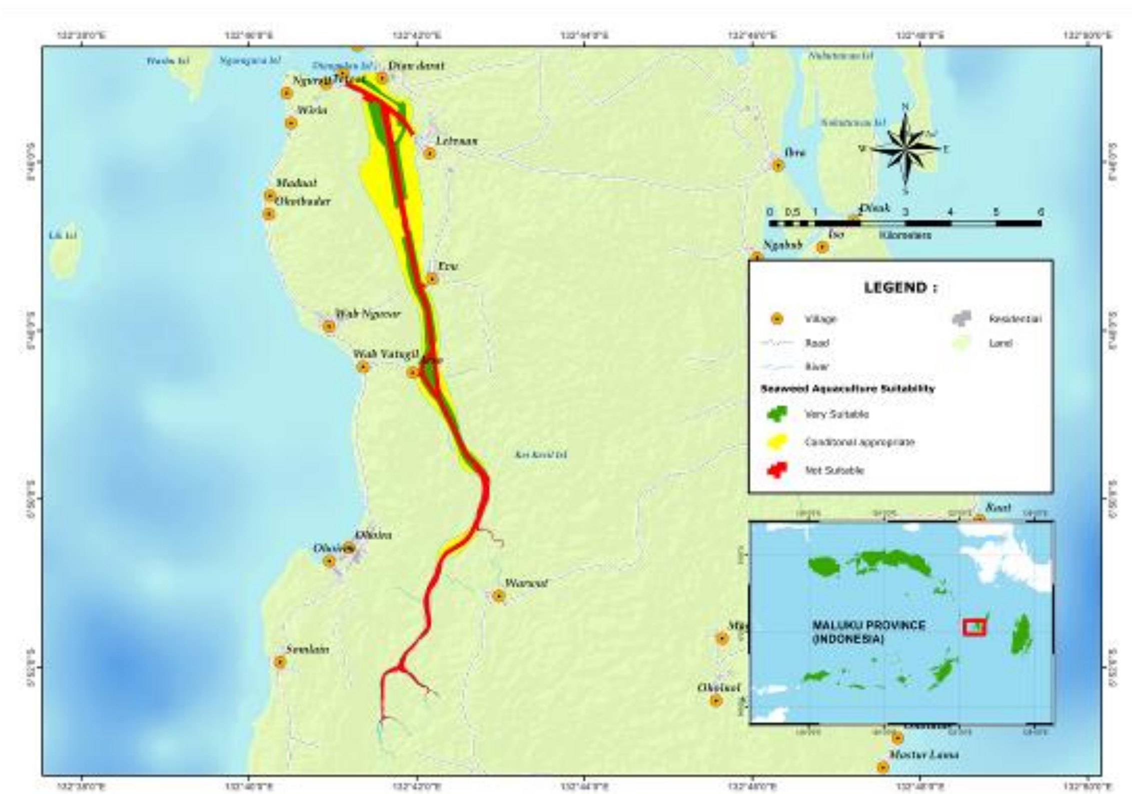

Fig. 2. Map of seaweed aquaculture suitability

2. Ecofisherytourism suitability

This work combines the suitability analysis of mud crab cultivation suitability and mangrove ecotourism suitability to create ecofisherytourism. The findings of the two suitability analysis can be broken down into the following specifics.

Mud crab cultivation suitability

According to the following criteria of mud crab cultivation suitability, the state of the waters in Hoat Sorbay Bay can be stated as follows: (1) Land in the slope class category 0 - 25% is concentrated along the coast of Hoat Sorbay Bay and some land around the mangrove forest, while the slope classes 2 - 8% and > 8% are distributed on the mainland; (2) The Hoat Sorbay Bay area's dispersed and identified land cover is made up of five different types of use: gardens, reeds, forests, bushes, and settlements; (3) Because the texture is primarily composed of mud, the area surrounding the mangrove forest has a preponderance of fine soil textures, whereas the area behind the mangrove forest has a preponderance of medium to coarse soil textures; (4) Rainfall in the Hoat Sorbay area ranges from 41.9 to 483.0mm each month, with an average of 243.9mm; (5) Hoat Sorbay Bay's land topography consists mostly of hilly and wavy; (6) Mud is the dominant soil type; (7) Distance from river <500m; (8) Distance from the sea <2000m; (9). Coastal vegetation dominated by mangroves, and (10) The salinity content ranges from 28.0-30.0ppt. Based on the results of the analysis according to suitability parameters, the suitability area for mud crab cultivation area is obtained, as seen in Fig. (3).

The degree of suitability of mud crab cultivation area is separated into three categories of suitability with varying type areas, according to an analysis of the suitability of mud crab cultivation sites utilising confinement techniques (Fig. 3). 772.04 hectares are very suitable, 115.43 ha are conditionally appropriate, and 2.90 ha are not suitable. These findings indicate that 887.47 hectares of mud crab cultivation area are available for development. 94.23% of the total area of mangrove forests in the Hoat Sorbay Bay area can be developed, which is a pretty high proportion.

Mud crab farming in Hoat Sorbay Bay is still mostly done on a local scale and according to traditional methods. Local fishers, especially from the Ohoi Evu community, primarily rely on capture-based practices in mangrove areas without structured farming systems such as fattening or grow-out ponds **(Siahainenia *et al.*, 2025)**. These activities are typically seasonal and depend heavily on wild stock availability, which poses sustainability concerns over time. This vast area presents an opportunity for transitioning from capture-based to culture-based systems, such as crab fattening in floating cages or semi-intensive ponds. To fully realize this potential, there is a need for investment in infrastructure, hatchery technology, training for local communities, and regulatory frameworks that support community-based and environmentally friendly cultivation.

Mud crab cultivation is important due to its high economic value, contributing to local fisheries and food security (**Nurlaila *et al*., 2024)**. Due to their limited availability in nature, mud crab cultivation is essential for sustaining crab populations. It also generates revenue, helps local livelihoods, and encourages sustainable practices **(Ramadona *et al*., 2022)**.

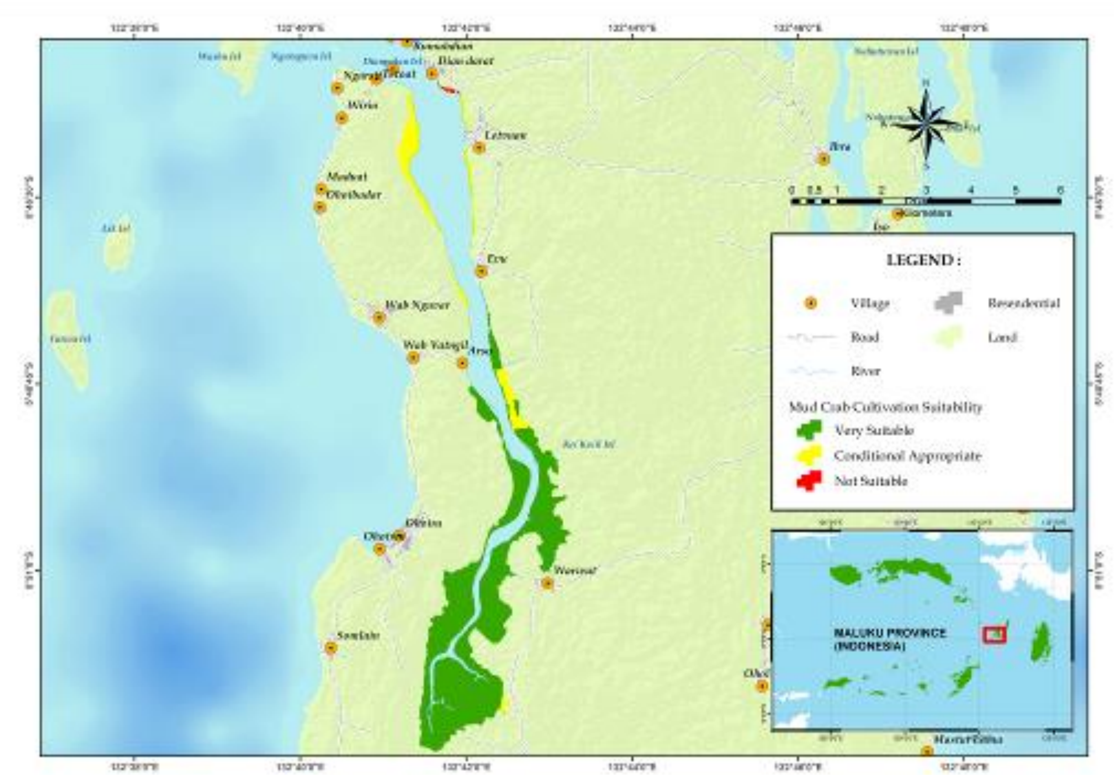

Fig. 3. Map of mud crab cultivation suitability

Mangrove ecotourism suitability

According to suitable criteria for mangrove ecotourism, Hoat Sorbay Bay's biophysical features include: (1) The mangrove thickness class is distributed as follows: the area covered by the <50m thickness class is 23.04 ha; the area covered by the 50m to 200m thickness class is 211.25 ha; the area covered by the 200 to 500m thickness class is 398.85 ha; and the area covered by the > 500 m thickness class is 800.56 ha; (2) The distribution of mangrove density classes is as follows: density class < 5 covered 197.69 ha, density class 5–10 covered 267.32 ha, density class > 10–15 covered 345.65 ha, and density class > 15–25 covered 130.77 ha; (3) *Bruguiera gymnorhiza*, *Bruguiera parviflora*, *Rhizophora apiculata*, *Rhizophora mucronate*, *Rhizophora stylosa*, and *Sonerati alba* are the six types of mangroves that are currently known to exist; (4) Black snakes with gold or yellow patches (*Boiga dendrophlia*), mud grouper, white snapper, giant prawns (*Macrobrachium rosenbergii*), tiger prawns (*Penaeus monodon*), *Scylla serrata*, *Scylla olivacea*, white-bellied mangrove snakes (*Fordonia leocobalia*), pelicans, and kingfishers are among the biota types discovered, and (5) The Tetoat-Dian Darat region up to Evu-Arso has an average tidal rise of 1 to 2 meters, and the Evu-Arso region up to Warwut has an average tidal rise of 0 to 1 metre. Based on the results of the analysis according to these parameters, the area of suitability for mangrove ecotourism is obtained, as seen in Fig. (4).

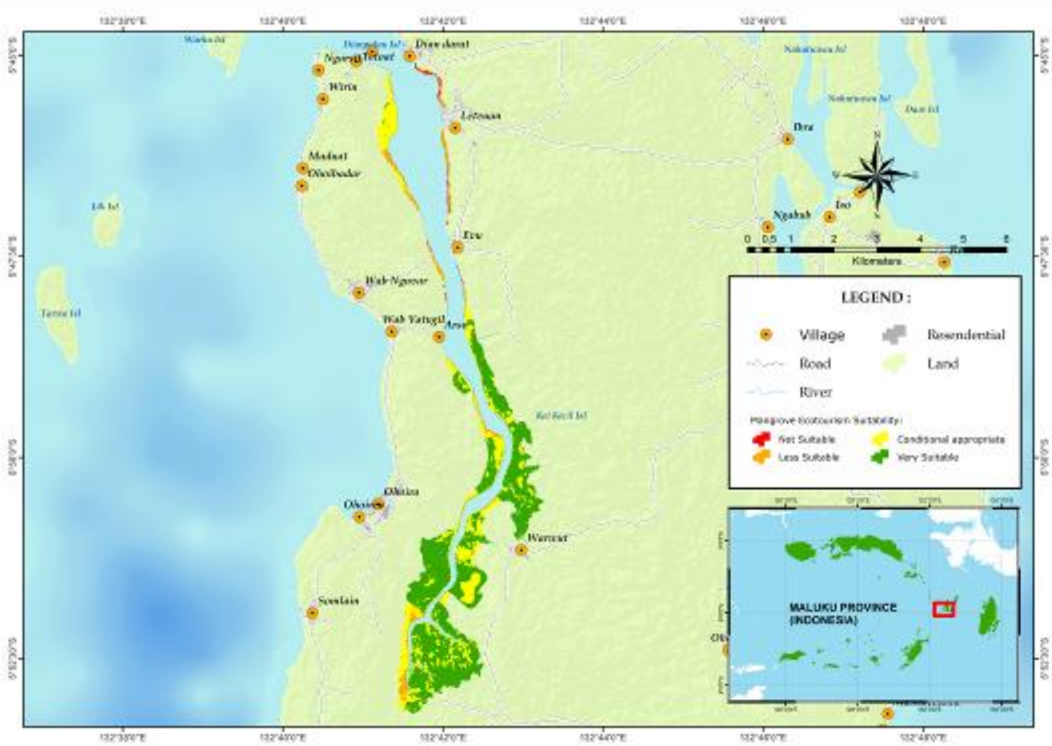

Fig. 4. Map of mangrove ecoturism suitability

An integrated aquaculture area management approach is crucial for regional economic diversification, even though analyzing the suitability of mangrove ecotourism areas is not the primary aquaculture activity in the Hoat Sorbay Bay area. An analysis of the mangrove ecotourism region's appropriateness demonstrates that there are four levels of acceptability for development in Hoat Sorbay Bay, each with a distinct area. These levels are as follows: very suitable area are 549.58 ha, conditionally appropriate area are 289.57 ha, not appropriate area are 56.98 ha and unsuitable area are 8.68 ha. Based on these findings, 839.15 hectares of mangrove ecotourism area are available for development.

The development of ecotourism in mangrove areas can enhance the welfare of surrounding communities by promoting sustainable resource utilization and socio-economic development **(Izzah & Islam, 2024)**. Mangrove ecotourism supports environmental conservation by raising awareness about the importance of mangrove ecosystems and promoting sustainable tourism practices **(Elida *et al*., 2025)**.

A total score for the two parameters of suitability for mud crab cultivation and mangrove ecotourism is obtained for the suitability of the ecofisherytourism. According to **Haris (2012)** and **Mukhti (2016)**, concept ecofisherytourism/minatourism is an intersection or combination of integrated use of space and fishery resources. Fig. (5) displays the findings of the analysis of suitability areas for ecofisherytourism.

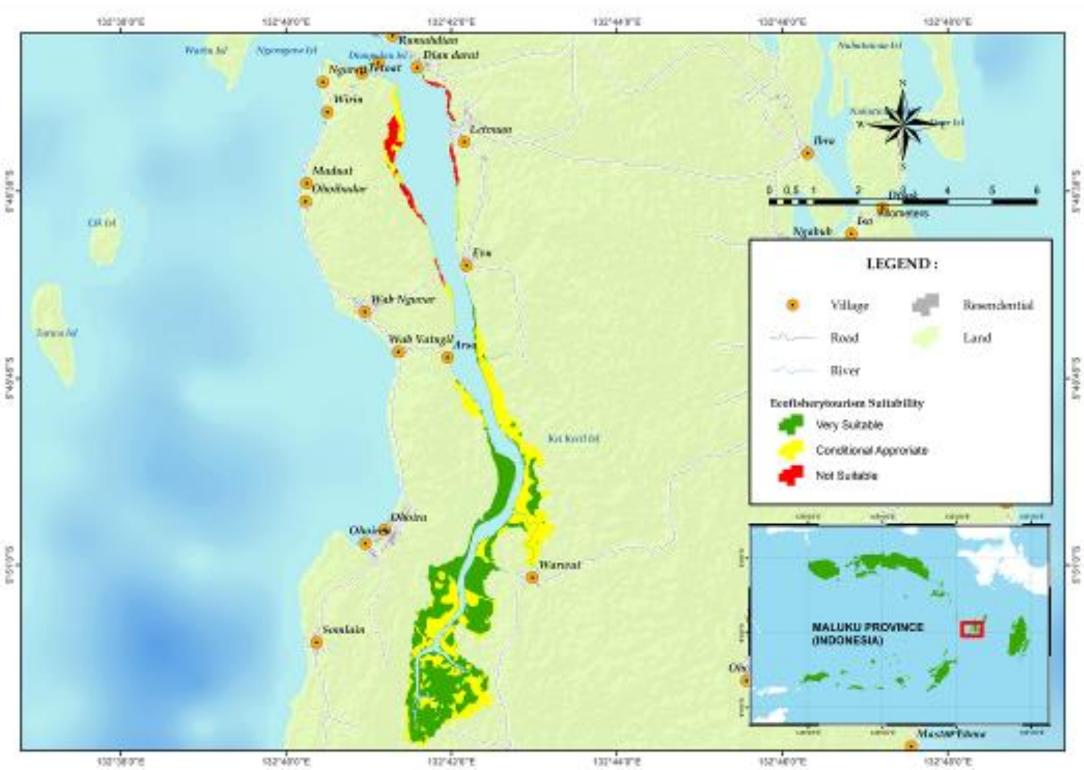

Fig. 5. Map of ecofisherytourism suitability

According to an analysis of the ecofisherytourism area's suitability, Hoat Sorbay Bay's development area is categorized into three degrees of suitability with varying areas. 432.03 hectares are very suitable, 412.40 ha are conditionally appropriate, and 45.94 ha are not suitable. Controlling human activity, resolving conflicts, and guaranteeing resource sustainability all depend on the management of marine space **(Violante *at al*., 2020)**.

3. Priority areas for mangrove conservation and ecofisherytourism

There is a sizable region that has to be managed as both a mangrove ecotourism area and a crab cultivation area, according to the findings of the study on the suitability of ecofisherytourism (Fig. 5). Thus, the growth of ecofisherytourism simply requires a specific location. This is carried out because it also considers protected areas' significance for the sustainability of the mangrove ecosystem and community usage areas. Fig. (6) displays the findings of MARXAN's analysis of the regions that should be prioritized for the development of ecofisherytourism or mangrove conservation area.

Several conservation strategies have been incorporated into the zoning plan, including mangrove protection zones, restoration of degraded areas, and ecofisherytourism development. These efforts are aligned with the biological requirements of mud crabs, which depend heavily on mangrove ecosystems throughout their life cycle. By maintaining and restoring these habitats, the sustainability of community-based crab fisheries can be better ensured in the long term.

Mangrove habitats offer ecological, economic, and social benefits, making their preservation crucial to the management of coastal areas **(Jahan & Sujarajini, 2024)**. For small-scale fisheries, securing fishing activity space is essential because it guarantees access to marine resources, fosters sustainable development, and supports social development, economic growth, and nutrition security for people who depend on these coastal areas **(Basurto *et al*., 2024)**.

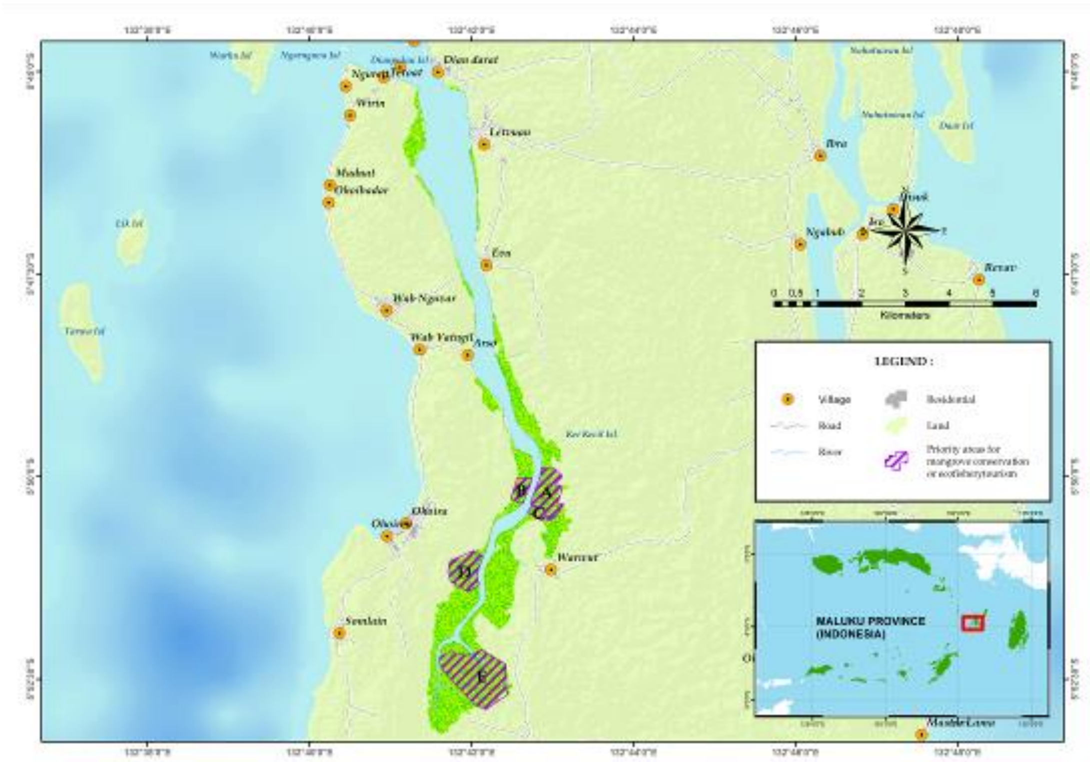

Fig. 6. Map of priority areas for mangrove conservation and ecofisherytourism

The results of the Marxan analysis prove that there are five zones with different areas (Fig. 6), respectively: Zone A is 53.879 ha; Zone B is 18.148 ha; Zone C is 9.107 ha; Zone D is 49.404 ha and Zone E is 135.650 ha. In accordance with these results, the opportunity for developing the ecofisherytourism or mangrove conservation area is 266.188 ha. Marxan is a GIS-based application that eventually aids in sustainable development and maritime spatial planning **(Wijayanto *et al*., 2022)**. Ecofisheriestourism refers to tourism activities centered around fishing that prioritize environmental conservation and community welfare **(Rohim *et al*., 2024)**.

Establishing conservation and ecofisherytourism zones within mangrove areas is crucial for sustaining mud crab populations. These zones serve as key habitats for both juvenile and adult crabs and protecting mangrove vegetation directly supports stock abundance. In the proposed zoning, rehabilitation and protection areas are placed adjacent to fishing grounds to allow for spillover effects. Beyond ecological aspects, these strategies are supported by community-based management approaches to ensure resource governance that remains inclusive and adaptable to local contexts.

4. Marine functional zoning

The overall suitability study indicates that the region may be managed in accordance with its suitability classification; nonetheless, in order to ensure the smooth and sustainable operation of all current activities, a spatial management plan is required. Fig. (7) shows how the coastal and marine regions of Hoat Sorbay Bay are arranged and developed in terms of spatial utilization based on marine spatial planning, particularly marine functional zoning. Hoat Sorbay Bay's coastal and marine areas are developed and arranged with consideration for space usage, development goals, and sociocultural and economic components of the community.

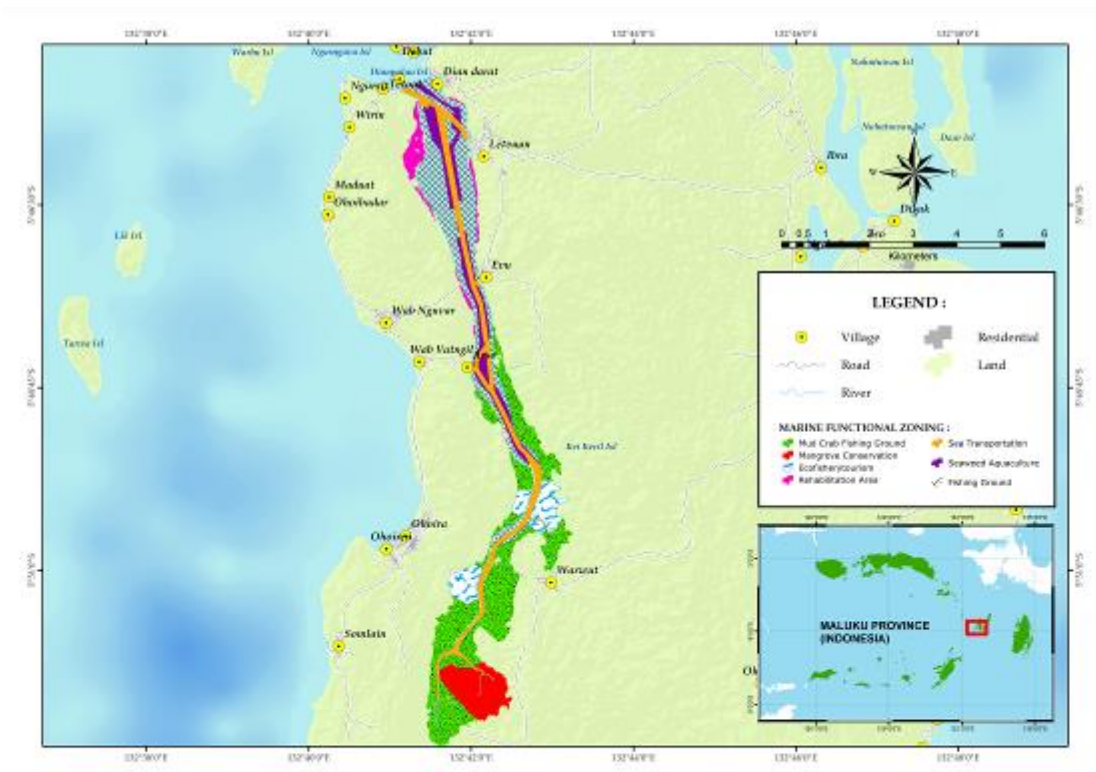

Fig. 7. Marine functional zoning in Hoat Sorbay Bay

The marine functional zoning in Hoat Sorbay Bay consists of seven designated zones, each with specific purposes and ecological, social, or economic functions that support sustainable resource management. The details of each zone are as follows:

a. Mud crab fishing zone (530.98 ha). This zone is allocated primarily for the harvesting of mud crabs (*Scylla* spp.), which are a key economic commodity for local fishers, particularly the community in Ohoi Evu. The area includes extensive mangrove habitats that serve as natural breeding and nursery grounds. By designating this zone, the management seeks to regulate access, prevent overexploitation, and provide spatial certainty to support both traditional and semi-culture crab fisheries.
b. Mangrove protection zone (135.65 ha). This zone comprises areas with dense and healthy mangrove vegetation that are crucial for shoreline stability, biodiversity conservation, and carbon sequestration. Activities in this zone are strictly limited to protection and non-destructive uses such as environmental education or monitoring. The goal is to maintain the ecological integrity of primary mangrove forests and preserve ecosystem services.
c. Ecofisherytourism zone (120.12 ha). Combining elements of ecotourism and sustainable fisheries, this zone is intended to promote community-based tourism linked with aquaculture and mangrove education. The zone is suitable for activities such as guided mangrove tours, crab feeding experiences, and demonstration plots of seaweed or crab cultivation, offering alternative income streams while fostering conservation awareness.
e. Mangrove rehabilitation zone (60.62 ha). This zone includes degraded mangrove areas targeted for active restoration through planting, hydrological improvement, and community engagement. Its designation supports long-term sustainability goals by expanding mangrove cover, enhancing coastal resilience, improving habitat quality for aquatic and terrestrial species, and enhance the capacity for carbon absorption **(Rahman *et al.*, 2020; Rahman *et al.*, 2024)**.
f. Fishing zone (331.84 ha). Allocated for general capture fisheries, this zone accommodates small-scale fishing activities for species other than mud crabs, such as reef fish and pelagic species. The zoning ensures that fishing efforts are spatially directed away from sensitive habitats and more compatible with sustainable yields, while also reducing conflict with non-fishing uses.
g. Sea transportation zone (211.46 ha). This area supports local navigation and boat traffic, including traditional transport routes between coastal villages. Its allocation minimizes conflict with aquaculture and conservation zones and ensures safe passage for fishing vessels and small-scale transport boats. Infrastructure development such as docks or jetties may be considered here under environmentally friendly guidelines.
h. Seaweed aquaculture zone (129.10 ha). This zone is designated for the cultivation of seaweed, particularly *Eucheuma* species. It is situated in areas with optimal environmental parameters such as water clarity, salinity, depth, and wave action. By concentrating aquaculture in designated zones, the plan helps prevent spatial overlap with fishing or transportation, thereby improving productivity and reducing ecological impact.

While the functional zoning assessment primarily focuses on ecological aspects, the social and economic dimensions of coastal communities are equally considered in this planning. The zoning has been carefully designed to avoid disrupting traditional fishing activities, particularly the mud crab fisheries operated by the Ohoi Evu community. On the contrary, the plan secures fishing areas and reduces potential spatial conflicts. Furthermore, the development of ecofisherytourism zones creates opportunities for supplementary income without compromising local access and rights to marine resources that have long supported their livelihoods.

Effective marine space utilization goes beyond ecological suitability; it also depends on how well planning responds to the needs and usage patterns of local communities. By integrating field data, resource potential, and stakeholder interests, the functional zoning proposed here is expected to minimize overlapping uses and enhance the efficiency of marine spatial management in Hoat Sorbay Bay.

Marine functional zoning plays a crucial role in helping governments optimize the use of marine resources while steering ocean development in a sustainable direction. It achieves this by promoting spatial balance among various marine activities, aligning human use with ecological protection, and fostering a more integrated relationship between resource utilization, environmental conservation, and economic growth in coastal and marine areas. **(Ma *et al*., 2022)**. The main requirement for attaining sustainable and ecosystem-based management is efficient zoning **(Day *et al*., 2019)**.

CONCLUSION

This study demonstrates that Marine Functional Zoning (MFZ) is a practical and strategic approach for managing the multiple uses of coastal and marine resources in Hoat Sorbay Bay. Through ecological suitability assessments and spatial analysis, seven functional zones were established: mud crab fishing, mangrove protection, ecofishery tourism, mangrove rehabilitation, general fishing, sea transportation, and seaweed aquaculture. The zoning framework effectively integrates ecological conservation with local socio-economic priorities, particularly by supporting the livelihoods of small-scale fishers such as those in the Ohoi Evu community. Priority areas totaling 266.19 hectares were identified for conservation and ecofishery tourism development using MARXAN, ensuring ecological integrity while promoting sustainable resource use. The functional zoning model provides a replicable framework for other coastal regions facing similar challenges, including spatial conflict and resource degradation. It aligns with national marine spatial planning policies and contributes to the achievement of the Sustainable Development Goals (SDGs), particularly **SDG 14** (Life Below Water) and **SDG 8** (Decent Work and Economic Growth). Effective implementation of this model will require strong institutional coordination, active community involvement, and adaptive management to respond to evolving ecological and socio-economic conditions.

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