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Original article

Suitability of Mangrove Ecosystems as a Protected Zone Based on Land-Use Changes

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Abstract
Purpose. Mangrove ecosystems have a protective function; they support high biodiversity and protect endemic/rare/endangered species. For these reasons, they are essential on a regional, national, and even world scale. The protected zone in the coastal region of Bungus Bay, Padang City, Indonesia is located in the coastal and river boundaries. It provides coastal protection for the coastal disaster-prone region. This research aims to determine the suitability of mangrove ecosystems as a protected zone in the coastal region of Bungus Bay based on land-use changes.
Methods and Results. The research method is based on the assessment of biophysical parameters and the suitability of mangroves as a protected zone. The remote sensing data from Landsat imagery with the Geographic Information System (GIS) have been used as a primary research tool. The research results reveal that the mangrove area of 111.67 ha is unsuitable and the area of 102.1 ha is suitable for the protected zone.
Conclusions. The unsuitable zone resulted from the land clearing in Labuhan Tarok village for the construction of a crude Palm Oil (CPO) plant which damaged the health of the coastal ecosystem and left it vulnerable to coastal disasters.

Keywords: GIS-mapping, suitability, protected, mangrove, coastal

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1. Introduction

The rapid development of the region in Bungus Bay is not balanced by the efforts to conserve the existing coastal ecosystem. Based on the research [1], the mangroves as a protected zone on the coastal and river borders decreased in the area from 75.2 ha in 2008 to 73.3 ha in 2014. The Sirih Cove area decreased significantly from 4.11 ha in 1995 to 2.48 ha in 2008 and disappeared in 2009, due to the Steam Power Plant (SPP) project development in the southern part of the coastal region of Bungus Bay in 2007.

The disappearance of mangroves as a protected zone occurred due to the land-use change for the SPP project development with a capacity of 2 x 112 MW in the southern part of the coastal region of Bungus Bay in 2007. The same problem occurred in the mangroves of Labuhan Tarok village, where the area decreased significantly from 20.7 ha in 2014 to 10.9 ha in 2015. The decline of mangroves was caused by land-use change for a CPO plant equipped with a pier. These locations are adjacent to marine tourism sites, ports, farms, and settlements due to converting the existing mangroves and the plywood mill owned by PT Sun Kiong [2].

The use of space not included in the planning has an impact on the limited space as a zone of use and a buffer between regions. This discrepancy potentially leads to a conflict between different uses of land [3]. The analysis implementing a spatial approach needs to be carried out by capturing the extent to which these lands potentially disable other lands and have the potential to continue to develop as they are intended [4, 5].

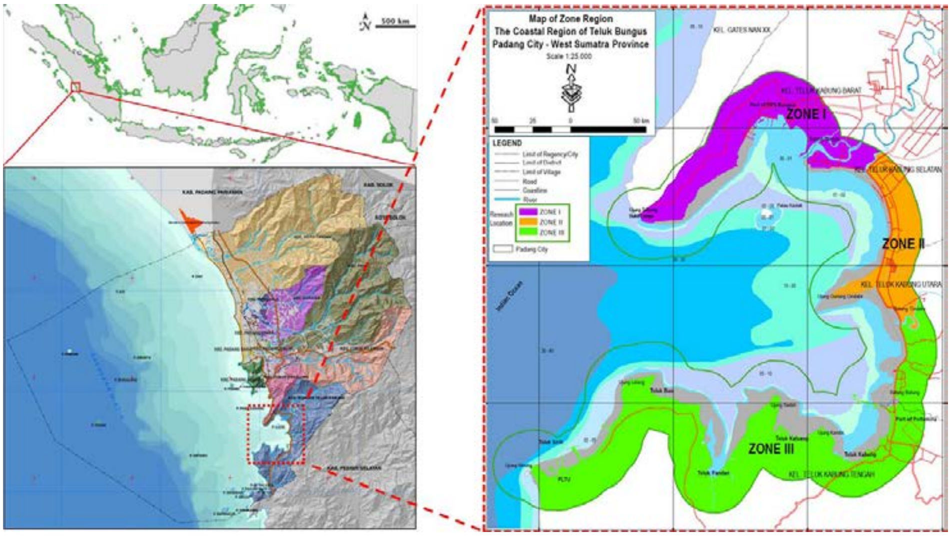
The regional development that utilizes protected zones as new areas makes space utilization increasingly overlapping and irregular. Space utilization which can eliminate other activities can reduce the value of the existing ecosystem utilization, both economically and ecologically, if not managed correctly [6]. Utilization zones in coastal regions that experience environmental stress and are prone to natural disasters should ideally be separated as black zones (not used for development) or be used as a buffer or protective area [7]. Furthermore, land conversion leads to regional development and an increasing amount of population in coastal regions. This can be seen from the land-use change that leads to building settlements, especially in the mangrove-protected zone, both on the coastal, as well as river boundaries. The land-use changes taking place in coastal regions aim to satisfy people's needs for settlements, industrial enterprises, and other developments sustainably and economically [8]. Identification of land-use changes is important to monitor the occurrence of environmental degradation, especially in the protected zone that is still in natural condition.

This research aims to determine the suitability of mangroves as a protected zone with the help of the Geographic Information System (GIS) using remote sensing data from Landsat imagery. The novelty of this research lies in the recommendation for local governments to manage coastal border areas based on the suitability of land designation to prevent future environmental degradation in Bungus Bay, Padang City, Indonesia.

2. Methods

The coastal region of Bungus Bay is located in the Bungus Teluk Kabung sub-district, Padang City, Indonesia. The research location in the Bay region is restricted byboundaries of 500 m from the coastline toward the sea and the land. Furthermore, theyare divided into 3 zones with 2 major rivers serving as boundaries.

Geographically, this area is located at coordinates 100°22'23"E – 100°29'13"E and 0°59'1"S –1°5'44"S with a coastline length of ± 21.050 m and a bay length of 5.418 m, and the volume of water in the bay is 223,255,052.2 m^3 and has a surface shape that tends to be rounded with a surface area of 1.384 ha. Fig. 1 presents a map of the research location.



F i g. 1. Map of the research location in the Bungus Teluk Kabung sub-district, Padang City, Indonesia

Determination of the field survey location is carried out at a place that has high accessibility and can represent all classes of area designation in the existing land-use so that the information obtained can be learned quickly and easily. It took place at locations that had been validated in the field, representing a proportion of 10 % protected zone, 60 % utilization zone, and 30 % special zone [1].

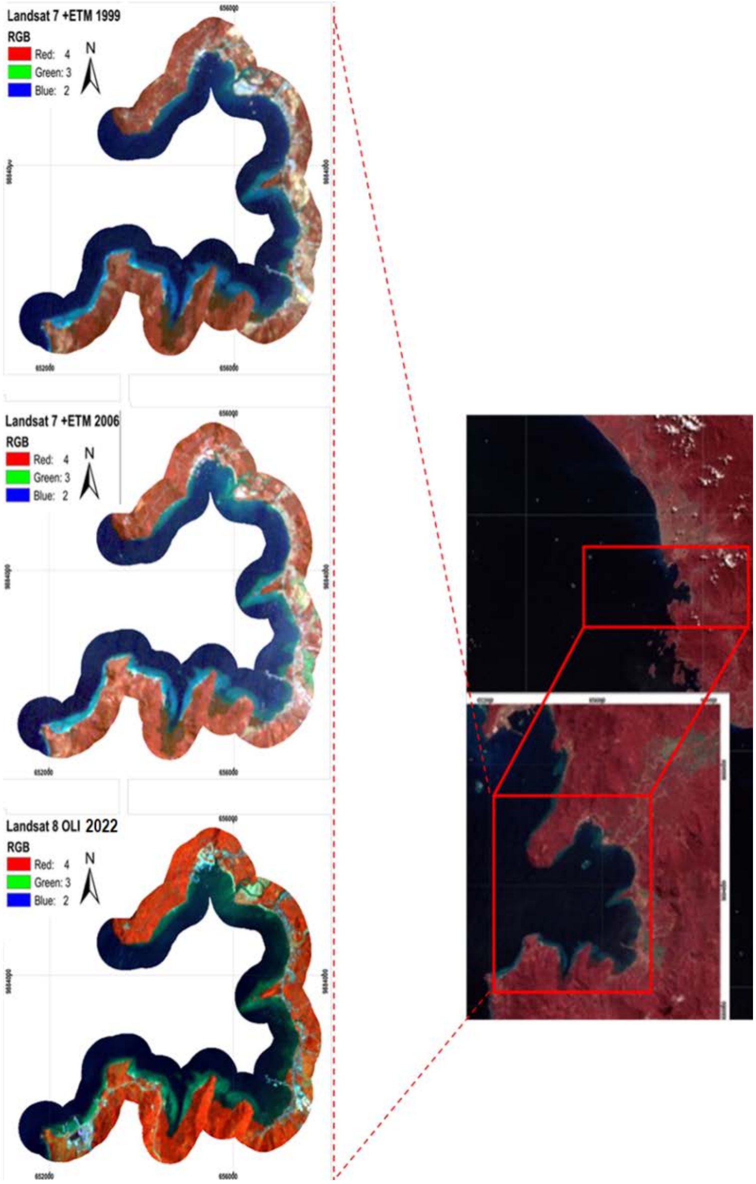
Based on the division into 3 zones (Fig. 1), it is delimited by 2 large river flows on the coast of Bungus Bay, namely Batang Bungus, and Batang Cindakir rivers. Table 1 shows the survey location points for the research samples.

T a b l e 1

Field survey locations for samples in the coastal region of Bungus Bay

Samples	UTM – 47 N WGS84	
	X	Y
1. Labuhan Tarok village	656394	9885814
2. Estuary-River Cindakir village	656375	9883513
3. Kabung Cove	656444	9881233
4. Kalung Cove	655699	9881541
5. Pandan Cove	654587	9880813

The watersheds and coastline boundaries are determined using the basic data from the Indonesian Earth Mapsheets 0714–6444 and 0714–6447, edition 2008, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) 1999, 2006 and Landsat 8 Operational Land Imager (OLI) 2022. The analysis used is the method of Maximum Likelihood Classifier (MLC), where pixels that are known to be textured are grouped based on quantitative evaluation of the variance and correlation of spectral patterns [9]. The cutting of the location is based on the coverage of 1 scene of Landsat imagery so that the location analyzed in the imagery is only the research location with its coordinate boundaries. Figure 2 shows the band combinations from Landsat imagery.



F i g. 2. The band combinations from Landsat imagery in the Bungus Teluk Kabung sub-district, Padang City, Indonesia

The band combination inland-use analysis with Landsat imagery consists of band 4 (red – vegetation), band 3 (green – coastline), and band 2 (blue – coastal and bathymetry) and was obtained using the formulas [10–13] from ENVI® Image Processing & Analysis Software. After getting the land-use classification results, the estimated area is then calculated. The area of land-use classes can be determined using the following formula [14]:

$$L = \Sigma P \cdot r \cdot 0.0001$$

where L is area (ha); ΣP is number of pixels; r is Landsat spatial resolution 30×30 m; and 0.0001 is a coefficient to convert m^2 to ha.

Calculating changes in an area is a process of identifying changes in an object or phenomenon by observing it at different times, calculating the rate of change in a land-use area with the help of interpretations of Landsat 7 ETM+ 1999, 2006 and Landsat 8 OLI 2022. Analysis of changes in the area is carried out using the overlay technique on two images so that the changes in the area of the object observed can be seen. The rate of change in the time series is obtained from the analysis of land-use changes so that the extent of them in the coastal region of Bungus Bay can be known spatially. The change rate analysis in a time series is explained with a formula from ENVI Classic help (Software).

$$V = \frac{N2 - N1}{N1} \cdot 100\ \%$$

where V is rate of change (%); N1 is first year area (ha); N2 is area of the n^{th} year (ha).

Table 2

Assessment of biophysical parameters of a protected zone in the coastal region of Bungus Bay

Space	Parameters	Score
Natural	Have an endemic	2
	Do not have an endemic	0
Coastal boundaries	100–200 m from the point of highest tide towards mainland	2
	From 0 to < 100 m from the point of highest tide towards mainland	0
River boundaries	100–200 m on the left-right of a big river, and 50 m on the left-right of tributaries	2
	From 0 to < 100 m on the left-right of a big river, and 50 m on the left-right of tributaries	0
Artificial	Have beach protection	2
	Do not have beach protection	0
Coastal disaster-prone	No occurrence of seawater intrusion	2
	Occurrence of seawater intrusion	0
	No occurrence of abrasion and accumulation	2
	Occurrence of abrasion and accumulation	0
	No occurrence of sea-level rise	2
	Occurrence of sea-level rise	0

Source: Regulation No. 23/2016.
Note: numbers: 2 is very suitable, and 0 is unsuitable.

Suitability of a region as a protected zone based on the biophysical parameters based on ecological information in the form of native/natural conditions that refer to biological and physical characteristics of the coastal region environment, including things such as biodiversity, climate conditions, ecosystem balance, and the impact of people’s activities on the environment. The native/natural conditions of a region help to determine the extent to which the environment has been affected by people’s activities. It was concluded that to assess whether a coastal region deserves to be a protected zone, it is necessary to carry out an analysis based on biophysical parameters to determine whether it should maintain its native/natural condition and ecological characteristics within it [14, 15]. Based on the Minister of Marine Affairs and Fisheries' Regulation No. 23/PERMEN-KP/2016 on the Management of Coastal Areas and Small Islands (hereinafter Regulation No. 23/2016), this biophysical feasibility assessment is conducted by identifying the biophysical requirements and then performing the weighting and scoring with the GIS approach. Table 2 below gives a detailed assessment of biophysical parameters.

3. Results

3.1. Land-use changes

The resulting analysis of land-use with the help of Landsat imagery 1999, 2006, and 2022 shows a decrease in the land area from 1999 to 2006: in agricultural land of − 41.17 ha/year, in shrubland of − 19.55 ha/year, and forest land of − 6.59 ha/year. At the same time, it shows an increase in land-use related to sedimentation 197.46 ha/year, mangrove ecosystem 26.56 ha/year, and building/settlement 24.12 ha/year. Table 3 presents the results of the land-use analysis in the coastal region of Bungus Bay.

Table 3

Land-use analysis results (land area, ha) in the coastal region of Bungus Bay in the period of 1999–2006

Land use	Year		Changes (ha)
	1999	2006	
Forest	525.55	518.99	−6.56
Agriculture	118.12	76.95	−41.17
Shrubland	54.15	34.61	−19.54
Mangrove ecosystem	54.15	80.71	26.56
Building/Settlements	71.22	95.34	24.12
Sedimentation	115.38	312.84	197.46
Total	938.58	1,119.43	315.41

Source: Data analysis in 2022.

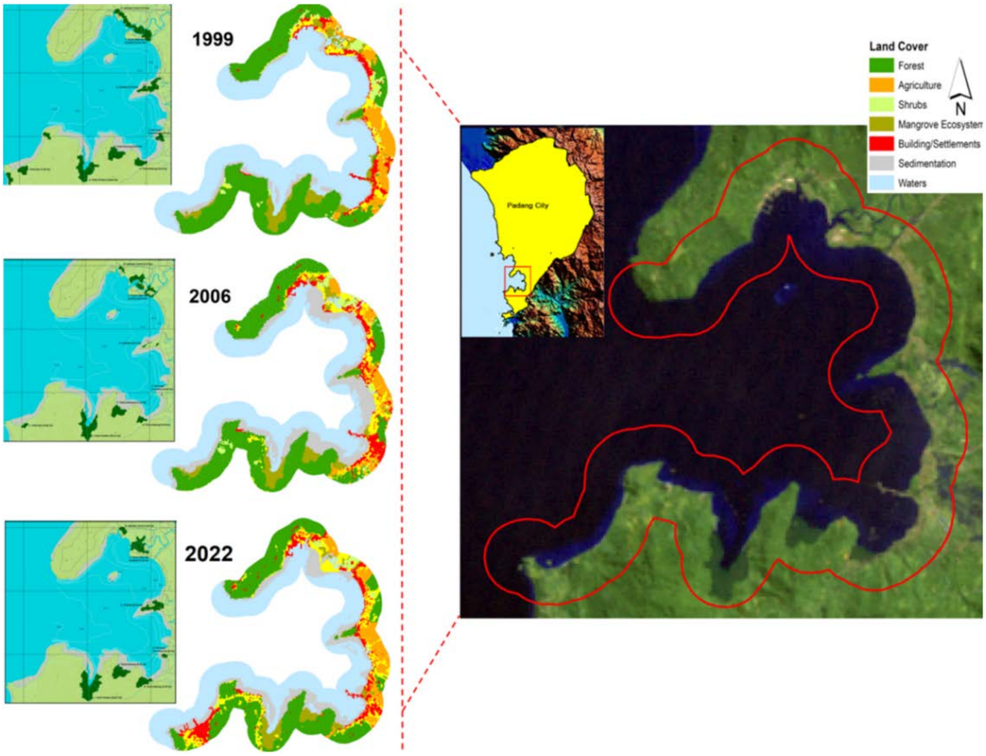
As can be seen in Table 3 above, from 1999 to 2006, the mangroves were still in their natural condition. Especially in Sirih Cove which was once a mangrove area before being developed into a steam-electric power plant site in 2008. The coastal and river boundaries in the coastal region of Bungus Bay were still dominated by shrubland, which were then turned into buildings/settlements. The environmental impacts of rapid development growth in 2008 resulted in high sedimentation deposition. The decrease in the land area in 2006–2022 occurred in the forest land of − 65.92 ha/year, mangrove ecosystem of − 20.36 ha/year, shrubland of 18.07 ha/year, and sedimentation of waters of − 66.59 ha/year. The increase in the land area occurred in the agricultural land of 10.42 ha/year, and building/settlement land of 26.59 ha/year. The rapid development in the coastal region of Bungus Bay resulted in the decrease of forest land, shrubland, and mangrove ecosystem as a protected zone. Table 4 and Fig. 3 below present the results of the analysis in more detail.

Table 4

Land-use analysis results (land area, ha) in the coastal region of Bungus Bay in the period of 2006–2022

Land-use	Year		Changes (ha)
	2006	2022	
Forest	518.99	453.07	− 65.92
Agriculture	76.95	87.37	10.42
Shrubland	34.61	16.54	− 18.07
Mangrove ecosystem	80.71	60.35	− 20.36
Buildings/settlements	95.34	121.93	26.59
Sedimentation	312.84	246.25	− 66.59
Total	1,119.43	985.51	315.41

Source: Data analysis in 2022.



F i g. 3. Analysis results of the Land-use map of 1999, 2006, and 2022 in the coastal region of Bungus Bay

The area of forests and mangroves within coastal boundaries experienced a considerable decline in the decade of 2003–2013, namely 224.8 ha/year, while the area of buildings/settlements acquired additional areas, namely 47.59 ha/year [1]. From the spatial analysis results, it can be concluded that in the last 10 years, the land-use of buildings/settlements continued to increase and was generally spread in the Southern and Northern parts of Bungus Bay.

3.2. Protected zone suitability

The scoring of spatial data using the GIS approach (Table 5) shows the following values in the coastal region of Bungus Bay, namely: sample 1 (Labuhan Tarok village) with an area of 55.84 ha indicates unsuitable category for the protected zone with a score of 16; sample 2 (Cindakir village in the estuary of the river) with the area of 15.01 ha indicates suitable category and the area of 55.83 ha indicates unsuitable category for the protected zone with an overall score value of 8; sample 3 (Kabung Cove), sample 4 (Pandan Cove), and sample 5 (Kalung Cove) with the area of 87 ha indicate suitable category for the protected zone with an overall score value of 40.

Table 5

The results of scoring spatial data for protected zone suitabilitywith the GIS approach

Sample	Score	Category
1	16	unsuitable
2	8	unsuitable
3	40	suitable
4		
5		

Source: Data analysis in 2022.

The results on suitable and unsuitable categories in the analysis of space utilization in the coastal region of Bungus Bay were obtained by considering various factors. In general, the land falls into the suitable category if it implements 1) sustainable utilization (utilization efforts that take into account sustainability principles, environmental protection, and coastal ecology); 2) local utilization (utilization efforts that take into account the needs of local people's, their traditional culture and wisdom); and 3) sustainable tourism development (well-planned tourism that protects the environment and provides economic benefits without damaging coastal ecosystems). Meanwhile, the land falls into the unsuitable category if its use 1) damages the environment (people's activities do not take into account the consequences for coastal ecosystems, such as destroying coral reefs or mangroves); 2) creates conflict (contradiction between the interests of local people's and large investments that can harm environmental sustainability and traditional livelihoods); and 3) is inconsistent with coastal spatial plans, causing environmental damage or an imbalance between economic development and environmental protection.

The zone in the center of industrial and economic activities of the people residing close to the coastal and river boundaries within 3–7 km from the sub-district center or government administration belongs to the unsuitable category. According to [16–18], the buffer areas without vegetation as a barrier are not suitable for protection in coastal regions, which are designated as central to industrial and economic activities. Therefore, it is necessary to make efforts and provide space utilization management in the coastal region of Bungus Bay. Conservation of coastal resources and connection between regions can be based on various principles, namely: 1) inter-regional cooperation; 2) sustainable management of natural resources; 3) wise land-use patterns; and 4) spatial planning and sustainable development. Overall, cross-sectoral cooperation, coordination, and joint action to ensure the protection of coastal resources for future generations are required in the coastal region of Bungus Bay based on the Regulation No. 23/2016. The limitations of mangroves as a buffer zone in the inter-zone region are not synergistic/mutually harmful and affect the decreasing quality of waters and coastal environment [19]. An area of 201.46 ha was allocated for the protected zone based on the Padang City Regional Spatial Plan 2010–2030 in Regional Regulation of Padang City No. 4/2012. Due to the land clearing in Labuhan Tarok village, which was against the Regional Regulation of Padang City No. 4/2012, the coastal ecosystem was damaged and the area became vulnerable to coastal disasters. The allocation of the buffer zone is necessary, especially in the region that can potentially impact other regions so that the decline of environmental quality in the protected zone can be anticipated. Based on field conditions, only agricultural and cultivational (fishery) areas have a buffer zone.

The matrix of compatibility relationships in the coastal region of Bungus Bay (Fig. 4) shows all sectors of activity bringing potential conflicts to other activities, such as waste contamination and changes in ecological functions. Protected zones such as forest, coastal, and river boundaries may decline in function due to the presence of industrial enterprises and ports, except farms and settlements. The minimum width of the buffer zone is 7.6 m plus 0.6 m for every 1% of the slope of the water surface with the mainland. Where the slope of the water surface or the slope of the water surface is measured by the angle formed between the water surface (such as the surface of a lake, river, or sea) and the surrounding horizontal surface. This slope angle affects the flow of water and the distribution of water in the area [20]. Steep slopes tend to produce faster water flow than flat or gentle slopes. In addition to the ecological function, the buffer zone serves to protect the quality of water mass as well as to retain pollutants and slow down runoff so that sedimentation can be reduced [1]. Fig. 4 shows the process in more detail.

	Mangrove Ecosystems	Industry	Settlements	Agriculture	Fishery cultivation	Special Port
Mangrove Ecosystems						
Industry	x					
Settlements	x	x				
Agriculture	x	x	0			
Fishery cultivation	x	x	x	x		
Special Port	x	x	x	x	x	

Information:
X = activities of mutual harm (conflict)
0 = normal

F i g. 4. The matrix of compatibility relationships in the coastal region of Bungus Bay

3.2.1. Natural (not disturbed)

Several species of "genuine" mangroves are found in the coastal region of Bungus Bay, such as *Rhizophora apiculata*, *Sonneratia alba*, *Nypafruticans*, and "mangrove associate species", such as *Terminalia catappa*, *Pandanus odoratissima*, and *Hibiscus tiliaceus*. Location 1 is the location of land clearing for the CPO factory manufacture. This location is an estuary region formed from sedimentation with several types of growing mangroves. The mangroves in Indonesia are described as very widely spread because they need wetland stretches with permanently watersaturated soils and shallow water [21]. Location 2 is habitat mangroves located in the estuary-river Cindakir village. Locations 3, 4, and 5 in the Southern part of the coastal region of Bungus Bay are mangrove habitats located in coves. The mangrove in these locations is a clean coastal ecosystem adjacent to the Office of Marine Affairs and Fisheries of West Sumatra Province and a strategic place for fishermen due to a spawning/nursery area protected from the influence of muddy river estuaries. The mangrove area is a living habitat for vertebrate and invertebrate animals [22, 23]. In Bungus Bay, mangrove areas provide a fertile and diverse environment for various species. The vertebrate animals that can be found in the Bungus Bay mangrove area include 1) types of birds, such as seagulls, herons, and owls; 2) types of fish, such as grouper and mullet; 3) types of reptiles, such as sea turtles and snakes. Meanwhile, invertebrate animals that can be found in the Bungus Bay mangrove area include 1) mangrove crabs which live around the roots of mangrove trees; 2) molluscs; and 3) types of tiger prawns. The presence of mangroves is not only important for the sustainability of marine ecosystems but also for local people because mangroves can function as natural fortresses that protect beaches from abrasion and storms. Therefore, preserving the mangrove area in Bungus Bay is very important to maintain the biodiversity and balance of the marine ecosystem.

T a b l e 5

Family and species of mangroves found in the coastal region of Bungus Bay

Criteria	Family	Species	Locations				
			1	2	3	4	5
Genuine	*Rhizophoracea*	*Rhizophora mucronata*	*	*	*	*	*
		Ceriopstagal	–	*	*	*	*
		Ceriopsdecandra	–	–	*	*	*
		Bruguierahainesii	–	*	*	*	*
	Primulaceae	*Aegicerascorniculatum*	*	–	–	–	–
	Myrsinaceae	*Aegicerasfloridum*	*	*	–	–	–
	Rubiaceae	*Scyphiphorahydrophyllacea*	–	–	*	*	*
	Lythraceae	*Sonneratia alba*	*	*	*	*	*
	Meliaceae	*Xylocarpus granatum*	*	–	–	–	–
	Arecaceae	*Nypafruticans*	*	*	–	–	–
	Acanthaceae	*Acanthus ilicifolius*	*	–	–	–	–
Mangrove associate species	*Malvaceae*	*Thespesia populnea*	–	*	–	–	–
		Hibiscus tiliaceus	*	–	–	–	–
	Pandanaceae	*Pandanus odoratissima*	*	*	–	–	–
	Combretaceae	*Terminalia catappa*	*	–	–	–	–

Source: Field survey in 2022 and site http://plantamor.com/.

* Found mangrove species

The increase in the mangrove area occurs due to conservation activities in several mangrove locations, as well as the natural growth of mangroves which takes place because of the suitable muddy soil substrate and the location in the bay that is protected from strong sea currents [24]. The decrease in the mangrove area is caused by the land-use change, as well as proximity to main roads and settlements, where the mangroves are used for firewood, building, and shipping materials. A decreased mangrove area can be found at location 1 and is caused by land clearing for the construction of an industrial site. Another decreased mangrove area is observed at location 2 and it is influenced by its proximity to the road and settlements. At the same time, the mangrove areas at locations 3, 4, and 5 are expected to increase, as they are situated in the bay that is protected from waves and currents, and the back section of the area is adjacent to the hills. In addition, those three areas are isolated by the forest and shrubland, so the possibility of converting them into settlements or agricultural enterprises is very small. For more details, one can refer to Table 6 below.

3.2.2. Coastal boundaries

The protected zone of coastal boundaries has important benefits for maintaining the sustainability of coastal ecosystem functions along a shoreline whose width is proportional to the shape and whose physical condition is a minimum of 100 cm from the high tide point and/or from coastal cliffs towards the mainland. At the coastal boundaries of Bungus Bay, there are 3 beach types, namely, the sandy beach, the muddy beach, and the cliff rock beach, where the mangrove ecosystem is a protected zone that is categorized as suitable because of the higher vegetation found at locations 3, 4, and 5. These locations are sub-systems of coastal ecosystems with muddy beach and sand characteristics located some distance from the northern and western parts of Bungus Bay. Based on the existing conditions, locations 3, 4, and 5 are beginning to be threatened due to land clearing, as they are adjacent to the SPP access road. Unlike the case with location 1, this location is classified as unsuitable due to the influence of a large clearing of land within the coastal boundaries and impacts of abrasion, while location 2 is still classified as suitable with its rocky/coral beach. The cliffs are composed of rocks, which are the main shape of this beach, where the rocks that are exposed to the abrasion process slowly become steep and directly border the seawater [23, 25, 26]. The dominance of this beach type can be seen in the cape part of the coastal Cindakir village which shows the resistance of the rocks to the geomorphological processes that occur and make mangrove plants grow against the influence of the ocean.

3.2.3. River boundaries

The field survey indicates that the condition of vegetation along the Bungus River estuary has already been damaged due to land conversion into open land for industrial construction and settlements. It concerns the development of industrial land directly adjacent to the river at a distance of ± 2…10 m, except in the middle and upstream parts that are close to agricultural locations and forests. The protected zone of the Bungus River boundaries is almost entirely overgrown with the mangroves *Nypafruticans* and *Rhizophora mucronata*, starting from the river estuary to the middle part near Simpang Ampek and Jurai Permai villages. The river in Cindakir village is located at a distance of 100 m from the banks of big rivers and a distance of 50 m from the banks of small rivers and it is a protection zone for the surrounding areas because it plays a role in maintaining sustainability, especially in the agricultural areas and settlements.

The field survey indicates that the condition of vegetation along the river estuary at Cindakir village has also been damaged due to the proximity of the main road and the land conversion into open land for settlement development, except for the land in the middle and upstream parts that are close to agricultural areas and forest. The river at Cindakir village is almost entirely overgrown with the mangroves *Nypafruticans* and *Rhizophora mucronata* starting from the river estuary to the middle part near the settlements of Lubuk Hitam village. The existence of a settlement within river boundaries is unsuitable by the provisions of Regional Regulation of Padang City No. 38/2011 government regulations. By them, a protected area should expand as far as 100 m from a large river and 50 m from a small river.

3.2.4. Coastal protection

Coastal protection is a coastal building system to reduce the effect of coastal hydrodynamics [27]. Based on the results of the field survey, the coastal building protecting the beach from abrasion at location 1 is in a heavily damaged condition. This coastal building is also damaged by the abrasion resulting from the influence of sediment transport flow along the coast. Locations 2, 3, 4, and 5 do not have any coastal buildings to protect the mangroves.

3.2.5. Coastal disaster-prone areas

Based on the field survey, it was identified that the coastal region of Bungus Bay had 4 types of coastal disasters, namely 1) intrusion of seawater into the estuary of the Bungus River (location 1). Almost all locations have experienced seawater intrusion, so clean water (for drinking purposes) is supplied through a local water company pipeline from the Timbalun village area; 2) sedimentation in the river estuary of Cindakir village (location 2) is caused by the sediment transport from Cindakir village due to poor land-use in the upland part and the clearing of land in the middle river part. In the upstream part which has a waterfall 4 km from the coast bringing sediment in gravel and even stones; and 3) abrasion that occurs at location 1 (starting from the estuary of the Bungus River to Carolina – a tourist location) resulting from the construction of a coastal protection structure (breakwater) and leading to abrasion in settlements in Pasar Laban village up to Cindakir village, and vice-versa, the construction of a coastal protection structure (breakwater) caused the Carolina coast to experience accumulation. At location 3, the residents anticipated this and constructed a flood-friendly type of building so that the impact of the flood would not disrupt their activities.

3.3. Unsuitable management of protected zones

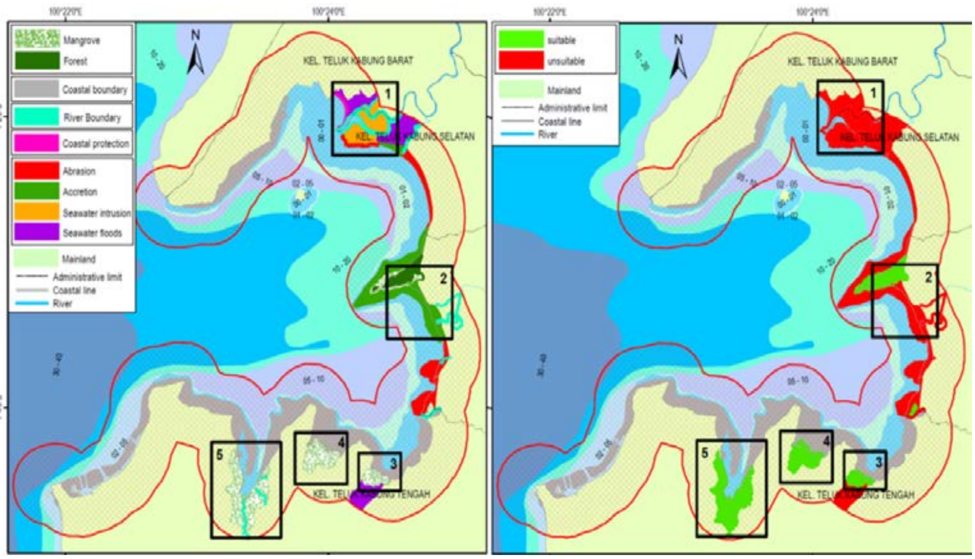
The protected zone was allocated a space of 211.2 ha. This was due to the large-scale land clearing at location 1 for the construction of a CPO plant covering an area of 79 ha causing damage to coastal ecosystem conditions and making it vulnerable to coastal disasters. As a result of this land clearing, the protected zone at location 2 covering an area of 35.45 ha (from 55.83 ha) of an unsuitable category was damaged due to the land clearing. Other local protections such as coastal borders and rivers with a reduced coverage area need to be re-optimized according to the criteria in the Regulation No. 23/2016.

T a b l e 7

Results of suitability of protected zone parameters in the coastal region of Bungus Bay

Locations	Parameters	Category	Score
1	Natural	Unsuitable	0
	Coastal boundaries	Unsuitable	0
	River boundaries	Unsuitable	0
	Coastal protection	Unsuitable	0
	Coastal disaster-prone	Unsuitable	0
2	Natural	Unsuitable	0
	Coastal boundaries	Suitable	4
	River boundaries	Unsuitable	0
	Coastal protection	Unsuitable	0
	Coastal disaster-prone	Suitable	2
3	Natural	Unsuitable	0
	Coastal boundaries	Suitable	4
	River boundaries	Suitable	4
	Coastal protection	Unsuitable	0
	Coastal disaster-prone	Unsuitable	0
4	Natural	Unsuitable	0
	Coastal boundaries	Suitable	4
	River boundaries	Suitable	4
	Coastal protection	Unsuitable	0
	Coastal disaster-prone	Suitable	2
5	Natural	Unsuitable	0
	Coastal boundaries	Suitable	4
	River boundaries	Suitable	4
	Coastal protection	Unsuitable	0
	Coastal disaster-prone	Suitable	2

Source: Data analysis in 2022.



F i g. 1. Protected zone suitability map in the coastal region of Bungus Bay

The unsuitable categories of the protected zones at locations 1 and 2 should be managed by relocating settlements > 100 m away from the coast and > 50 m away from the river, as well as constructing coastal protection structures. Meanwhile, the unsuitable category at location 3 should be managed by constructing a coastal protection building, a house model with stilts, and repairing the road leading to the main one. At location 3, which provides a natural habitat for mangroves and wetland farming, it is necessary to relocate the line distance limit and ship activity and make settling ponds for waste neutralization. For more detailed information related to the mangrove ecosystem suitability as a protected zone in the coastal region of Bungus Bay, Padang City, Indonesia, see Table 7 and Fig. 5 below.

Conclusions

The research indicates that there is an environmental impact from the unsuitable development allocation, namely, settlements. Theused zones are undergoing increasing changes, the mangroves and forests in the coastal region of Bungus Bay are being transformed, and the presence of a SPP does not reduce environmental damage. The protected zone of an unsuitable category should be managed by constructing a coastal protection structure and a house on stilts, and by repairing the road leading to the main one, as well as relocating the line distance limit and vessel activity. A study needs to be conducted with an environmental approach based on public policy on the impact of land clearing for the construction of a palm oil mill equipped with a jetty, reclamation of waters with mangroves revegetation as a utilization zone in location 1 (Labuhan Tarok village). Communication with related parties regarding logging activities in mangroves and forests as well as a firm action against illegal logging needs to be carried out. Better monitoring and management are needed in the present and future industries concerning threats from sewage or waste processing.

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