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A Vulnerability Analysis of Coral Reefs in Coastal Ecotourism Areas for Conservation Management

Harsuko Riniwati *, Nuddin Harahab and Zainal Abidin

Faculty of Fisheries and Marine Science, University of Brawijaya, Malang 65145, Indonesia
* Correspondence: riniwatisepk@ub.ac.id

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Abstract: Coral reef ecosystems provide many ecological, economic, and social benefits. Despite their numerous functions, coral reefs are in a vulnerable state due to the effects of human activities. The condition of coral reefs has decreased in many parts of the world. Therefore, coral reef examinations need to be carried out continuously in order to formulate management strategies that can reduce their vulnerability over time. This study aims to analyze the vulnerability index of coral reefs, the sensitivity of coral reefs to the causes of vulnerability, and the adaptive capacity to anticipate vulnerability. The primary data are the perceptions of respondents' who filled out a prepared questionnaire which included eight dimensions: information on the environmental conditions, fishing ports, fishing areas, coastline settlements, tourism management, tourism attractions, socio-economic conditions and population, and aquaculture. The data were analyzed using multidimensional scaling (MDS). The results of the analysis revealed that fishing ports, fishing areas, and environmental condition are high vulnerability indexes which cause damage to coral reefs. The highest coral reef vulnerability sensitivity was found to be triggered by the distance from fishing areas and the distance from fishing vessel channels. An inverse relationship between vulnerability and adaptive capacity was shown. Hence distance from fishing areas and distance from fishing vessel channels are the attributes that have low adaptive capacity.

Keywords: coral reef conservation; vulnerability index; sensitivity; adaptation capacity; marine tourism

1. Introduction

Effective management of coral reefs requires strategies that help to protect coral reefs from damage due to cumulative human activity. Over the past few decades, the global biodiversity of coral reefs has been subject to extensive degradation [1,2]. In Malaysia, coral reef damage increases as a result of the natural environment and anthropogenic stress [3].

Coral reefs have important functions in marine ecosystems as they are the main structure and substrate and provide shelter for various biota and organisms [4]. In addition, coral reefs have other ecological, economic and social benefits. Regarding their ecological functions, coral reefs serve as life support systems, excellent sources of biodiversity, and coastal barriers; they also prevent global warming [5]. From an economic aspect, coral reefs are a food source, a form of medicinal and cosmetic ingredients, tourism objects, means of livelihood, and cultivation resources [1,5]. Regarding their social functions, coral reefs not only support educational activities and research activities but also become recreational facilities for people in general [5].

Despite the numerous functions and benefits of coral reefs, these underwater ecosystems are imperiled throughout the world. The causes of damage to coral reefs in each location are very diverse. The following table presents the causes of coral reef damage and descriptions of the aims of vulnerability analysis taken from several studies (Tables 1 and 2).

Table 1. The causes of coral reef damage.

Descriptions	Reference Numbers
• Destructive fishing, sedimentation due to land-based activities, global warming and ocean acidification.	[1]
• Nature, anthropogenic stress, and overfishing.	[3]
• Fishing and extraction of sand and coral, regulated tourism, sedimentation, distance of tourist facilities, and number of visitors.	[6]
• The cause of coral reef damage is land use	[7]
• Nature (sedimentation), anthropogenic activity (building of Nusantara Fisheries Port), adjacent human activities, and unconnected tourism activities.	[8]
• Pests, weeds, pollution, and habitat conversion.	[9]
• Society, economy, demography, technology, politics and culture, logging, land clearing, agricultural expansion, urbanization, infrastructure, mining, hydrological changes, salinization, soil type, climate and topography, geographical variables such as proximity to population centers and infrastructure, including roads, irrigation systems, extractive activities, transformation with urbanization, expansion of infrastructure, spread of invasive plants and animals, and extractive land such as agriculture, grazing, logging, mining, and land use.	[10]
• Compared to fishing activities, the impact of scuba diving on the coral reef is lower, resulting as more sustainable and ecologically non-destructive.	[11]

Table 2. The aims of the vulnerability analysis.

Descriptions	Reference Numbers
• Analyzing the causes of vulnerability towards an investment is very crucial. The aims and benefits of vulnerability analyses from several studies are to provide rational, accountable, and cost-effective conservation management to counteract the two types of stressors.	[1]
• Vulnerability and risk are related to the analysis of how to reduce risks effectively. Therefore, vulnerability analysis was employed in this study.	[12]
• Vulnerability analysis is a powerful analytical tool to describe the vulnerability of a system towards damage, inability, and marginality of physical and social systems, and to guide a normative analysis of actions in order to improve welfare through risk reduction.	[12]
• In general, vulnerability indicates damage or danger. Vulnerability analysis also reveals the effect of the damage, as shown from an indicator in a certain dimension (sensitivity).	[12]
• Vulnerability can be defined as a tendency to influence facts, sensitivity, and the capacity to overcome problems and adapt to changes.	[13]
• Vulnerability indicators are useful tools for (a) identifying and examining vulnerability over time and space, (b) developing a better understanding of the processes underlying vulnerability, (c) developing and prioritizing a strategy to reduce vulnerability, and (d) determining the effectiveness of the strategy.	[14]
• Vulnerability analysis is considered as the appropriate step to achieve effective risk reduction and to promote disaster resilience.	[13–15]
• The term "vulnerability" is now a central concept in studies in various contexts, and it has been used in various ways.	[14–16]

Table 2. *Cont.*

Descriptions	Reference Numbers
• The concept of "vulnerability" is prevalent in the public domain, health care, social institutions, and multidisciplinary research. It is also defined as social loss or deficiency. Vulnerability is one of the poor determinants or inhibiting factors in the recovery process. The standards of the vulnerability component can be grouped into four areas: having inadequate material resources, being and feeling unable to take responsibility, taking part in risky activities and behaviors, and experiencing inadequate social support.	[17]
• Cognitive vulnerability can provide important insight into several risk factors.	[18]
• Informally, vulnerability is an "unexpected thing" that can occur in a program.	[19]
• It is important to secure and protect the investment against potential threats and violations which results in millions of dollars of annual losses	[20]
• The results of the vulnerability index offer insight into understanding complex needs.	[21]
• The aim of vulnerability analysis is to evaluate the assessment of potential vulnerabilities and risks. In addition, vulnerability analysis is also beneficial for taking corrective steps to anticipate potential vulnerability. Vulnerability analysis involving vulnerability factors is a very inexpensive method.	[22]
• The purpose of vulnerability assessment is to identify stressful points	[23]

Employing the results of vulnerability analysis as a consideration in decision making gives several advantages, for example, it is relatively inexpensive and easy. Besides, the results can be regularly updated. Updating the results will reduce the risks of the previous vulnerability pattern and reveal the variable which needs more protection [9]. Moreover, it can be used to analyze whether a system is vulnerable or unable to cope with adverse effects. Vulnerability analysis on how to reduce risk effectively can be carried out to gain an understanding of the environment and to prioritize limited resources in response to coral reef damage [12]. The results of vulnerability analysis are useful for formulating approaches and concepts such as joint decision making, empowerment, and promotion [24]. Besides, vulnerability analysis is helpful for planning and is very significant for the development of reliable management policies [25].

Therefore, in the present study, vulnerability analysis of coral reefs in relation to coastal ecotourism is conducted to protect the functions of coral reefs and to anticipate future pressures and causes of damage. This study aims to (1) analyze the vulnerability index of coral reefs and the sensitivity of indicators that cause vulnerability, and (2) analyze the adaptive capacity related to the vulnerability of coral reefs.

2. Theoretical Framework

The conceptual vulnerability model consists of exposure, sensitivity, and adaptive capacity. The exposure concept gives a profile of vulnerability in general. Then, the sensitivity capacity indicates the most vulnerable part. Vulnerability analysis covers the identification of adaptive capacity from each dimension. In terms of the adaptive capacity, socio-economic factors increase the potential for damage [13,15]. There is an inverse relationship between the adaptive capacity and vulnerability. Adaptive capacity is used to overcome problems and adapt to change. A higher adaptive capacity indicates lower vulnerability. The sensitivity of the system reflects the level of response to change. There is a strong relationship between dependence and vulnerability. The theoretical framework is presented in Figure 1.

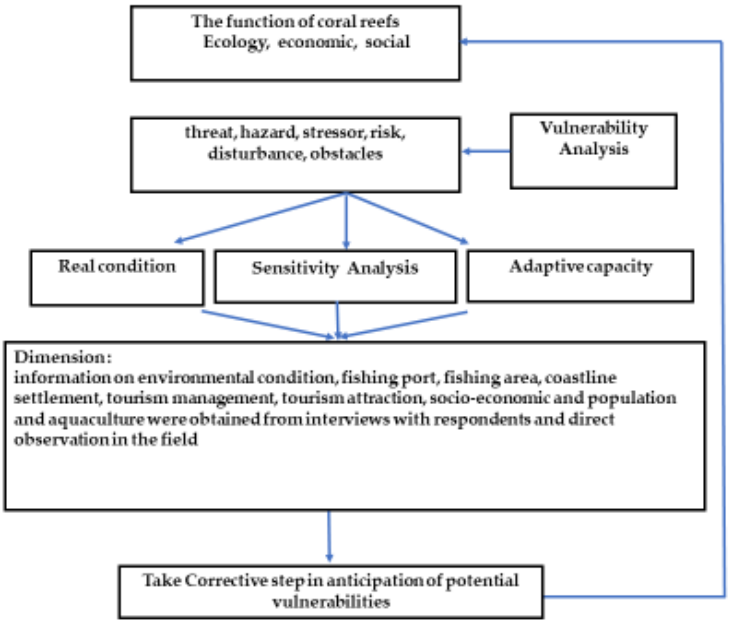

Figure 1. Theoretical framework of the research.

3. Research Methods

3.1. Research Location

This research was conducted on the southern coast of Malang Regency, Indonesia. The precise location was in the Clungup Mangrove Conservation (CMC) area, Tiga Warna beach. The study was conducted in October–November 2018. The Clungup Mangrove Conservation (CMC) area is a conservation area of 117 ha (71 ha of mangrove, 10 ha of coral reef, and 36 ha of protection forest) managed by the Sendang Biru local community as an ecotourism destination. There are six beaches in the CMC area which have unique views. These beaches are the mangrove conservation areas Clungup Beach and Gatra Beach and the coral reef conservation areas Sapana Beach, Mini Beach, Batu Pecah Beach, and Tiga Warna Beach (Figure 2). This destination has the best coastal management system according to the Fisheries Marine Ministry Indonesia.

CMC is an ecotourism area based on community conservation. It was established more than six years ago and is widely known through social media and other media. Community-based management makes CMC a unique barometer of ecotourism that is recognized at the national level. Visitors need to be informed further about natural resources conservation in the CMC area, which has wide biodiversity. Information and education are commonly given verbally by the tour guides. However, it would be better if there were supporting media or written information about conservation as well.

The tourism management system at CMC is based on conservation, in which the tourists visiting the ecotourism area have positive and supportive impacts on environmental sustainability. Furthermore, the visitors who want to visit Tiga Warna Beach must register themselves, since there is a quota for the number of visitors per day. In addition, all visitors are required to check in their belongings that may litter the area. These regulations aim to encourage visitors to be responsible for their trash. It is expected that there will be no negative environmental impact for the local coastal ecosystem.

The characteristics of the CMC destination are its blend of mangrove forest and landscape underwater conservation. The management prioritizes visitor safety. In addition, the visitors can experience genuine nature conservation and a peaceful atmosphere. The CMC area also optimizes private time for gathering. Visitors can share experiences with local guides involved in coastal conservation.

The main differences of CMC to mass tourism destinations are the implementation of the carrying capacity of Tiga Warna Beach area and the impressive mangrove forest that can be explored with

solar-powered emission boats. Therefore, many visitors choose Tiga Warna Beach as their main ecotourism destination. The CMC landmark on Tiga Warna Beach hill has become a distinctive and memorable spot for visitors.

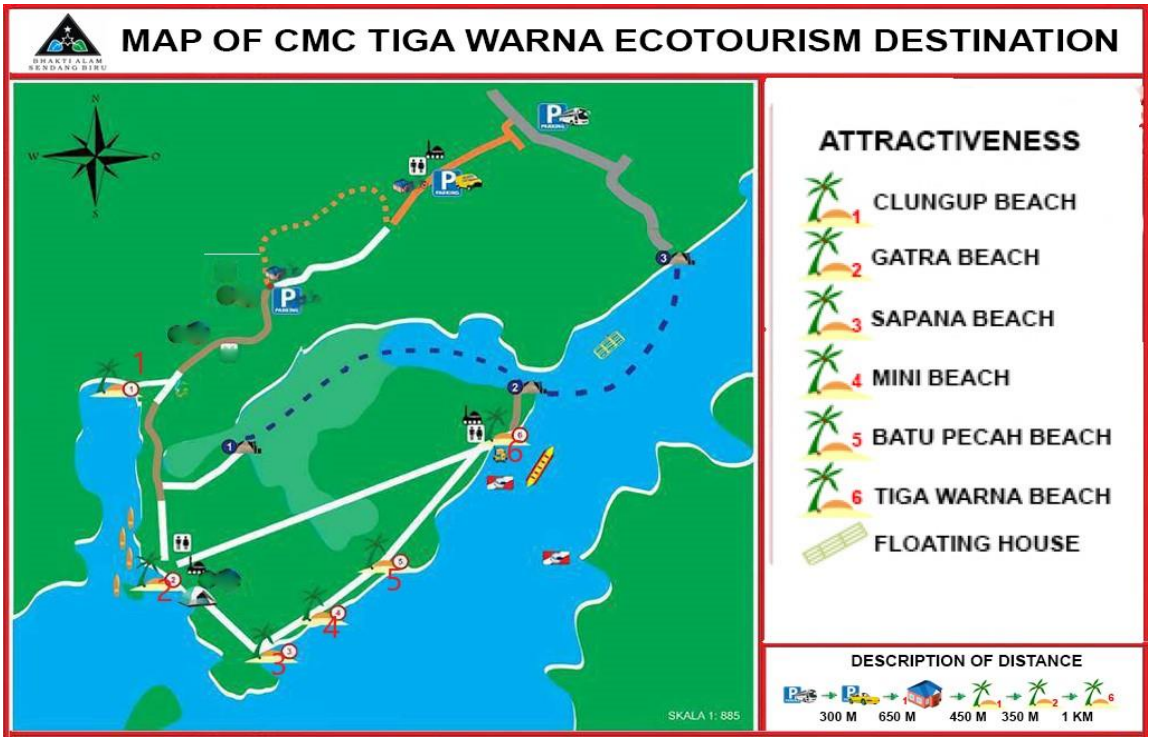

Figure 2. Research location.

3.2. Data Collection and Research Sample Method

This study used both primary and secondary data. The primary data included the perceptions of respondents related to dimensions such as information on the environmental conditions, fishing ports, fishing areas, coastline settlements, tourism management, tourism attractions, socio-economic conditions and population, and aquaculture, which was obtained from interviews with respondents and direct observations in the field. Interviews were conducted using a prepared list of questions. The secondary data included the extent of the protected areas and rehabilitation, and these data were obtained from the institutions that manage coastal areas. The respondents used as samples in this research were stakeholders of coastal ecotourism areas, namely Clungup Mangrove Conservation (CMC) area and Tiga Warna Beach. The sampling technique used in this study was purposive, as the respondents in this study were experts (consisting of ecotourism and fisheries management groups) or those who were familiar with the research area and tourism management at the research location. The number of samples obtained was 33. The data were collected by conducting structured interviews and distributing questionnaires to the respondents. They had to answer and give their perceptions related to dimensions and attributes of this research.

3.3. Data Analysis Method

A vulnerability analysis of coral reefs at coastal ecotourism sites was conducted by adapting the Rapfish or Rapid Appraisal for Fisheries methods to the needs of this study [26]. The evaluation of the vulnerability of coral reefs and mangroves at coastal ecotourism sites included eight dimensions: environmental conditions, fishing ports, fishing areas, coastline settlements, tourism management, tourism attractions, socio-economic conditions and population, and aquaculture.

First, each the number of attributes for each dimension was pre-determined and adjusted to the needs of vulnerability research. The selected attributes were chosen to reflect the level of vulnerability in each dimension, and they were tailored to the availability of information that could be obtained from the resource studied in the research area. All specified attributes were rated on a scale of 1 to 3. A score of 1 was seen as a poor vulnerability measure, while the maximum score of 3 was seen as a high vulnerability measure. The attributes used in this study are presented in Table 3.

Table 3. The attributes number of each vulnerability dimension.

No	Dimension	Attributes	Scale	Score
1.	Environmental Condition	Protection forest cover	Protection forest cover >50% Protection forest cover 30%–50% Protection forest cover <30%	1 2 3
		Mangrove forest cover	Mangrove forest cover >50% Mangrove forest cover 30%–50% Mangrove forest cover <30%	1 2 3
		Coral reef cover	Coral reef cover >50% Coral reef cover 30%–50% Coral reef cover <30%	1 2 3
		Distance from river	Distance from river >3000 m Distance from river 500–3000 m Distance from river <500 m	1 2 3
2.	Fishing Port	Distance from fishing port location	Distance from port location >2000 m Distance from port location 500–2000 m Distance from port location <500 m	1 2 3
		Distance from fishing vessel channel	Distance from fishing vessel channel >2000 m Distance from fishing vessel channel 500–2000 m Distance from fishing vessel channel <500m	1 2 3
3.	Fishing Area	Distance from fishing area	Distance from fishing area >3000 m Distance from fishing area 500–3000 m Distance from fishing area <500 m	1 2 3
		Percentage of fisherman catching fish in coral reef area	Percentage of fisherman <30% Percentage of fisherman 30%–50% Percentage of fisherman >50%	1 2 3
4.	Coastline and Settlement	Coral reef distance from road	Coral reef distance from road >3000 m Coral reef distance from road 500–3000 m Coral reef distance from road <500 m	1 2 3
		Coral reef distance from coastline	Coral reef distance from coastline >3000 m Coral reef distance from coastline 250–3000 m Coral reef distance from coastline <250 m	1 2 3
		Coral reef distance from settlement	Coral reef distance from settlement >5000 m Coral reef distance from settlement 1000–5000 m Coral reef distance from settlement <1000 m	1 2 3
5.	Tourism Management	Management organization	Complete and clear organizational structure including working procedure Having organizational structure but ambiguous working procedure Having organizational structure but no working procedure	1 2 3
		Tour supervisor and guide service	Standby supervisor and tour guide Occasional supervisor and tour guide On call supervisor and tour guide	1 2 3
6.	Tourism Attraction	Diving	Limited divers according to the carrying capacity Occasional diver limitation Unlimited divers	1 2 3
		Snorkeling	Limited tourists according to the carrying capacity Occasional tourist limitation Unlimited tourists	1 2 3
7.	Socio-Economic and Population	Economic source from fisheries sector	Income from fisheries sector < 30% Income from fisheries sector 30%–50% Income from fisheries sector >50%	1 2 3
		Economic source from forestry sector	Income from forestry sector <30% Income from forestry sector 30%–50% Income from forestry sector >50%	1 2 3
8.	Aquaculture	Distance from fish farming location to coral reef area	Distance from fish farming location to coral reef area >3000 m Distance from fish farming location to coral reef area 500–3000 m Distance from fish farming location to coral reef area <500 m	1 2 3
		Distance from seaweed farming location to coral reef area	Distance from seaweed farming location to coral reef area >3000 m Distance from seaweed farming location to coral reef area 500–3000 m Distance from seaweed farming location to coral reef area <500 m	1 2 3

Basically, the Rapfish method uses multidimensional scaling statistics techniques. Multidimensional scaling statistics techniques are commonly used for problems involving attribute

components or dimensions to evaluate the effect of each component on the observed problem based on data from a group of subjects [26]. The value for each of these attributes was obtained from both primary and secondary data. After the data was collected, the analysis process was continued with the help of Microsoft Excel 2003 software with additional Rapfish add-ins. The tests relating to Rapfish multidimensional scaling statistics techniques were feasibility and significance tests and an assessment of the vulnerability index.

3.3.1. Feasibility of Vulnerability Analysis

The feasibility of vulnerability analysis was determined by measuring the level of goodness or goodness-of-fit between the distance between the point of estimation and the original point. This was done by employing the calculation of S-stress. The technique used to determine the goodness-of-fit was the least-squares method based on the root of the Euclidian distance (squared distance) or the algorithm of scale method. This algorithm of scale method optimized the squared distance to the squared data of the origin. The S-stress value was calculated by the following formula:

$$S - stress = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\frac{\sum_i \sum_j \left(d_{ijk}^2 - O_{ijk}^2\right)^2}{\sum_i \sum_j O_{ijk}^4}}. \quad (1)$$

A low S-stress value indicates high accuracy (good fit), while a high S-stress value reveals poor accuracy (poor fit). Commonly, an S-Stress value of less than 0.25 is deemed to represent a good fit for the analysis of vulnerability. However, a value more than 0.25 indicates that the analysis was a poor fit.

3.3.2. Assessment of the Vulnerability Index

Pitcher and Preikshot [26] classified and mapped the results of the vulnerability measurement of each dimension's attributes into two types of points: bad-down points and good-up points. The classification of the assessment of vulnerability index was divided into four categories, which are shown in Table 4.

Table 4. Category of the vulnerability index.

No.	Index Value Dimension	Description
1	0–24.99	Not vulnerable
2	25.00–49.99	Less vulnerable
3	50.00–74.99	Quite vulnerable
4	75.00–100.00	Highly vulnerable

Source: Modification of Pitcher and Preikshot Category (2001) [26].

3.3.3. Sensitivity Analysis

Sensitivity analysis is used to examine which attributes of each dimension most influence the ordination of the vulnerability index. In this study, the sensitivity analysis was conducted by the leverage analysis approach. The leverage of each attribute was obtained through a stepwise method, where sequential ordination was done by dropping attributes one at a time. Then, for every dropped attribute, the sum of squares of the difference between the ordination scores with full attributes and the scores with dropped attributes was calculated. Attributes with high leverage values had high influence on the ordination of MDS [26].

4. Results

The results of the goodness-of-fit calculation for the MDS-Rapfish analysis are displayed in Table 5.

Table 5. Summary of the goodness-of-fit of the Multidimensional Scaling (MDS)-Rapfish Analysis.

Dimension	Stress (S)	R-Square (R)
Environmental conditions	0.1923	0.9546
Fishing ports	0.2024	0.9034
Fishing areas	0.2199	0.9168
Tourism management	0.2192	0.9267
Tourism attractions	0.2099	0.9057
Socioeconomic conditions and population	0.2269	0.9047
Aquaculture	0.2389	0.9046
Coastline settlements	0.2256	0.9080

According to Table 5, the S-stress values of the eight dimensions were all less than 0.25 and the R-square values were all more than 0.90. This means that the result of MDS-Rapfish analysis can be verified. Since the criteria for goodness-of-fit was fulfilled, the analysis to assess the vulnerability index for each dimension could be carried out.

4.1. The Vulnerability Index of Coral Reefs and Sensitivity

Table 6 shows the vulnerability index and the attribute sensitivity for the all dimension, respectively.

Table 6. Summarized results of the MDS analysis.

No.	Dimension and Attribute	Dimension Index	Attribute Sensitivity	Overall Vulnerability Index (The Average of the Dimension Index)
1	Environmental conditions	53.324		45.528
	Protection forest cover		11.97	
	Mangrove forest cover		5.17	
	Coral reef cover		23.75	
	Distance from river		7.82	
2	Fishing ports	60.13		
	Distance from fishing port location		23.22	
	Distance from fishing vessel channel		24.01	
3	Fishing areas	54.61		
	Distance from fishing area		31.74	
	Percentage of fisherman catching fish in the coral reef area		30.07	
4	Coastline settlements	36.29		
	Coral reef distance from road		13.64	
	Coral reef distance from coastline		23.14	
	Coral reef distance from settlement		13.40	
5	Tourism management	33.18		
	Organization management		19.78	
	Tour supervisor and guide service		19.40	
6	Tourism attraction	38.31		
	Diving		22.12	
	Snorkeling		21.86	
7	Socio-economic conditions and population	39.18		
	Economic source from fisheries sector		19.71	
	Economic source from forestry sector		22.49	
8	Aquaculture	49.20		
	Distance from fish farming location to coral reef area		27.06	
	Distance from seaweed farming location to coral reef area		26.00	

Table 6 shows that the vulnerability index for the environmental condition dimension is 53.32 or classified as quite vulnerable. The indicator coral reef cover needs to be considered, since its sensitivity is the highest. It has high potency to cause coral reef vulnerability. The vulnerability index for the fishing port dimension is 60.13. The index lies between 50 and 74.99, which means that the vulnerability index of the fishing port dimension is classified as "quite vulnerable." The vulnerability index of fishing port dimension can be reduced by giving more attention to the attribute which has the highest leverage. This attribute is the distance from the fishing vessel channel. The vulnerability index for the fishing area dimension is 54.61, which is between 50 and 74.99. In the other words, the vulnerability index for this dimension is "quite vulnerable." The most sensitive attribute is the distance from the fishing area, since its leverage is the highest. In other words, the indicator "distance from fishing area" has the potential to cause coral reef vulnerability. The vulnerability index for tourism management is 33.18, which lies between 25 and 49.99, meaning that this dimension is "less vulnerable." In order to decrease the vulnerability index of the tourism management dimension, the indicator "management organization" must be managed well, since it has high sensitivity or a high leverage value. The vulnerability index for tourism attractions is 38.31, which indicates that that the dimension is classified as "less vulnerable." The most sensitive indicator for tourism attraction is diving. Diving can lead to coral reef vulnerability. The vulnerability index of the socio-economic conditions and population index is 39.18, and this dimension is classified as "less vulnerable." The indicator of the socio-economic conditions and population dimension that needs to be considered is "the economic source from the forestry sector," since its leverage is the highest. The vulnerability index for the aquaculture dimension is 49.20 which is between 25 and 49.99, so this dimension is classified as "less vulnerable." The distance from the fish farming location to the coral reef area must be managed well in order to decrease the vulnerability index of the aquaculture dimension. The vulnerability index of the coastal settlement index is 36.29, and this dimension is classified as "less vulnerable." The indicator of the coastal settlement dimension that needs to be considered is the distance of the coral reef from the coastline, since its leverage is the highest.

4.2. Multidimension Vulnerability Index

Based on the results of the multidimensional analysis, the vulnerability index of the fishing port has a value of 60.13% (quite vulnerable). This is followed by the fishing area dimension with a value of 54.61% (quite vulnerable), and the environment condition dimension with an index value of 53.32% (quite vulnerable). The vulnerability index of coral reefs related to tourism based on the eight dimensions can be seen in Figure 3.

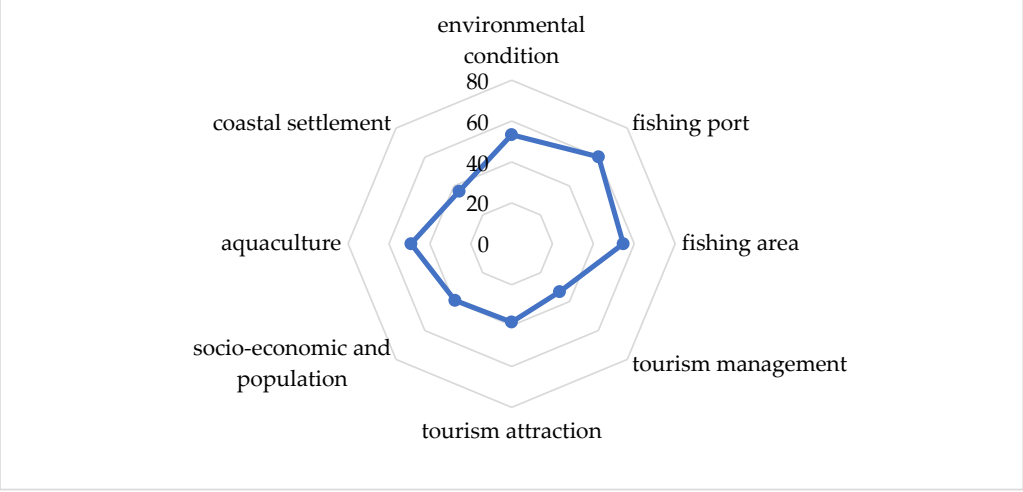

Figure 3. Overall vulnerability index.

Figure 3 shows that the vulnerability index of all used dimensions (the average of all dimension indexes) is 45.528. This is classified as less vulnerable (25.00–49.99). This value describes the situation and conditions in CMC management having a low vulnerability status. The "quite vulnerable" dimensions are the fishing port, fishing area, and environment conditions.

5. Discussion

The results of the analysis indicate that the vulnerability index of the environmental condition dimension is classified as "quite vulnerable." This is supported by the results of research from Luthfi, Rahmadita, and Setyohadi [4], which states that the range of live coral cover is 6.94%–42.4%, and it is classified as highly damaged. There is a very high percentage of dead coral in this area (80.76%), even though this research site is the only nature reserve in Malang Regency and has a coral reef area of less than 10 ha. The most sensitive indicators or attributes which are associated with vulnerability are coral reef cover and forest cover protection, which are from the environmental condition dimension.

Wilson et al. [10] explained that deforestation can cause sedimentation in the waters where coral reefs are situated. Sedimentation in coral reef areas leads to vulnerability in the environmental conditions dimension. The research results of Riniwati [27] showed that the conversion of protected forest into tourism facilities and infrastructure has caused ecological and economic loss, and massive ecological recovery is required. Fishery production has also decreased due to the sedimentation of saltwater. It is suggested that ecotourism should be considered for tourism development instead of mass tourism. According to Tessema and Simane [13], the higher the vulnerability level is, the lower the adaptive capacity is. Similar to the environmental condition dimension, the adaptive capacity of the coral reef cover is low. Nienaber, Hofeditz, and Romeike [28] explained that elevation, land cover, vegetation cover, distance to water source, distance to roads, distance to recreation areas, and land management categories are environmental variables that can potentially affect species adaptation. Mangrove forest cover has the highest adaptive capacity. There is a tourist spot called the Clungup Mangrove Conservation Area at the research site which focuses on mangrove forest conservation. Thus, the adaptive capacity of mangrove cover in this study area is high.

In addition, the vulnerability index of the fishing port dimension is classified as "quite vulnerable." The most sensitive indicator or attribute which causes vulnerability is the distance from fishing vessel channels. This result indicates that the adaptive capacity of the distance from fishing vessel channels is lower than the distance from the fishing port location. The existence of fishing ports is a threat to the coral reef surrounding the port. The threat can be in the form of physical and non-physical disturbances related to human activities near the port. In relation to coral reef existence in the future, in [29,30] it was explained that the degradation trend of local coral reefs caused by adverse human activities can be reduced or recovered. Using the results of the vulnerability analysis as a consideration in decision making is beneficial, since it is inexpensive and easy [9]. Determining the distance from the coral reef to the fishing ports is considered to be easier than determining the distance from fishing vessel channels, according to respondents' answers. Therefore, strong law enforcement is needed, so that there is no violation of the provisions of the fishing vessel channels.

The next vulnerability index dimension is the fishing area, which was classified as "quite vulnerable." The most sensitive attribute is the distance from the fishing area, since its leverage is the highest. In other words, the distance from the fishing area has the potential to cause coral reef vulnerability. Magris, Grech, and Pressey [1] and Praveena, Siraj, and Aris [3] explained that the pressure on coral reefs is caused by destructive fishing. Therefore, the distance from the fishing area must be managed properly. Based on the adaptation capacity, persuading the fishermen to stop catching fish in the coral reef area is easier than determining the fishing distance from the coral reef location.

The pressure on coral reefs from fishing activities is seen from the distance of a coral reef to the fishing location (fishing ground). The increases in population and in market demand for fish have caused uncontrolled fishing activities affecting the fish habitat and stocks. As explained by [31,32],

all forms of local pressure, overfishing, and destructive fishing are kinds of threats that are commonly spread, and these threats have affected more than 55% of coral reefs around the world.

Another vulnerability index dimension is tourism management, which is less vulnerable due to the excellent community involvement in managing ecotourism at the research site. Community involvement is essential for managing ecotourism. This statement is supported by a study from Praveena, Siraj, and Aris [3], which explained that establishing a legal system, employing science-based management, and involving the community can reduce threats, damage, and risks to coral reefs. The communities at the research site have low awareness of conservation and ecological functions due to poverty and unemployment. In fact, they realize the need for conservation and ideal ecological function, but their economic index causes them to put aside the conservation motive. According to Jacqueline and Coyle-Shapiro [33], public participation has a positive effect on the program or activity. Meanwhile political-based community participation will interfere with activity [34]. Long-term public policy funds, continuous examination, assessment, and changes to policy strategies following the production of new information and data are crucial [35]. The party in charge must retain the natural resources and anthropic culture and heritage of the tourist spot, and pay attention to management in terms of environmental protection, waste management, use of energy sources, and the sustainability of the area [36]. Higher participation can lead to the dissemination of organizational strategies and the improvement of policy effectiveness [37]. Direct and indirect, spoken and written, horizontal and vertical, and formal and informal approaches contribute to smooth and effective communication [38]. According to Riniwati et al. [39], ecotourism management in the Malang Regency coastal area needs improvement as follows: attendance at meetings, group participation in discussions, involvement in physical activities, and willingness to contribute or donate. The participation of informal institutions in ecotourism management can be increased by giving equal responsibility, freedom in decision making, authority in proposing ideas and compulsions with positive aims, for example, imposing ideas and demanding participation in discussions and other activities. According to the research results of Riniwati et al [40], the improvement of human resources performance related to ability, motivation, and opportunities is important. A greater level of community participation is correlated with the increasing use of mitigation techniques and choices. Planning orientation helps to determine the level of community participation [41]. The dimension of community participation has the highest level of vulnerability in mangrove conservation [42].

Regarding the vulnerability index for tourism attractions, the result indicates that this dimension is classified as "less vulnerable." The most sensitive indicator for tourism attractions is diving. Diving can put coral reefs in danger. Inappropriate management and irresponsible tourists cause damage to coral reefs. This statement is supported by the research results from Handriana and Ambara [43], which show that many factors affect responsible behavior in the environment such as travel quality, visitor perceptions, destination image, and satisfaction. In order to increase visitor satisfaction, ecotourism management must improve the standard of tourist attributes in terms of aspects such as accessibility, attractions, and activities for visitors as well as maintenance of the surrounding environment which protects the ecosystem. According to Adeleke [44], female residents participate more in the Kwazulu-Natal protected area than males. Hence recruiting female workers may give more benefits.

The vulnerability index of the socio-economic conditions and population is classified as "less vulnerable." The indicator of the socio-economic and population dimension that needs to considered is "the economic source from the forestry sector." The adaptive capacity of the economic source from the forestry sector relates to the socio-economic conditions of the surrounding community which requires income and a certain mentality from the formal authorities. If the government performs its role well, it will become a strong mediator towards achieving blue economy-based community empowerment [45].

The vulnerability index for aquaculture dimension is classified as "less vulnerable." In order to maintain the sustainability of coral reef ecotourism, it is important to consider the most sensitive

attribute which increases the vulnerability of the aquaculture dimension—the distance of aquaculture to the coral reef area. Thus, it is necessary to continually increase cultivators' compliance in determining the locations of aquaculture to prevent coral reef damage and vulnerability.

Lastly, the vulnerability index of coastal settlements is classified as "less vulnerable." The indicator of the coastal settlement dimension that needs to be considered is "coral reef distance from the coastline," because it has the highest leverage. The high sensitivity of the coral reef distance from the coastline makes its adaptive capacity low.

The following are some efforts that can reduce damage, threats, and risks to the vulnerability of coral reefs: (1) conservation through policy, legislation, and educational and economic instruments [10]; (2) mitigation and adaptation to eliminate the sources of threats [23]; (3) potential actions that can minimize threats in other places (for example, moving housing development to nearby areas); (4) developing the understanding of conservation actions to improve the anticipation of the positive and negative consequences of each action, to make conservation planning more effective [46]; (5) the development of a community-based participatory management approach based on local knowledge and wisdom [13].

Several studies provide the following recommendations related to ecotourism management. The establishment of an Ecotourism Management Triangle (EMT) could be an alternative to build a sustainable ecotourism management system. According to Wanie [47], EMTs include World Ecotourism Sites (WESS), Standardized Indicators for Sustainable Ecotourism (SISE), and an Ecotourism Experts Support System (EESS). All management elements including the local community should be involved in the decision making process so that the management of ecotourism can run better [48]. In a holistic way, ecotourism management is able to improve social justice and reduce inequality through a combination of community-based tourism and pro-poor tourism [49]. The results of the analysis show that the involvement of private managers (investors) has no significant effect on the success of ecotourism. On the other hand, the involvement of one of the local or international NGOs (Non Government Organizations) affects the success of ecotourism. However the management will not run well if both parties are involved [50]. The volunteer-based tourism program has high potential to provide environmental, cultural, and educational sustainability, financial security, business risk management strategies, volunteer satisfaction, and conservational benefits in the management of local destinations [51]. Four alternative ecotourism development strategies have been proposed: dissemination, optimization, strengthening, and reformation. Moreover, tourism businesses have difficulty surviving due to corruption within the government, obstacles in logistics fulfillment, unconnected management systems, and inadequate human resources [52]. Building a non-formal educational institution could improve the resilience or sustainability of tourism industry development [53]. Community participation is considered one of the main factors in natural resource conservation as it involves the local community [54]. Community participation is able to strengthen forest conservation, although there is a negative relationship between the economic index level and forest conservation support [55]. Failure to improve the community's standard of living is due to the neglect of the role of the local community in managing the local area and involvement of the community in the decision-making process. Moreover, the private sector only pays attention to company profits without considering the local communities [56].

6. Conclusions and Suggestions

6.1. Conclusions

On the basis of the research findings and discussion presented in the preceding sections, some conclusions related to the vulnerability analysis of coral reefs were drawn. The high vulnerability indexes which cause damage to coral reefs are fishing ports, fishing area, and environmental conditions. The categories with the highest sensitivity classification for coral reef vulnerability are distance from the fishing area, distance from fishing vessel channels, and coral reef cover.

There is an inverse relationship between vulnerability and adaptive capacity. The distance from the fishing area, distance from the fishing vessel channel, and coral reef cover are the attributes that have low adaptive capacity. Attributes that have low adaptive capacity must be considered serious issues that require proper management in order to avoid the risk of damage to coral reefs.

6.2. Suggestions

Based on the research findings and discussions, the researchers suggest reducing the coral reef vulnerability and sensitivity and increasing the adaptive capacity through conservation, mitigation, knowledge enhancement, informal education, effective strategic plans, community participation, and volunteer involvement in environmental conservation.

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