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Sustainability assessment of mangrove management in Madura Strait, Indonesia: a combined use of the rapid appraisal for mangroves and the remote sensing approach

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COVER LETTER

Dear Marine Policy Chief Editor,

I am sending herewith a copy of the manuscript, which I would like to submit to Marine Policy. The paper is entitled:

Sustainability assessment of mangrove management in Madura Strait, Indonesia: a combined use of the rapid appraisal for mangroves and the remote sensing approach

by Zainul Hidayah and Abd. Rahman As-syakur

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Keywords: mangroves, rapid appraisal for mangroves, remote sensing, Madura Strait

1. Introduction

Mangroves are typical tropical forest types that found along coastlines, mudflats, and river banks (Field, 1999). Mangroves have unique physical and biological mechanisms that make them survive against the constant change of fluctuations in water level, high salt concentrations in seawater and sediment, hydrodynamic energy, high temperature, low air humidity, nutrient availability, and anoxia (Quisthoudt et al., 2012; Srikanth et al., 2016). Numerous researches have been done to investigate mangrove's roles as spawning, breeding, and nursery habitats for many commercial fishes and other marine organisms (Musa et al., 2020; Rejeki et al., 2019). The roots act as a sediment trap, prevent pollutant to enter the sea (Sari et al., 2019). The canopy of the mangroves above the water becomes a habitat for many species of reptiles, mammals, birds, and insects (Nagelkerken et al., 2008; Zakaria & Rajpar, 2015). Mangroves also have a vital function as natural barriers in protecting shoreline against tsunamis, cyclones, and storm surge by reducing and dispersing their destructive energy of waves (Nehru & Balasubramanian, 2011; Marois & Mitsch, 2015; Shedage & Shrivastava, 2018). Moreover, as ecosystem services mangroves can provide several benefits including nutrient cycling, soil formation, wood production, ecotourism, and carbon (C) storage (Murdiyarso et al., 2015; Nuarsa et al., 2018). Mangroves, however, have been degraded at a very alarming rate and threatened by various human activities, such as pollution, over-harvesting, aquaculture development, siltation, boating activity, and salt production (Adeel & Pomeroy, 2002; Moriizumi et al., 2010).

Indonesia is no exception, as a country that has the largest mangrove area in the world, the mangrove areas along Indonesia's 95,000 km of coastline have been lost, dropping from 4.2 Mha in 1980 to 3.2 Mha in 2009 (FAO, 2007; Hartini et al., 2010). The main cause of mangrove loss in Indonesia was aquaculture development, waste pollution, illegal logging, overexploitation, and other coastal development (Ilman et al., 2016; Rahmanto, 2020). In Indonesia, around 22% of the population with a 3.6% growth rate resides in coastal areas and

50% of their economy depends on the ability to exploit natural resources in coastal areas, including mangrove forests (Hidayah et al., 2015). Indonesia's population is concentrated in Java Island, which is the most populous island in Indonesia and the world (Firman, 2017). Java Island has mangroves covering an area of 34.5 kha and East Java Province has 53% of the total mangrove area in Java (Hartini et al., 2010). East Java is the province with the second highest population in Indonesia, after West Java, with a population exceeding 40 million people in 2020, and 32% of this number live around the Madura Strait. The Madura Strait is one of the busiest straits in Indonesia, it lies between Java Island and Madura Island (Mulyadi et al., 2014). This strait is passed by various types of ships heading to several ports such as Cement Port, Smelting Port, Petrochemical Port, and the busiest port centre is Tanjung Perak located in the city of Surabaya (the second largest city in Indonesia). Apart from being due to human pressure, lack of awareness in the sustainability of mangrove rehabilitation strategies also contributes to the damage of the mangroves area in Indonesia (Cameron et al., 2019). Given these conditions, hence mangrove management and conservation policies should be implemented.

Sustainable mangrove management is needed to maintain the health of the mangrove ecosystem and to reduce the rate of mangrove loss. In addition, assessing and knowing the status of mangrove sustainability also essential for better conservation planning and management (Schmitt and Duke, 2015). The sustainability assessment is intended to foster consistent approaches to ecological risk assessments of the mangrove management, by identifying key issues used in these assessments (Norton et al., 1992). In general, the concept of sustainability assessment requires balanced involvement between the three dimensions of sustainability which are environmental, economic, and social aspects (Mebratu, 1998). From previous studies, there are several methods to assess the sustainability of mangrove management. Moriizumi et al. (2010) used the life cycle sustainability assessment (LCSA) framework to asses mangrove management sustainability in Thailand, Chakraborty et al. (2019) performed the future mangrove suitability index (FMSI) using the analytic hierarchy process (AHP) method in the north and middle Andaman island for sustainable forest management, and Melo et al. (2020) implemented rapid appraisal techniques to analyse the status of mangrove management sustainability and determined the influencing factors in Gorontalo Province, Indonesia. However, according to Onat et al. (2017), there are still some shortcomings of LCSA framework which are lack of understanding the mutual dependencies, complex interactions among the sustainability indicators, and still show disjointed results from the three main dimensions of sustainability. The FMSI using the AHP method not use all sustainability dimensions, where this model only uses the environmental dimension rather than the other two dimensions. Meanwhile, rapid appraisal technique is an approach used to quickly collect relevant information that identifies, defines, and prioritizes environmental conditions, where this technique is very useful when there are constraints of time, money, and manpower (Eichler et al., 2020). Although not a substitute for detailed studies, the method can be used to identify key issues and problem areas and to give direction for further investigation (Pido et al., 1996).

To formulate an appropriate and applicable policy for sustainable management of mangrove, the need for data on the condition and extent of mangrove area from a different period is very necessary. Monitoring the changes in mangrove areas using remote sensing satellite images by far is the most effective method (Kanniah et al., 2015). Remote sensing approaches have been proven effective, accurate, timely, and cost-effective for mapping mangrove species, estimating their biomass, and assessing changes in their extent over time (Wang et al., 2019; Pham et al., 2019). Remote sensing is the main data that used to analysed changes in mangrove areas in regionally and globally (Hartini et al., 2010; Giri et al., 2011). Meanwhile, several studies have used remote sensing data to assess the condition and sustainability of mangrove ecosystems. For example, Rajakumari and Rajaram (2021) assessed the mangrove ecosystem sustainability that adjacent to the aquafarm location with remote sensing data on the Southern Tamil Nadu coast; Chakraborty et al. (2019) applied remote sensing data to analysed sustainable mangrove management in the north and middle Andaman districts, India. Apart from the above, there are several amounts of work that the remote sensing domain also does in the mangrove ecosystem, such as to assess mangrove ecosystem services (Vo et al., 2015) and to assess their economic value (Putranto et al., 2018).

Sustainable Development Goals (SDGs) have implied addressing future global threats, including environmental degradation as the results of uncontrolled human activities. Mangrove ecosystems, particularly in Indonesia, have faced such challenges. It can threaten the sustainability of the ecosystem in the future. Therefore, studies to analyse the sustainability of mangrove's ecosystem and their impact on the environment and coastal communities are needed. The studies should integrate important aspects in mangrove management, including environmental, economic, social, and institutional factors. Multi-Dimensional Scaling (MDS) is one of the methods that can be used to assess the sustainability status of mangrove ecosystems. The most applicable tools to run MDS analysis is called RAPFIS (rapid appraisal for fisheries), where this application has been widely used in various studies on the sustainability status of fisheries management (Pitcher and Preikshot, 2001; Pitcher et al., 2013). The RAPFISH is a multidisciplinary method for the analysis and evaluation of fisheries' sustainability using semi-quantitative scoring in five dimensions: ecological, economic, social, technological, and ethical/institutional. Later, with a slight modification, this tool was also used to determine the sustainability status of other coastal resources such as mangroves and coral reefs (Handayani et al., 2020). Rapid appraisal for mangroves is an operational translation of RAPFISH with emphasis on the mangroves management sector. Where appropriate, rapid appraisal for mangroves considers the relevant elements of the entire mangrove management system.

This study aimed to assess sustainability management of mangrove ecosystems in Madura Strait, Indonesia by combined rapid appraisal for mangroves with multi-temporal remote sensing data. The effort of rapid appraisal should lead to a wide variety of options and possible alternative arrangements for mangrove management. Current study using the rapid appraisal method to identify key factors that have a significant impact on mangrove ecosystems. Furthermore, the selected key factors can be used as a basis to formulate strategy to improve mangrove ecosystem management. This is important, because by definition sustainability assessment is the use of integrated frameworks to identify and evaluate the potential effects of alternative undertakings and find the best options for progress towards sustainability (Devuyst, 1999). RAPMangroves approach that combined with remote sensing data will allow further investigations of vegetation dynamics along the coastal regions of Madura Strait. Management of mangroves ecosystem is not only about environmental factors, but also involves social, economic, and institutional purposes. All those aspects should be taken into account to formulate comprehensive strategies in protecting as well as to ensure the sustainability of mangrove ecosystems in the future. Therefore, another objective of this study is to measure the level of sustainability and its management from multi-dimensional perspectives. It is expected that the results can provide valuable reference for policy makers, scholars, and any others who concerned about the preservation of mangroves in this region.

2. Materials and methods

2.1. Study area

This study was conducted in coastal regions of Madura Strait, East Java Indonesia. The region is located between 112^{o}40’05” S - 114^{o}45’05” S and 07^{o}05’20” E - 07^{o}35’07” E (Figure 1). Madura Strait separates Java and Madura Islands, it consists of 11 districts and 66 sub-districts. A total of 17 sub-districts are located on Madura Island, while the rest are located on the island of Java. The coastal area of the Madura Strait reaches 3565.85 km^2 or about 7.56% of the total area of East Java Province. There are 4 small islands in the strait, namely Mandangin (Sampang Regency), Gili Raja, Gili Genting (Sumenep Regency), and Gili Ketapang (Probolinggo Regency). The coastal area of Madura Strait is dominated by flat and muddy beaches. Sandy beaches can only be found in several places such as Pasir Putih Beach of Situbondo.

Madura Strait is a fishing ground for approximately 92.480 fishermen with more than 9.000 units of fishing vessels. The total area of the strait is around 10.963 km^2. When compares to another sea in East Java at the provincial authority limit of 0-12 miles, the Madura Strait ranked 3rd after the Java Sea in the north (36.027 km^2) and the Indian Ocean in the south (11.536 km^2) and much larger than the Bali Strait in the east (1.350 km^2). Madura Strait fisheries potential reaches 214.097 tons, but its production has reached 227.427 tons since 2008, so it falls under over-fishing status (Hidayah, 2018). Unfortunately, there is no current research has been conducted to determine the recent condition and status of fisheries resources in the area. The use of destructive fishing gear and massive environmental degradation along the coastal areas in the last 15 years considered as the foremost causes of the declining fisheries production in the area.

2.2. Satellite Imagery Data

To measure the extent of the mangroves ecosystem and its change-over-time, a series of remote sensing data was used in this study. A moderate resolution satellite image of Landsat 8 acquired in 2020 was used for recent measurement, whereas Landsat ETM-7 images from 2000 were utilized to identify mangroves area from previous periods. Landsat 8 has an On-board Operational Land Imager (OLI) Sensors and Thermal Infrared Sensor (TIRS) with a total amount of 11 bands (band 1-9 OLI and band 10-11 TIRS).

2.3. Remote sensing data analysis

Landsat satellite images that have been obtained for this study were not fully used in the analysis, for this reason, image cropping was necessary. It aims to limit the area according to the location of the study. Afterward, image recovery was carried out to enhance its quality. It consists of two steps namely radiometric and geometric correction. A radiometric correction was performed to eliminate factors that reduce image quality using the histogram adjustment technique. Whereas geometric correction was intended to correct distortion due to the position or location of objects. This distortion is produced by factors such as variations in satellite height, signal strength, and speed.

Identification of mangroves coverage was done simultaneously with land cover analysis using supervised classification. This image analysis method requires representative samples to be used as training areas. To assist the analyst, False Colour Composites (FCC) was created by combining bands 543 in Landsat 8 and bands 432 in Landsat 7. Under these composite conditions, mangrove vegetation appeared bright red. That is because mangroves have a very good sensitivity to near-infrared wavelengths. The software then uses these “training areas” and applies them to the entire image. Envi 4.5 and QGIS a free open-source geospatial software (available at https://qgis.org/id/site) have been used for image analysis and generate maps of mangrove's spatial distribution in this study. The results of the classification were compared to the results of the ground check to produce the level of accuracy.

Supervised classification techniques were used to cluster objects in the image, based on their pixel value similarity. The maximum likelihood algorithm was then applied to assign each pixel value into certain classes. The main assumption in this algorithm was that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Therefore, each pixel is assigned to the class that has the highest probability. Besides, to measure the density of mangroves and separates mangroves from other vegetations, the Normalized Difference Vegetation Index (NDVI) was applied (Tucker, 1979). The basic concept of NDVI is by measuring the difference between Near-Infrared and Red wavelengths. Vegetation leaves tend to strongly reflect near-infrared, on the other hand, they absorb visible red wave-length. According to the Indonesia Ministry of Forestry classification of the NDVI is as follows: low density (NDVI< 0.35), medium density (0.35 < NDVI<0.60), high density (NDVI>0.60). The NDVI is calculated from the Landsat data using the formula in Eq. 1.

$$NDVI = \frac{near\ infred - red}{near\ infred + red} \quad (1)$$

2.4. Rapid appraisal for mangroves

The MDS analysis was carried out using the rapid appraisal for mangroves (RAPMangroves) application which eventually a modified version of standard RAPFISH method (Kavanagh & Pitcher, 2004). The RAPFISH method was develop by Fisheries Centre, University of British Colombia. Initially this method was used to analyse the sustainability of capture fisheries resources. However, through modification in its attribute data, this method can also be used to measure the sustainability of the management or exploitation of other coastal resources (Haya & Fujii, 2020). The basic of RAPFISH method is grouping ordination of scored attributes into several evaluation fields or dimensions using MDS. Specific attributes or indicators from various references are assigned into each dimension. The selected attributes are related to the sustainability of mangrove ecosystem management.

2.4.1 Identification of attributes

Each dimension consists of several indicators that described in more detail about current conditions of mangrove management related to resource sustainability. In total there are 29 attributes used in this study and then classified into 4 dimensions: ecology (n=8), economy (n=7), social (n=7) and institutional (n=7). The complete attribute data is presented in Table 1.

2.4.2 Definition and scoring of attributes

A certain score was given as a representation of the current condition. The score ranged from 0-3 depending on the state of each attribute that was interpreted from bad to good. The “bad score” indicates that the condition of the attribute will have a negative impact on the mangrove ecosystem, meanwhile the “good score” designates otherwise. Primary data collection for this study was carried out through field surveys and filling out a questionnaire containing the RAPMangroves assessment sheet, as modification from RAPFISH.

2.4.3 Multi-Dimensional Scaling (MDS)

Multi-Dimensional Scaling (MDS) is a multivariate statistical method to visualize the degree of similarity of individual cases from a data set. In a more practical function, MDS is used to translate information about paired distance between a set of *n* objects or individuals" into a configuration of *n* point mapped into a Cartesian space (Pitcher and Preikshot, 2001). Data input of MDS used in this study are based on attributes scores. Since the attributes of this analysis come from a wide range of distinctive sources, Standardization of attributes scores are important to eliminate differences.

As the basis of MDS, the ordinance technique was determined based on the multi-dimensional Euclidean distance of two points (d_{12}), whereas x_i and y_i represent the location of each point on the horizontal and vertical axis. The points are then projected into a 2-dimensional Euclidean distance (D_{12}) based on the regression formula. The basic equation for Euclidean distance and its projection is as follows:

$$d_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + \ldots} \quad (2)$$

$$d_{12} = a + bD_{12} + e; e \text{ is and error} \quad (3)$$

In RAPMangroves which is a modified version of RAPFISH, the ALSCAL algorithm operated with automatic imposition (a =0), as in this following equation (Haya and Fujii, 2020):

$d_{12} = bD_{12} + e$ (4)

The regression process as formulated in equation 3 uses the ALSCAL algorithm by running the iteration of the regression process in such a way to obtain the smallest error value (*e*). The iteration process will stop if the stress (S) value (goodness of fit /feasibility of the model) was lower than 0.25 (S <0.25). Stress calculation is explained in the following equation:

$$Stress = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left[\frac{\sum_i \sum_j \left(D_{ijk} - d_{ijk}\right)^2}{\sum_i \sum_j d_{ijk}^2}\right]} \qquad (5)$$

2.4.5 Rotation and Index Scale

Points from the results of RAPMangroves MDS analysis is defined as a sustainability value then rotated and projected in the horizontal axis and given a range of value i.e., 0 for extreme “bad” position and 100 for extreme “good” position. Sustainability values for each dimension are stated as the Sustainability Index, which ranges from 0 (bad) to 100 (good). This index is divided into 4 intervals as described in Table 2.

2.4.6 Sensitivity Analysis

Sensitivity analysis is used to determine the attributes that significantly affect the level of sustainability. The result of this analysis is represented as a change in the value of Root Mean Square (RMS). The greater the change in RMS, the more sensitive the attribute is in increasing the sustainability status. The sensitive attributes are then used as a basis for recommendations to increase the level of sustainability. The model is categorized as goodness of fit if S<0,25 and Squared Correlation (RSQ) >0.8 (Kavanagh & Pitcher, 2004).

2.4.7. Monte Carlo Analysis

Monte Carlo analysis is applied to estimate the effect of errors or uncertainty in the analysis process at 95% confidence level. Errors that appear in the calculation of RAPMangroves can be caused by several factors, including (1) assessment's inconsistency; (2) difference method of assessment; (3) repetitive level of model's stability; (4) data errors and (5) high stress value (Haya & Fujii, 2020).

3. Results

3.1 Changes in Mangrove coverage from remote sensing data

The accuracy levels with respect to the mangrove coverage for each type objects are shown in Table 3. The overall accuracy achieves to 78.30%. For mangrove classes, their user's accuracy is higher than 90%. However, due to spectral similarity between mangrove and vegetation non-mangroves, the producer's accuracy just reaches to 80.65%. These accuracies are acceptable in this study.

According to the results of Landsat images of 2000 and 2020 analysis, mangroves forests in the Madura Strait were scattered along the coast and near to the estuaries. The largest area of mangroves was in the Delta Brantas which includes the coast of Surabaya and Sidoarjo districts. Mangroves forest in patches continues to cover along the coast of Pasuruan to Situbondo in the east. Meanwhile, on the southern coast of Madura Island, mangrove forests were spread from the western end of Bangkalan district to Kalianget, Sumenep district (Figure 2 and Figure 3). Further calculations show that the area of mangroves in the Madura Strait decreased from around 6526.77 Ha in 2000 to 5902.06 Ha in 2020 (Table 4). The annual mangrove loss rate in this area is around 31.23 Ha / year. The southern coastal areas of Madura and Sidoarjo experienced the largest loss of mangrove areas compared to other areas.

Further analysis to determine the density of mangrove forests using the NDVI value showed that in 2000, 74.77% of mangrove forests had low density (<1000 trees / Ha). While the rest are included in the medium (≥1000-1500 trees / Ha) and high density (> 1500 tress/Ha) categories with area percentage of 10.41% and 14.82% respectively. Furthermore, the results of the analysis in 2020 show that there is a significant change in density as indicated by the increase in areas with high density up to 62.55% (Figure 4).

Mangrove species of *Avicennia marina, Rhizophora mucronata*, and *Sonneratia alba* were the dominant species and can be found in almost every region along the coast of Madura Strait. Mangrove species listed in Table 5 were generally known as true mangrove vegetations, live in tidal areas, and absorb salt from the water. These vegetations have a unique adaptation that enables them to remove excess salt through stems and leaves. Opposite to these species were the mangroves associated species, lives further inland, and have limited ability to remove salt from their body. Examples of these species include *Cerbera manghas*, *Spinifex littoreus*, *Thespesia populnea*, *Pandanus tectorius*, *Terminalia cattapa*, *Ipomoea pes-capre*, and *Barringtonia asiatica*.

3.2 Sustainability Analysis of Mangroves Management

Four dimensions of mangrove management in the Madura Strait East Java were analysed in this study. Each dimension consists of several indicators that described in more detail about current conditions of mangrove management related to resource sustainability. Scores were given based on the findings of previous research and interviews with key respondents from government officials, fishermen, community leaders and local marine ecologists. Modus of each attribute were assigned as score for further analysis using RAPMangroves (Table 6).

Data compilation revealed that the sustainability of mangroves management in the Madura Strait of east Java had 29 attributes, classified into four RAPMangroves dimensions (ecology, economy, social and institutional). In general, the value for the four dimensions was 53.77, where the class status of mangrove management sustainability in the Madura Strait is a “moderately sustainable". As shown in Figure 5, the results of RAPMangroves analysis showed a variety of sustainability indexes. The index value for the threats in the ecological

RAPMangroves dimension was 30.82 and categorized as "less sustainable", indicating that all attributes in the ecological dimension posed serious threats to the status of the mangroves ecosystems in the study area. The highest index occurred for the social dimension (78.57) and was categorized as "sustainable". Even though it has an "sustainable" category, the results of the analysis still showed that one sensitive attribute affecting the social dimension that is knowledge about mangroves values. The other two dimensions, economy and institutional have an index value of 55.21 and 68.14, respectively (Table 7). On the sustainability index, both dimension threats to mangroves ecosystem were categorized as "moderate sustainable". Of the seven attributes in the economic dimension, leverage analysis showed that the tourism activity posed the greatest threat, followed by the average local income (Figure 6). Meanwhile, leverage analysis of the seven attributes in the institutional dimension showed that the most sensitive attributes were the action against illegal logging, followed by monitoring and supervision. These results represent the current condition of mangrove management in the area.

Uncertainties in the RAPMangroves analysis in each of the attribute scores can be expressed in the MDS analysis for each evaluation field through Monte-Carlo analysis associated with *S-values* and RSQ estimates (Spence and Young 1978). The result of analyses showed that the dimensional *S-values* ranged from 0.128 to 0.150, whereas RSQ ranged from 0.945 to 0.953 (Table 7). The range of *S-values* and RSQ indicating that statistically the RAPMangroves analysis in this study has sufficient goodness of fit (*S-values* < 0.25; RSQ > 0.90). Meanwhile, Monte Carlo analysis for each dimension resulted in reasonably small differences from the MDS Score (< 1), it showed the stability of the iterative MDS analysis process and the level of error of RAPMangroves analysis was acceptable.

4. Discussions

4.1. The current status and threats of mangrove ecosystems

The remote sensing analysis indicated that there was a significant decline of mangroves areas along the coast of Madura Strait in the last 20 years. It is important to note that in many regions particularly in Indonesia destruction and degradation of mangrove forests driven by land conversion, coastal development, and pollution is occurring at an alarming rate. In general opinion, mangrove forests have often been considered unproductive land. Therefore, many mangrove forests are then cleared and converted into aquaculture and agriculture areas, human settlements, ports, and industrial estates. In many developing countries, clearing mangroves for tourist developments and salt farms have also occurred. Mangrove's land clearing is the main reason behind mangrove's loss in the world. Whereas another factor that has an important influence on mangrove loss is illegal logging. Traditional people use mangrove trees for firewood and charcoal, while for modern industry mangroves are sometimes use as raw materials for wood chip and pulp production.

Apart from being a natural habitat for various types of aquatic biota, the mangrove forest on the coast of the Madura Strait was also a habitat for various species of birds. There were 83 species of birds, 7 species of primates and 53 species of insects found along the mangrove forest located on the east coast of Surabaya including *Charadrius javanicus*, *Numenius arquata*, and *Tringa hypoleoucos*. Several other species of birds were commonly found in mangrove forest areas on the coast of the Madura Strait, including *Egretta profit*, *Leptoptilos javanicus*, *Dondrocygna arquata*, *Anhinga melanogaster*, and other water-bird species. Some of them were listed as protected species according to IUCN and CITES (Idajati et al., 2016).

The results of the leverage analysis show that sustainability in the ecological dimension was strongly influenced by four attributes i.e., mangroves coverage, density, rehabilitation and protection programs, and the role of conservation groups (Figure 6). The existence of the mangrove coverage area is one of the main indicators of sustainable coastal development. A large area of mangrove forests could provide many benefits not only for the fisheries economy but also for the environment directly. Indonesia’s Ministry of Marine and Fisheries affairs claims that under a pristine condition, mangrove forests contribute at least 1.5 billion USD/year from the fisheries economy. While the estimated contribution of mangroves to the economy may vary in each country, several studies have reported its significant correlation (Anneboina & Kumar, 2017; Hutchison et al., 2014)

The lack of rehabilitation and protection activities in this area makes it one of the pressures in the ecological dimension. Comprehensive mangrove rehabilitation programs should be a top priority for the East Java province authority. However, the availability of conservation budget each year limit the government's ability to rehabilitate mangrove forest along the coast of Madura Strait. One way that can be taken is by empowering coastal communities by forming community-based conservation groups. The government can facilitate these groups to obtain legal entities. Furthermore, through continuous training on how to get benefits from mangrove natural resources and assistance from the government, community groups are expected to independently conserve mangrove forests in their area.

Mangrove forests with high density of vegetation provide coastal protection against erosion due to waves and current. The thick and solid root system traps sediments flowing down rivers and off the land, therefore it maintains the stabilization of the coastline. By filtering out sediments, water mass that passes through the forest would have better quality. Based on remote sensing data analysis, the average mangrove coverage in the Madura Strait is less than 50%. It means that most of the mangrove areas are under critical condition. As revealed in the institutional dimension, the greatest threats are the absence of monitoring and supervision as well as the lack of action against illegal logging from the government may be the cause of the criticality of the mangrove. Land conversion and illegal logging are suspected as the main problems the cause of critical condition of mangrove. If it is not immediately handled and prevented, the damage to the mangrove ecosystem will get worse and could have a severe impact on the coastal environment.

The economic dimension revealed that exploitation and tourism have a significant impact on the sustainability of mangrove forest management (Figure 6). Uncontrolled and irregulated exploitation not only damages the forest directly but also reduces its economic value for a longer period. The economic value of a mangrove forest is calculated based on the use-value (direct and indirect value) and non-use value (option and existence value). These values have emphasized the components of ecosystem services, fish resources, firewood, coastal protection, biodiversity, and carbon removal (Sondak et al., 2019). Parameters that are used in economic valuation highly depend on the current condition of the mangroves ecosystem. A well-preserved mangrove forest will have a high economic valuation and vice versa. Therefore, exploitation of mangrove resources and land conversion should be carefully monitored. Unfortunately, the economic valuation of mangrove forests in the entire Madura Strait has not been done yet. However, using comparison with other studies in Indonesia, the economic value of mangrove forests ranged from US$ 8101 to US$ 8791 ha-1 year-1 (Kusumawardani, 2019; Rumahorbo et al., 2019)

Mangrove eco-tourism is a very strategic conservation approach. The RAPMangroves leverage analysis showed that it can contribute greatly to the sustainability of mangroves management in the Madura Strait. The main objective of mangrove eco-tourism is to increase local income while at the same time ensuring mangrove conservation. However, given the complexity in creating environmentally-based tourist destinations, mangrove eco-tourism in the Madura Strait is not well developed. The most popular sites are only in Surabaya and Probolinggo, and their contribution to the local economy is significant. One of the benefits of ecotourism in Surabaya and Probolinggo is the increase in the mangrove area in the region as shown in Table 4. Therefore, more initiatives are needed to empower local communities. The infrastructure supports, entrepreneurship training, and promotions of the mangrove ecosystems are among key factors that can be delivered by the government or Non-Governmental Organizations to raise the creativity of local communities in developing mangrove-based tourist destinations.

Increasing public knowledge on mangrove's function is also an important factor that can influence the sustainability of conservation, particularly in the Madura Strait. Although the benefits of the mangrove ecosystem in protecting coastal areas and contributing to the local economy are well known, there is still a view that mangrove areas are not productive so they can be converted to other land-use systems. There is no doubt that local communities have a very important role in deciding the type of development in their region (Sawairnathan & Halimoon, 2017). Therefore, they need to understand the value of the mangrove ecosystem to prevent land conversion. Introducing the mangrove ecosystem as early as possible through formal education is strongly advised. Information of mangrove ecosystems can be embedded in subjects about science and the environment at various levels of education. As for non-formal ways, conservation actions and campaigns are need to be carried out continuously to elevate awareness among the communities.

4.2. Recommended Strategies to improve management of mangrove ecosystem

The results of RAPMangroves analysis showed that improvements need to be done in the ecological, economic, and institutional dimensions to increase sustainability status of mangrove ecosystem management in the Madura Strait. It also needs a slight increase from the social dimension to raise the status value close to 100, especially in increasing community knowledge about the benefits and ecological values of mangroves. In the ecological dimension, there are attributes that can provide leverage to increase the sustainability status, namely: mangrove coverage and density, rehabilitation protection programs and conservation groups. Meanwhile, for the economic dimension, one attribute i.e. tourism, is estimated to be able to provide a significant support to increase the level of sustainability. Finally, attribute of knowledge on mangrove's function and values is addressed as the leverage for the social dimension.

Recommendation for ecological dimension is to intensively conduct mangrove rehabilitation programs. This program should be a top priority because the condition of a good mangrove ecosystem will greatly affect other attributes. Naturally, mangroves can grow by themselves. However, through initiated mangrove rehabilitation program, degraded mangrove ecosystems can be rapidly repaired. Protection of newly planted mangrove vegetation is also very important. Newly planted mangrove seedlings are susceptible to damage due to natural and human factors. However, the availability of conservation budget each year limit the government's ability to rehabilitate mangrove forest along the coast of Madura Strait. One way that can be taken is by empowering coastal communities by forming community-based conservation groups. The government can facilitate these groups to obtain legal entities. Furthermore, through continuous training on how to get benefits from mangrove natural resources and assistance from the government, community groups are expected to independently conserve mangrove forests in their area. In addition, improving mangrove ecology by making it a protected area controlled by the government can be an alternative. As shown by Nuarsa et al. (2018), mangrove areas that are made as protected area established by government can improve the ecological quality of mangroves as indicated by the increased ability of mangroves to absorb carbon from the atmosphere, even under pressure from land use changes.

Mangrove eco-tourism is a very strategic conservation approach (Salam et al., 2000). The RAPMangroves leverage analysis showed that it can contribute greatly to the sustainability of mangroves management in the Madura Strait. The main objective of mangrove eco-tourism is to increase local income while at the same time ensuring mangrove conservation. However, given the complexity in creating environmentally-based tourist destinations, mangrove eco-tourism in the Madura Strait is not well developed. The most popular sites are only in Surabaya and Probolinggo, and their contribution to the local economy is significant. Therefore, more initiatives are needed to empower local communities. The infrastructure supports, entrepreneurship training, and promotions of the mangrove ecosystems are among key factors that can be delivered by the government or NGOs to raise the creativity of local communities in developing mangrove-based tourist destinations.

To increase public knowledge on mangroves function and value, introducing the mangrove ecosystem as early as possible through formal education is strongly advised. Information of mangrove ecosystems can be embedded in subjects about science and the environment at various levels of education. As for non-formal ways, conservation actions and campaigns are need to be carried out continuously to elevate awareness among the communities.

5. Conclusions

The sustainability assessment of mangrove ecosystems management in Madura Strait, Indonesia were studied based on combined of RAPMangroves analysis with multi-temporal remote sensing data. The result of remote sensing analysis shows that the mangrove area has been decline from 7358.76 Ha in 2002 to 5456.35 Ha in 2019. Although it has decreased during the study period, the mangrove areas have increased in the areas that have ecotourism activities. Moreover, the RAPMangroves analysis indicated the overall cumulative index of mangrove ecosystem sustainability from the four dimensions was 53.77, within a threshold denoting a “moderately sustainable” status. In detail, mangrove ecosystem sustainability was denoting as “less sustainable” for ecological, "sustainable" for social, and "moderately sustainable" for institutional and economic.

Based on leverage analysis of RAPMangroves in Madura Strait, several priority alternative strategies were obtained to improve the status of the mangrove ecosystem in the region, where the highest priority was the greatest attribute value, such as tourism activities, rehabilitation and protection, as well as monitoring and supervision. The existing alternative strategies should be implemented in order of priority, although there will be several interacting factors that can threaten the sustainability of mangrove management. Therefore, this recommendation is expected to be strongly adopted by policy makers and can continue to preserve the sustainability of mangrove management. In practice, the results of this findings are expected can provide valuable information for policy makers, scholars, and any others who concerned about the preservation of mangroves to formulate the right strategy to ensure the sustainability mangrove ecosystems management.

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Figure

Click here to access/download;Figure;Sustainability RAPMangroves - Figure.docx

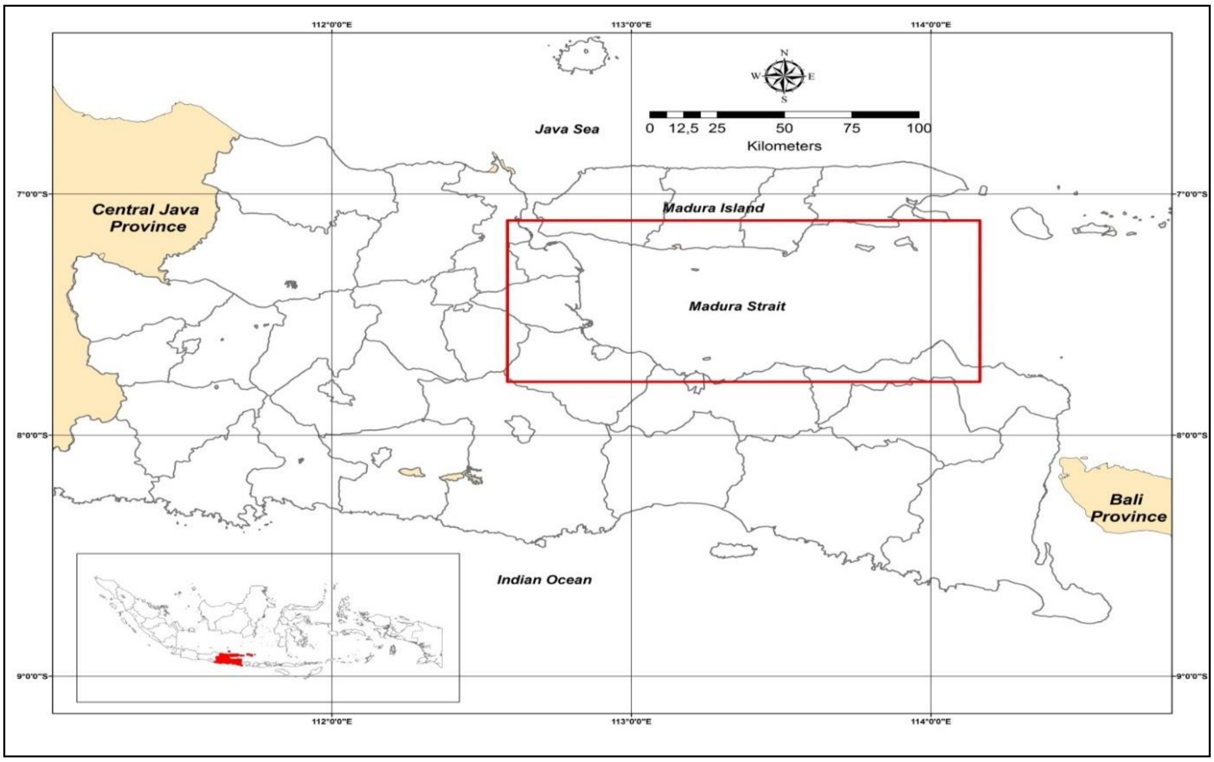

Figure 1. Study Area the Madura Strait of East Java

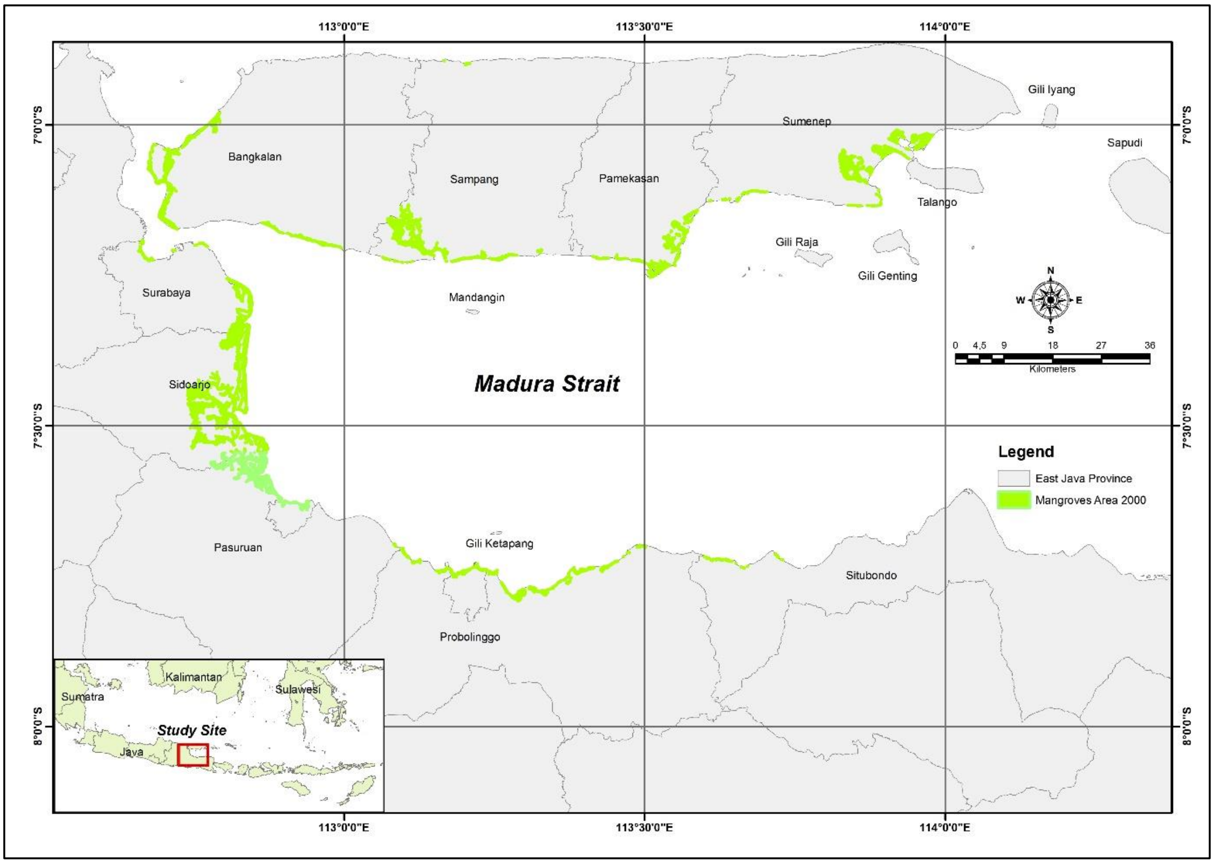

Figure 2. Mangrove's Distribution of Madura Strait in 2000

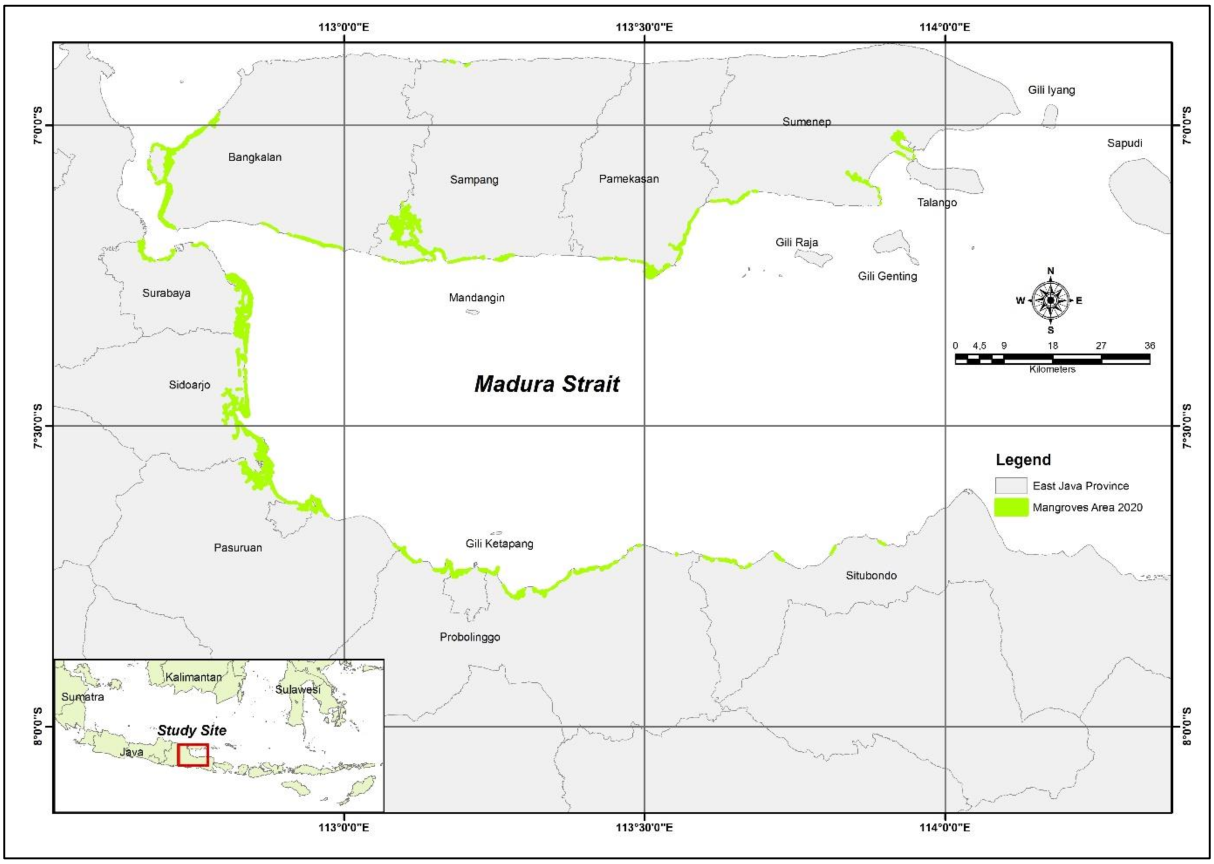

Figure 3. Same as Figure 2, but for 2020

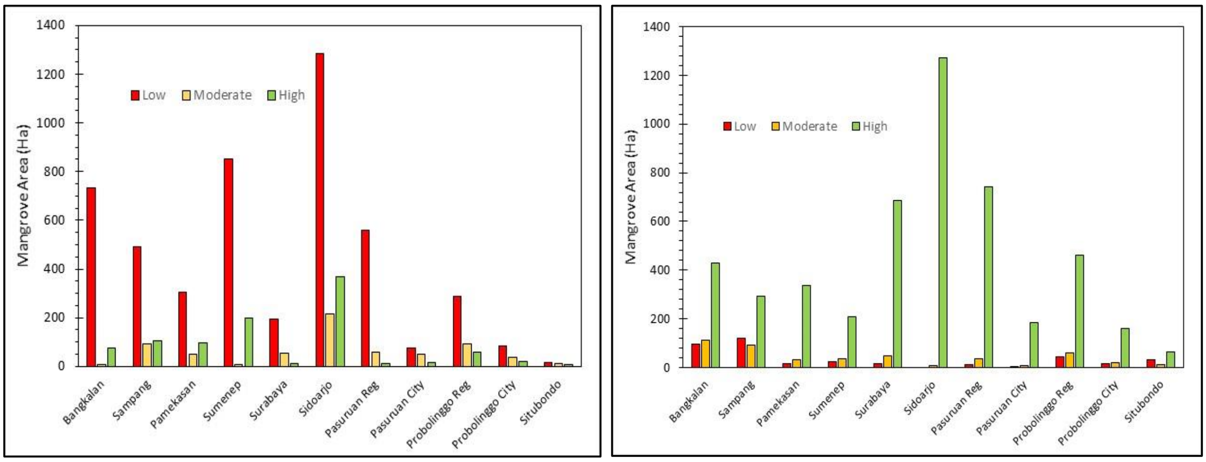

Figure 4. The change in mangrove area based on density (NDVI values)

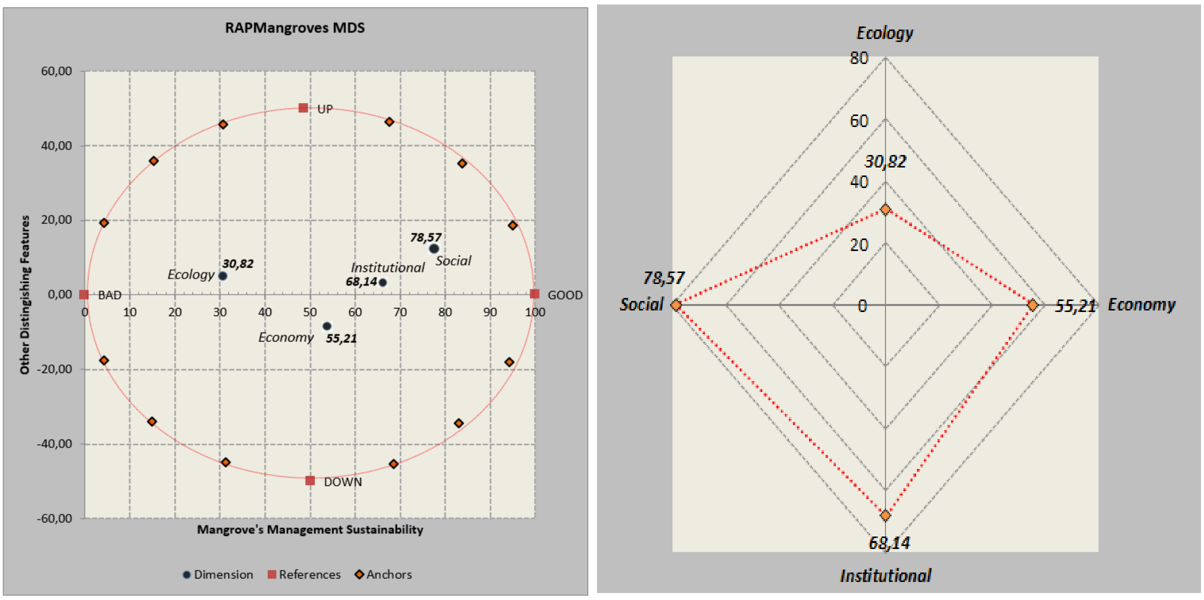

Figure 5. (a) Two-dimensional RAPMangroves for mangrove ecosystem management assessment in Madura Strait. The horizontal axis represents sustainability index (0% bad – 100% good); (b) Kite diagram showed the relative position of sustainability index for each dimension

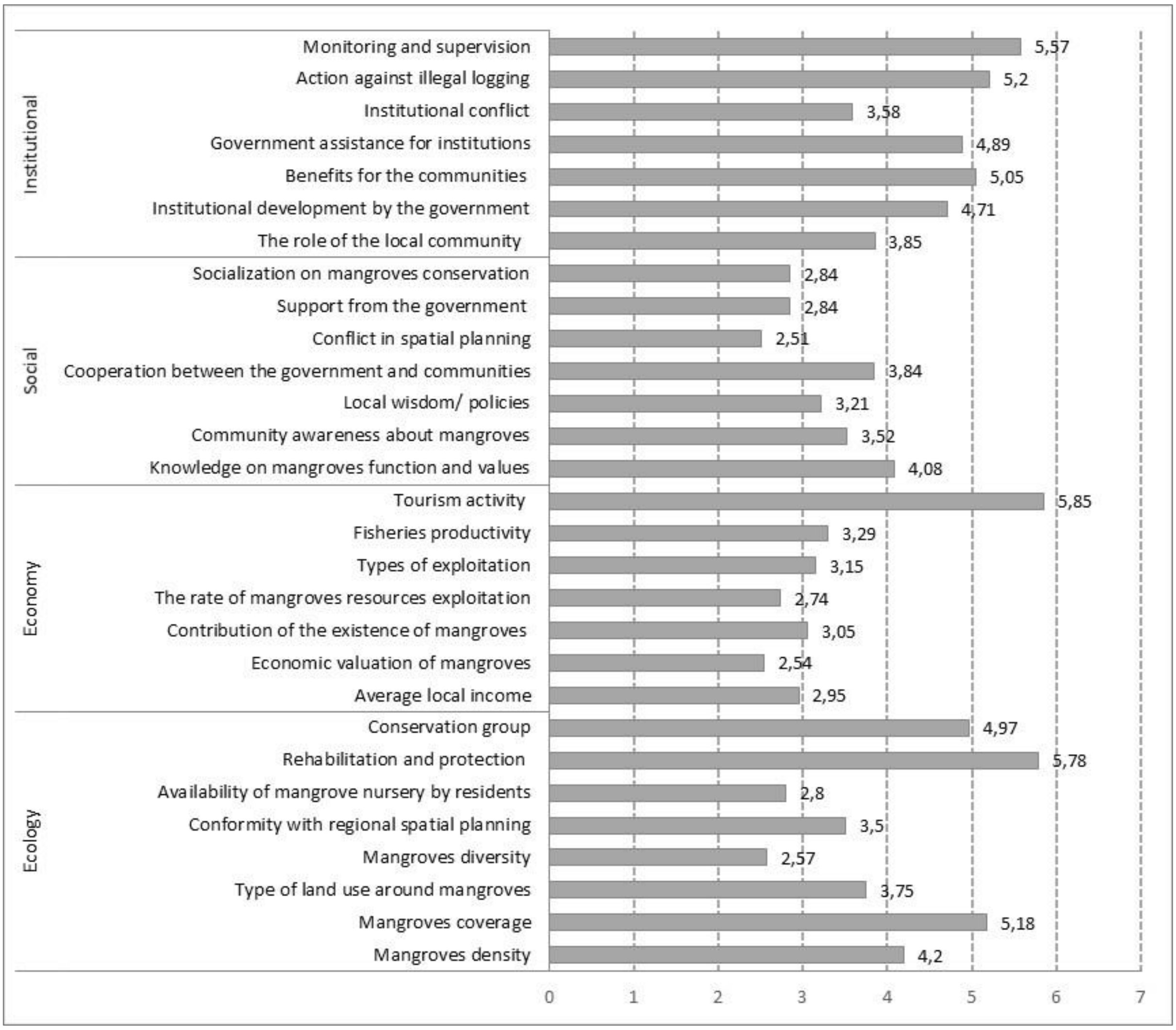

Figure 6. Attribute of leverage analysis of RAPMangroves for mangrove ecosystem management assessment in Madura Strait, based on the standard error (%)

Table 1. Attributes of RAPMangroves for mangrove ecosystem management assessment in Madura Strait

No	Attribute	Score (*Bad – Good*)	Criteria	Source
A	**Ecology Dimension**			
1	Mangroves density	0; 1; 2	NDVI value: 0 = <0.32; 1 = 0.32-0.42; 2 = >0.42	(Khairuddin et al., 2016)
2	Mangroves coverage	0; 1; 2	Estimation of area coverage based on NDVI: 0 = < 50%; 1 = 50-70%; 2 = >70%	(Hidayah et al., 2015)
3	Type of land use around mangroves	0; 1; 2; 3	Land use in vicinity based on image analysis: 0 = aquaculture; 1 = settlements; 2 = agriculture; 3 = vegetation	
4	Mangroves diversity	0; 1; 2	Shannon-Wiener Index (H'): 0 = H'<1; 1 = 1<H'<3; 2 = H' > 3	(Malik et al., 2019)
5	Conformity with regional spatial planning	0; 1	Spatial planning policy as protected areas: 0 = not suitable; 1 = suitable	
6	Availability of mangrove nursery by residents	0; 1;2	Provision of mangrove seeds in the area: 0 = not available; 1 = available from other areas near the forest; 2 = available in the areas	(Zen et al., 2017)
7	Rehabilitation and protection	0; 1;2	Re-plantation and protection by communities: 0 = no protective measures; 1 = conditionally; 2 = frequently	(Van Oudenhoven et al., 2015)
8	Conservation group	0; 1; 2	Formation of community group assigned to protect and supervise mangrove areas: 0 = not available; 1 = available without activities; 2 = available with routine activity	(Melo et al., 2020)
B	**Economy Dimension**			
1	Average local income	0; 1; 2; 3	Local income compares to regional minimum wage (RMG): 0 = below RMG; 1 = 75% RMG; 2 = same as RMG; 3 = above RMG	(Zen et al., 2017)
2	Economic valuation of mangroves	0;1;2	Availability of estimated mangroves values: 0 = not available; 1 = partially available; 2 = fully available	(Rizal et al., 2018)
3	Contribution of the existence of mangroves	0;1;2;3	Estimated impact of mangroves to local economic: 0 = no contribution; 1 = low impact; 2 = moderate impact; 3 = significant impact	(Sari & Patria, 2020)
4	The rate of mangroves resources exploitation	0;1;2	Level of exploitation: 0 = high; 1 = moderate; 2 = low	(Sari & Rosalina, 2016)
5	Types of exploitation	0;1;2;3	Types of mangrove resources exploitation: 0 = logging; 1 = leaves for cattle feed; 2 = marine biota; 3 = tourism location	
6	Fisheries productivity	0;1;2	Local perspective regarding fisheries productivity in the mangrove area in last 5 years: 0 = decline; 1 = steady; 2 = increase	(Sukardjo, 2004)
7	Tourism activity	0;1;2	Utilization of mangroves area for tourism: 0 = not available; 1 = newly developed; 2 = have been developed and already operated	(Melo et al., 2020)
C	**Social Dimension**			
1	Knowledge about mangroves values	0; 1	Communities knowledge about mangroves function for coastal environment: 0 = in-sufficient; 1 = sufficient	(Khairuddin, 2016)
2	Community awareness about mangroves	0; 1; 2	Communities understanding about mangroves function: 0 =lack of awareness; 1 = moderately aware; 2 = fully aware	
3	Local wisdom/ policies	0; 1; 2; 3	Availability of policy/ wisdom formulated by local people to protect mangroves: 0 = not available; 1 = available, not implemented; 2 = partially implemented; 3 = fully implemented	(Huda, 2008)
4	Cooperation between the government and communities	0; 1; 2	Collaboration in protecting mangroves: 0 = no cooperation; 1 = occasionally; 2 = excellent partnership	(Huda, 2008)

No	Attribute	Score (*Bad – Good*)	Criteria	Source
5	Conflict in spatial planning	0; 1; 2	Conflict between stakeholders: 0 = happens frequently; 1 = happened in the last 5 years; 2 = no records of conflict	(Khairuddin, 2016)
6	Support from the government	0;1;2	Support from the government for mangroves rehabilitation: 0 = no support from the government; 1 = occasionally; 2 = excellent support	(Melo et al., 2020)
7	Socialization on mangroves conservation	0;1;2	Example of the role of the government: 0 = no socialization; 1 = occasionally; 2 = frequently	(Hardin et al., 2019)
D	**Institutional Dimension**			
1	The role of the local community	0; 1	Responsibility of local communities in protecting mangrove areas: 0 = no significant role; 1 = active participation	(Syafikri et al., 2019)
2	Institutional development by the government	0;1;2	Institutional technical guidance: 0 = none; 1 = available, irregular; 2 = available, regularly	(Syafikri et al., 2019)
3	Benefits for the communities	0;1;2	The amount of benefit: 0 = not useful; 1 = quite useful; 2 = very useful	(Hardin et al., 2019)
4	Government assistance for institutions	0;1;2	Institutional technical guidance: 0 = none; 1 = available, irregular; 2 = available, regularly	
5	Institutional conflict	0; 1	Conflict in the last 5 years: 0 = regular conflict; 1 = no conflict	(Asihing, 2014)
6	Action against illegal logging	0; 1	Legal actions for violations: 0 = none; 1 = applied	(Hakim et al., 2017)
7	Monitoring and supervision	0;1;2	Institutional supervision: 0 = none; 1 = available, irregular; 2 = available, regularly	(Khairuddin, 2016)

Table 2. Sustainability Index Classification

No	Intervals	Sustainability Status
1.	0-25	Not Sustainable
2.	26-50	Less Sustainable
3.	51-75	Moderately Sustainable
4.	76-100	Sustainable

Table 3. Comparison of Image Analysis and Ground Check

	Mangrove Identification Results			
	Objects	**Mangroves**	**Non-Mangroves**	**Total**
Ground Check	Mangroves	75	5	80
	Non-Mangroves	18	8	26
	Total	93	13	106

Overall Accuracy = 78.30%
Mangrove User's Accuracy = 93,75%
Mangrove Producer's Accuracy = 80,65%

Table 4. Mangrove’s Area Change in the Madura Strait

Region	**Mangroves Area (Ha)**		
	Landsat ETM 7 2000	**Landsat 8 2020**	**Change**
Bangkalan	818.56	640.43	-178.13
Sampang	685.94	508.62	-177.32
Pamekasan	452.87	384.09	-68.78
Sumenep	1062.11	269.19	-792.92
Surabaya	257.13	753.48	496.35
Sidoarjo	1864.38	1280.07	-584.31
Pasuruan Regency	629.00	793.80	164.80
Pasuruan City	140.00	198.45	58.45
Probolinggo Regency	440.19	567.99	127.80
Probolinggo City	145.00	198.80	53.80
Situbondo	31.59	106.56	74.97
Total	**6526.77**	**5701.48**	**-825.29**

Table 5. Distribution of Mangroves Dominant Species in the Madura Strait

Mangrove Species	Surabaya	Sidoarjo	Pasuruan	Probolinggo	Situbondo	Bangkalan	Sampang	Pamekasan	Sumenep
Avicennia alba	v	v	-	-	-	-	v	v	-
Avicennia corniculatum	v	-	-	-	v	-	-	-	-
Avicennia marina	v	v	v	v	v	v	v	-	-
Brugueira gymnorrhiza	v	-	-	v	v	v	-	v	v
Ceriops tagal	-	-	-	-	-	v	v	-	v
Exoecaria agallocha	v	v	v	-	v		v	-	v
Rhizophora apiculata	v	-	-	-	v	v	-	v	-
Rhizophora mucronata	v	v	v	v	v	v	v	v	v
Rizophora stylosa	v	-	v	-	-	v	v	v	v
Sonneratia alba	v	-	-	v	v	v	v	v	-
Sonneratia caseolaris	-	-	v	-	v	v	-	v	-

Table 6. Dimensions and Attributes of RAPMangroves for mangrove ecosystem management assessment in Madura Strait

No	Attribute	Score (*Bad – Good*)	Modus Score of Madura Strait	No	Attribute	Score (*Bad – Good*)	Modus Score of Madura Strait
A	**Ecology Dimension**			**C**	**Social Dimension**		
1	Mangroves density	0; 1; 2	1	1	Knowledge about mangroves values	0; 1	0
2	Mangroves coverage	0; 1; 2	1	2	Community awareness about mangroves	0; 1; 2	2
3	Type of land use around mangroves	0; 1; 2; 3	1	3	Local wisdom/ policies	0; 1; 2; 3	2
4	Mangroves diversity	0; 1; 2	2	4	Cooperation between the government and communities	0; 1; 2	2
5	Conformity with regional spatial planning	0; 1	1	5	Conflict in spatial planning	0; 1; 2	2
6	Availability of mangrove nursery by residents	0; 1;2	1	6	Support from the government	0;1;2	1
7	Rehabilitation and protection	0; 1;2	1	7	Socialization on mangroves conservation	0;1;2	2
8	Conservation group	0; 1; 2	1				
B	**Economy Dimension**			**D**	**Institutional Dimension**		
1	Average local income	0; 1; 2; 3	1	1	The role of the local community	0; 1	1
2	Economic valuation of mangroves	0;1;2	0	2	Institutional development by the government	0;1;2	1
3	Contribution of the existence of mangroves	0;1;2;3	3	3	Benefits for the communities	0;1;2	2
4	The rate of mangroves resources exploitation	0;1;2	0	4	Government assistance for institutions	0;1;2	2
5	Types of exploitation	0;1;2;3	3	5	Institutional conflict	0; 1	1
6	Fisheries productivity	0;1;2	0	6	Action against illegal logging	0; 1	1
7	Tourism activity	0;1;2	2	7	Monitoring and supervision	0;1;2	1

Table 7. Stress Values, RSQ and MDS Score of RAPMangroves Analysis

No	Dimension	Stress (S)	RSQ	MDS Score	Monte Carlo	Sustainability Status
1	Ecology	0.133	0.945	30.82	31.25	Less Sustainable
2	Economy	0.150	0.947	55.21	54.83	Moderately Sustainable
3	Social	0.128	0.950	78.57	78.69	Sustainable
4	Institutional	0.135	0.953	68.14	67.85	Moderately Sustainable