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Spatial Multi-criteria Analysis to Capture Socio-Economic Factors in Mangrove Conservation

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Abstract

Mangrove forests are among the most productive ecosystems, located in tropical and subtropical coastal waters and river estuaries. Mangroves benefit both people and the environment by providing shelter for brackish-water organisms, such as fish and shrimp. They form a green-belt area that protects land from abrasion and tsunamis, along with goods and services for people, e.g., fruit, fish and charcoal. However, unmanaged use of mangrove ecosystems has resulted in a widespread decline in their function and conflicts between users. A paucity of research on mangrove management and spatial zoning is also contributing to the decline of these ecosystems. This study develops a prioritisation process with Spatial Multi-criteria Analysis (SMCA) for social-ecological mangrove management, based on a case study in Baros, Yogyakarta, Indonesia. We include social (participation and perception), demographic, economic (economic value of mangroves) and ecological criteria (water quality, mangrove density and diversity, phytoplankton diversity and density) criteria and spatial considerations informed by remote sensing imagery. We consider the three different conservation scenarios of habitat protection areas, sanctuary areas, and restricted areas to help configure management plan options. We demonstrate how SMCA can support managers and policymakers in mapping conservation areas based on complex and diverse social-ecological data. However, further discussion with stakeholders in Baros is required to validate the produced map for future use. The involvement of stakeholders and governing bodies from the beginning or within the SMCA analysis will always be crucial in community-based prioritisations.

***Keywords**: ecosystem, ecological criteria, mapping, conservation management, social criteria.*

1. Introduction

Mangrove ecosystems are found in Africa, America, Asia and the Pacific region and cover an estimated 22%; 30%; 38% and 10% respectively of the total mangrove area worldwide (Vegh et al., 2014). Mangrove ecosystem services include fisheries, timber, coastal protection, tourism, recreation, carbon sequestration, biodiversity and filtration (Vegh et al., 2014). They provide nursery, spawning and feeding grounds for associated organisms such as fish and shrimp (Adeel and Pomeroy, 2002). However, these wetland ecosystems are threatened by overexploitation, pollution, urban development and land-conversion (Alongi, 2002; Giri et al., 2008), which has caused a 62% global loss of mangrove area worldwide (Goldberg et al., 2020). Effective management strategies are required to reduce these threats. Management strategies need to be matched to ecosystem service needs, for example, whether the mangrove system is to be maintained or improved for coastal protection, food provisioning, or timber production. Conserving existing mangrove ecosystems enables ecosystem services to be maintained, and it is more economical and easier to prevent mangrove loss rather than to restore degraded mangroves (Schmitt and Duke, 2015).

Indonesia's mangrove forest is one of the largest in the world, covering an area of approximately 3 million hectares; 22.6% of the total global mangrove area (Giri et al., 2011). This ecosystem contributes significant ecological and social-economic benefits to local communities. It is estimated that the total economic value of mangrove resources in Indonesia is US$3,624–US$26,734.61/ha/year (Rizal et al., 2018). This value results principally from provisioning services, such as wood, tannin, charcoal, food and material for the paper industry. It also provides protective benefits by protecting land from coastal abrasion, salt-intrusion, storm and tsunami damage and ecological benefits by providing nursery and breeding areas for a range of organisms (Rizal et al., 2018). However, the extent of Indonesian mangroves has been declining due to over-exploitation of wood resources and their conversion to brackish water aquaculture and coastal development e.g., villas, housing areas and roads (Andika et al., 2019). Management and conservation strategies are vital to halt the decline, to sustain the ecosystem, and preserve its functions for ecological and social-economic purposes. However, decision-making for mangrove conservation and management can be problematic because many parties, from the government to the local community, are involved. It can be challenging to meet the needs of every stakeholder. Thus, decision-making strategies that incorporate not only ecological factors, but also social-economic variables to reflect the needs of different stakeholders are necessary.

Multi-criteria analysis is a tool that can assist decision-making for ecosystem management. It supports mixed-data analysis with the direct involvement of stakeholders and local user groups (Mendoza et al., 2000). The approach allows researchers to combine complex multidimensional data, such as socio-economic, ecological and management information, to explore management and conservation options in a particular area (Cortina & Boggia, 2014). For example, the Analysis Hierarchy Process (AHP) – a hierarchically structured approach to multi-criteria decision making – can help to integrate heterogeneous data and specify interactions between a large numbers of criteria (Chen et al., 2013). While multi-criteria analysis aims to investigate a complex issue, combining it with spatial contexts allows policy makers to better understand how the outputs are spatially distributed (Boggia et al., 2018). Thus, spatial multi-criteria analysis (SMCA) approaches that can combine qualitative and quantitative data and produce maps are useful to managers and stakeholders who want to assess the benefits of conservation projects or options.

Effective management strategies are required to balance its various economic, commercial uses and conservation goals. It is essential to consider both the ecological and socio-economic factors in a transparent prioritisation process. Hence, multi-criteria analysis provides a powerful approach to achieving this integration (Comino et al., 2016). The ability to combine multi-criteria decision-making approach with spatial data or Geographic Information Systems (GIS) has been studied in other ecosystems worldwide, such as using SMCA in forest conservation planning (Phua et al., 2005), SMCA for Marine Protected Areas (MPA) zoning and management (Habtemariam et al., 2016), and SMCA for assessing mangrove health (Vaghela et al., 2018). Therefore, we believe that we could use SMCA for mangrove conservation planning and SMCA is the most suitable method to facilitate and manage the complex interactions between users and managers who have different goals and reasons for managing the mangroves.

In this study, we investigated the possible social and ecological criteria used for SMCA analysis and prioritise areas for different types of use. Unlike most SMCA studies that use only community perceptions (Karlsson et al., 2017; Danumah et al., 2016), which are prone to bias, we used a combination of community perceptions, mangrove economic value, and ecological observations to support the analysis. Furthermore, we applied three main management types, i.e., core zone, buffer zone and transition zone in conservation area, akin to UNESCO's Biosphere zonation (Batisse, 1990). Specifically, our goals were to (1) understand spatial, ecological and socio-economic parameters that are suitable and applicable for conservation management planning of mangroves; and (2) demonstrate how multi-criteria analysis can be employed in spatial conservation planning for mangrove ecosystems. To demonstrate the framework, this study developed possible management and conservation options for the Baros mangrove forest.

2. Case study methods: incorporating socioeconomic factors into SMCA

2.1 Study area

Mangrove restoration has been extensively undertaken in Indonesia and include both top-down (government-driven) and bottom-up (community-driven) efforts (Turisno & Siti, 2020; Van Oudenhoven et al., 2015). One such community-driven example comes from Baros, located between 07°59’25’’- 08°00’45’’S and 110°16’46’’- 110°17’22 E. The study area, which is located in Tirtohargo village, covers 281.89 hectares, with the majority of land used for farming (approx. 176.6 hectares of the total area) (**Figure 1**). A significant part of the community are farmers (67.5%), who plant various seasonal crops (Tirtohargo Village, Demographic data, 2013). Baros is located adjacent to the coast and an estuary. Therefore, salty winds and salt-water intrusion have become major threats to crops. Recognising the potential benefits of mangroves, this community established a new mangrove forest in a previously unforested coastal area in 2003. Over the following ten years, the area was expanded to a 5-hectare mangrove forest, dominated by *Avicennia* sp., *Rhizophora* sp., *Bruguiera* sp., and *Nypa fructicans* comprising 60%, 20%, 10% and 10% respectively (Trialfhianty et al., 2014). This process resulted in numerous benefits for the local community, including protecting farmland from salty winds which regularly destroy crops as well as abrasion along the coast.

In 2014, the area was designated as a conservation area managed by the local government and Ministry of Marine and Fisheries (MMAF) Indonesia. However, the conversion from a freely used area to a conservation area led to conflict between users (i.e., community) and managers (i.e., local government). Thus, to facilitate both the local government and the local community in setting up an ideal conservation zone, we propose a conservation zoning area for Baros mangrove using SMCA by incorporating heterogeneous data such as spatial, ecology and socioeconomic from the local community in Baros. Ecological and socioeconomic data were collected between June 2013 and February 2014. Six distinct locations were randomly chosen (inside and outside mangrove area) as stations for the field observations (**Figure 1**, Supplementary data Table S1).

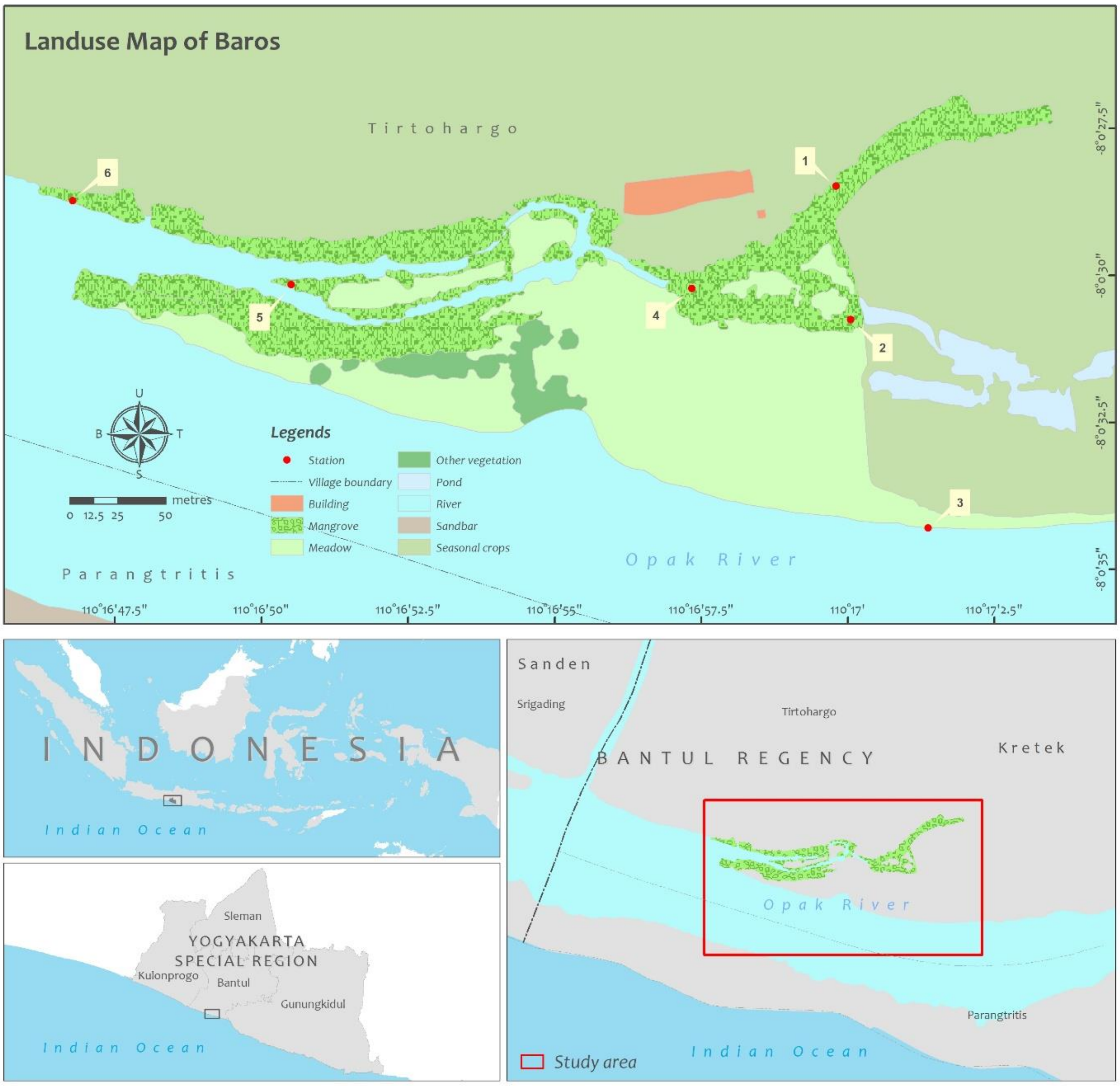


Figure 1. Case study location in Baros, Yogyakarta Province, Java Island, Indonesia

2.2 Research design

We divided the research process into five steps (**Figure 2**). In the research design step, we identified what activities mangrove users carry out and the type of benefits local people obtain from mangrove ecosystems in the area. Using a questionnaire, people were asked if they benefit from mangroves, what sort of activities they do to benefit and how often they do it. From this ecosystem services identification, we chose the criteria for management options. Finally, then we propose a zoning scenario for mangrove conservation management that has the potential to be implemented in the Baros mangrove area following Gubbay (2004). The zoning scenarios consist of various criteria that were generated from multiple parameters (**Table 1** for a detailed parameter and its source).

The next step was data collection of ecological and socioeconomic data for our SMCA. We applied an Analysis Hierarchy Process (AHP) matrix approach to determine weights for each criterion and factor. AHP allowed us to measure the importance of each parameter in each criterion in a hierarchical structure. This measurement helped with the decisions about which parameters or criterion were more or less important.

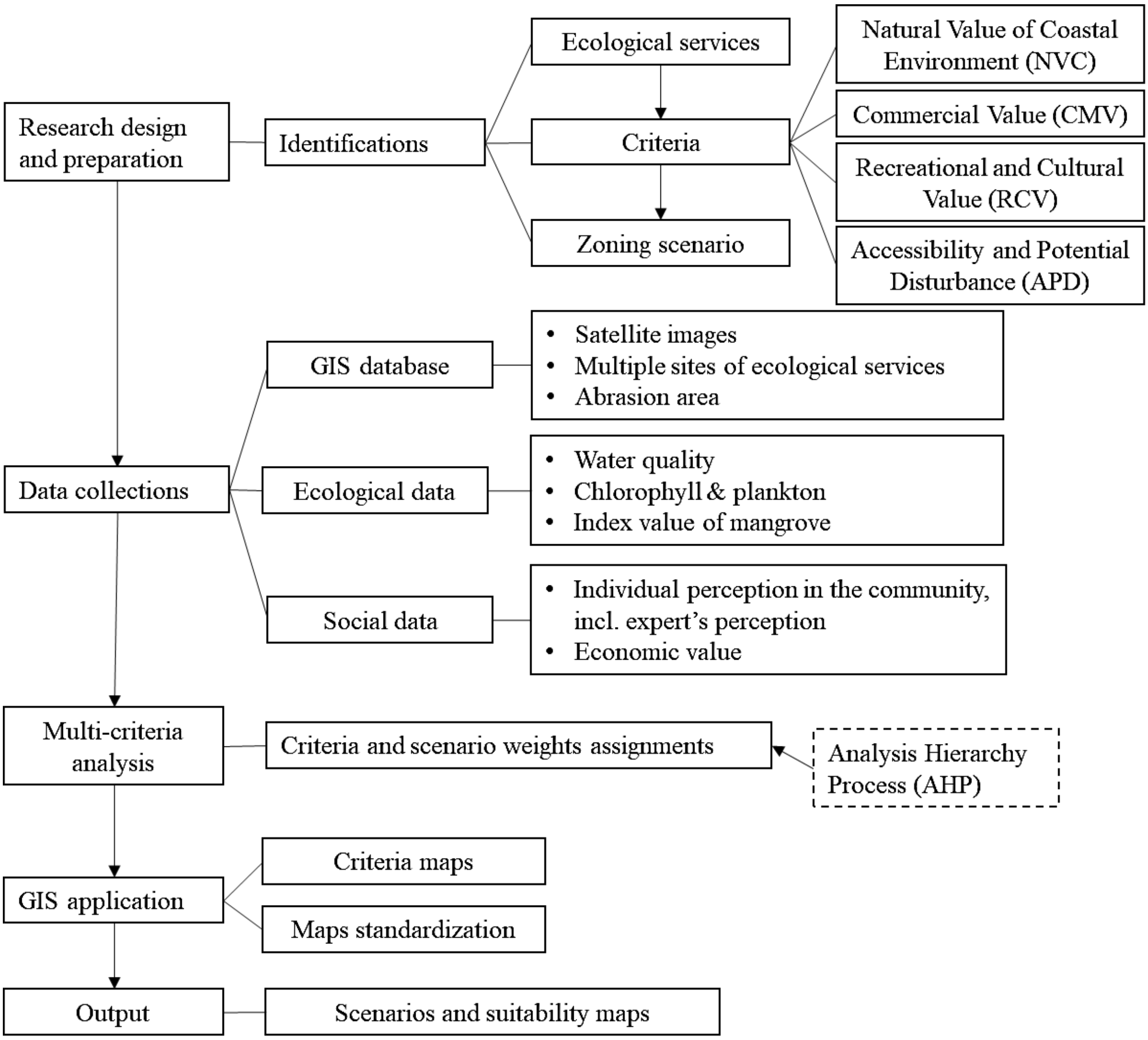


Figure 2. Flow chart of the study method using SMCA in the mangrove area.

2.2.1 Spatial Multi-criteria Analysis (SMCA)

2.2.1.1 Identification of criteria

Defining the criteria for conservation options (Habtemariam & Fang, 2016) is a key requirements for the spatial multi-criteria approach. These criteria can be established by examining social data, such as stakeholder preferences, to identify priority areas for various uses (Strager & Rosenberger, 2006), but also the environmental and socio-economic functions of the area (Portman, 2007). However, here, we did not only rely on stakeholders' perceptions or preferences concerning land management options. We also investigated several ecological data types that were collected to justify whether the area was suitable for such criteria. For example, we explored potential physical disturbances such as abrasion to capture the protection services of mangroves. Based on our field observations, the Baros area is prone to abrasion and flooding of coastal land, so we included Accessibility and Potential Disturbance (APD) as one of the criteria assessed in this study. Identifying criteria that are relevant for the location is important and can be undertaken by looking at either the social or ecological aspects.

Criteria used in this study included Natural Value of Coastal Environment (NVC), Commercial Value (CMV), Recreational and Cultural Value (RCV) and Accessibility and Potential Disturbance (APD). NVC describes the mangrove function as protection of farming land from salty wind and salt-water intrusion. Farmers reported that salty wind and salt-water from the sea are the biggest threats to their crops, resulting in severely damaged crops and decreasing production. If the area is to be expanded as conservation land to maintain its value/benefit, several parameters were required to build the NVC criterion. Here, we used ecological data, for instance, water quality, chlorophyll and plankton identification, along with the significance of the mangrove to develop the NVC criterion (**Table 1**). These data described the suitability of the area for a mangrove nursery and planting, besides its function as a green-belt area for farming.

The commercial value (CMV) of the mangrove ecosystem in Baros was reported as a commercial benefit to local people. The mangroves have benefited locals in three different ways; a) they have served as a fish habitat to improve fishers' yields, b) they provided a brackish water habitat suitable for shrimp aquaculture that is an important income stream, and c) they increased biodiversity/vegetation in the surrounding terrestrial area used as a feeding area by cattlemen (grazing cows, goats and ducks). Thus, we used three parameters to build the CMV criterion: aquaculture, feedlots and traditional fishing.

The Recreational and Cultural Value (RCV) encompasses mangrove benefits for tourism and education purposes. There was a camping ground that was established to allow people to spend the night in the natural area the mangroves provide, including research and bird watching. The parameters required to develop the RCV criterion included education, research and tourism.

Table 1. Details of criteria, type and source of data used in this study

Criteria	Parameter	Type of Data	Source of Data and Methods			
			Remote Sensing Imagery	Interview/ questionnaire	Field obs.	GIS
Natural Value of Coastal Environment (NVC)	Green-belt area for farming	Water quality	-	-	X Sampling using various laboratory tools	Interpolation
	Mangrove nursery and planting	Chlorophyll & Plankton	-	-	X Sampling using a plankton net	Interpolation
		Important value index of mangrove	-	-	X Quadrant transect	
Commercial Value (CMV)	Aquaculture	aquaculture area and its economic value	-	X	X	Interpolation
	Feedlots	Feeding ground and its economic value	-	X	X	Interpolation
	Traditional fishing	Fishing ground and its economic value	-	X	X	Interpolation
Recreational and Cultural Value (RCV)	Education and research	Sites and their economic value	-	X	X	Interpolation
	Tourism; bird watching and camping		-	X	X	Interpolation
Accessibility and Potential Disturbance (APD)	Coastal abrasion and flood	Area of prone disaster	X	X	X	Visual interpretation and interpolation

2.2.1.2 Identification of zoning scenario

We propose and analyse three different management zones for the conservation area in Baros (Gubbay, 2004):

1) Restricted access zone
   This area is established as a no-take and no entry zone focused on improving ecological habitat. A mangrove nursery could be located in this area to support future mangrove expansion.
2) Sanctuary zone
   This zone is highly protected and free from commercial use. However, low-risk activities, such as tourism and education/research may be allowed.
3) Habitat protection zone
   This area allows access for commercial use with clear rules regarding how the local community can access and use the area.

2.2.2 Analysis Hierarchy Process (AHP) in SMCA

2.2.2.1 Criteria and scenario weighting for AHP

Weights were given to each parameter and criterion to construct the AHP matrix, following the method introduced by Saaty (1977). The matrix has a row and column, listing all parameters or criteria in each row and column. A matrix construction aims to calculate the weight and score of each parameter to indicate which parameter is stronger in comparison to others.. Measuring the weight using the AHP allowed many criteria to be simplified and numbered. It should be noted that this comes from individual preferences or perspectives about ecosystem services. Furthermore, AHP is easily compatible with GIS ranking models (Strager & Rosenberger, 2006). The paired comparison analysis is based on the matrix (Saaty, 1977):

$$\begin{array}{c|cccc} & A_1 & A_2 & \dots & A_n \\ \hline A_1 & W_1/W_1 & W_1/W_2 & \dots & W_1/W_n \\ A_2 & W_2/W_1 & W_2/W_2 & \dots & W_2/W_n \\ : & \dots & \dots & \dots & \\ A_n & W_3/W_1 & W_3/W_2 & \dots & W_3/W_n \end{array} \tag{1}$$

A = parameters; criteria
W = weight

Here, we first valued each parameter within each criterion by assigning weights. Weights can be drawn from local knowledge or by asking stakeholders about their individual preferences (Strager & Rosenberger, 2006). We employed several data, such as economic calculations of mangrove services, ecological survey, and social survey to help us justify the value of each parameter. Then, each parameter within each criterion and each criterion within each scenario was subsequently weighted for pairwise comparisons and suitability rating using Analysis Hierarchy Process (AHP) analysis (**Table 2**).

Table 2. Suitability and importance value for each criterion

Comparative Importance	Suitability Rating	Numerical Expression*
Equal importance	Not suitable	1

Moderate importance of one over another	Marginally suitable	3
Essential or strong importance	Moderately suitable	5
Very strong importance	Highly suitable	7
Extreme importance	Optimally suitable	9
Intermediate values		2,4,6,8

*following Saaty (1977) and Zabihi et al., (2019)

The weight assignment was based on the importance value and suitability between each parameter. For example, here in the NVC matrix, water quality (listed in column) and chlorophyll (listed in row) were only moderately linked (given a value of 5), while water quality had a very strong importance for the value index of the mangroves (given a value of 8). An identical parameter (when a parameter/criterion is compared to itself), such as water quality (listed in row) and water quality (listed in column) is given equal importance presented by the number 1. However, not only identical parameter was given equal importance. Certain parameters, for example, traditional fishing and aquaculture, were also equally important, because they were considered as similar activities that had a similar impact on the mangroves and had a similar annual economic benefit to the community (Supplementary methods F Matrix calculation 1 and 2).

The similar process of weight assigments were also applied to construct AHP matrix for each criterion within each scenario. For example, here in all matrix scenarios for Restricted Access Zone, Sanctuary Zone and Habitat Protection Zone, APD (listed in row) and NVC (listed in column) were strong importance one to other (given value of 5) because nature value of mangrove ecosystem and accessibility of mangrove ecosystem and its potential disturbance had to be strongly considered when designing mangrove conservation zone (Supplementary methods F Matrix calculation 3).

In order to validate the derived scores, we calculated the Consistency Ratio (CR) for the AHP matrix based on the matrix' Eigenvalue and a Consistency Index (CI) (Saaty, 1977):

$$\lambda \text{ max} = \sum_{j=1}^{n} \text{aij}\left(\frac{\omega \text{j}}{\omega \text{i}}\right) \text{..............................} \ (2)$$

a_{ij} is A from the matrix (1)
ω = weight
λmax = maximum eigen value

$$\text{Consistency Index (CI)} = \frac{\lambda \text{ max} - \text{n}}{\text{n} - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

n = number of elements

$$\text{Consistency Ratio (CR)} = \text{CI}/\text{RI} \ \text{.......................}(4)$$

where RI is the random index (**Table 3**).

Table 3. Random index matrix following Saaty (1980).

Number of criteria	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The matrix calculation has a Consistency Ratio (CR) between 0.051 (5.1%) and 0.094 (9.4%) (Supplementary methods F). CR is the value of the Consistency Index divided by the Index of the corresponding random matrix. The assessment of the importance of each criterion may be inconsistent/unreliable if the CR value exceeds 0.1 (10%) (Saaty, 1977). It is important to calculate the CR and ensure that the assessment is reliable prior to making a decision.

2.3 Data collection

2.3.1 Spatial ecological and environmental data

Mangrove data were collected using a quadrat sampling method that captured a 100m^2 area in each station. The sample area was marked using a 40m rope (creating a quadrat with 10m sides), and mangrove data were collected, i.e., species, number of mangrove trees in the area and diameter of mangrove trees, following the method employed by Curtis and McIntosh (1950) (Supplementary methods B*)*.

The coastal area south of Yogyakarta, where the Baros mangrove forest was established, is prone to coastal abrasion. The sandy beach material in the study area is vulnerable to change due to erosion or sedimentation (Saputro et al., 2017). Therefore, we also included data for coastal abrasion estimation in the area (as Accessibility and Potential Disturbance criterion) for future decisions in managing the Baros mangroves. These data were collected using satellite datasets, interviewing local people, undertaking a literature study and via field observation. The classification was determined based on two factors, i.e., elevation and distance from the shoreline (Naufal et al., 2019).

Firstly, we studied an abrasion susceptibility assessment in Baros (Naufal et al., 2019) (Supplementary methods D). Secondly, we asked local people to identify areas affected by abrasion. Then, using Google Earth, we marked areas based on interview data. Finally, we gathered all the information above to identify mangrove areas that are susceptible to abrasion. Additional ecological data, such as water quality and phytoplankton were taken from published data (Agustina, 2014) (Supplementary data C and D).

2.3.2 Spatial socio-economic data

A total of 72 respondents were identified using the snowball sampling method or chain-referral-sampling (Somekh and Lewin, 2005). We first interview the leader of village and ask him to separately provide a list of potential key informants most suited to answer questions related to our study. Using gatekeepers (leader of village and local NGO) to identify key informants can reduce the risk of getting false information because they (the gatekeepers) know better than anyone especially about the area, conservation projects, related rules and activities. Asking various gatekeepers can minimise any potential bias, leading to one reliable and accurate list of information. From the key informants, we went into the field and asked farmers/fisher/cattleman who are currently working on the field inside and outside mangrove area to fill out our questionnaire.

Qualitative data were collected using a questionnaire comprising open-ended questions for the respondents, and in-depth interviews, using a topic guide, for key informants. The questions in the questionnaire covered the perceptions of each individual in the community regarding mangrove benefits, their participation in mangrove conservation activities, management of the mangrove and their knowledge of the mangrove's conditions and locations. A Likert scale (5 points from completely disagree to completely agree) was applied to record each respondent's answer to each question. The questionnaire also collected quantitative data, such as the economic value associated with the mangroves and the total number of each ecosystem service used by each individual in the community (how often and how many people benefit from mangrove ecosystem services) (Trialfhianty et al., 2014, Supplementary data E and F). To calculate the economic value, people were asked by means of the questionnaire what benefit they received from the mangrove and the value associated with it. For example, if they thought that the existence of the mangrove provides a habitat for fishes and they were fishing in the area, we asked them how much profit (production minus effort) they earn from the fishing activity.

Data were processed using SPSS IBM 26 for statistical analysis. Prior to the data collection, the questionnaire was piloted with a small set of volunteers to reduce errors and misunderstandings.

2.4 Spatial analysis and prioritisation

Spatial analysis to conduct interpretation and interpolation procedures used ArcGIS Pro software to create spatial data related to the Baros mangroves (Menno-Jan Kraak & Ormeling, 2010). We created maps pertaining to each parameter and criteria, which are subsequently combined to create a conservation and management map for each scenario. Spatial data was acquired from UAV photography using fixed-wing and completed with Ground Control Points (GCPs) in 2011, high-resolution satellite imagery derived from SPOT 6 and Worldview-2 in 2013. These data were collected from *Badan Informasi Geospasial* (Geospatial Information Agency as national map authority of Indonesia).

Interpretation, together with the digitisation of remote sensing imagery, was conducted using visual techniques to generate land use maps (Shalaby & Tateishi, 2007) and to identify vulnerability to abrasion and flooding (Marfai, 2011). Land-use maps were employed to define the zoning scenario and distinguish the boundary between mangroves and other land uses nearby, while a vulnerability map was employed to define Accessibility and Potential Disturbance (APD) criterion. The overall accuracy percentage for this map is 88 % (Supplementary methods A).

Inverse distance weighting (IDW) interpolation was utilised to convert field measurement data into a spatial data set (Varatharajan et al., 2018). IDW interpolation works by predicting a value for an unmeasured area using weights based on the value of neighbouring areas. The influence of a measured point is diminished by the distance from that point (Lu and Wong, 2008). The coordinate points of the five sample locations were converted into a shapefile in ArcGIS as a parameter layer, together with the score given for each parameter as data attributes.

IDW interpolation enabled the calculation of raster format data that covers every specific location on a map (Siska & Hung, 2001). However, standardisation was required to normalise the data using fuzzy logic, so that each had the same interval on a continuous scale between 0 to 1 (Malczewski, 2004, in Hizbaron et al., 2012). A criteria map was derived by combining parameter maps of each criterion through an overlay process using the Spatial Analyst Tool in ArcGIS, which weighs the value of each parameter in each criterion according to the AHP process (Habtemariam & Fang, 2016). The last calculation defined the scenario map that combines all criteria with different weight value compositions (Habtemariam & Fang, 2016). This process applied the same technique (IDW interpolation) as described previously and it resulted in three different final maps.

3 Results

Three zoning scenarios consist of various weights relating to each criterion assigned using the AHP tool **(Figure 3)**. The NVC criterion weight varies among zoning scenarios by 65.8% (read from 0.658, Figure 3) for a restricted access zone, 55.4% for a sanctuary zone and 50.8% for a habitat protection zone. These results demonstrate that the largest protected area has the largest NVC value, because it reveals which area is suitable for mangrove planting to support its function as green-belt area for crop protection. In contrast to this, the CMV weights were decreased from 21.3% in the habitat protection zone to 15% in the sanctuary zone and 7.5% in the restricted access zone. The expansion of the protected area would diminish the commercial value of mangroves, because fewer people would be able to visit the area for fishing, grazing or to set up aquaculture activities.

Interestingly, the NVC criterion had the largest value in all scenarios. If we look closely at the NVC's parameters, it consists of water quality, chlorophyll, and important value of mangrove, from which water quality weighed 74.2%. This result showed that water quality is the most essential element that support many activities in mangrove areas, such as fishing, aquaculture, mangrove planting and recreation.

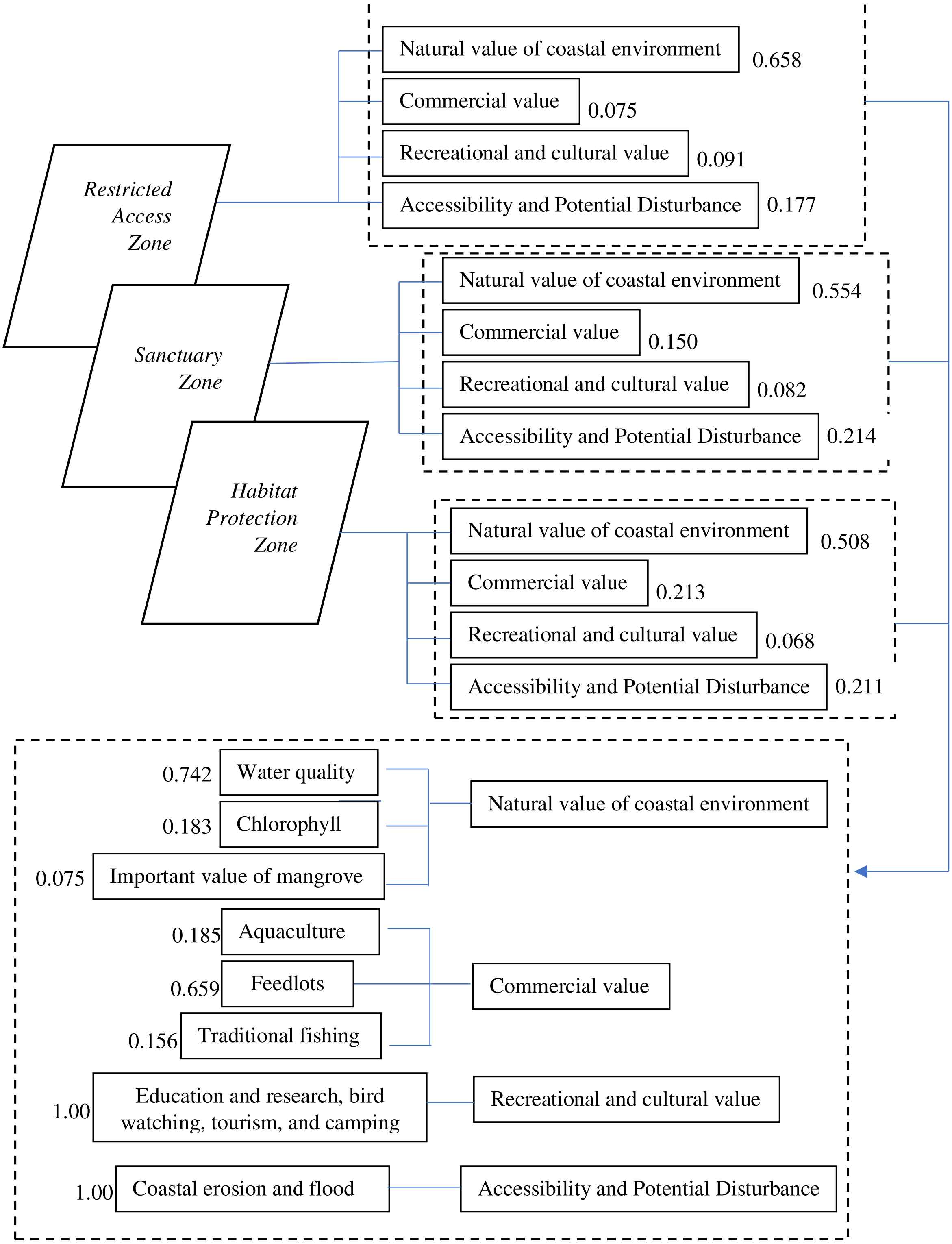
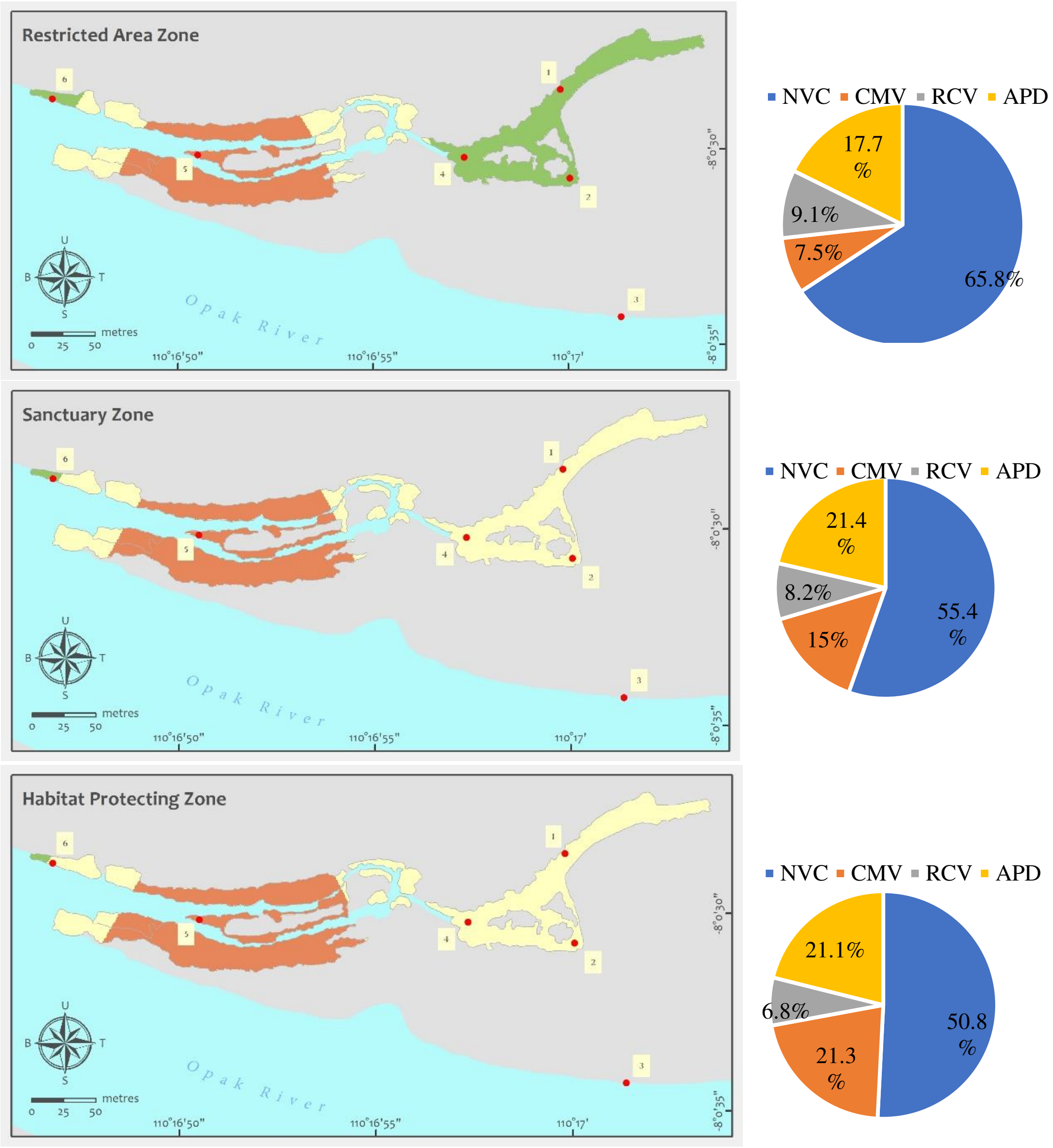
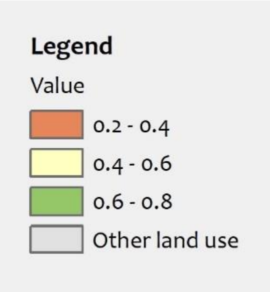


Figure 3. The summary of weights in each criterion and scenario in each conservation zone.

Geospatial interpretation of the spatial multi-criteria analysis results confirmed that each zoning scenario has a different management scheme based on criteria weights (**Figure 3**). We divided the suitability value into three categories. The lowest values represent areas that are suitable for utilisation, the middle value (ranging from 0.4 to 0.6) represents areas that may be used for both utilisation and protection. The highest values represent areas that are suitable for a protected area.

Both Sanctuary Zone and Habitat Protection Zone scenarios revealed results that were virtually similar (**Figure 4**), only the area suitable for utilisation in Habitat Protection Zone is bigger than in Sanctuary Zone. In all scenarios, we found that location 5 (middle area) was suitable for utilisation or commercial purposes, for instance, traditional fishing, aquaculture and feedlots. An alternative location was suitable for a buffer zone or an area that could support limited commercial purposes and encourage ecosystem protection, such as recreational and educational activities. These zones also displayed similar weight proportions with respect to the NVC, CMV, RCV and APD criteria. The Sanctuary Zone has a NVC of 55.4%. This is followed by APD (21.4%), RCV (8.2%) and CMV (15%), whereas the Habitat Protection Zone has a NVC (50.8%), followed by APD (21.1%), RCV (6.8%) and CMV (21.3%).





Values	Description
0.2 – 0.4	Suitable for utilisation
0.4 – 0.6	Moderate
0.6 – 0.8	Suitable for protected area

Figure 4. Map of Baros mangrove area under several scenarios, such as Restricted Area Zone, Sanctuary Zone and Habitat Protection Zone determined by its suitability value and proportion of criteria weight, such as the Natural Value of Coastal Environment (NVC), Commercial Value (CMV), Recreational and Cultural Value (RCV) and Accessibility and Potential Disturbance (APD).

The combination of the analysis in the three maps above shows a finalised map of the mangrove conservation zone (**Figure 5**), the middle area of the mangrove is suitable for commercial utilisation as Habitat Protection Zone (sample location 5), with the area outside it appropriate for recreational and educational purposes. The outer area of the mangrove is suitable for protection with nursery and planting areas. In the protected zone (read as Restricted Area Zone on the map), shows that sample locations 1, 2, 4 and 6 need to be protected. These areas are highly suitable to support mangrove nursery and planting, and function as a green-belt to protect farming areas. Mangrove nurseries can be located in dry areas far from the river/estuary. When the seedlings are ready, they can be transferred to a muddy substrate located on the edge of the river/estuary.

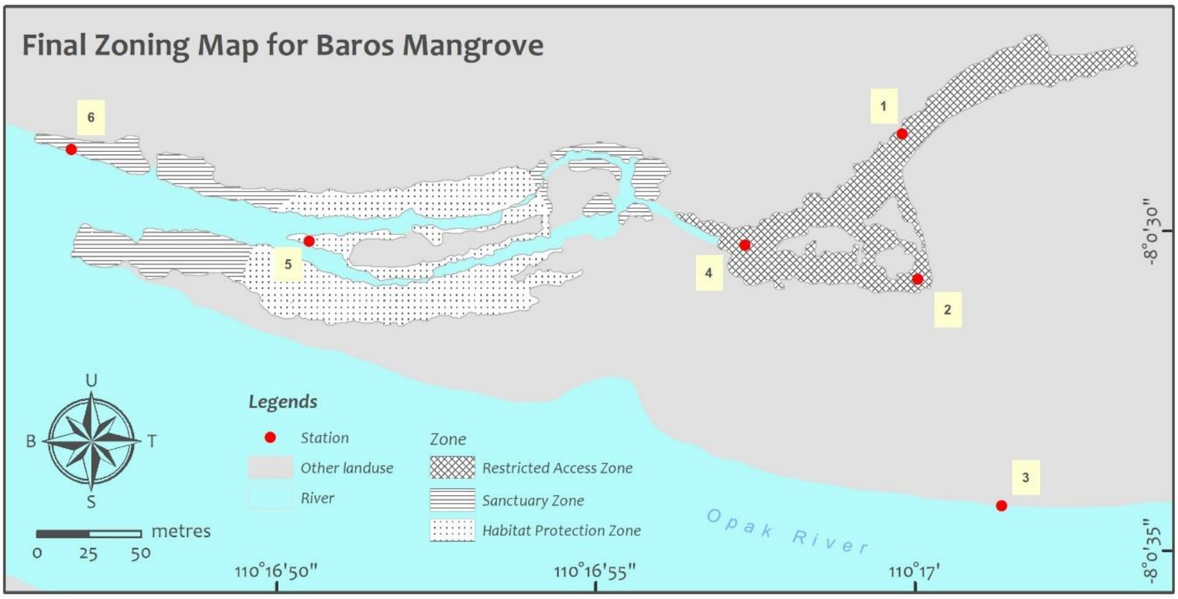


Figure 5. Proposed conservation zoning area for the Baros Mangrove.

4 Discussion

This paper presents how Spatial Multi-Criteria Analysis (SMCA) and the Analytic Hierarchy Process (AHP) can be applied for spatial planning in mangroves. A case study was conducted in the Baros mangrove area, Indonesia. The area has several specific characteristics, such as: (1) the mangrove ecosystem was established by the local community and later managed by the local government; (2) it provides both economic and ecological benefits to local people; and (3) it is used simultaneously for several activities related to commerce, recreation, and conservation. For spatial planning, we applied the SMCA method which allowed us to include both qualitative and quantitative data drawn from social, economic and ecological surveys. We were thus able to include local stakeholder values. The inclusion of local stakeholder values in conservation planning is critical to understand human influence on resources, examine multiple-use objectives and identify and resolve conflicts within the area (Pomeroy and Douvere, 2008). Spatial analysis that is supported by quantitative and qualitative data suggests that the management scenarios identified here should be well-understood by various stakeholders from various backgrounds, because they highlight which areas need to be protected or utilised. The outcomes of this study may also be suitable for future decision-making about management-related conservation for a particular area. It is imperative that effective decisions are made, with the aim of ensuring that conservation projects achieve good outcomes for both local community and environment. By examining the result of this study, we argue that the common approach to conservation zoning introduced through biosphere reserves may not be appropriate for certain ecosystems in specific areas due to their particular ecological or socioeconomic conditions.

The SMCA in this study follows the methods of several other case studies conducted by Habtemariam & Fang, (2016); Villa et al., (2002); Raaijmakers, Krywkow & van der Veen, (2008) and Strager & Rosenberger, (2006). SMCA is a proven approach to combine multi-criteria decision analysis and spatial analysis to achieve effective management decisions under several scenarios or options. The method supports decision-making in complex environments and combines both quantitative and qualitative data (Varatharajan et al., 2018). SMCA also has been widely used in intra-disciplinary studies, including land suitability for crops (Rahman and Saha, 2008); land-suitability for construction (Jamali et al., 2014); determining natural hazard susceptible areas (Karlsson et al., 2017); urban land-use planning (Mosadeghi et al., 2015) and for mangrove management such as mangrove vulnerability assessment (Omo-Irabor et all., 2011) which also include social and ecological data into its analysis. Most of the studies in SMCA were using various, quantitative and qualitative data into the analysis to create a detailed and specific goal either in management or conservation. Thus, a method in this study that uses SMCA and AHP tool with various data and assessment including socioeconomic can also be applied to any spatial planning for any purposes including conservation in mangrove area not only in Indonesia but also other parts of the world with similar environments.

The use of various data in conservation planning to support the decision-making process for future management is essential. Spatial analysis and planning also help to clarify the management objectives and reduce conflict by involving stakeholder perceptions and interests to support the analysis (Collie et al., 2013). In this study, we also included ecosystem services data by asking respondents what sort of benefits they obtain from the mangroves. Integrating ecosystem services data into spatial planning can reduce the trade-offs between ecological and socioeconomic aspects (Grêt-Regamey et al., 2017), thus, strengthening the analysis for future management options. Furthermore, the inclusion of socioeconomic value in this study also helps to provide reliable data and analysis. For example, the Baros mangrove area has a total feedlots value of US$1,458.23/ha/year (Supplementary data F) that is higher than fishing or aquaculture economic value. Thus, under CMV criterion, feedlots has the highest weight among all parameters. Our study revealed that the use of various quantitative and qualitative ecological and socioeconomic data is vital and will better support local conservation management planning and decision-making.

Using the AHP tool in SMCA has a potential drawback, because AHP is not capable to address uncertainty inherent to the social data (such as individual perceptions in the community and expert's perception). Although we have calculated the Consistency Ratio (CR) to ensure that we had a reliable judgement, we need a sensitivity analysis included in the process of assigning weights in AHP. Thus, we recommend including matrix sensitivity or weight sensitivity (Chen et al., 2010; 2013) for future studies using AHP tool in SMCA. In this case, we need to emphasise that although the final result of this study has proposed what we believe to be an ideal mangrove conservation zone, it is important to validate the result with all stakeholders (local community, manager and local government) before any action can be taken to avoid disagreement and conflict in the future.

Biosphere reserves, with the concept of spatial zoning for conservation, were introduced by UNESCO (1996). These reserves have a core zone (non-take zone) surrounded by a buffer zone, where low-impact human activities are possible. Beyond the buffer zone is an outer area, known as a transition zone, that allows medium-impact activities, such as small-scale farming and selective fishing (Coetzer et al., 2014). This concept is used for protected areas around the globe, where managers plan for a non-take zone protected by a buffer and transition zone, supposedly to enable resource accumulation in the core with spill-over into the buffer or transition zones and to build cooperation between human and conservation where both activities are possible (Jaisankar et al., 2018).

In contrast, this case study discovered the opposite. The outer area is suitable for a protected area and the middle is most suited to commercial activity (**Figure 5**). Mangrove nurseries must be protected from anthropogenic disturbance, for instance, waste, destructive human activities and are frequently located in areas far from the river/estuary. In this study, the area that would be identified as a buffer zone following the UNESCO approach would be more suited to be a core habitat because the area is essential for the survival and preservation of biological diversity (Semlitsch et al., 2001). Similar to this, the conservation zone in Matang Mangrove Forest also showed that most of restricted and protected area are at the outer zone, whereas all productive zone (cultivation zone) located in the centre area of the mangrove (Otero et al., 2019). In additional, landward buffer zones need to be placed to maintain mangrove development (Harty, 2004) and all human settlement needs to locate at least >10 km from the outer mangrove zone (Vaghela et al., 2018). These discoveries make zoning for mangrove conservation potentially different to what is used for other ecosystems or other local contexts. Thus, further studies on spatial conservation zoning in mangrove forests are crucial.

5 General Implications

Mangrove ecosystems are unique as they are located at the interface of estuaries, the sea, and land ecosystems. A study involving a mangrove suitability index showed that most mangroves can only survive with muddy substrate (Chakraborty et al., 2019). Furthermore, the juvenile of mangrove trees needs to be protected from the strong waves while receiving a brackish water from river and sea. Thus, mangrove conservation planning can be hard if not supported by multi-disciplinary knowledge that involves ecology and social aspects, including stakeholder perceptions and local understanding on mangrove socio-cultural and economic dimensions (Borges et al., 2017).

In this study, we plan a multi-use zoning plan for mangroves in Baros. We believe that our approach could be applied elsewhere, particularly for areas with heterogeneously distributed mangroves. The Baros mangrove area is approximately 5-hectare large and has been benefiting locals by providing shelter for fish, blocking salty wind onto croplands, providing space for shrimp aquaculture, and providing a natural venue for tourism. The extent of ecosystem services provided by mangroves and the size of mangrove area in different places might require different approaches depending on the services presence (e.g. firewood availability in larger mangroves (Christensen et al., 2008) that was not considered for Baros) and the preferences of the community. These different considerations are particularly relevant for old-growth mangrove forests, where sustainable management requires considering the biodiversity and socio-economic value of old versus restored mangroves, accessibility, and wider ecosystem impacts beyond the local scope that we discuss here. Yet, considering multiple factors, including social, cultural, ecological and community values, and their spatial context, will always be a crucial component of mangrove management.

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