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Sustainability Strategy for Mangrove and Crab Conservation in Tarakan, Indonesia: A Social-Ecological System Approach

Yulma[1,2*], Asihing Kustanti[3], Soemarno[4], Mohammad Mahmudi[5]

[1] Postgraduate Program, Faculty of Agriculture, Universitas Brawijaya, 65145 Malang, Indonesia
[2] Aquatic Resources Management, Faculty of Fisheries and Marine Science, Borneo Tarakan University, 77115 Tarakan, Indonesia
[3] Department of Socio-Economic, Faculty of Agriculture, Brawijaya University, 65145 Malang, Indonesia
[4] Soil Department, Faculty of Agriculture, Brawijaya University, 65145 Malang, Indonesia
[5] Aquatic Resource Management, Faculty of Fisheries and Marine Science, Brawijaya University, 65145 Malang, Indonesia

* Correspondence: Yulma (yulma.yuki@gmail.com)

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Abstract: Management of the Mangrove and Crab Conservation Area (KKMK) has not been optimal, making it vulnerable to damage. A Social-Ecological System (SES) approach is needed to understand the linkages between community dynamics, governance, and mangrove ecology. This research aims to provide recommendations for mangrove ecosystem sustainability strategies using the SES approach. Data and information came from primary data (surveys and interviews) and secondary data (agencies and previous research). Management strategies in KKMK refer to the key variables of SES, which are then further analyzed using Participatory Prospective Analysis (PPA). The strategy for RS-RG connectivity is to conduct regular data collection related to mangrove ecology. The strategy for RS-RA is to supervise the use of mangrove resources. The strategy for RS-RU is to carry out rehabilitation to increase density and species diversity. The strategy for RU-RA is to limit the capture of mangrove crabs to maintain the population in nature. The strategy for RU-RG is to increase supervision and create new policies that align with the conditions in KKMK. The strategy for RA-RG is to provide socialization to RA on the importance of preserving mangroves and take firm action against perpetrators of mangrove ecosystem destruction.

Keywords: Mangrove; Conservation; SES; PPA; Sustainability strategy; Coastal management; Stakeholder engagement

1 Introduction

Coastal communities have strong social-ecological interactions with mangrove ecosystems and are, therefore, highly dependent on the ecosystem services provided by mangroves. Mangrove ecosystems provide important habitats for a variety of organisms as well as nurseries for fish and crustaceans and are, therefore, critical in supporting fisheries production and the livelihoods of coastal communities. Communities have long utilized mangrove ecosystems for traditional medicine, fishing, collection of forest products, and recreational activities that illustrate the cultural and economic values developed over generations. Socially, mangrove ecosystems are closely linked to communities' cultural practices and knowledge, further strengthening the relationship between communities and their environment.

The great potential of mangrove ecosystems makes them vulnerable to damage caused by human activities and the environment. The loss of mangrove biodiversity not only reduces the number of flora and fauna but also affects the livelihoods of fishermen and coastal communities. Furthermore, the loss of mangrove ecosystems can increase the vulnerability of coastal areas to flooding and coastal erosion as well as increase the frequency of extreme weather events such as storms and tsunamis. One of the mangrove forests that has experienced degradation and land use change is the Mangrove and Crab Conservation Area (KKMK). This area has experienced logging and land use change into shrimp and milkfish farming areas and then converted to residential areas. Logging of mangrove forests due to urbanization not only reduces the physical extent of mangroves but also exacerbates the ecological pressures

that mangrove ecosystems receive. Damage to KKMK's mangrove ecosystem can be minimized with proper and sustainable management based on the Social-Ecological System (SES). SES analysis can describe interactions and connectivity so that it can be used in mangrove ecosystem management [1]. This management aims to overcome mangrove degradation and rehabilitate while empowering stakeholders to participate in policy-making. The purpose of this research is to formulate a strategy for the sustainability of KKMK mangrove ecosystem management through a social-ecological approach.

2 Methods

2.1 Research Location

The research site was in the Mangrove and Crab Conservation Area (KKMK) of Tarakan City, North Kalimantan Province (Figure 1). Geographically, KKMK is located at 3°29' 65.33' North Latitude and between 117°61' 06.30' East Longitude. The research site is directly adjacent to the Pamusian River to the south, Rusunawa and Tenguyun Market to the north, PT Idec Abadi Wood Industries to the east and soka crab farming ponds to the west. KKMK was designated as a conservation area based on Local Regulation No. 04 of 2002 with an area of about 35 ha, but only 25 ha remains.

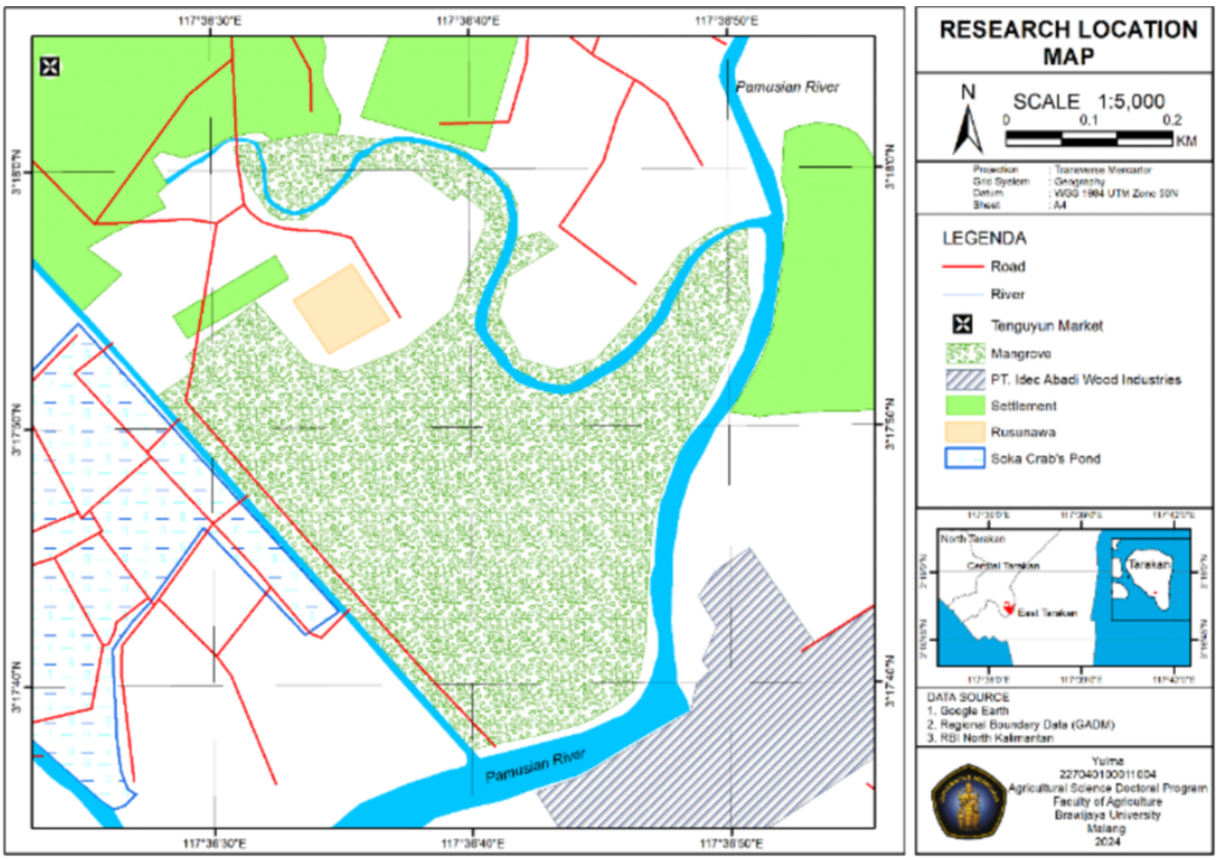

Figure 1. Research location

2.2 Social-Ecological System (SES) Mangrove KKMK

Mangrove Social-Ecological System (SES) describes the interaction between mangrove ecosystems and coastal social systems. SES consists of four components, namely, Resources System (RS), Resources Unit (RS), Resources Actors (RA), and Resources Governance (RG) [1]. Interactions and connectivity between SES components were analyzed using RStudio software. Each component consists of variables that describe SES in the KKMK mangrove ecosystem, namely RS (mangrove ecosystem, density, diversity, water quality parameters, and substrate), RU (plankton, fish, crab, Avicennia & Rhizophora, Nipah, bridges and buildings), RA (fishing gear, Bubu, net, fishing line, community, fishermen (fish and crab fishermen)), and RG (Tarakan City Government, Environment Agency (DLH), Ministry of Agrarian Affairs and Spatial Planning/National Land Agency of Tarakan City (ATR/BPN), Public Works and Spatial Planning Office (PUPR), Public Housing and Settlement Areas and Land Office, Tarakan City Resort Police, Pertamina, State Electricity Company (PLN), Tarakan City Fish Quarantine and Quality Control Centre (BPKIM), report, regulation, Regional Spatial Plan (RTRW).

2.3 Data Collection and Analysis

This study used a purposive sampling technique based on the respondents' level of understanding of mangrove management and utilization in KKMK. Respondents used in this study, consisting of: community leaders as many as five people, fishing groups as many as eleven people, and stakeholders as many as nine people. Information data collection for each variable in the four SES components used primary and secondary data. Primary data was obtained by conducting surveys to KKMK and interviews using questionnaires while secondary data was obtained from related agencies and previous research results.

Mangrove ecosystem management strategies in KKMK refer to the key variables obtained from the SES, which are further analyzed using Participatory Prospective Analysis (PPA). This analysis was used to develop a diagram of stakeholder involvement in determining the key factors of mangrove ecosystem management in KKMK. PPA analysis has several stages, according to the study [2] in Figure 2.

Further management strategy analyses were conducted on the interaction of each SES component with a positive sign (+) if management and results are directly proportional and a negative sign (-) if management and results are inversely proportional. Management strategies can be implemented by analyzing the relationship between each component.

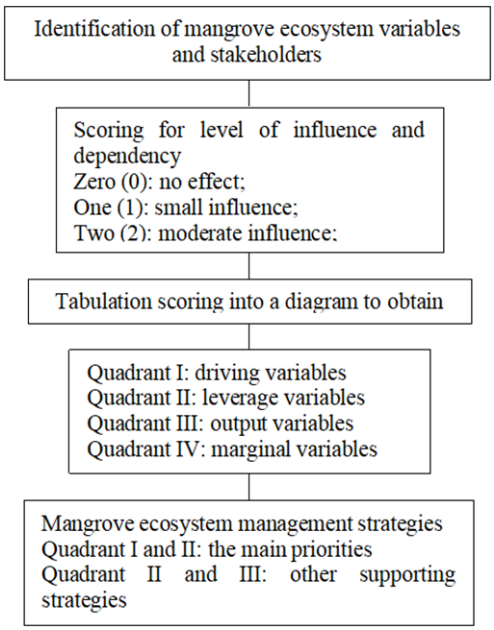

Figure 2. Stages of the PPA analysis

3 Results and Discussion

3.1 Identification of SES Components in KKMK

3.1.1 Resource System (RS)

RS is an exogenous force or driver of changes in circumstances for Resource Actors (RA). Mangrove ecosystems have an essential role in the SES framework, making mangroves a vital resource in the SES. The existence of mangrove resources in KKMK is influenced by density, diversity, water quality and substrate. A dense and diverse mangrove community structure is more resistant to disturbance and can increase the overall productivity of the mangrove ecosystem. The substrate of the mangrove ecosystem in KKMK is dominated by clay loam and sandy clay loam [3], where this type of substrate is still favorable for mangrove growth in KKMK. This is under research conducted by Putri et al. [4] that mangroves in West Kalimantan grow well on dusty clay loam and sandy loam substrates with salinity and pH conditions that support their growth.

3.1.2 Resource Unit (RU)

RU refers to the specific components of the RS used by the Resource Actor (RA) within the governance framework. The RU of mangroves in KKMK consists of phytoplankton, fish, crabs, Avicennia & Rhizophora, Nipah, bridges, and buildings. Phytoplankton plays an important role in mangrove ecosystems not only as a determinant of aquatic productivity but also as an ecological indicator. High mangrove density is positively related to the abundance of fish and other biota, where sustainable mangroves can increase fishermen's catch. If mangrove forest degradation occurs, it can cause a decrease in phytoplankton diversity and abundance, indicating a loss of ecosystem functionality.

Mangrove forest degradation can lead to a decrease in phytoplankton diversity and abundance, indicating a loss of ecosystem functionality [5]. The dominant mangrove species in KKMK is Rhizophora mucronata, which is closely related to the presence of mangrove crabs. Mangrove crabs (Scylla serrata) show a preference for mangrove forests dominated by Rhizophora, where there is a strong relationship between mangrove crab species and mangrove structural complexity [6].

3.1.3 Resource Actor (RA)

RA is defined as an individual or group that utilizes, manages or influences the use of a Resource Unit (RU) in a Resource System (RS) and is an integral part of the Resource Governance (RG) of this system. RA in KKMK consists of fishing gear (Bubu, net, and fishing line), the community, and fishermen (fish and crab fishermen). People living in KKMK work as pond keepers, furniture makers, loggers, taxi drivers, freelancers, boat builders, and mangrove crab fishermen. They purchased mangrove land plots from the 'Baya Damo Laid' fishermen group without receiving an official land ownership certificate, only purchase receipts. Purchasing and trading mangrove land plots is evidence of community non-compliance with existing regulations, even though they are needed to protect critical lands such as mangroves. In addition, many transactions are carried out without official documents, causing legal problems in the future. Mangrove forests are often viewed as unproductive land that can easily be converted to agriculture or housing [7]. This indicates a lack of understanding of the ecological and social value of mangroves.

3.1.4 Resource Governance (RG)

RG is a system that has the authority to regulate RS conditions and determine actions in ongoing situations. The parties involved in mangrove resource governance in KKMK are Tarakan City Government, Environment Agency (DLH), Ministry of Agrarian Affairs and Spatial Planning/National Land Agency of Tarakan City (ATR/BPN), Public Works and Spatial Planning Office (PUPR), Public Housing and Settlement Areas and Land Office, Tarakan City Resort Police, Pertamina, State Electricity Company (PLN), Tarakan City Fish Quarantine and Quality Control Centre (BPKIM), while the output of these parties is in the form of Report, Regulation, Regional Spatial Plan (RTRW). The complexity of mangrove ecosystems in tidal areas requires coordinated governance across marine and terrestrial areas. Conceptual models are needed to describe the connectivity of functional relationships within mangrove ecosystems, emphasizing the need for a Social-Ecological System approach to governance. Efforts in engaging multiple stakeholders for natural resource management contribute to better policies and increase acceptance of conservation measures from various parties. Understanding the relationship between Resource System, Resource Governance, and stakeholders in the context of crab fisheries to align management strategies with local needs and ecological conditions [8]. In addition, the governance framework must be adaptable to the unique socio-economic context of the mangrove area. The negative correlation between community practices and resource sustainability suggests a gap that the government must address through policy [9].

3.2 SES Connectivity in KKMK

The social-ecological components of mangrove ecosystems are interrelated, influencing one another. The relationship between components forms a connectivity system that creates a reciprocal process between components. Connectivity occurs between RS and RG; namely, RG is a party that has the authority and power to issue policies in mangrove ecosystem management, which acts as an RS. This policy is needed by the RS so that the ecosystem remains sustainable and well-maintained, and existing uses can be sustainable without damaging the ecosystem. The RG authorized to manage the KKMK mangrove ecosystem is the Tarakan City Government. Meanwhile, PUPR plays a role in preserving the KKMK mangrove ecosystem by including KKMK in the medium- and long-term RTRW. RS consists of ecological conditions and ecosystem management aspects that have an important role in maintaining RU, which can then be utilized or used by RA [10]. Governance in mangrove ecosystem management must consider community needs, ecology, and economic incentives as fundamental components to ensure the resilience and health of this ecosystem [1]. Failure to address SES dynamics can lead to resource depletion caused by ineffective governance [11].

The RS component and RU have very close connectivity between components. The condition of the RS affects the catch of fish and mangrove crabs, thus determining the income level of fishermen. The abundance of fishermen's catches in the form of fish and mud crabs greatly affects the income of fishermen. However, crab fishing by fishermen in KKMK also has a negative impact on the mangrove crab population. For example, in China, there is a high consumer demand for mud crabs, which has increased fishing pressure and led to unsustainable practices and subsequent population declines [12]. In addition, there are negative interactions in the utilization of mangroves by the community, which uses wood from Avicennia & Rhizophora as bridges and buildings, and Nipah for making brooms. Avicennia wood is renowned for its durability and resistance to decay when exposed to the marine environment. Furthermore, Rhizophora wood has density and mechanical properties that make it suitable for load-bearing applications in bridge construction and other infrastructure development [13].

The connectivity that occurs between RU and RA is RA as a user of RU. Fish and mangrove crabs found around the mangrove ecosystem are important commodities for fishermen. Fishing activities carried out by fishermen using bubu, nets, and fishing rods will affect the catch. Community activities and low awareness of the importance of mangrove ecosystems adversely affect the balance of coastal ecosystems and disrupt the sustainability of mangroves. Community activities such as land conversion for aquaculture and settlement can cause serious damage to mangrove forests that serve as shoreline protection and habitat for a variety of marine species [14]. Catches on the coast of Bali Island have fluctuated, with 60% of fishers reporting their catches declining due to mangrove habitat destruction [15]. This can lead to conflict and requires the involvement of the RG in providing solutions. The connectivity between RG and RA is that RG can generate policies that regulate all forms of RA activities in the utilization process. RG has the authority to impose sanctions on community behavior that damages mangrove ecosystems. Overlapping government policies and lax law enforcement as significant barriers to effective mangrove protection [16]. Collaboration between government, law enforcement, and communities is essential to ensure compliance with rules and minimize violations in mangrove ecosystem management [17]. Furthermore, cooperation between law enforcement agencies and communities can increase the effectiveness of environmental law enforcement.

The connectivity between RG and RU is that RG supervises mangrove utilization activities. For example, KKMK supervision is carried out by DLH and Public Housing and Settlement Areas and Land Office by making violation reports to the Tarakan Police. Pertamina, PLN and BPKIM carry out conservation efforts to preserve flora and fauna in KKMK by planting mangroves and releasing mangrove crab seeds (Scylla serrata). The success of the RU can also be an indicator of the success of the program established by the RG. Effective mangrove forest management can influence the growth and production of crab populations. Conversely, mangrove degradation results in habitat loss and environmental degradation, causing mangrove crab populations to decline [18].

3.3 Mangrove Ecosystem Management Factors KKMK

Table 1. The value of the degree of dependence and influence of each component

No.	Variables	Dependency	Influence
1	Mangrove Ecosystem	1.4	2.0
2	Mangrove density	2.0	2.2
3	Avicennia & Rhizophora	1.9	1.6
4	Bridges and buildings	1.1	1.1
5	Crab	1.5	1.1
6	Fish	0.5	0.4
7	Community	1.9	1.8
8	Crab fishermen	0.3	0.3
9	Regulation	1.7	2.0
10	Report	1.6	1.5
11	Tarakan City Government	1.6	1.7

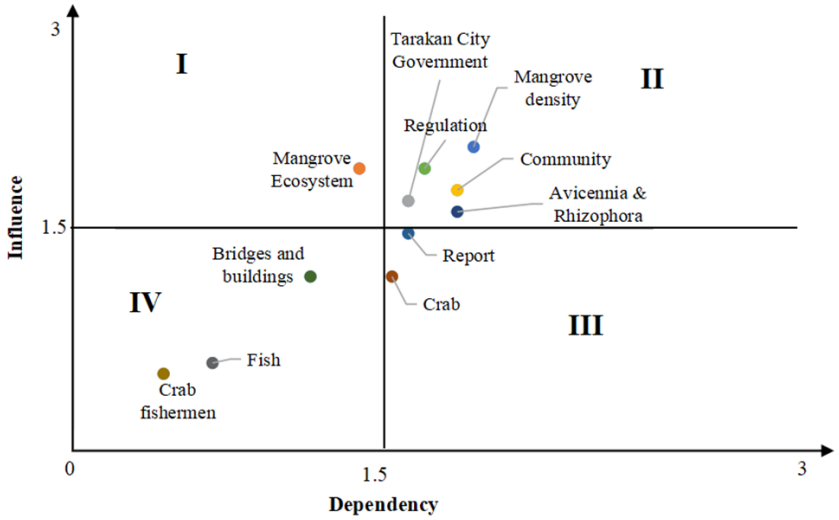

Figure 3. KKMK mangrove management PPA analysis results

KKMK mangrove ecosystem management variables were determined based on key variables from SES and field observations, so eleven variables were selected and then processed using PPA analysis. The variables were selected by adjusting the SES components, RS consists of two variables, namely mangrove ecosystem and mangrove density, RU consists of four variables, namely Avicennia & Rhizopora, bridges & buildings, crabs, and fish; RA consists of two variables, namely community and crab fishermen, and RG consists of three variables namely regulations, reports and Tarakan City Government. The results of the PPA analysis illustrate the level of dependency and influence exerted by the components of mangrove ecosystem management factors in mangrove ecosystem management activities in KKMK (Table 1).

The management factor components of the SES variables were then grouped into four quadrants (Figure 3).

Quadrant I is a determinant of mangrove ecosystem management in KKMK, where variables located in Quadrant I play an important role in the successful management of KKMK.

In quadrant I, one of the eleven variables, the mangrove ecosystem, is analyzed. Mangrove ecosystems function as natural habitats that support the life of aquatic organisms, spawning grounds for fish and shelter for various biota [19].

Variables in quadrant II are connecting factors consisting of mangrove density, regulation, community, Tarakan City Government and Avicennia & Rhizopora. These variables describe mangrove ecosystem management by emphasizing the linkages of ecological health, community and governance frameworks. Interactive governance can encourage local community involvement in the decision-making process, thereby increasing the adaptability and resilience of mangrove management systems in the face of changing environmental conditions [1].

Table 2. The value of the degree of dependence and influence of each component

No.	Connectivity	Sign	Strategy
1	Resources System - Resources Governance	(+)(+)	• Regular data collection related to mangrove ecology (monthly or quarterly), including mangrove area, density, diversity and water quality. • Enforcement and application of regulations made by RG by conducting regular patrols (monthly or quarterly).
2	Resources System - Resources Actors	(+)(-)	• Regular supervision (monthly or quarterly) by various RG agencies (Tarakan City Government, DLH, Perkim and Tarakan Police) related to mangrove resource utilization and the community in monitoring mangrove crab fishing. • Installing signs/signs prohibiting activities around the mangrove area. • Prohibition of logging and utilization of mangrove wood for building construction.
3	Resources System - Resources Unit	(+)(+)	• Conduct rehabilitation to increase the density and diversity of mangrove species to increase water productivity. • Conduct replanting, monitoring and evaluation related to rehabilitation activities that have been carried out.
4	Resources Unit - Resources Actors	(+)(-)	• Socialization to the community regarding the capture and sustainable use of mangroves by conducting counselling by field officers. • Restrictions on mangrove crab fishing to maintain populations in the wild: a. Referring to PERMEN-KP No. 1 Year 2015, the minimum size that can be caught is a carapace length of 15 cm. b. Mangrove crab weight must be at least 100g. c. Restrictions on catching female crabs entering Ovarian Maturity Level (TKO) II, III and IV.
5	Resources Unit - Resources Governance	(+)(+)	• RG needs to increase direct supervision of mangrove and crab conservation sustainability programs by providing field officers or extension workers. • RG can create new policies that align with conditions in the field so that resource sustainability is maintained.
6	Resources Actors - Resources Governance	(-)(-)	• Socialization to RA related to mangrove conservation area regulations by conducting counselling, training and installing attributes around KKMK. • Increase public awareness of mangrove ecosystems by including mangrove curriculum in learning at the elementary school to college level. • Providing reprimands and sanctions to RA who have destroyed mangrove ecosystems following Law No. 32 of 2009 concerning Environmental Protection and Management. • RG needs to provide socialization and training related to mangrove crab cultivation to crab fishermen and the community.

Variables in quadrant III are dependent factors that are highly dependent and have little influence, namely reports and crabs. Variables in quadrant III include outputs in mangrove ecosystem management that reflect the success of mangrove ecosystem management strategies in KKMK. Successful restoration activities correlate with increased biodiversity of flora and fauna, provided that restoration follows ecological guidelines [20].

Quadrant IV consists of three variables that have a low or small level of influence and dependence on the management of the KKMK mangrove ecosystem so that these variables can be removed or ignored. Variables in quadrant IV are categorized as independent variables, namely bridges & buildings, fish and crab fishermen. Although the presence of fish and crab fishermen does not have a major effect on the management of KKMK mangrove ecosystems, the profession of fish and crab fishermen can be an alternative additional livelihood so as to increase income and community welfare. Successful mangrove management models can integrate economic benefits, showing that community involvement can lead to sustainable sources of income [21].

3.4 KKMK Mangrove Ecosystem Management Sustainability Strategy

Variables located in quadrants I and II are selected in the sustainability of KKMK mangrove ecosystem management. Thus, six variables can be selected as the most influential variables on the system, namely mangrove ecosystem, mangrove density, Avicennia & Rhizopora, community, regulation and Tarakan City Government. These variables are a mixture of ecological, social and economic components that are important for the preservation and sustainability of the KKMK mangrove ecosystem. Mangrove ecological stability is strongly influenced by various factors such as mangrove density, diversity, and environmental conditions where mangroves grow. Furthermore, the community can utilize the economic value of mangroves as a source of income while maintaining the preservation and sustainability of this mangrove ecosystem.

KMK is based on Presidential Regulation No.73 of 2012 concerning the national strategy for mangrove ecosystem management with the aim of synergizing mangrove ecosystem management policies and programs covering ecological, socio-economic, institutional, and legislative fields to ensure the functions and benefits of mangrove ecosystems in a sustainable manner for the welfare of the community. In addition, the draft management strategy also considers connectivity between components of the Social-Ecological System and analyses management factors (Table 2).

4 Conclusion

The results of the PPA analysis showed there are eleven key variables in determining the KKMK mangrove sustainability strategy, namely mangrove ecosystem and mangrove density, Avicennia & Rhizopora, bridges & buildings, crabs, fish, communities and crab fishermen, regulations, reports and Tarakan City Government. The strategy for RS-RG connectivity is to conduct regular data collection related to mangrove ecology and enforcement and application of regulations made by RG. The strategy for RS-RA connectivity is to conduct strict supervision in the utilization of mangrove resources by installing signs/signs prohibiting activities around the mangrove area and prohibiting logging and utilization of mangrove wood. The strategy for RS-RU connectivity is to carry out rehabilitation to increase the density and diversity of mangrove species with the aim of increasing water productivity. The strategy for RU-RA connectivity is to provide socialization to RA regarding mangrove conservation area regulations and restrictions on mangrove crab fishing to maintain populations in nature. The strategy for RU-RG connectivity is that RG needs to increase direct supervision in mangrove and crab conservation sustainability programs and RG can make new policies that are in accordance with conditions in the field so that resource sustainability is maintained. The strategy for RA-RG connectivity is to provide socialization to RA regarding the importance of preserving mangroves, giving warnings and sanctions to RA who have destroyed mangrove ecosystems and RG needs to provide training related to mangrove crab cultivation to crab fishermen and communities.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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