A Social-ecological Network Analysis for Understanding Small-scale Fisheries Management in Sukabumi Coastal, West Java Province, Indonesia

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Abstract. In Sukabumi Regency, West Java Province, fishing is dominated by small-scale fishers who rely on it for their livelihoods. Environmental changes affect fishing activities, leading to unstable incomes and broader socio-economic impacts. Managing small-scale fisheries is challenging due to the complex social, economic, and ecological contexts. As social-ecological systems (SES), small-scale fisheries require management that considers the resource system, its units, and the actors depending on them. Understanding the interdependent relationships within these systems is crucial. This study analyzes the social-ecological system (SES) of small-scale fisheries in the Sukabumi Coastal area using Social-Ecological Network Analysis (SENA). The analysis identifies key variables that influence the network : Regulations, Landing Spot, Coastal Area, and National Government. The results reveal a synergy between the resource system (RS), resource unit (RU), resource actor (RA), and resource governance (RG), which is essential for creating optimal and sustainable management of small-scale fisheries in Sukabumi Coastal, West Java Province.

1 Introduction

Small-scale fisheries in developing countries play an important role as a livelihood for most fishers, unlike the developed countries that look at small-scale fisheries from a business scale perspective. Small-scale fisheries contribute half the global catch, employing more than 90 percent of the world's fishers and fishing workers [1]. Thus, aquatic ecosystems are fundamental to the livelihoods of small-scale fishers in nutrition and food sustainability, poverty alleviation, improved well-being, and sustainable use of resources [1-2]. However, on the other hand, small-scale fishers are increasingly marginalized due to low earnings and

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restrictions on political, economic, social, and cultural rights. The fishing activities in Indonesia are dominated by fishers who use traditional fleets known as small-scale fisheries. Small-scale fishing activities dominate fishing activities in Indonesia, which makes up around 95 percent of Indonesia's fishing sector.

Figure 1 shows that in 2024, the number of fishers in Sukabumi Regency reached 10,403 people, which is an increase of 3.58 percent from 2023. Over the past 7 years, the number of fishers in Sukabumi Regency has increased by 13% [3]. More than 80% of fishers in Sukabumi Regency are small-scale fishers, possessing vessels smaller than 10GT. Sukabumi Regency is the second largest regency on the island of Java, with an area of 4,182 km², 40% of which borders the ocean. This causes the fisheries sector to be the main livelihood for most of the community [4].
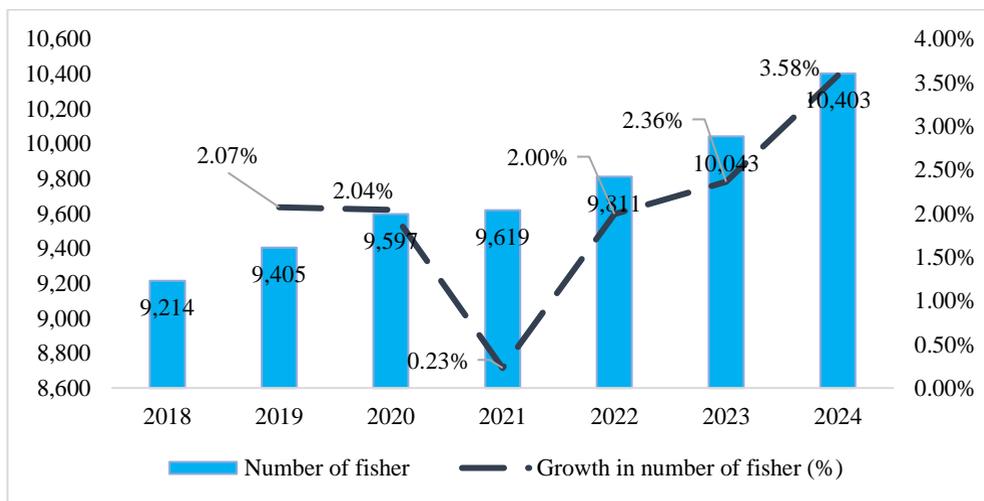

Fig. 1. Number and growth of small-scale fisher in Sukabumi Regency, West Java Province, 2018 – 2022 [4].

The dependency of fishers' households on catch yields shows that the dependence of fishers' livelihood on natural conditions (i.e. climate change) is very high. In Sukabumi, West Java Province, the climate change conditions have been characterized by several trends and impacts. The coastal of Sukabumi Regency has experienced rising sea surface temperatures over the past decades [5]. This trend is consistent with global warming patterns and has been associated with increased frequency of heatwaves. Changes in rainfall patterns have been observed, including more intense and irregular precipitation [6]. This has led to an increase in the frequency and severity of both droughts and flooding events. The rainy season has become less predictable, which has significant implications for capture fisheries. Sea level rise is contributing to coastal erosion, increased salinity of groundwater, and greater risk of storm surges, affecting communities and ecosystems along the coast [7].

The most prominent environmental changes linked to climate change were distribution range shifts of fish and other marine species, changes in fish abundance or productivity of fish stocks, an increased occurrence of newly immigrated species, and the factor which was attributed as the main cause of these changes, ocean warming. This condition can trigger vulnerabilities to fishers's livelihoods both socially and economically [8-9]. On the economic side, fishers's households will face uncertainty about catch, price volatility, and income instability. Rising sea surface temperatures can alter fish distribution and behavior, affecting fish availability [10]. Moreover, fluctuations in fish availability can lead to price volatility, further impacting incomes. Fluctuations in fish catch lead to unstable incomes for small-scale fishers, making it difficult to plan for the future and invest in better equipment or education.

Besides, fishing communities often lack access to alternative livelihoods, making them more vulnerable to the impacts of climate change.

Small-scale fisheries management is crucial to achieving food sustainability, poverty eradication, sustainable livelihoods, social stability, and economic growth. Governments must be able to support the sustainability of small-scale fisheries through inclusive, non-discriminatory, and economical policies in the exploitation of marine and coastal areas so that small fishers get a good return on their work, and promote sustainable conservation and management of natural resources. Small-scale fisheries must pursue fishing practices that minimize damage to the aquatic environment and associated species and promote the sustainability of such resources.

Ecological systems in coastal areas are closely related to/and influenced by one or more social systems. This approach is known as the Social-Ecological System (SES) for coastal and ocean areas. The contemporary approach to social-ecological-based coastal and ocean management is an integration between ecological understanding and socio-economic value. The objective of socio-ecological-based coastal and marine management is to maintain the sustainability and integrity of the ecosystem so that at the same time it can ensure the sustainability of the supply of resources for the socio-economic interests of humans.

Social-ecological systems (SES) analysis in integrated coastal area management provides an interdisciplinary approach and framework for sustainable resource management. In this study, SES is developed as a framework to find out how small-scale fisheries are managed in Sukabumi coastal fisheries, West Java Province, which is expected to be a knowledge base to systematically address complex issues in integrated coastal and marine management. SES develops a knowledge-based strategy in studying ecological and social processes at various dimensions and scales of the system, from local to global.

2 Material and methods

2.1 Site selection

The research site is located in the coastal area of Sukabumi, which consists of 9 Districts (Figure 2). The population in the coastal areas of Sukabumi in 2024 is 2.802.404 people, with population growth over the past 5 years of 3.33% [4]. The number of fishers in 2024 is 10.403 total fishers, which above 80% of the fishers whose main livelihood is as small-scale fishers. The coastal area of Sukabumi has the potential to be utilized for capture fisheries, aquaculture, and tourism. The Integrated Coastal and Conservation Areas are included in the Development Area in Regional Medium-Term Development Plan (RPJMD) 2024 of Sukabumi Regency in the concept of utilizing economic areas. The priorities in this development area are 1) the development of an international standard tourism industry along the coast, and 2) improving the quality of human resources for tourism and fisheries. With the direction of policy that focuses on tourism, it will have an impact on capture fisheries and aquaculture. This perspective is assumed to bring changes to the fisheries system in the coastal area of Sukabumi, both ecologically and socially. This indicates a threat to the environment, resources, and the lives of the surrounding community, both directly and indirectly. The small-scale fisheries ecosystem in this area can be understood from the perspective of the social-ecological system.
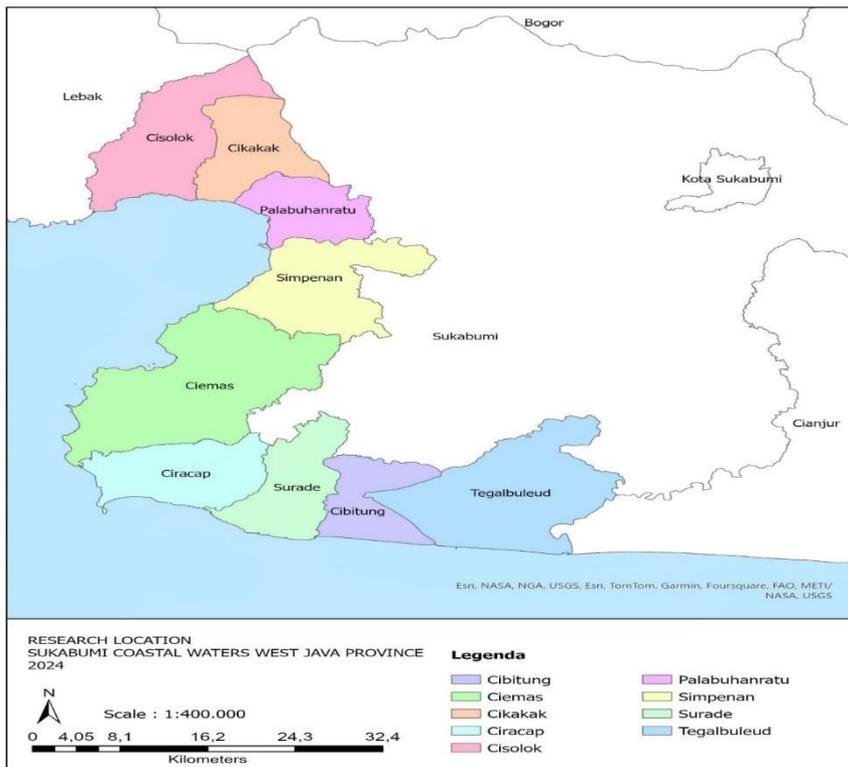
Fig. 2. Research location in the coastal area of Sukabumi Regency, West Java, Indonesia.

2.2 Data collection

The data in this study consists of primary and secondary data. Primary data were obtained through direct observation and in-depth interviews using structured questionnaires with the respondents. The respondents interviewed are listed in Table 1. These respondents are considered representative to meet the information and data needs. The respondents were selected using purposive sampling, ensuring representation from stakeholders involved in the activities and management of fisheries in coastal of Sukabumi Regency, West Java Province. Secondary data were obtained from regional statistical books from the Department Fisheries of Sukabumi Regency and West Java Province, as well as related books or scientific journals.

Table 1. Interview in research.

No	Institutions	Representative	Numbers of interviewee
1	Department of Marine Affairs and Fisheries of West Java Province	Government	1
2	Department of Fisheries of Sukabumi Regency	Government	2
3	PPN Palabuhanratu	Government	2
4	Landing site officer	Government	1
5	Vessel Owner	Actor	1
6	Fishing Crew	Actor	1
7	Fishers Association	Association	1
	Total		10

2.3 Social-ecological network analysis

The Social-Ecological System (SES) framework is regarded as the most suitable framework for comprehending the dynamics of the relationship between biophysical and human subsystems. The SES study can be expanded by incorporating network analysis, which enables the observation of community understanding, participation, and perception of the environment. The primary feature of the Social-Ecological Network Analysis (SENA) study is the use of complexity to characterize the degree of interconnectivity on dimensions that are precisely scaled. [11] introduced the Russian Doll SES framework, which has been modified to clarify the characteristics of the research study area. The SES framework employed in the SENA analysis is designed to offer a comprehensive understanding of the dynamics involved in the management of small-scale fisheries. The SENA analysis delineates a variety of interrelated research variables that are derived from the primary data collection stage. The SES classification is used to categorize these variables into units. This group of elements includes Resource Actors (RA), Resource Governance (RG), Resource Systems (RS), and Resource elements (RU). A network approach (SENA) is employed to investigate the dynamics of the variables within these units, thereby identifying the dominant and critical variables. The SENA analysis numerical results provide a foundation for comprehending the issue and identifying potential policy solutions.
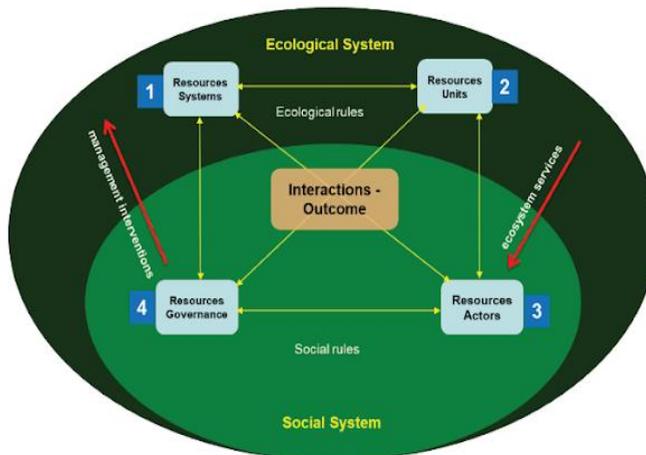

Fig. 3. Russian doll social-ecological system framework [11].

The interconnectivity of components within the social-ecological system is evaluated to investigate the patterns of interdependence in the governance system by social-ecological network analysis utilizing R-studio. The analysis utilized the igraph package script and was organized into a folder within the working directory, adhering to the framework established for the community matrix and function matrix in interpreting the basic network input from the DIA file. This analysis aims to investigate the links established among components of a subsystem. The identification of components in mapping the social-ecological system entails differing degrees of significance and complexity, necessitating precision for enhanced suitability [12]. The evaluated attributes of the system's connectivity encompass network size represented by nodes, density indicated by edges, centrality measured through degree centrality and eigenvector centrality values reflecting hubs and authorities, along with community detection or clustering [13].

3 Result and discussion

3.1 Social-ecological network model

In the SES for small-scale fisheries on the coast of Sukabumi, there are four interrelated main components: Resource Systems (RS), Resource Users (RU), Resource Actors (RA), and Resource Governance (RG). Each of these components plays a role in maintaining the sustainability of marine resources and supporting the welfare of small-scale fishers' communities.

Table 2. Description of social-ecological system variables.

Variable/ Node	Code	Definition*	Connection with the other nodes
Small-scale fisheries system (SSF)	RS1	These fisheries are typically characterized by small fishing vessels (< 10 GT), limited-use technology, and simple gear like nets, which allow fishers to stay close to shore. Local fishers focus on catching various high-value species sold locally or consumed by fishing households, contributing to local food security and the region's economy.	Fishing ground (RS2), Landing spot (RS3), Coastal area (RS4), Fish resource (RU1), National government (RG1), and Regulations (RG5)
Fishing ground	RS2	Specific areas along the coast of Sukabumi, where local fishers regularly catch fish and other marine resources.	Climate stressors (RS5), Fish resources (RU1), and Boat (RU3)
Landing spot	RS3	Specific locations along the coast where fishers bring their catch ashore after fishing trips.	SSF (RS1), Coastal area (RS4), Fish resources (RU1), Fishing trip (RU5), National government (RG1), Regional Government (RG2), Local government (RG3)
Coastal area	RS4	The coastal area includes beaches, nearshore waters, and estuaries where many fishing activities, such as small-scale, occur. It is also the zone where fishing boats are launched and landed.	SSF (RS1), Tourism value (RU2), Regional government (RG2), landing spot (RS3), Local community (RA5), Woman role (RA6).
Climate stressor	RS5	A condition related to climate that negatively impacts ecosystems, communities, or economic activities. These stressors are typically driven by climate change or variability, affecting temperature, weather patterns, precipitation, and sea levels, among other factors.	Fishing ground (RS2), Fish resources (RU1), Tourism value (RU2), Fishing trip (RU5).
Fish resources	RU1	Diverse populations of fish and other marine organisms found in the coastal waters of Sukabumi are harvested for economic and subsistence purposes.	SSF (RS1), Fishing ground (RS2), Landing spot (RS3), Climate stressors (RS5), Small-scale fishers (RA1)

Variable/ Node	Code	Definition*	Connection with the other nodes
Tourism value	RU2	The economic, social, and cultural benefits that a location or attraction provides through tourism activities.	Coastal areas (RS4), Climate stressors (RS5), Local NGO (RG4), Tourism service providers (RA3), Tourist (RA4)
Boat	RU3	Vessel < 10 GT used by fishers	Gear (RU4), National government (RG1), Regulations (RG5)
Gear	RU4	The fishing gear used by fishers are gillnets, trammel nets, and hand lines.	Regulations (RG5), Boat (RU3), Fishing trip (RU5)
Fishing trip	RU5	The expedition was undertaken by fishers to catch fish	Landing spot (RS3), Climate stressors (RS5), Gear (RU4), Regulations (RG5)
National government	RG1	Central government	SSF (RS1), Landing spot (RS3), Boat (RU3), Gear (RU4), Regional government (RG2)
Regional government	RG2	Province government	Landing spot (RS3), Coastal area (RS4), National government (RG1), Regulations (RG5), Local government (RG3),
Local government	RG3	Local government	Landing spot (RS3), Regional government (RG2), Regulations (RG54)
Local NGO	RG4	Local NGO focused on marine sustainability and anti-drug movements: *Gerakan Indonesia Selamat Laut dan Anti Narkoba*	Coastal area (RS4), Tourism value (RU2)
Regulations	RG5	Regulations relating to the operational management of small-scale fisheries	SSF (RS1), Boat (RU3), Gear (RU4), Fishing trip (RU5), National government (RG1), Regional government (RG2), Local government (RG3), Tourism service providers (RA3)
Small-scale fishers	RA1	Fisher who conducts fish catching to meet his/her daily needs operating without or with a fishing boat ≤ 10 GT	Fish resources (RU1), Middle man (RA2), Woman role (RA6)
Middleman	RA2	Middleman also known as *pengepul* or *tengkulak*, play a critical role in the local fish supply chain. These individuals or small business owners act as intermediaries between small-scale fishers and larger markets, helping to facilitate the sale of	Landing spot (RS3), Small-scale fishers (RA1)

Variable/ Node	Code	Definition*	Connection with the other nodes
		fish from coastal fishing villages to urban markets, or processing centers.	
Tourism service providers	RA3	Tourism center	Tourism value (RU2), Local government, (RG3), Regulations (RG5), Local community (RA5)
Tourist	RA4	The individual who visits the coastal areas of Sukabumi to experience the local fishing culture, explore marine environments, or engage in related recreational activities (fish shopping and fishing recreation)	Tourism service providers (RA3), Tourism value (RU2)
Local community	RA5	Joint venture, Fishing community: *Himpunan Nelayan Seluruh Indonesia (HNSI)*	Coastal area (RS4), Tourism service providers (RA3)
Woman role	RA6	Many women in Sukabumi engage in small-scale fish processing businesses, producing fish-based products such as dried fish, salted fish, shrimp paste, and fish crackers, contributing to the local economy and providing alternative income streams.	Coastal area (RS4), small-scale fishers (RA1)

*Based on interviews and observation, and further developed by researchers.

Resource Systems (RS) is a foundational component that represents the natural or ecological part of the environment from which resources are extracted, used, or managed by a community or society [14]. Resource System refers to the coastal and marine ecosystem in small-scale fisheries, particularly the areas that serve as fishing grounds for local fishers. This system includes the waters of the Indian Ocean, which have high biodiversity and play an important role as a habitat for various types of catch fish. This aquatic area is influenced by environmental factors such as temperature and fish migration patterns, all of which affect the availability of fish resources. This connectivity is related to the sustainability of the ecosystem; changes in one part (such as overfishing in one area) can impact the entire fish population in that region. In this study, the components of the RS include small-scale fisheries systems, fishing grounds, landing spots, coastal areas, and climate stressors.

Resource Units (RU) in Sukabumi coastal small-scale fisheries encompass key elements that sustain both the ecological and economic aspects of fisheries. In this context, the Resource Units studied include Fish Resources, Tourism Value, Boats, Gear, and Fishing Trips. Each variable has a distinct role in supporting the livelihoods of local communities, contributing to sustainable fishery practices, and maintaining the balance within the SES. Each Resource Unit in Sukabumi's small-scale fisheries contributes to the SES in specific ways, with Fish Resources, Boats, and Gear influencing the ecological sustainability of fishing, while Tourism Value and Fishing Trips impact economic and social aspects. Maintaining the balance between these Resource Units is essential to support the SES framework, as each component affects both fishers' livelihoods and the health of the marine ecosystem. Coordinated resource management can ensure that these RUs support not only economic growth but also long-term ecological sustainability for the fisheries in Sukabumi.

Resource Governance (RG) variables—National Government, Regional Government, Local Government, Local NGOs, and Regulations—represent various institutions and actors that create and enforce rules, manage resources, and support sustainable fishing practices. The National Government provides broad policies and resources; the Regional Government

adapts these policies to local conditions ; the Local Government manages on-the-ground enforcement and community relations; Local NGOs support sustainability and community engagement ; and Regulations enforce sustainable practices through both formal laws and informal norms. For effective SES management, alignment and cooperation across these levels are crucial to support sustainable fisheries and community livelihoods.

   The primary variables of Resource Actors (RA) identified in this context are Small-Scale Fishers, Middlemen, Tourism Service Providers, Tourists, Local Community, and the Role of Women. The interaction between these Resource Actors creates a dynamic SES in the small-scale fisheries. Small-scale fishers and Middleman are central to the direct use and market dynamics of fisheries resources, while Tourism service providers and Tourists add economic diversification. The Local community and Women's roles reinforce social cohesion and contribute to sustainable practices. Balancing these interactions through adaptive management and community collaboration is key to sustaining the fisheries sector and supporting socioeconomic and environmental resilience.
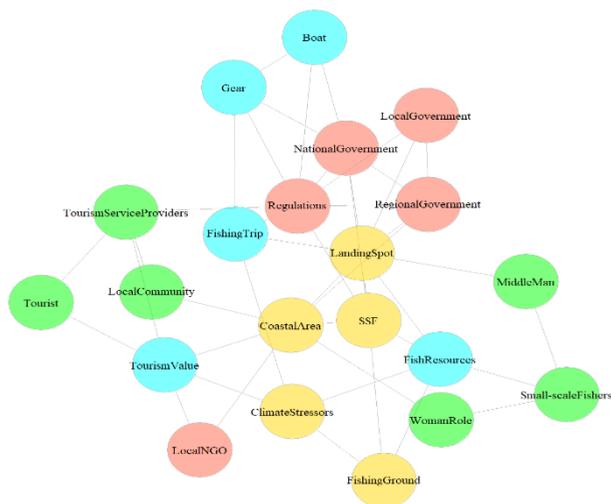

Fig. 4. Social-ecological system model of small-scale fisheries in Sukabumi coastal fisheries, West Java Province.

3.2 Connectivity of social-ecological systems based on centrality degree

The quantity of connections to other actors in the network is determined by degree analysis. Degree analysis results in this study indicate that the SES model of small-scale fisheries has 21 components (nodes) and 44 relationships (edges). Landing Spot and Regulations have a statistically significant relationship between other nodes, with a degree value of 8. Furthermore, the Coastal Area, which has a degree value of 7, underscores the significance of coastal areas as a source of sustainable subsistence for the community and as a habitat for a variety of marine biota. The National government has a relationship with another node, with a degree value of 6. The role of the national government in catch zone policies, banning the use of destructive fishing gear, providing fuel subsidies, implementing environmentally friendly fishing training programs, and empowering alternative economic activities for fishing communities. Similarly, SSF, which has a degree value of 6, is an important pillar for economic resilience, social welfare, and environmental sustainability. Support for SSF can strengthen the resilience of coastal communities and support sustainable marine resource management. In addition, Fish Resource, Tourism value, and Regional government have a

degree value of 5 with other nodes. The node size in small-scale fisheries of Sukabumi Coastal is depicted in Figure 5, which is determined by the magnitude of the SES degree value.
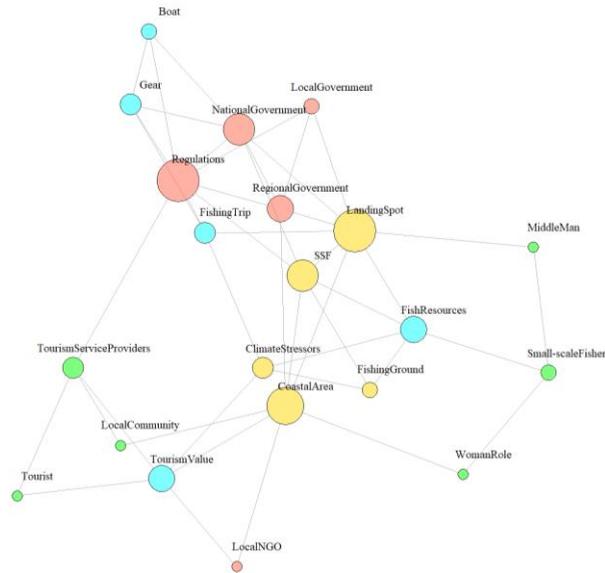

Fig. 5. Social-ecological system connectivity based on centrality degree of small-scale fisheries in Sukabumi coastal fisheries, West Java Province.

3.3 Connectivity of social-ecological systems based on betweenness value

The betweenness value indicates a variable that connects to other variables. The higher the betweenness value of a variable, the more important that variable functions as a connecting path [22]. The analysis results show that the relationship between Regulations and Tourism service providers has the highest betweenness value. Regulations and Tourism service providers create a symbiotic relationship that promotes both environmental stewardship and economic growth, which is essential for long-term sustainability. This relationship ensures that tourism contributes positively to the community while aligning with regulatory efforts to preserve the marine ecosystem. Next, Landing spots with Coastal areas also have high betweenness values. High betweenness values for Landing spots and Coastal areas indicate that they are central to various SES processes. Their position within the SES framework underpins economic transactions, regulatory enforcement, community engagement, and tourism, highlighting their indispensable role in the sustainability and resilience of Sukabumi small-scale fisheries.Tourism and climate stressors also have high betweenness values. Tourism catalyzes economic opportunity but demands careful management to prevent ecological degradation. Meanwhile, climate stressors underscore the need for resilience in fishing practices and coastal management policies to maintain system sustainability. The value of these relationships is the highest aggregate value in the SES small-scale capture fisheries network. The edge sizes based on the magnitude of betweenness values in the network are displayed in Figure 6.
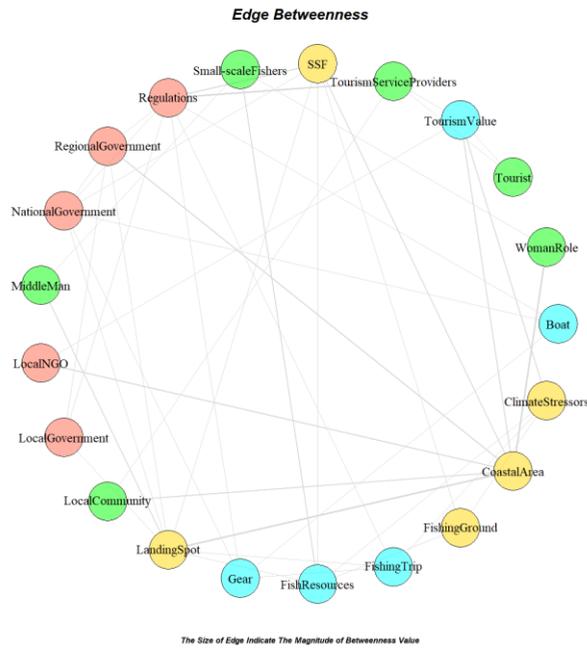
Fig. 6. Social-ecological system connectivity based on betweenness value of small-scale fisheries in Sukabumi coastal fisheries, West Java Province.

3.4 Connectivity of Social-Ecological Systems Based on Community Detection

Clustering assessment is a process that entails the evaluation of multiple group variables based on similarities in relationship characteristics and structural patterns. The clustering results indicate that the SES network is clustered. The node similarity matrix and edge betweenness are used to estimate the clustering. Figure 10 illustrates the clustering of community detection. The SES network comprises six primary groupings, as indicated by the analysis of the results from the small-scale fisheries of Sukabumi coastal. Cluster one (I) includes Tourists, Tourism value, Tourism service providers, Local NGOs, and Local communities. Women's roles, Small-scale fishers, and Middleman comprise Cluster two (II). Cluster three (III) includes SSF, Regulations, National government, Gear, and Boats. The regional government, local government, landing sites, and coastal areas comprise Cluster four (IV). Fishing trips is included in cluster V. The last cluster consists of Fish resources, Fishing ground, and Climate stressors.
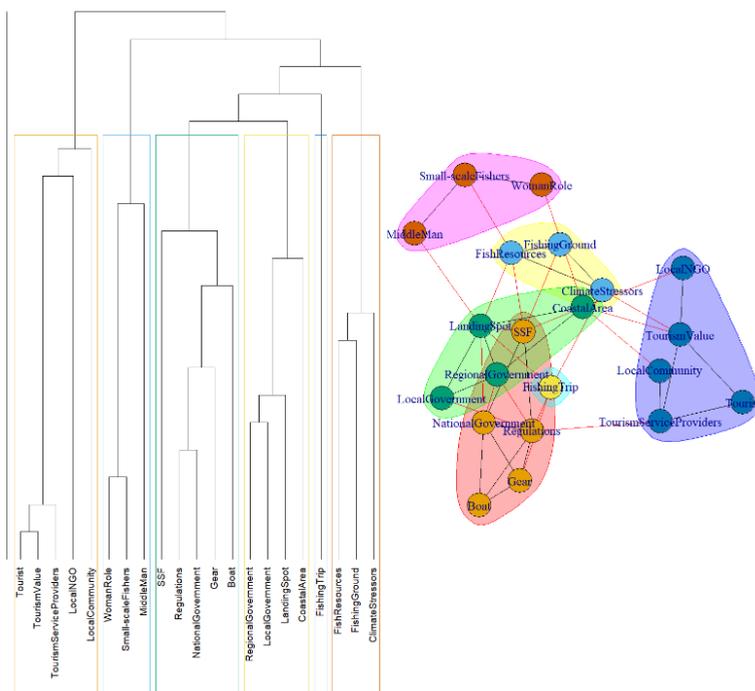
Fig. 7. Social-ecological system connectivity based on clustering community of small-scale fisheries in Sukabumi coastal fisheries, West Java Province.

4 Conclusions

In conclusion, there were 21 nodes (elements) and 44 edges (relationships) in the basic of SES network model of small-scale fisheries in Sukabumi Coastal fisheries, West Java Province. The key variables that most affect the small-scale fisheries network are Regulations, Landing Spot, Coastal Area, and National government. Thus, the dominant ones in the system are Resource System (RS), and Resource Governances (RG). Based on betweenness value, variables that have high relevance are Regulations and Tourism service providers, as well as between Landing spot and Coastal Area. In the system, apart from the Resource System (RS), and Resource Governances (RG), Resource Actors (RA) also play a role in managing small-scale fisheries on the Sukabumi coastal. However, to achieve optimal and sustainable small-scale fisheries management, it is crucial to establish synergy between the resource system (RS), resource unit (RU), resource actor (RA), and resource governance (RG). Governing small-scale fisheries in the Sukabumi coastal, West Java Province, through the SES framework requires integrating resource sustainability with community welfare.

References

1. FAO, Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (Rome, 2014)
2. S. Heck, C. Béné, R. Reyes-Gaskin, Fish Fish. **8**, 211 (2007)
3. Sukabumi Regency Fisheries Service, Fisheries Performance Data of Sukabumi Regency (2024)
4. BPS Sukabumi Regency. Statistic of Sukabumi Regency, (2024)
5. Bappenas (Indonesian Ministry of National Development Planning), Indonesia Climate Change Sectoral Roadmap (ICCSR). Indonesia: Jakarta, (2019)
6. R.J.T. Klein, M.J. Smit, H. Goosen, Climate change, adaptive capacity and development, (2017)
7. R. Paramita, C. P. Subodh, C. Rabin, C. Indrajit, S. Asish, S. Manisa, J. Environ. Manage. **330** (2023)
8. M. C. Badjeck, E. H. Allison, A. S. Halls, N. K. Dulvy, Mar. Policy **34**, 375 (2010)
9. J. E. Cinner, T. Daw, T. R. McClanahan, Conserv. Biol. **23**, 124 (2009)
10. A. Deepak, A. S. Seerappalli, K. Ayyathurai, E. Suresh, A. R. Mohd, R. Gowrimanohari, J. Appl. Ichthyol. **1** (2024)
11. L. Adrianto, Book of Scientific Orations, IPB Univ. (2023)
12. L. Kluger, S. Kochalski, M. S. Muller, P. Gorris, G. Romagoni, YOUMARES 6, Bremen, German Society for Marine Research (2015)
13. D. Luke. A user's guide to network analysis in R. (Springer, New York, 2015)
14. E. Ostrom, Presented at the 2007 AAAS Annual Meeting, Sci. Technol.