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A social–ecological systems perspective on shark and ray fisheries: Evidence from port-based fisheries in Lamongan Regency, East Java, Indonesia

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Abstract. Shark and ray fisheries face increasing conservation and governance challenges in complex, multi-species fisheries systems. This study provides insights into the social–ecological system (SES) of elasmobranch fisheries at Brondong National Fishing Port (PPN Brondong), a major fishing hub on the northern coast of East Java, Indonesia. Landing data, species composition, and IUCN conservation status were integrated with social–ecological network analysis to assess the structure and relative roles of SES components. The results indicate that landings are dominated by Critically Endangered and Vulnerable taxa, with *Sphyrna lewini* and *Rhynchobatus australiae* exhibiting the highest landing frequencies. The SES structure highlights strong linkages between production activities and market dynamics, alongside the relatively limited influence of local governance in regulating catch and trade. These findings suggest the need for targeted management interventions, including species-based measures, to better align conservation priorities with socio-economic objectives. This study demonstrates the value of an SES-based approach in strengthening the information base for sustainable elasmobranch fisheries management. Keyword: elasmobranch conservation; East Java Province; fisheries management; social–ecological systems; network analysis

1. Introduction

Coastal areas are highly productive ecosystems with significant ecological importance, as they simultaneously support a wide range of ecological, social, and economic functions [1]. Globally,

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more than one-quarter of the world's population resides in coastal regions, making these areas zones of intensive interaction between humans and the environment. This condition also renders coastal areas particularly vulnerable to multiple pressures, including coastal development, natural resource exploitation, and environmental change [2]. From a systems perspective, coastal regions can be conceptualized as social–ecological systems (SES), defined as integrated and complex systems comprising ecological and social subsystems, in which reciprocal interactions, feedback mechanisms, and mutual dependencies play a critical role in shaping long-term sustainability [3].

As the world's largest archipelagic country, Indonesia has a coastline exceeding 108,000 km and occupies a strategic position as one of the world's leading fish-producing nations. One of the most important fishing grounds supporting national fisheries is the Java Sea, which is part of Indonesia's Fisheries Management Area (FMA) 712. This region is characterized by relatively shallow waters, high primary productivity, and abundant nutrient availability, which collectively support high levels of marine biodiversity. These conditions make the Java Sea a critical habitat for a wide range of elasmobranch species, including sharks and rays. These species are captured both as target species and as bycatch across various types of fisheries, ranging from small- to medium-scale operations [4]. The Java Sea contributes a relatively high share to national elasmobranch production, with estimated annual landings of approximately 7.885 tons of sharks and 11.903 tons of rays, accounting for about ±37% of Indonesia's total elasmobranch catches [5]. Shark and ray products have significant economic value and are traded in various forms, including meat, fins, skins, and internal organs. These commodities are distributed from major landing ports— including Brondong National Fishing Port (PPN Brondong)—to both domestic and international markets [6]. This situation positions elasmobranch fisheries as economically valuable fisheries commodities, while at the same time rendering them highly vulnerable to exploitation pressures and sustainability risks. This vulnerability is further exacerbated by the life-history characteristics of elasmobranchs, which are generally characterized by slow growth rates, delayed sexual maturity, long lifespans, and low reproductive output [7]. The combination of these biological trait's limits population recovery capacity, such that intensive fishing pressure can rapidly lead to stock declines. Ecologically, declines in elasmobranch populations as apex predators have the potential to disrupt trophic structure and reduce the stability and resilience of marine ecosystems [8]. This condition is reflected in the global conservation status of elasmobranchs, with a significant proportion categorized as *Critically Endangered* (CR), *Endangered* (EN), or *Vulnerable* (VU) on the IUCN Red List. However, the sustainability of elasmobranch fisheries is influenced not only by ecological and biological factors but also by socio-economic dynamics, market demand, and fisheries governance frameworks [9]. Although several studies have examined the diversity and dynamics of elasmobranch fisheries in Indonesia, research integrating species composition, conservation status, and socio-economic context within a single social–ecological systems (SES) framework remains relatively limited, particularly along the northern coast of Java. This gap constrains understanding of how interactions between ecological pressures and social factors shape exploitation patterns and sustainability risks for elasmobranchs at the local level. Accordingly, this study explicitly aims to identify the species composition of sharks and rays landed at the Brondong National Fishing Port (PPN Brondong), analyse the conservation status elasmobranch species based on IUCN Red List categories; and contextualizing these ecological findings within a social-ecological system framework. By adopting the SES approach, this study provides new insights that not only describe the proportion of elasmobranchs, but also understand the relationship between resources, fisheries practices, and coastal social contexts as scientific information that can support sustainable management.

2. Methods

2.1 Study Area

This research was conducted from July to September 2024 in the coastal area of Lamongan Regency, East Java Province, with primary data collection focused at Brondong National Fishing Port (PPN Brondong) (Figure 1). PPN Brondong plays a strategic role as a major hub for capture fisheries along the northern coast of East Java. The port also serves as a central point for the consolidation, trade, distribution, and monitoring of fishery resources, including sharks and rays, which are the primary focus of this study.

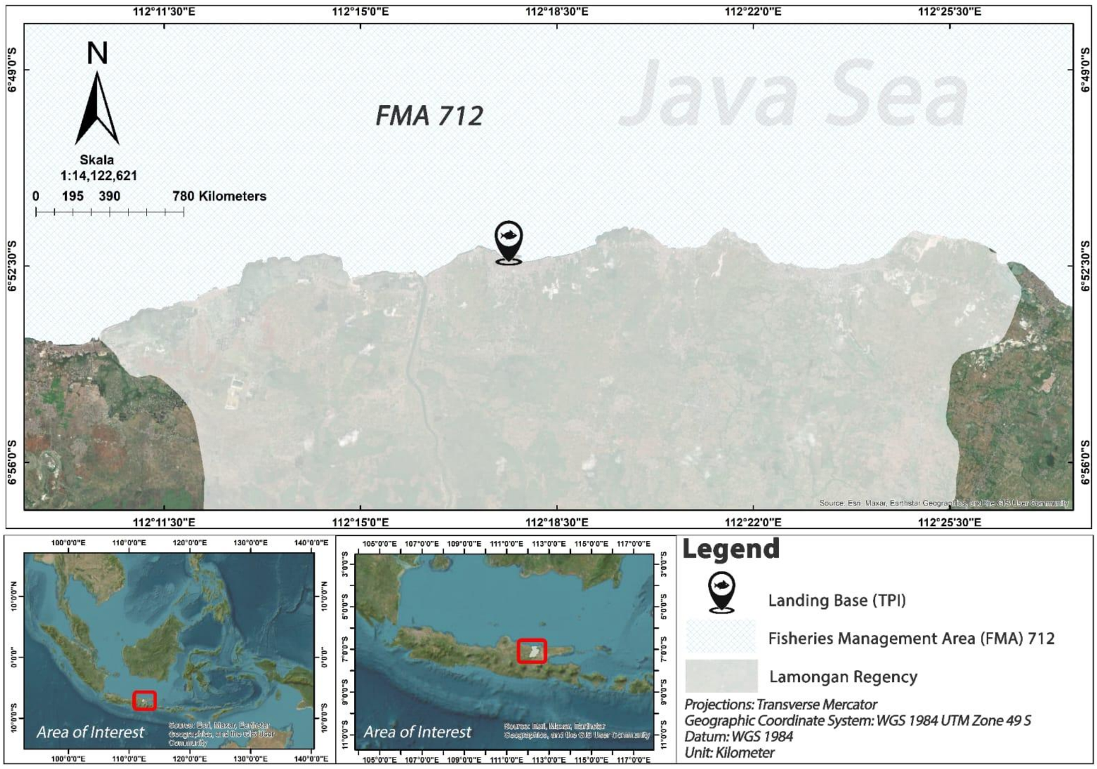

Figure 1. Location of Brondong National Fishing Port (PPN Brondong), Lamongan Regency, East Java, Indonesia

2.2 Data Collection

This study employed a mixed-methods approach, integrating both secondary and primary data to provide a comprehensive understanding of the social-ecological dynamics of shark and ray fisheries in the study area. Secondary data consisted of biological baseline information derived from time series of fish landings between February–December 2022 and February–October 2023, compiled by the Denpasar Coastal and Marine Resources Management Agency (BPSPL). These data formed the primary basis for analyzing species composition, catch trends and temporal variations in landings.

Primary social data were collected at Brondong National Fishing Port (PPN Brondong) through discussions with the Fish Auction Site Manager, the Port Manager, and representatives from the Fisheries Service on 17 October 2024. A focus group discussion (FGD) was subsequently conducted on 16 May 2025, involving the Chair of the Brondong Fishermen's Association, the Chair of the Blimbing Fishermen's Association of Lamongan District, five boat owners, three captains, and eight crew members. The FGD aimed to: (i) identify institutional governance mechanisms regulating shark and ray fisheries, (ii) understand the organizational structure of local resource user groups, and (iii) define the operational scope of the research in accordance with the local context. A participatory dialogue approach was employed to align the social–ecological systems (SES) analysis framework with both on-the-ground realities and the perspectives of the local community. This multi-stakeholder involvement ensured that ecological and socio-cultural dimensions were considered in a balanced manner throughout the research design and data interpretation [3].

2.3 Analysis data

Data analysis was conducted descriptively to examine temporal trends in shark and ray landings, species composition, and conservation status. Monthly proportional distributions were analyzed to identify fluctuations and dynamics in fishery catches [10]. Each species was taxonomically identified and classified according to the most recent IUCN Red List categories—*Critically Endangered*, *Endangered*, *Vulnerable*, *Near Threatened*, *Least Concern*, *Data Deficient* and *Not Evaluated*—in order to assess the dominance of vulnerable and under-documented species [11].

The resulting biological findings were integrated with social and institutional data using the Social–Ecological Systems (SES) framework, which combines The Institutional Analysis and Development (IAD) framework approach with the ‘Russian-doll’ SES concept [3,12]. This framework hierarchically organizes the system into four main components—Resource Systems, Resource Units, Actors, and Governance Systems—to identify cross-scale linkages in shark and ray fisheries. The analysis was conducted using a socio-ecological network approach, where each SES component was represented as a node and the relationships between components as links. These relationships were established based on empirical connections derived from biological and social data. The data were collected through interviews, focus group discussions (FGDs), and supported by relevant literature on elasmobranch fisheries. The network was constructed as a binary and undirected system, under the assumption that the presence of a link indicates a functional interaction between system components. Network structure was validated through multi-stakeholder triangulation, a process in which relationships between components were confirmed and aligned by involving fishery port managers, fisheries authorities, and representatives of fishing groups. This approach ensured that the constructed network was not only theoretically coherent but also reflective of actual management practices and socio-ecological dynamics at the study site. All data analyses and visualizations were performed in RStudio (R version 4.5.1), using the *igraph*, *statnet*, *ggraph*, *ggplot2*, *tidyverse*, and *scales* packages for the construction, analysis, and visualization of social-ecological networks.

3. Result

3.1 Temporal Variation in Shark and Ray Landing Proportions

Time series analysis of elasmobranch landings during the period from February 2022 to October 2023 shows that the proportion of ray catches was consistently higher than that of shark catches, ranging from ±45% to ±78% of total monthly catches. The proportion values in May 2022 (±78%) and August 2022 (±77%) represent the highest phase of ray dominance throughout the period. On the other hand, shark landings showed a variation in proportion between ±22% to ±55%, with an upward trend in the early and late months of the year, particularly in February 2022 (±40%), November 2022 (±46%) and September 2023 (±50%). Temporally, the higher dominance of rays occurred in the middle of the year. This pattern was consistently repeated over two years, indicating seasonal dynamics in catch composition and confirming alternating periods of dominance between rays and sharks in local elasmobranch fisheries (Figure 2). In addition to fishing and seasonal activities, this may also be influenced by the distribution and trade of sharks and rays in the study area.

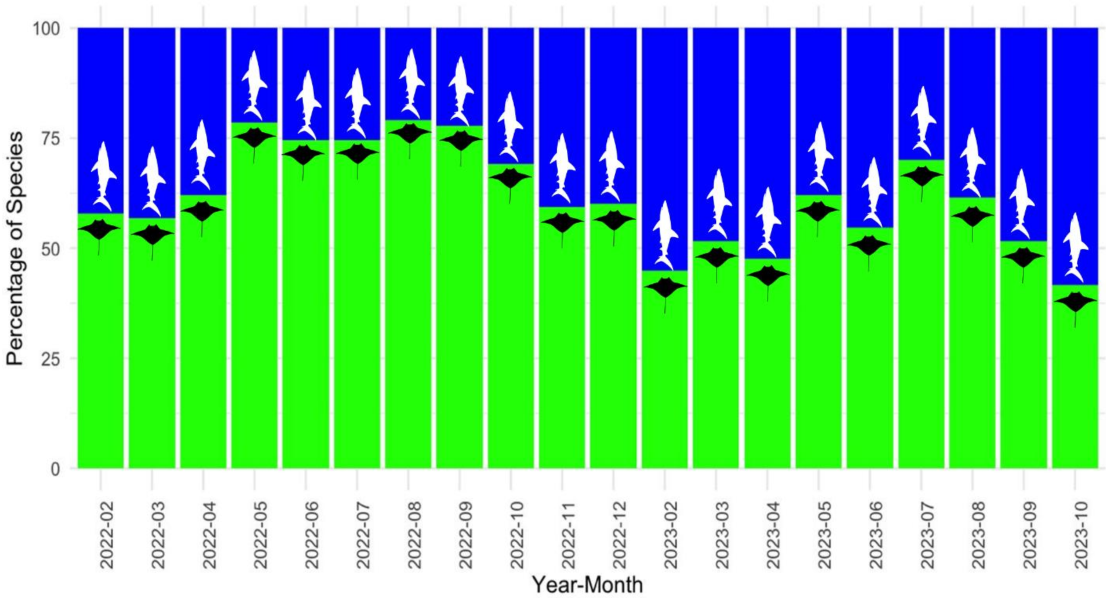

Figure 2. Location of Brondong National Fishing Port (PPN Brondong), Lamongan Regency, East Java, Indonesia

3.2 Composition of Shark and Ray Landings by IUCN Conservation Status

Shark landings at Brondong National Fishing Port (PPN Brondong) were dominated by species classified as *Critically Endangered* (CR), which accounted for 39.8% of all identified species. The dominant species within this category was *Sphyrna lewini*. Species categorized as *Vulnerable* (VU) comprised 36.3%, including *Carcharhinus sealei*. *Near Threatened* (NT) species accounted for 20.6%, predominantly *Chiloscyllium punctatum* and *Rhizoprionodon oligolinx*. *Endangered* (EN) species represented approximately 3,3%, while species of *Least Concern* (LC) were relatively few, at 0.1%. These results indicate a high diversity of shark species being landed at PPN Brondong, with a substantial proportion facing significant conservation risks. For rays, the CR category was overwhelmingly dominant, comprising 81,1% of landings, primarily *Rhynchobatus australiae* and

Rhynchobatus springeri. Species of Least Concern (LC) made up 9.7%, dominated by *Neotrygon orientalis*. *Vulnerable* (VU) and *Endangered* (EN) species accounted for 4.9% and 3.6%, respectively. These proportions demonstrate that most ray landings consist of species classified under the highest extinction risk categories. The proportions of sharks and rays based on IUCN conservation status are illustrated in Figure 3. Overall, these findings underscore the urgent need to strengthen conservation and fisheries management efforts for sharks and rays, in order to reduce fishing pressure on species at high risk of extinction.

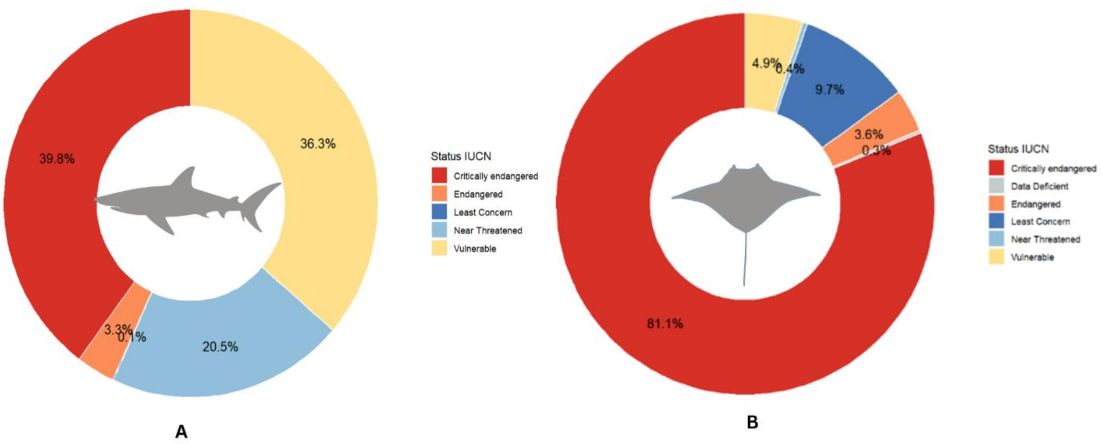

Figure 3. Proportional composition of shark and ray landings categorized by IUCN conservation status: (a) shark (b) ray

3.3 Interactions and Connectivity in the Social–Ecological System of Shark and Ray Fisheries

The social-ecological system of fisheries is a complex network consisting of natural resources, actors, institutions, and various forms of interaction that collectively shape the dynamics of biological resource use and management. In the context of shark and ray fisheries, the interrelationships between resource systems, biological resource units, governance systems, and actors are summarised in Table 1.

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Table 1. Patterns of relationships between components of the social-ecological system of Shark and Ray fisheries

Component 1 (Node)	**Category**	**Component 2 (Node)**	**category**	**Type of Relationship**	**Direction of influence**	**Direction of relationship and system implication**
Climate	Externality	Fishing Activity	Interaction	Environmental pressure	Indirect	Climate variability influences the intensity and pattern of fishing activities through changes in oceanographic conditions and fishing seasonality.
Fisheries Management Area (FMA/WPP)	Governance System	Regulation	Governance System	Policy framework	Uni-directional	The FMA designation becomes the spatial basis for the formulation of fisheries management regulations, including sharks and rays.
MMAF	Governance System	Regulation	Governance System	Policy authority	Uni-directional	The ministry establishes national regulations governing quotas, gear types, and species protection.
Provincial Government	Governance System	Regulation	Governance System	Policy implementation	Uni-directional	Local governments implement national policies into operational management at the provincial level.
Regulation	Governance System	Capture Fisheries	Resource System	Management control	Bidirectional	Regulations constrain fishing activities, while fishing practices provide feedback on the effectiveness of policies.
Capture Fisheries	Resource System	Fishing Activity	Interaction	Operational	Uni-directional	Fishing activities
Fishing Activity	Interaction	Elasmobranchii	Resource Unit	resource utilization	Uni-directional	Fishing activities have a direct impact on the level of exploitation of sharks and rays.
Elasmobranchii	Resource Unit	Fishery Commodities	Resource Unit	Product transformation	Uni-directional	Economic value of elasmobranchii
Fishery Commodities	Resource Unit	Commodity Prices	Resource Unit	Market mechanism	Bidirectional	The availability of commodities affects prices, while prices affect the intensity of exploitation.

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Component 1 (Node)	**Category**	**Component 2 (Node)**	**category**	**Type of Relationship**	**Direction of influence**	**Direction of relationship and system implication**
Commodity Prices	Resource Unit	Market Actors and Distributors	Actor	Economic incentive mechanisms	Bidirectional	Commodity prices shape market behavior and demand, while also being influenced by distribution networks
Market Actors and Distributors	Actor	Logistic	Resource System	Distribution	Bidirectional	Market actors rely on logistics systems to distribute products to domestic and export markets
Transshipment	Interaction	Market Actors and Distributors	Actor	Distribution flow	Uni-directional	Transshipment expands distribution reach and accelerates the flow of fishery products.
Brondong Archipelago Fishery Port	Resource System	Auction Process	Interaction	Market facilitation	Uni-directional	The port becomes an auction center as a link between fishermen and market actors.
Auction Process	Interaction	Shark Collectors	Actor	Transaction	Bidirectional	The auction process brings together collectors with shark and ray products from fishermen.
Shark Collectors	Actor	Market Actors and Distributors	Actor	Supply chain	Uni-directional	Collectors act as a link between local production and the wider market.
Quota Rule	Governance System	Fishing Activity	Interaction	Restrictions	Uni-directional	Quota rules limit the volume and composition of shark and ray catches.
BPSPL	Governance System	Brondong Archipelago Fishery Port	Resource System	Supervision	Bidirectional	BPSPL monitors landings and receives coordination feedback from the port.
Local Community	Actor	Fishing Activity	Interaction	Social dependency	Bidirectional	Local communities depend on fishing for their livelihoods and this influences the intensity of fishing activities.
Local Community	Actor	Regulation	Governance System	Compliance and adaptation	Bidirectional	Regulations influence fishermen's practices, while fishermen's responses

Component 1 (Node)	**Category**	**Component 2 (Node)**	**category**	**Type of Relationship**	**Direction of influence**	**Direction of relationship and system implication**
						Influence the effectiveness of policies.
Logistic	Resource System	Fishery Commodities	Resource Unit	Post-harvest handling	Uni-directional	Logistics infrastructure determines the quality and selling value of shark and ray products.

Interaction processes within the social–ecological fisheries system encompass fishing activities, regulatory enforcement, and market mechanisms, which collectively shape the flow of information and materials across system components. These interactions influence how resources are utilized, distributed, and governed. External factors such as climatic conditions can further affect resource availability and the efficiency of these utilization processes. The relationships among these variables are illustrated in Figure 4, which depicts the patterns of interconnections and flows within the social–ecological network.

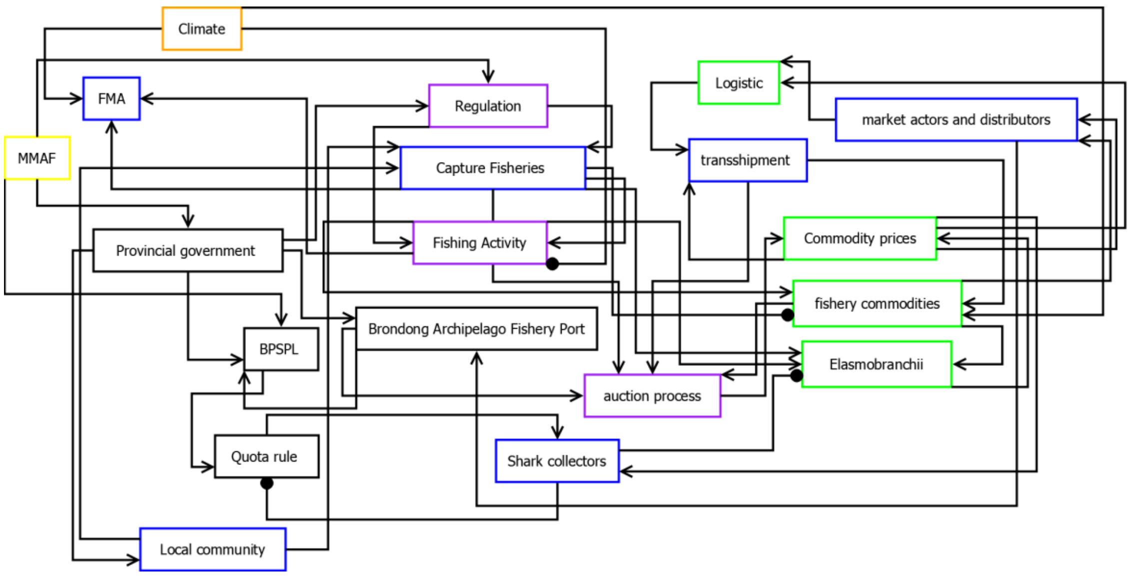

Figure 4. illustrates the interconnected ecological, social, and institutional variables that structure the social–ecological system of shark and ray fisheries.

3.4 Network dynamics of Shark–Ray fisheries

The social-ecological network analysis of the shark-ray fishery system (Figure 5) identified Fishery Commodity as the most central node, with the highest degree centrality (7) and maximum eigenvector score (1.0000), forming a dominant production-market relationship with Capture Fisheries (degree = 7; eigenvector = 0.9418) and Fishing Activities (degree = 6; eigenvector = 0.8543). This relationship connects the biophysical component Elasmobranchii (degree = 5; eigenvector = 0.7957) with downstream market actors, indicating that commodity flows serve as the primary driver of system dynamics. Economically, Commodity Price (degree = 6; eigenvector

= 0.6870) and Auction Process (degree = 5; eigenvector = 0.7320) provide important controls on fishing intensity and product distribution, enabling rapid feedback between production and demand. Collectively, these quantitative patterns reveal a commodity-driven social-ecological system (SES), in which ecological resources, market signals, and trading institutions are closely intertwined, suggesting that sustainability outcomes are shaped by both biological availability and market incentives.

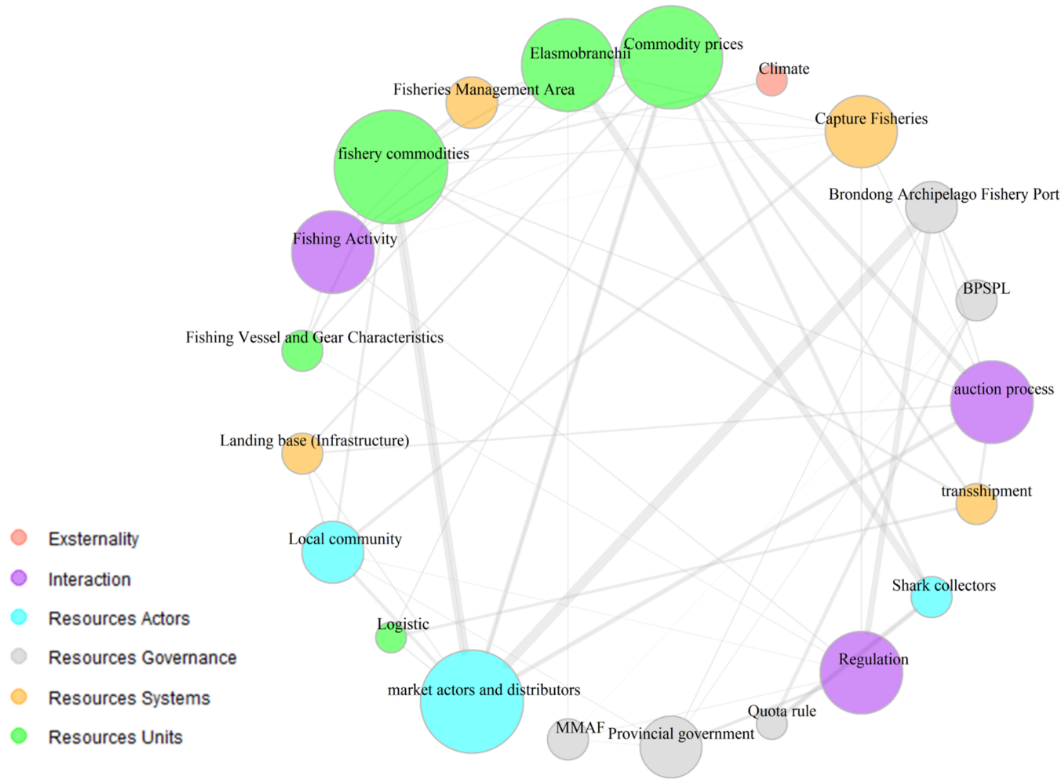

Figure 5 Social–ecological network model depicting shark and ray fisheries. Nodes are scaled by degree values, while edge width reflects eigenvector centrality, indicating the relative influence of nodes within the network.

Mapping degree centrality (DC) against eigenvector centrality (EC) (Figure 6) reveals a commodity-driven structure in the shark-ray fishery system. Fisheries and Capture Fisheries Commodities occupy dominant positions (DC ≈ 7; EC ≈ 0.95–1.00), functioning simultaneously as direct connectors and structural influencers, indicating that production-market linkages form the core of the system's operation. Fishing Activity and Commodity Prices serve as secondary systemic drivers (DC ≈ 6; EC ≈ 0.68–0.85), indicating that harvest intensity and price fluctuations reinforce downstream and upstream interactions. Meanwhile, Elasmobranchs and Auction Processes represent 'hidden influencer' with moderate connectivity (DC ≈ 5) but high structural influence (EC ≈ 0.72–0.80), suggesting that species characteristics and distribution mechanisms can influence system behavior despite not appearing dominant in transactional flows. In contrast, the Provincial Government acts as an operational hub (DC ≈ 5; EC ≈ 0.30), indicating administrative involvement without deep integration into influential nodes. Contextual elements such as Regulation, Market Actors and Distributors, Climate, and especially Quota Rules cluster at

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lower centrality values (DC ≤ 4; EC ≤ 0.50), indicating that formal governance instruments and environmental drivers currently exert weak structural influence on elasmobranch fisheries practices. Overall, these patterns suggest that interventions targeting commodity management, fishing activities, and market mechanisms can generate broader systemic impacts than strategies focused solely on regulatory instruments.

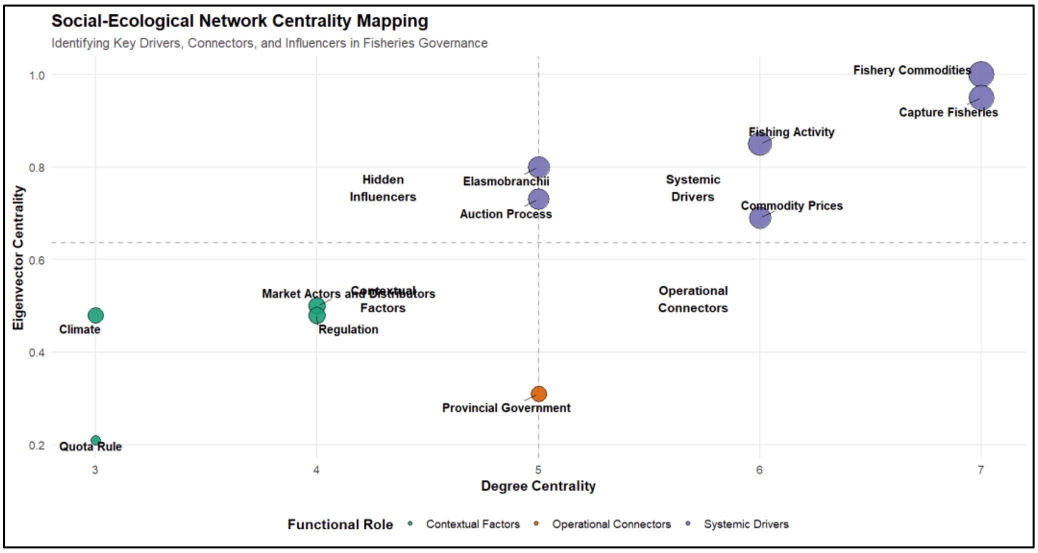

Figure 6 Functional centrality in Shark–Ray fisheries networks

4. Discussion

From a Social–Ecological Systems (SES) perspective, the Brondong National Fisheries Port (PPN Brondong) functions as a strategic node that links resource extraction processes with social and economic dynamics along the northern coast of East Java Province. With an average landing volume of approximately 200 tonnes per day and the capacity to serve fishing vessels exceeding 30 GT, the port operates not only as a landing site but also as a coordination centre for material flows, economic value creation, and institutional interactions within the regional fisheries system [13].

The presence of port infrastructure—including docks, loading and unloading areas, storage facilities, and fish auction halls—plays a critical role in accelerating commodity circulation and strengthening linkages between local fishing activities and regional market networks. Within the SES framework, PPN Brondong can be conceptualized as a boundary object that mediates interactions among resource units (fisheries commodities, including sharks and rays), actors (fishers, collectors, and traders), and the governance system (regulatory frameworks and management institutions). This central position enables the port to structure fishing behaviour and market access, thereby shaping the overall social–ecological dynamics of shark and ray fisheries along the northern coast of East Java.

The composition of shark and ray landings at PPN Brondong indicates a high level of ecological vulnerability, as the majority of recorded species fall within the *Critically Endangered* (CR) and *Vulnerable* (VU) categories. This pattern reflects sustained and intensive fishing pressure on elasmobranch populations, which are inherently sensitive due to their slow growth

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rates, late maturity, and low reproductive output [14]. These findings provide a critical empirical baseline for examining the sustainability of shark and ray fisheries within the SES framework. From an SES perspective, conservation status represents not only biological information but also a structural indicator of fisheries systems that are highly integrated into economic networks. The continued exploitation of threatened species suggests that ecological feedbacks—such as declining abundance or shifts in size distribution—have not been effectively translated into adaptive fishing practices or responsive management interventions. This decoupling between ecological signals and social or institutional responses is consistent with global evidence from tropical fisheries, where degradation signals often fail to trigger timely and effective policy adjustments [15].

Network-based SES further reveals that fisheries commodities and fishing activities function as the primary drivers of the system, occupying central positions with high structural influence. Fishing effort and commodity prices act as secondary drivers, linking production dynamics directly to market fluctuations and reinforcing economically driven feedback loops. In contrast, governance components—such as regulations, local government institutions, and environmental management measures—are positioned peripherally within the SES network, exhibiting relatively low levels of connectivity and influence over core system dynamics. This configuration indicates a market-dominated management regime, in which formal governance mechanisms remain insufficient to counterbalance strong economic incentives driving the exploitation of shark and ray resources, particularly species classified as Critically Endangered. Similar SES structures have been widely documented in tropical small-scale fisheries, where rapid market integration is not matched by corresponding institutional capacity or enforcement effectiveness [16]. From a Social–Ecological Systems perspective, pathways toward sustainability require a deliberate rebalancing of system structure by strengthening governance feedbacks and enhancing the adaptive capacity of key actors. Potential leverage points include the integration of species-specific monitoring within port-based management systems, the incorporation of sustainability criteria into market mechanisms, and the development of incentives that align economic benefits with conservation objectives [17].

5. Conclusion

Shark and ray fisheries in Lamongan Regency, East Java, are structured as a port-based social–ecological system, in which resource extraction processes, market dynamics, and social interactions are closely interconnected. From a Social–Ecological Systems (SES) perspective, the PPN Brondong functions as a key infrastructural node that connects resource utilization, commodity flows, and institutional interactions within the regional fisheries system. The majority of landed shark and ray species are classified as *Critically Endangered* and V*ulnerable*. From an SES perspective, these biological risks are largely driven by market demand and commodity values, while governance and regulatory mechanisms exert relatively limited influence. This imbalance underscores the urgent need for stronger management interventions that explicitly integrate biological vulnerability into fisheries governance.

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References

[1] Barbier, Edward B 2017 *Curr. Biol*. **27**, 11
[2] Neumann B, Vafeidis A T, Zimmerman J, Nicholls R J 2015 *PLoS ONE*. **10**, 3
[3] Ostrom E 2009 *Science*. **325**, 5939
[4] Dharmadi, Fahmi, White W 2009 *Ind.Fish Res. J.* **15-**1
[5] Safitri A, Redjeki S, Widowati I 2022 *J. Mar. Res* **11**, 1
[6] Muttaqin E, Simeon B, Dharmadi M I, Prasetyo A P, Booth H L, Yulianto I 2024 *FAO Fish. Aquac. Tech. Pap. Rome*
[7] Dulvy N K, Fowler S L, Musick J A, Cavanagh R D, Kyne P M, Harrison L R, Carlson J K, Davidson L N K, Fordham S V, Francis M P 2014 *eLife* **3**
[8] Ferretti F, Worm B, Britten G L, Heithaus M R, Lotze H K 2010 *Ecol. Lett.* **13**, 8
[9] Samusamu A S, Sulaiman P S, Rachmawati P F, Oktaviani D, Wiadnyana N N 2021 *J. Penelit. Perikan. Ind.* **27**, 3
[10] Booth H L, Chaya F, Ng S, Tan V, Rao M D, Teepol B, Giyanto, Putra M I H 2021 *Mar. Freshw. Ecosyst.* **31**, 11
[11] Cailliet G M, Smith W D, Mollet H F, Goldman K J 2006 *Environ. Biol. Fish*. 77, 1
[12] Adrianto L 2023 *IPB Univ. Prof. Sci. Oration*
[13] Nurhijayat A, Adrianto L, Booth H L, Boer M, Zairion, Salim M G, Vitner Y, Tawang F 2025 *BIO Web Conf*. **176**, 01003
[14] Dulvy N K, Pacoureau N, Rigby C L, Pollom R A, Jabado R W, Ebert D A et al 2021 *Curr. Biol.* **31**, 21
[15] Berkes F, Colding J, Folke C 2003 *Cambridge Univ. Press*
[16] Cinner J E, Barnes M L 2019 *One Earth* **1**, 1