Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 691 – 706 (2025)
www.ejabf.journals.ekb.eg

The Socio-Ecological System of Coral Reef Conservation in Gorontalo Bay

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ARTICLE INFO

Article History:
Received: June 8, 2025
Accepted: Aug. 29, 2025
Online: Sep. 15, 2025

Keywords:
Socio-ecological systems,
Coral reef conservation,
Coastal community resilience,
Gorontalo Bay

ABSTRACT

Coral reef ecosystems in Gorontalo Bay face significant socio-ecological pressures arising from environmental degradation and the strong economic dependence of coastal communities on marine resources. Conventional biological and physical conservation approaches have proven inadequate to address this complexity. This study explores the key socio-ecological attributes that determine conservation success and develops a contextual, inclusive conceptual framework grounded in the social-ecological systems (SES) approach. A mixed-methods exploratory sequential design was employed, combining in-depth interviews, participatory observation, and questionnaire surveys of 60 respondents. Data were analyzed using qualitative thematic analysis and quantitative leverage analysis across seven SES elements. The results show that the attributes with the highest leverage are: (1) coral reef health as a foundation of community well-being, (2) livelihood dependence on the sea, and (3) understanding of conservation zoning. These findings highlight the need to integrate social resilience, cultural values, and adaptive governance into conservation strategies. Active community participation and the involvement of local leaders were found to strengthen conservation effectiveness by fostering collective norms and promoting ecological awareness. In conclusion, conservation success depends not only on ecological conditions but also on the social capacity to adapt and engage. This study makes a strategic contribution to the design of transformative and sustainable community-based conservation policies.

INTRODUCTION

Coral reef ecosystems are among the most complex and productive ecological systems on Earth. Within tropical ecology, these ecosystems play a vital role not only in maintaining marine biodiversity but also in providing livelihoods for coastal communities through diverse ecosystem services.

In Indonesia—the world's largest archipelagic nation with the second-longest coastline—coral reefs hold significant ecological and socio-economic value **(Moberg & Folke, 1999; Hasim, 2021)**. Unfortunately, over the past two decades, various anthropogenic pressures and climate change have severely degraded these ecosystems. Physical damage from destructive fishing practices, sedimentation, eutrophication, and bleaching triggered by rising sea temperatures are among the main threats to coral reef sustainability **(Hughes *et al.*, 2017)**.

These conditions directly affect the welfare of coastal communities whose livelihoods depend on marine resources. In conservation areas such as Gorontalo Bay, the connection between coral reef health and the socio-economic conditions of local communities is particularly evident. Studies indicate that coastal populations in this region rely heavily on marine ecosystems for food, income, and protection from coastal disasters such as erosion and tidal flooding **(Hamzah *et al.*, 2024; Rahmawati *et al.*, 2024)**. Under such circumstances, coral reef degradation not only leads to ecosystem loss but also fuels a cycle of social vulnerability. Declining fish catches, reduced marine tourism appeal, and the breakdown of social structures due to increased resource competition are tangible impacts of disturbances to coastal ecosystems **(Cinner *et al.*, 2009; Gurney *et al.*, 2019)**.

To address this complexity, conservation research and practice have shifted over the past decade. Whereas earlier efforts focused largely on biophysical aspects, a social-ecological systems (SES) approach has emerged that considers humans as integral parts of ecosystems. This perspective emphasizes understanding the reciprocal relationships between ecological conditions and social dynamics when formulating sustainable management strategies **(Ostrom, 2009)**. Within the SES framework, elements such as resource systems, governance, social actors, and ecological and social outcomes are analyzed holistically to evaluate overall system resilience **(Folke *et al.*, 2005; Armitage *et al.*, 2009)**. This approach has made important contributions globally, including the Philippines **(Christie *et al.*, 2003)**, in coastal areas of Chile **(Gelcich *et al.*, 2010)**, and Costa Rica **(Palou-Zúñiga *et al.*, 2023)**.

In Indonesia, however, the application of the SES approach to marine conservation area management remains limited. Most programs still adopt a top-down technocratic model that insufficiently accommodates local social dynamics, such as community perceptions of conservation, livelihood practices, and leadership structures **(Mascia *et al.*, 2010; Bennett *et al.*, 2014)**. Yet, conservation success depends heavily on social legitimacy gained through participatory processes and shared understanding of long-term benefits. When conservation is perceived as an external project that restricts community access to resources, resistance often arises, undermining conservation goals **(Christie *et al.*, 2009)**.

The urgency of this research in Gorontalo stems from the growth of marine ecotourism and the expansion of coastal conservation policies, which directly intersect

with communities' strong socio-economic dependence on marine resources. Previous studies highlight the importance of social factors—adaptive capacity, environmental literacy, and leadership involvement—as key determinants of conservation success **(Pretty & Smith, 2004; Cinner *et al.*, 2018)**. However, systematic analyses that integrate social and ecological attributes into a single framework remain scarce in Indonesia, especially in emerging areas such as Gorontalo Bay. This gap is particularly significant given the region's socio-ecological complexity, characterized by limited livelihood alternatives, high marine dependence, and distinctive social-communal structures **(Hasim *et al.*, 2025)**. Thus, integrative research is both academically important and practically urgent for formulating adaptive, inclusive, and context-sensitive conservation policies.

This study addresses that gap by examining the social-ecological systems of coral reefs in Gorontalo Bay through three key areas: identifying influential socio-ecological attributes, mapping the interactions among perceptions, livelihoods, and ecological conditions, and developing a contextual SES conceptual framework. Preliminary findings highlight crucial attributes such as reef health, dependence on the sea, and understanding of zoning as key factors in determining management effectiveness **(Hasim *et al.*, 2025)**.

MATERIALS AND METHODS

This study employed a sequential exploratory mixed-methods approach, integrating qualitative and quantitative data in stages. This design was selected to capture the complex socio-ecological dynamics of Gorontalo Bay while prioritizing the local context of coastal communities.

1. Research location

The study was conducted in two coastal villages—Olele and Botutonuo—within the Gorontalo Bay conservation area. Olele functions as a conservation-based marine tourism site, whereas Botutonuo represents a traditional fishing community highly dependent on marine resources.

2. Research design

The research design was guided by **Ostrom**'s **(2009)** social-ecological systems (SES) framework, which includes seven core elements: resource system (RS), resource units (RU), governance system (GS), actors (A), interactions (I), outcomes (O), and related ecosystems (ECO).

3. Data collection techniques

- **Qualitative data**: In-depth interviews were conducted with 13 key informants, including community leaders, religious leaders, village officials, fishers, and tourism actors. The number of informants was determined by thematic saturation, which was reached after the 11th interview. Two additional interviews were conducted for triangulation and validation.

- **Participatory observation**: Observations during village meetings, conservation activities, and daily resource use practices were carried out to complement interview data and to provide contextual depth.
- **Quantitative data**: Structured surveys were administered to 60 respondents, selected through proportional stratified random sampling across both villages. Although modest in size, the sample is appropriate given the small populations and the exploratory nature of the study. The survey instrument comprised 22 closed-ended items aligned with SES attributes.
- **Documentation review**: Relevant materials—such as conservation zoning regulations, institutional records, and activity reports—were reviewed to support contextual interpretation.

4. Data triangulation and validation

Triangulation was applied across three dimensions: (1) data sources (community members, government agencies, and stakeholder institutions), (2) methods (interviews, observations, and surveys), and (3) researchers (internal peer-review sessions). Member checking was conducted after transcription and preliminary coding; summary transcripts and interpretations were returned to informants for confirmation and clarification. This ensured both accuracy and community validation.

5. Data analysis

- **Qualitative analysis**: Thematic analysis was conducted using a coding system structured around the seven SES elements. NVivo software was used to manage, code, and visualize data, facilitating the identification of dominant themes and interconnections.
- **Quantitative analysis**: Leverage analysis, adapted from the RAPFISH (Rapid Appraisal for Fisheries) multidimensional scaling method, was employed to identify SES attributes with the strongest influence on conservation effectiveness. Each attribute was rated on a five-point Likert scale. Sensitivity tests were then applied to assess how changes in individual attributes affected overall conservation outcomes **(Cinner *et al.*, 2009)**. Inferential statistics were not prioritized due to the small sample size and exploratory intent; however, leverage values allowed comparative assessment of attribute importance within and across SES dimensions.
- **Integrated data analysis**: Qualitative and quantitative findings were synthesized in a unified interpretation process. Thematic insights from interviews and observations were used to contextualize numerical results from leverage analysis. This integrative approach strengthened the explanatory power of the SES framework in capturing the complexity of coral reef conservation in Gorontalo Bay.

RESULTS

Based on the analysis conducted on each SES dimension, the attributes that most influence conservation effectiveness were identified.

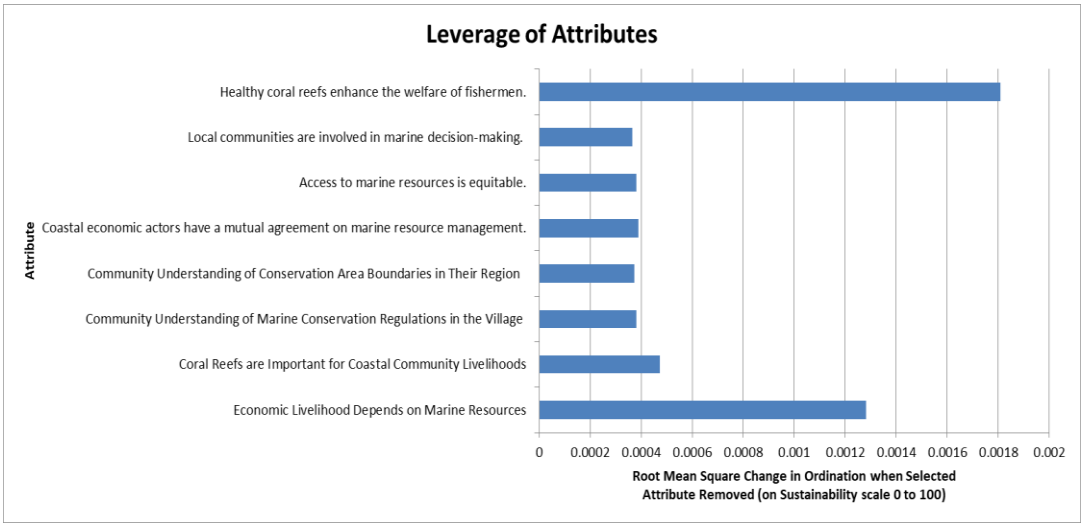

Fig. 1. Socio-ecological characteristics of coral reef ecosystems in the Gorontalo Bay conservation area

Fig. (1) shows the results of the leverage analysis on the socio-ecological characteristics dimension, which yielded the three most influential attributes, namely (1) healthy coral reefs improve welfare, (2) the community's economic livelihood depends on marine resources, and (3) coral reefs are important for the livelihood of coastal communities. These three attributes illustrate how community characteristics and perceptions influence the socio-ecological system within the Gorontalo Bay conservation area.

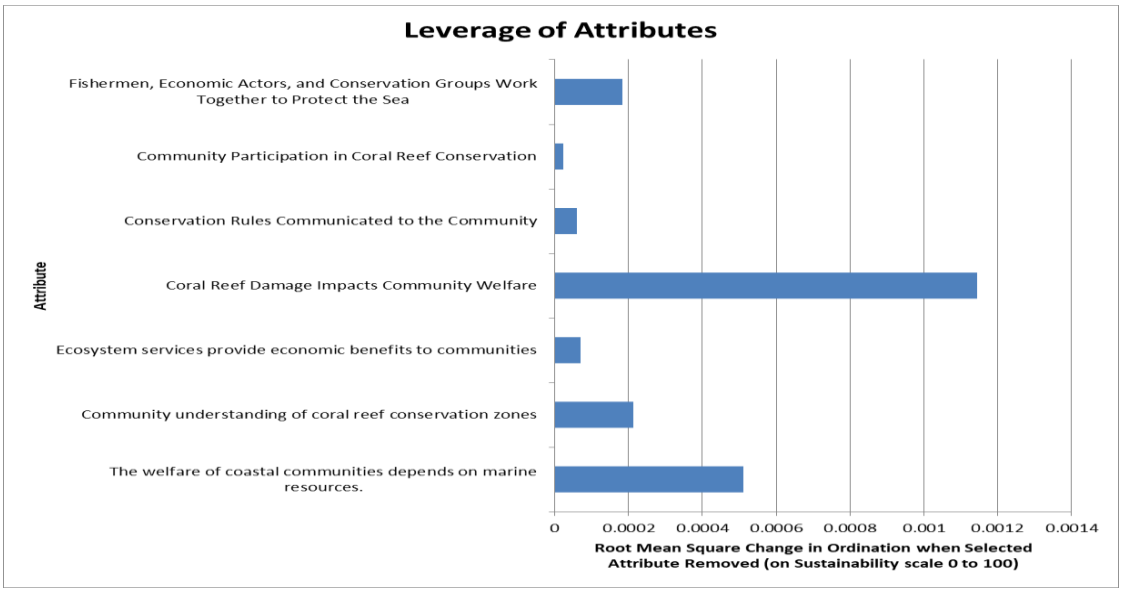

Fig. 2. Social-ecological interactions in coral reef ecosystems in the Gorontalo Bay conservation area

Fig. (2) shows the results of leverage analysis on the socio-ecological interaction dimension, with the three most influential attributes being : (1) coral reef damage impacts well-being, (2) coastal community well-being depends on marine resources, and (3) community understanding of coral reef conservation zones. These three attributes describe the interaction between communities and coral reef ecosystems in the Gorontalo Bay conservation area.

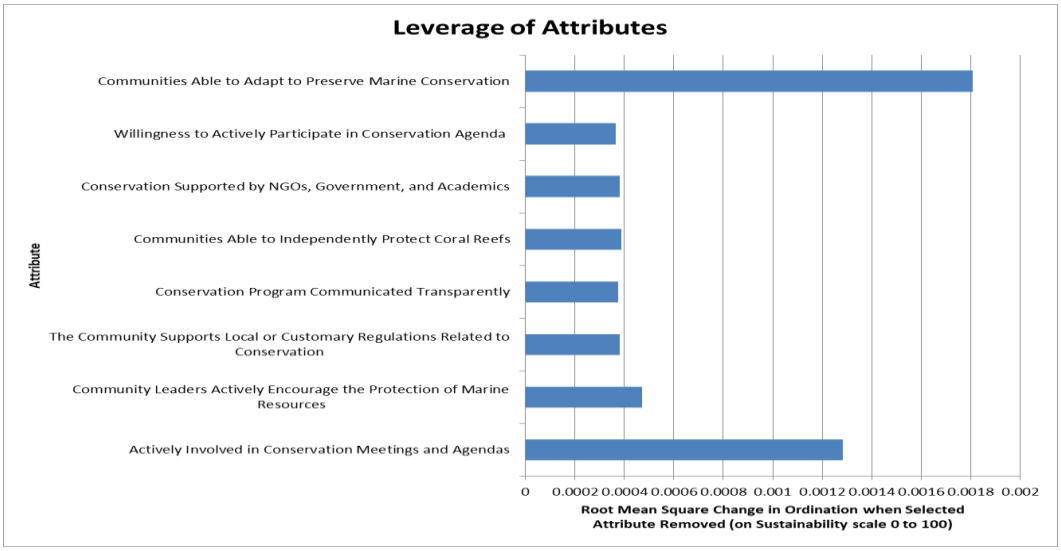

Fig. 3. Determining factors for conservation success in the Gorontalo Bay area

Fig. (3) shows the three attributes with the highest leverage that influence conservation effectiveness, namely: (1) the community's ability to adapt to maintain marine sustainability, (2) active involvement in conservation meetings and agendas, and (3) the role of community leaders in encouraging the protection of marine resources. These three attributes illustrate the effectiveness of conservation activities.

DISCUSSION

1. Socio-ecological characteristics of coral reef ecosystems

Fig. (1) presents the results of the leverage analysis of socio-ecological characteristics, showing the three most prominent attributes as follows. .

1.1. Healthy coral reefs and well-being

The first and most influential attribute is *"Healthy coral reefs improve well-being."* This shows that ecosystem health is directly related to the social and economic aspects of coastal communities. Coral reefs provide various ecosystem services, including fishery resources, natural protection against coastal erosion, and marine tourism attractions. According to **Adger *et al.* (2005)**, the well-being of coastal communities is significantly influenced by the ecological integrity of coastal ecosystems, including coral reefs. Empirical evidence from various tropical countries indicates that coral reef degradation results in reduced fishermen's income, loss of eco-tourism-based jobs, and increased vulnerability to natural disasters. Therefore, maintaining the health of coral reefs is not only a conservation issue but also an ecosystem-based development strategy.

1.2. economic dependence on the sea

The second attribute indicates that *"the community's economic livelihood depends on marine resources."* High economic dependence on the sea increases socio-ecological risks if the ecosystem is damaged. **Bennett *et al.* (2014)** state that in this context, conservation approaches that do not consider economic dependence tend to fail because they trigger social resistance. Areas such as Gorontalo Bay, which have traditional coastal communities and few livelihood alternatives, are highly dependent on the stability of marine ecosystems. Therefore, conservation policies must consider mechanisms for livelihood diversification, economic incentives, and strengthening the capacity of local sustainable businesses. Blue economy development programs are important as a complement to conservation programs.

1.3. The importance of coral reefs for livelihoods

The third attribute is *"Coral reefs are important for the livelihoods of coastal communities."* This underscores the multifunctional value of coral reefs in the daily lives

of communities. They are not only a source of protein and income but also hold symbolic and cultural value in local traditions. **Cinner *et al.* (2009)** emphasized that communities' perceptions of the ecological and cultural value of coral reefs significantly influence their level of participation in conservation efforts. When communities view coral reefs as part of their social identity, there is a collective drive to protect and restore them.

1.4. Implications for Gorontalo Bay

These three attributes are highly relevant in the context of Gorontalo Bay. The area is significantly dependent on fishing, ecotourism, and other marine environmental services for its economy. Therefore, conservation programs in this area must be designed not only to preserve biodiversity but also as tools for strengthening the local economy. Successful conservation programs should aim for integration between conservation and livelihoods, such as payment for environmental services, certification of sustainable fisheries products, and the development of community-based educational tourism. Such interventions enable the creation of a symbiosis between social well-being and ecological integrity.

2. Socio-ecological interactions in coral reef ecosystems

Fig. (2) shows the results of the analysis of socio-ecological leverage, displaying the three most prominent attributes as follows.

2.1. Coral reef damage and its impact on well-being attributes

"Coral reef damage impacts well-being" is a key indicator in understanding the causal relationship between ecosystem degradation and the decline in the socio-economic conditions of communities. Damaged coral reefs lead to reduced fish catches, the destruction of marine tourism potential, and increased risks of coastal erosion. **Hughes *et al.* (2017)** state that ecological regime shifts can trigger social crises, particularly in areas with high dependence on marine resources.
In the context of Gorontalo Bay, coral reef damage can affect food security and the income of traditional fishermen. Local studies indicate that damage caused by destructive activities such as bombing and the use of toxins further accelerates social vulnerability. Therefore, ecosystem restoration cannot be separated from efforts to improve community welfare; both are two sides of the same coin.

2.2. Dependence of well-being on marine resources

The second attribute, *"The well-being of coastal communities depends on marine resources,"* emphasizes the structural relationship between community economic systems and the health of coastal ecosystems. When local economic systems are based on fragile ecosystems, any ecological disturbance will have a major impact on the social dimension.

McClanahan *et al.* (2011) highlight that coastal communities with limited livelihood options face greater pressure in responding to environmental crises. Therefore, it is crucial to promote economic diversification and introduce sustainable economic practices, such as rights-based fisheries, sustainable aquaculture, and ecosystem service payment schemes. In the context of Gorontalo Bay, dependence on small-scale fisheries without sustainable management places communities in a cycle of vulnerability. The solution is not simply to prohibit or restrict access but must be accompanied by strategies to strengthen economic capacity that is adaptive to ecological change.

2.3. Understanding conservation zones as an instrument of compliance

"Community understanding of coral reef conservation zones" serves as a cognitive instrument that shapes attitudes and behavior toward conservation regulations. When communities understand the objectives, boundaries, and benefits of conservation zones, compliance levels increase significantly **(Christie *et al.*, 2009)**. The failure of many marine conservation areas to achieve their objectives is often due to a lack of socialization and environmental education.
In a study by **Mascia *et al.* (2010)**, compliance with conservation regulations is directly proportional to the level of public understanding of the area's ecological and social functions. A two-way communication approach, the involvement of traditional and religious leaders, and the provision of contextual and locally-language learning media must support the implementation of conservation zones in Gorontalo Bay. This approach will shape new social norms that support long-term conservation.

2.4. Implications for management in Gorontalo Bay

This attribute highlights the importance of a holistic socio-ecological approach. Conservation area management should not only focus on ecological dimensions or law enforcement but must also address the understanding, dependency structures, and perceptions of local communities. Adaptive co-management models are the most relevant approach, as described by **Armitage *et al.* (2009)**, because they integrate shared learning, policy flexibility, and social inclusion.
Conservation strategies in Gorontalo Bay must also consider socio-economic incentive instruments, such as ecosystem insurance schemes, financial support for micro-enterprises based on the sea, and enhanced conservation education capacity at the school and community levels. With such an approach, the socio-ecological system in Gorontalo Bay will not only become more resilient to ecological pressures but also more socially equitable and sustainable in the long term.

3. Determining factors for the success of coral reef conservation

The success of coral reef conservation in a socio-ecological context is not determined solely by ecological aspects. It is also greatly influenced by the social

dynamics of the surrounding communities. The graph (Fig. 3) shows the three attributes with the highest leverage affecting conservation effectiveness: (1) the community's ability to adapt to maintain marine sustainability, (2) active involvement in conservation meetings and agendas, and (3) the role of community leaders in encouraging marine protection. Together, these attributes illustrate the synergy between adaptive capacity, participation, and leadership as fundamental elements of conservation success.

3.1. Social adaptation as a pillar of conservation resilience

The first attribute—*"the community's ability to adapt to maintain marine conservation"*—ranks the highest in leverage. Adaptive capacity is crucial for sustaining coral reef ecosystems, as it enables communities to learn, innovate, and adjust to environmental and policy changes. According to **Folke *et al.* (2005)**, adaptive capacity is a core component of resilient socio-ecological systems. Adaptation in tropical coastal communities takes the form of livelihood shifts, acceptance of zoning policies, and adoption of environmentally friendly technologies. As **Cinner *et al.* (2018)** argue, these adaptations are not merely coping strategies but fundamental elements of long-term resilience. Environmental literacy, education, and access to information further enhance adaptive capacity. When communities understand that marine sustainability directly impacts their well-being, they are more likely to support conservation initiatives.

3.2. Involvement in the conservation agenda as social capital

The second attribute—*"active involvement in conservation meetings and agendas"*—underscores the importance of participation in decision-making. Active participation fosters a sense of ownership, making communities feel like partners rather than passive recipients of external policies. **Reed (2008)** shows that authentic stakeholder participation is key to successful environmental management. Participation must go beyond consultation to become collaborative and deliberative, ensuring that community voices shape outcomes. In marine conservation cases across the Philippines and Indonesia, bottom-up approaches have proven more effective than top-down models **(Christie *et al.*, 2003)**. In Gorontalo Bay, participation in conservation meetings also facilitates knowledge exchange, clarifies regulations, and fosters new social norms. This is critical in preventing conflicts that often arise from information gaps and social exclusion.

3.3. Role of community leaders as agents of change

The third attribute—*"community leaders actively encourage the protection of marine resources"*—emphasizes the pivotal role of local actors in bridging policy and practice. Leaders, both formal (e.g., village heads) and informal (e.g., traditional or religious leaders), hold legitimacy and influence that can mobilize collective behavior. In Chile, **Gelcich *et al.* (2010)** demonstrated that visionary local leaders successfully drove

community transformation toward sustainable resource management. In Indonesia, leaders often mediate conflicts, build coalitions, and reinforce customary rules that support conservation. They also mobilize trust, solidarity, and cooperation, strengthening social capital—the foundation of community-based conservation **(Pretty & Smith, 2004)**.

3.4. Implications for Gorontalo Bay

In Gorontalo Bay, these three attributes provide both practical and conceptual guidance. Communities exhibit strong dependence on marine resources but also possess robust social structures and rich local knowledge. Conservation strategies that rely solely on technocratic approaches are unlikely to succeed without also strengthening adaptive capacity, promoting genuine participation, and empowering local leaders. Co-management approaches, as proposed by **Ostrom (2009)**, ensure that communities are actively involved not only in implementation but also in policy design and evaluation. In this way, conservation becomes a process of social transformation as well as ecological protection.

4. Conceptual framework of the socio-ecological system of coral reef ecosystems in the Gorontalo Bay conservation area (based on Ostrom, 2009)

1) Resource system (RS)

- Unit of Analysis: Coral reef ecosystems in the Gorontalo Bay conservation area.
- Characteristics: Provide food, coastal protection, and ecotourism services.
- Current Condition: Healthy but under pressure from destructive fishing practices such as bombing and poisoning.

2) Resource units (RU)

- Unit of Analysis: Reef fish, valuable marine biota, and tourism services.
- Characteristics: Limited in supply, high in economic value, highly dependent on reef quality.
- Threats: Overfishing, habitat destruction, and lack of income diversification.

3) Governance system (GS)

- Unit of Analysis: Conservation zoning policies, utilization rules, and the role of government and customary institutions.
- Key Issues: Weak understanding of conservation rules, poor law enforcement, and limited adoption of adaptive co-management.

4) Actors (A)

- Unit of Analysis: Local fishers, community leaders, religious leaders, women, and youth.
- Capacity: Strong adaptive potential but high economic and informational vulnerability.
- Strategic Role: Leaders as change agents, women as central to coastal households, and religious figures as advocates of environmental ethics.

5) Interaction (I)

- Unit of Analysis: Resource use, compliance with regulations, and participation in conservation.
- Findings: Participation fosters social ownership; zoning knowledge strengthens compliance; ecosystem degradation undermines well-being.

6) Outcomes (O)

- Positive: Healthy reefs enhance well-being; high participation strengthens conservation.
- Negative: Degraded reefs reduce livelihoods; exclusionary conservation increases resistance.

7) Related ecosystems (ECO)

- Unit of Analysis: Adjacent coastal waters in Tomini Bay, mangroves, and seagrass beds.
- Interrelationships: Ecological connectivity supports food webs and marine reproduction.

Scientific explanation

Ostrom's framework offers a holistic understanding of conservation in Gorontalo Bay. A systemic view reveals that ecological sustainability cannot be separated from social capacity and local governance. From RS and RU, communities' dependence on coral reefs means ecological damage directly threatens income, food security, and social stability. This aligns with the ecosystem-based development perspective of **Adger *et al.* (2005)**, which argues that sustainable development must rest on ecosystem health.

From the GS and A dimensions, conservation success depends on leadership quality and community participation. Visionary leaders, as highlighted by **Gelcich *et al.***

(2010), foster collective norms that strengthen conservation. Yet weak governance structures often hinder policy implementation. Interaction (I) is shaped by communities' understanding of rules and benefits. When benefits are clear, compliance and engagement rise. Adaptive co-management—characterized by flexibility and collaboration—offers a strategic pathway **(Armitage *et al.*, 2009)**.

Outcomes (O) are dualistic: technocratic, exclusionary conservation breeds resistance and continued degradation, whereas participatory, inclusive conservation generates positive feedback between ecological integrity and social well-being. Thus, long-term success in Gorontalo Bay depends on framing conservation as both ecosystem protection and social transformation.

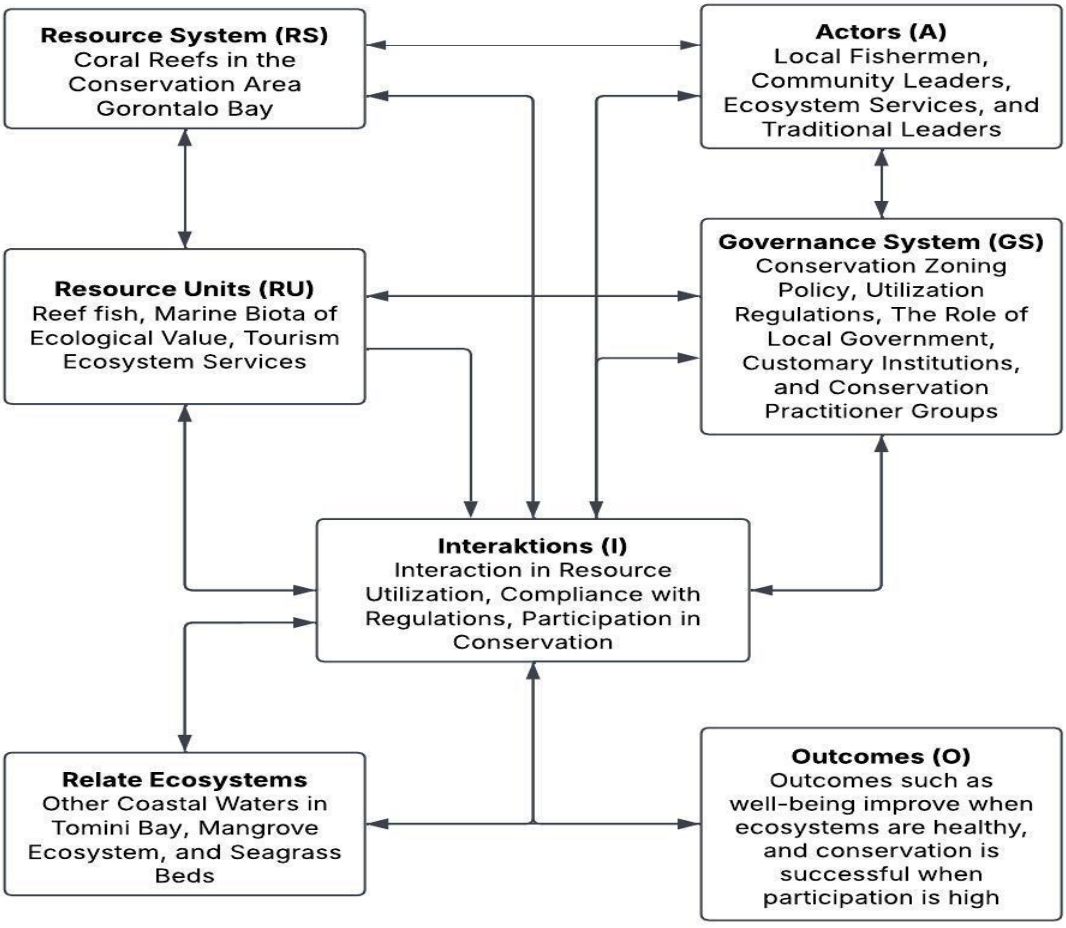

Fig. 4. Conceptual diagram of the social-ecological system of the coral reef ecosystem in the Conservation Area of Gorontalo Bay

CONCLUSION

This study confirms that the social-ecological system (SES) approach can provide a comprehensive understanding of the sustainability dynamics of coral reef conservation areas, particularly in Gorontalo Bay. Findings indicate that attributes such as coral reef health, economic dependence on the sea, and community understanding of conservation zoning are key determinants of management success. Moreover, conservation success is significantly influenced by community adaptive capacity, active participation in conservation forums, and the transformational role of community leaders. Technocratic approaches that overlook social aspects have proven inadequate in areas with strong social and communal structures and high ecological dependence. Therefore, the SES-based conceptual framework developed in this study can serve as a strategic foundation for designing inclusive, adaptive, and locally-driven conservation policies. For further research, longitudinal studies are needed to monitor long-term changes in socio-ecological dynamics. Additionally, integrating quantitative spatial methods such as GIS-based participatory mapping can enhance the analysis of interactions between actors, conservation areas, and ecological conditions in a more precise and contextual manner.

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