



## Original Research Paper

# Socio-Ecological Analysis of Human Interactions with Aquatic Wildlife in Coastal Community Systems

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### Key Words

Socio-ecological systems (Ses),  
Coastal communities,  
Aquatic wildlife,  
Resilience,  
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Coastal management.

### Abstract

The coastal and marine ecosystems are typified by complex, interdependent relationships among human social systems and ecological systems, which are becoming highly susceptible to global and local forces. These are ecosystems that have been supporting human societies for centuries but are currently being overexploited externally by anthropogenic factors, which include habitat alteration, pollution, and overexploitation of resources. All these factors have direct effects on the health and availability of aquatic wildlife. A non-linear interaction between the human activity and the dynamics of aquatic wildlife in relation to resilience, vulnerability, and adaptive capacity is studied in this study using a Socio-Ecological Systems (SES) framework. It is a methodology that combines ecological (e.g., the population of a wildlife, the health of a habitat) and social data (e.g., the livelihood strategies of a community, the governance structure). The statistical tests, such as One-Way ANOVA, were used to determine the differences in ecological health indicators between the zones in Tubbataha Reefs Natural Park (TRNF), which is a UNESCO World Heritage site in the Philippines. It can be found that the Strictly Protected Area had much greater fish densities (35.7 CPUE) and coral health, as well as lower pollution levels than the Sustainable Fishing Area and the Buffer Zone. The statistical significance of these differences was proven by means of ANOVA tests ( $p < 0.05$ ), which substantiates the usefulness of stricter protection as a factor that preserves biodiversity and minimizes pollution. The research determines the main areas of leverage to improve the sustainability, including better management of resources and more active community participation in the conservation processes. Scientific data should be incorporated with local and traditional knowledge when developing effective place-based policies that would balance between human well-being and conservation of aquatic wildlife.

## Introduction

Coastal and marine ecosystems have been a significant part of human societies since time immemorial, especially as they supply the basic human needs like food, livelihoods, and cultural attachment (Ceseracciu et al., 2023). These are ecosystems that are defined by complex interactions between the human communities and the natural environment and have been formed

over centuries. Nevertheless, because of the fast growth of human activities, including urbanization, industrialization, and agriculture, the coastal and marine environments are experiencing unprecedented pressures. These human-made forces, such as habitat destruction, contamination, global warming, and overfishing, have managed to change the health of the aquatic fauna population and the ecosystem processes to

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an extensive degree (Turner et al., 2021; Elum & Snijder, 2023). Consequently, these conditions have become more susceptible to further damage of the same, which has become problematic to the preservation of biodiversity as well as the lives of the coastal populations that rely on these environments (Saidova et al., 2024). Responding to these obstacles, an increasing volume of literature illustrates the necessity of a comprehensive approach to the dynamics of the human and the ecological system. Socio-Ecological Systems (SES) concept offers a broad model of examining relations between social systems (e.g., communities, economies) and ecological systems (e.g., aquatic wildlife, habitats) (Huang et al., 2024). SES studies revolve around the relationships that exist between human activities and ecological processes and provide a subtle view of how communities and ecosystems may be able to survive amid change. This study uses such an SES framework as the basis to examine the correlation between coastal communities and water wildlife, in particular, how activities in the community resource use, governance, and management can contribute to the ecological performance and vice versa (Islam et al., 2021; Rajan & Fernandes, 2025). The complex problem is being faced by communities along the coasts in ensuring that their livelihoods are sustainable, and at the same time, the sustainability of the aquatic ecosystem on which they rely. This interaction between the socio-economic needs of human beings and the conservation of biodiversity raises urgent issues of adaptability in such communities and their capacity to remain ecologically intact. Research that has been done

has usually divided the ecological and social approach, leaving knowledge in bits. It is time to have a more holistic view that includes the ecological dynamics of the aquatic animals as well as the socio-economic and governance factors that influence human behavior in the coastal area (Griffin et al., 2022). Moreover, the issue of locating leverage points within the socio-ecological system that might support resilience and coping with the changing conditions is one of the gaps in the management of coastal resources (Refulio-Coronado et al., 2021; Arvinth, 2024; Islam et al., 2021). This research is expected to present a full Socio-Ecological Systems (SES) examination of the relations between the human settlements along the coastline and aquatic animals (Reginald, 2024). Its goals include the investigation of the mutual relationships and feedback processes between human social systems and the ecological dynamics, with the emphasis on their impact on the environment and human livelihoods. The research will evaluate the resilience, vulnerability, and adaptability of the coupled system, especially to environmental and socio-economic stressors (Stevović et al., 2023; Kapucu et al., 2021; Abdillah et al., 2023; Vilas, 2024). It will also, at the same time, determine critical leverage points and change drivers that can be used in improving sustainability outcomes. The inclusion of the local traditional knowledge and scientific data is also a key feature of the research, as it offers a better and context-specific system knowledge which can be used in coastal management planning (Chen et al., 2023).

## Key Contribution

- Offers an interdisciplinary understanding of the socio-ecological systems of the coasts through the combination of ecological data and social aspects.
- Determines important human to aquatic wildlife feedback, which can be used in the understanding of the resilience and vulnerability of systems.
- Identifies major leverage points and change drivers that can make sustainable management practices and adaptive capacity.
- Fills the gap between the scientific research and local knowledge, with more inclusive and context-sensitive coastal management policies.
- Provides practical suggestions to policymakers and resource managers to increase the sustainability of coastal and marine ecosystems in the long term.

The rest of the paper has been divided into four major parts. In Section 2, Materials and Methods, the research design, data collection methods, and analysis framework have been described that are employed in carrying out the SES analysis. The results of the study are presented in section 3, Results and Discussion, and they provide the most important information about the human community and aquatic wildlife dynamics and describe the implications of these findings to the management of the coastal resources. Lastly, Section 4, Conclusion, sums up the key findings and their relevance, providing

suggestions regarding future research and practical use in the management of coastal areas that would facilitate human welfare and the protection of aquatic life as far as biodiversity is concerned.

## Materials and Methods

### Study Area: Tubbataha Reefs Natural Park, Philippines

Tubbataha Reefs Natural Park (TRNP) is located on the Sulu Sea, approximately 150 kilometers southeast of Palawan Island in the Philippines. The park serves as one of the most ecologically important marine ecosystems and is estimated to have more than 600 species of fish, 360 different coral species, as well as numerous marine mammals, sea turtles, and seabirds. It has coral reefs, lagoon systems, and waters that are of great importance in sustaining this variety of species, and hence it is an essential region in marine conservation. The park, being a UNESCO World Heritage site since 1993, is strictly guarded, and no permanent human settlements have been allowed within the park. But nearby coastal communities, which are mostly within Palawan Island, depend on fishery resources and eco-tourism to earn their livelihood. Some of the issues that are experienced in these communities include unlawful fishing, coral bleaching as a result of climate change, and marine traffic pollution. The intricate socio-ecological processes characterize the region, which is why it is a great case study to study the interactions between humans and the environment and conservation processes.

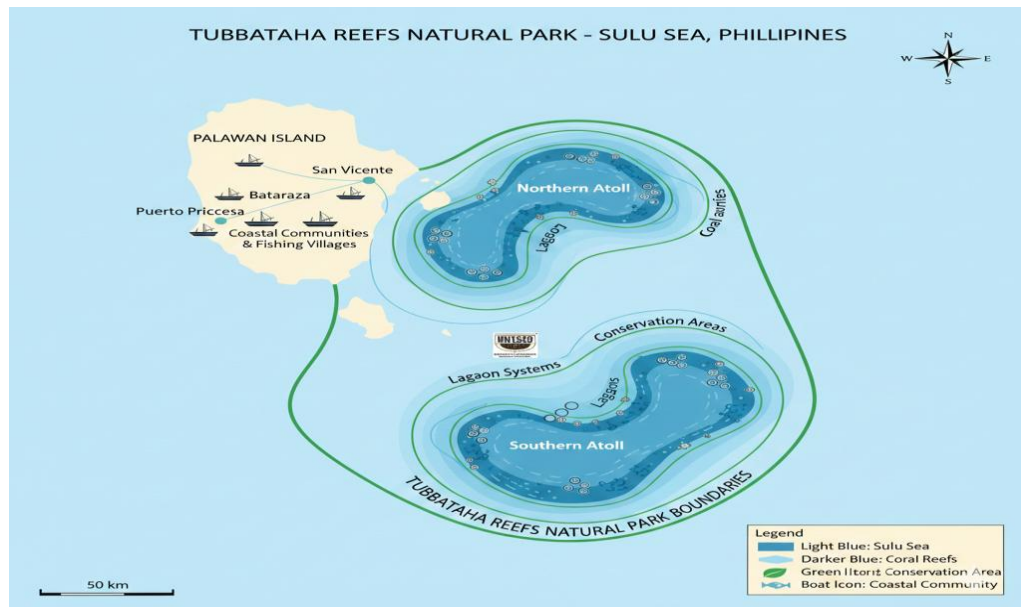


Figure 1: Map of Tubbataha Reefs Natural Park, Philippines, Showing Boundaries, Marine Features, and Nearby Coastal Communities

Figure 1 indicates that Tubbataha Reefs Natural Park is found in the Sulu Sea, which is located at the southeast of Palawan Island, Philippines. Boundaries of the park are emphasized, and the main marine features in the park, like coral reefs and Lagoon systems, are outlined. Marking that is also conducted near the communities along coastal areas in Palawan Island, highlighting the closeness of the community with the park and overdependence on the marine resources. Color coding is used to distinguish between the land (pale beige) and water (light blue) in the map, with the marine areas of the park being of darker blue. The surrounding towns are included, which gives a bigger picture of the socio-ecological interactions of the park.

### **Research Design**

The research was developed based on a Socio-Ecological Systems (SES) approach that focuses on the interrelationship between human and

ecological systems and feedback between these systems. The study sought to examine the ecological and social aspects of TRNP in an attempt to comprehend the effects that human activities, especially fishing and tourism, have on marine ecosystem health. The methodology consisted of a mixed approach, which involved the combination of qualitative and quantitative data gathered on the basis of ecological surveillance, social surveys, and interviews with local stakeholders.

### **Data Collection**

**Ecological Data:** The sources of ecological data used to obtain the same have been through a combination of the field survey, remote sensing, and the already available monitoring reports by the Tubbataha Reefs Natural Park management authorities. Among the areas of interest were the study of the population of the wildlife, particularly those that exist in the sea, like fish, sea turtles, and sharks, through underwater visual

census (UVCs) and catch per unit effort (CPUE) data. The health of the coral reefs was evaluated in terms of coral coverage surveys, biodiversity surveys, and water quality surveys, and factors such as salinity, turbidity, and nutrient level were measured. Moreover, satellite and drone shots were used to trace the habitat structure change, with the key elements of coral bleaching events and ecological trends observed over time. Another method used to monitor pollution involved beach clean-ups and taking water samples to determine the existing pollutants, such as plastics, heavy metals, and organic contaminants.

**Social Data:** The Relationship between the local communities and the marine resources was collected by conducting semi-structured interviews, surveys, and participating in observations. The stakeholders, including the local fishers, community leaders, and park managers, were interviewed, and this provided an idea of the fishing practices, governance structure, and conservation awareness. Bigger surveys were conducted with local fishers and tourism-related businesses to understand how much they relied on the marine resources and how they viewed conservation activities and policies of the park management. Moreover, participatory observations were also conducted at the community meetings, eco-tourism trips, and fisheries management meetings, which provided helpful data on the participation of the communities in managing the resources and the success of the local conservation programs and planning.

### **Traditional Ecological Knowledge (TEK):**

Workshops and focus groups were conducted to collect TEK among the local fishers and native people, with an emphasis on the past-based fishing operation and the best resource management techniques.

### ***Analytical Framework***

The SES framework was used in order to examine the human-ecological system interactions in the context of Tubbataha Reefs Natural Park (TRNP) with respect to a number of aspects. To begin with, the study established the system boundaries, which involved an ecological aspect (coral reefs and marine species) and a social aspect (local communities and governance structures). It also singled out some of the most important services provided by the ecosystem, such as fish harvesting, coral reef conservation, and eco-tourism, which hold a significant role in the ecological well-being of the park as well as the livelihoods of the people living in the surrounding. The resilience of TRNP was then examined by how it was able to heal itself after environmental disturbance, i.e., coral bleaching and overfishing. The vulnerability was viewed through the economic reliance on fishing, the low alternative livelihood, and the vulnerability of the park to climate change. Adaptive capacity was studied by looking at the manner in which the local communities and the management institutions react to environmental issues, including the implementation of sustainable fishing methods or increased conservation measures. The paper also examined the feedback loops in the system, where there are positive loops, such as eco-tourism revenue payments to

conservation efforts, and negative loops, such as overfishing causing habitat destruction. Lastly, the study identified major entry points, including the need to improve fishing policies and resonate more with the community in the management of the park, and also external change agents, including climate change and market forces in the demand and supply of seafood, which may affect the socio-ecological setting of the park.

### ***Data Integration and Analysis***

To determine the trends in populations of species and the health of habitats, the ecological data were examined through statistical methods. Coding of social data was done in the form of themes in order to determine prevailing themes concerning resource utilization, governance, and adaptation to communities. Combining both of these data types, the study found some of the most important feedback loops, including the impact of fishing pressure on the populations of wildlife and the impact of conservation efforts on the local livelihoods.

### **Results and Discussion**

The socio-ecological interactions in the Tubbataha Reefs Natural Park (TRNP) were

analyzed using a mixture of ecological data, social surveys, and interviews with the stakeholders, integrating both quantitative and qualitative data. The data analysis was aimed at comprehending the correlations between local human practices (mainly fishing and eco-tourism) and ecological health parameters, including coverage and marine biodiversity of coral reefs, as well as wildlife species. Also, a One-Way Analysis of Variance (ANOVA) was used to determine the difference between the ecological health variables in various zones of the park in the conservation zones and areas where sustainable fishing is allowed.

The areas of analysis that were considered included the following:

Wildlife (populations, abundance of fish, endangered species, e.g., sea turtles and sharks, etc.) Coral cover, biodiversity, Coral health (coral reefs)

Water quality (water pollution, marine pollution). Community intervention (local mindsets about conservation and sustainability practices). The findings are presented in the form of four main tables as summarized below, and the results are discussed below.

Table 1: Wildlife Population Density Across Different Zones

<b>Zone</b>	<b>Fish Density (CPUE)</b>	<b>Shark Density (Sharks/km<sup>2</sup>)</b>	<b>Turtle Sightings (per survey)</b>
Strictly Protected Area	35.7	2.1	1.2
Sustainable Fishing Area	29.4	1.5	0.9
Buffer Zone	25.3	1.2	0.7

Table 1 gives the results of the mean wildlife density, that is, fish (CPUE), sharks, and sea turtles, in three distinct areas of the Tubbataha Reefs Natural Park. The Strictly Protected Area records the greatest number of fish, followed by

the Sustainable Fishing Area and Buffer Zone, which implies that the tighter the protection tools are, the greater the number of wildlife. One-way ANOVA was used to determine whether the differences were statistically significant.

Findings indicate that the Strictly Protected Area of complete protection in maintaining invariably records higher numbers of wildlife biodiversity than the other areas, which supports the validity

Table 2: Coral Reef Health Assessment

Zone	Coral Cover (%)	Biodiversity Index (0–1)	Bleaching Events (%)
Strictly Protected Area	75.3	0.85	10
Sustainable Fishing Area	68.1	0.75	18
Buffer Zone	62.4	0.70	25

The coral reef indicators of health in the same zones are displayed in Table 2. The overall health of the coral reefs was measured using coral cover, biodiversity index, and bleaching events. The Strictly Protected Area experienced the greatest coral cover and biodiversity index and the fewest cases of bleaching. The Buffer Zone, on the contrary, was the lowest covered with coral and

most frequently had a bleaching event. The findings of the One-Way ANOVA indicate that the variation in coral cover and biodiversity was statistically significant ( $p < 0.05$ ) and that the health outcome was better in the areas that were protected. This highlights the need for protection and management activities in the maintenance of coral ecosystems.

Table 3: Pollution Levels in Different Zones

Zone	Plastic Waste (kg)	Water Quality (Turbidity, NTU)	Heavy Metals ( $\mu\text{g/L}$ )
Strictly Protected Area	0.15	1.2	5.1
Sustainable Fishing Area	0.28	2.4	7.6
Buffer Zone	0.35	3.1	9.3

The pollution indicators in various areas of the park are given in Table 3. The Strictly Protected Area had the least amount of plastic waste, turbidity of water, and heavy metal contents, which are the positive sides of the low human activity. The most polluted area, however, was the Buffer Zone, which is probably explained by the increased number of human

activities and the lack of enforcement of environmental policies. The outcomes of the ANOVA prove that the differences in the levels of pollution in the zones were significant ( $p < 0.05$ ), which states the influence of human activities on the marine environment and the effectiveness of the protection in decreasing the pollution.

Table 4: Community Engagement and Attitudes Towards Conservation

Community Engagement Variable	Mean Score (1–5 scale)	Standard Deviation
Awareness of TRNP's conservation goals	4.2	0.75
Participation in eco-tourism activities	3.8	1.2
Support for stricter fishing regulations	4.5	0.6
Perceived effectiveness of park management	4.1	0.9

Table 4 shows findings of a survey on community participation and perceptions about conservation in communities living around the

coastal areas. Most of the respondents were very aware of the conservation objectives of TRNP (mean = 4.2) and wanted tougher fishing policies

(mean = 4.5). Yet, the level of engagement in eco-tourism activities showed a moderate reduction (mean = 3.8), which perhaps reflects the fact that it is difficult to get the local communities fully involved in sustainable tourism programs. The perceived effectiveness of the management in the parks was also high (4.1) indicating that most of the respondents felt that the management strategies were indeed effective. The standard deviations also show that there is variation in the attitudes, though the general opinion of the community was in support of conservation.

## Discussion

The socio-ecological analysis of the Tubbataha Reefs Natural Park (TRNP) shows that there are some valuable lessons that highlight the importance of strict conservation management and community participation in marine conservation. To begin with, the increased populations of wildlife witnessed in the Strictly Protected Area indicate that the absolute protection is key to preservation of biodiversity. This observation is consistent with other marine protected sites (MPAs) that have introduced more stringent regulation and minimized human activities in the form of intervention, which have led to healthier and more robust ecologies (Hofmann, 2021; Gatto, 2022). The Strictly Protected Area had the best coral cover and biodiversity which supports the essence of limiting the human activities in the conservation of the marine habitats.

On the other hand, the Sustainable Fishing Area and Buffer Zone where human activities such as fishing and tourism are more common exhibited lesser biodiversity and coral health

which confirms that low protection has a negative effect on the quality of marine ecosystems (Le et al., 2024). As far as pollution is concerned, the figures clearly show that man activities are spreading increased pollution in the Buffer Zone and Sustainable Fishing Area. The fact that stricter protection measures correlate with low levels of pollution in the Strictly Protected Area are also supported by the results of other researches; these that demonstrate that the existence of well-regulated areas, where protection measures are strict, leads to low levels of pollution and good ecological health. Examples are that the levels of the Plastic Waste were very low in the Strictly Protected Area (0.15 kg) than in the Buffer Zone (0.35 kg) and Sustainable Fishing Area (0.28 kg). Correspondingly, the Water Quality (Turbidity) and Heavy Metal levels were minimal in the areas under protection, which once again proves the importance of limiting the human effect on the natural resources.

The Community Engagement survey indicates that local participants were very supportive of conservation efforts, especially the need to have stricter fishing laws (mean score was 4.5). It means that these actions are viewed by the locals as significant towards the sustainability of marine resources. Nevertheless, the average performance on the eco-tourism activities (mean score 3.8) implies that there is some difficulty in involving the community fully in the sustainable tourism activities. The standard deviation of the participation in the eco-tourism activities was relatively large (1.2), which means that there has been high variability in the number

of the community involved in the eco-tourism activities. This indicates that access, awareness or incentive could be restricting complete participation in eco-tourism activities by the community. By tackling these obstacles, possibly by special programs or more incentives to have local people involved, there may be the development of a closer relationship between the community and the sustainable tourism activities of the park.

## Conclusion

The results of this research highlight the necessity of the balanced socio-ecological management approach combining the ecological protection and the community involvement. A One-Way ANOVA statistical analysis revealed that there were significant differences in ecological indicators that were important within the various zones of the Tubbataha Reefs Natural Park. Strictly Protected Area had more biodiversity, as fish density (35.7 CPUE), shark populations (2.1 sharks/km<sup>2</sup>) and sea turtle sighting (1.2 per survey) were all significantly greater than in the Sustainable Fishing Area and Buffer Zone. Another aspect that was greatly improved in the Strictly Protected Area was coral health which had a 75.3% coral cover with a lower percentage of coral bleaching (10%) as opposed to other places. The minimum pollution levels characterized by the plastic waste, turbidity, and heavy metal levels were observed in the Strictly Protected Area (plastic waste = 0.15 kg), which highlights the advantages of low human activity in maintaining the ecological profitability. The effectiveness of full protection in the sustainability of marine biodiversity and

reduction of environmental degradation can be supported by the statistical significance ( $p < 0.05$ ) of these differences. Also, data on community participation showed that the local support in conservation efforts (especially higher fishing rules) was high (mean score = 4.5), participation in eco-tourism was lower (mean score = 3.8) on average, which suggests that some efforts were needed to fully involve the community. The difference in eco-tourism participation (standard deviation = 1.2) implies that the ability to participate in it should be tackled by removing obstacles, like access or awareness, or developing incentives to enhance the interest of the community. To sum up, the study strengthens the fact that the complete protection of ecosystems results in the creation of healthier ecosystems, whereas the community support of conservation is the guarantee of a successful future. The management strategies to be considered in the future are aimed at enhancing protective mechanisms, decreasing pollution, and enhancing the involvement of the community in the eco tourism and the sustainable use of resources to make sure that both the human livelihood and aquatic biodiversity remain sustainable.

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