

Research Article

Ecosystem resilience in action: Evaluating structural, functional recovery, and socio-economic impact of mangroves after restoration efforts

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Abstract

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Mangrove ecosystems are important biodiversity supporters, coastline protectors and climate stabilizers. However, human activities and environmental changes pose increasing risks to these areas. This study examined the environmental and social impacts of a five-year effort to restore mangroves in Abucayan Sur, Calape, Bohol, Philippines, an area that was once used for fishponds. The project ran from 2019 to 2024. Quadrat sampling was conducted along with transects and local residents were interviewed to assess changes in mangrove species richness, tree growth (basal area, canopy diameter, tree height), the number of macroinvertebrates, and community perceptions of the restoration efforts. The results indicate that both the number of mangroves and their diversity index have improved significantly. After restoration, we identified seven (7) true mangrove species, with *Rhizophora apiculata* becoming the most common. Structural indicators showed considerable improvement. Both canopy diameter and tree height increased, demonstrating robust forest growth. The number of macroinvertebrates, particularly razor shells and mangrove crabs, increased as habitats recovered, although we observed some short-term declines following typhoons. Socio-economic statistics reveal that coastal communities continue to rely primarily on fishing and other coastal resources for their livelihoods. Despite this, there are still challenges, such as the effects of climate change and a lack of educational opportunities. In conclusion, community-based mangrove recovery can cause considerable ecological restoration and social and economic benefits within five years. The results emphasize the need for continuous monitoring, adjusting management measures, and involving stakeholders for sustainably maintaining and resilient mangrove forests in the Philippines in the long term.

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Introduction

Sustainability is a complex idea that means meeting the requirements of the current generation without making it impossible for future generations to meet their demands. There are three (3) main parts to it: economic, social, and environmental sustainability (Purvis et al., 2019). This all-encompassing method understands that all of these aspects need to be looked at collectively in order to be successful in the long run. Sustainability is very important for both global climate

action and ocean health in mangrove ecosystems (Sustainable Development Goals 13 and 14). Mangroves are great at storing carbon dioxide, which helps slow down climate change. They also provide important homes for marine life, which helps keep seas healthy and works toward SDG 14. We can improve both climate resilience and the health of marine ecosystems by protecting these ecosystems in a way that lasts. This introduction sets the stage for a discussion of how protecting mangroves fits with important SDGs while also stressing more general

ideas of sustainability. The Philippines is an archipelago of 7,107 islands that is completely inside the tropics of Southeast Asia. The country has a long coastline that is around 36,289 kilometers long. It is flanked by many large bodies of water: the Celebes Sea and Sulu Sea to the south, the South China Sea to the west, and the Philippine Sea to the east (Long and Giri, 2011). This archipelago is well known for being one of the best places in the world for biodiversity. It is home to a wide range of endemic species, making up around 1.9% of all endemic plants and animals in the world (Myers et al., 2000). In addition, a study by Calumpang and Menez (1996) shows that the coastal areas of the Philippines have some of the most diverse marine plant life in the world.

Mangroves are very important coastal ecosystems that provide numerous ecological, economic, and social benefits, including shoreline protection, fisheries support, carbon sequestration, and livelihood opportunities for coastal communities (Lovelock et al., 2024). They are home to many different types of marine life, keep beaches from eroding, and help people in the area make a living. But human activities like deforestation, urbanization, and climate change have had a big effect on these important ecosystems (Bhagarathi and DaSilva, 2024). Many projects around the world have started to fix mangroves that have been damaged in order to bring them back to health and function. Researchers have found that mangrove recovery can be stable during this time period, with big changes in the structure and function of the vegetation. However, the success of these efforts can depend on the factors at each site, such as the hydrology, the type of sediment, and the status of the mangrove ecosystem before it was rehabilitated. It is very important to know what the present state of mangrove ecosystems is like after they have been restored. This will help make policy decisions and make conservation efforts work better as the environment continues to change.

While studies show that restoring mangroves is a complicated and multi-faceted process, it needs careful planning, community involvement, and continual monitoring. Effective mangrove rehabilitation extends beyond tree planting and must integrate ecological restoration with community participation, livelihood support, and social sustainability to ensure long-term success and local stewardship (Valenzuela et al., 2020). Getting local people involved in the restoration process makes them feel like they own it and are responsible for it, which is important for the long-term viability of the initiatives.

The goal of this study was to evaluate mangrove ecosystems five years (5) after rehabilitation efforts, from 2019 to 2024. This project is an important aspect of the university's outreach work to plant and restore mangroves in the neighboring neighborhood. Because the area was a fishpond, it needs ecological restoration right away to bring the environment back to life and

keep it that way. The study tried to give useful information about how well restoration plans work while also looking at how long they will last.

Materials and Methods

Study area

The research took place in Barangay Abucayan Sur, which exists within Calape municipality in the island province of Bohol, Philippines. The site exists at geographical coordinates 9.9066° N latitude and 123.9087° E longitude, while its height reaches 9.9 meters above mean sea level. The coastal area contains a narrow strip of mangrove vegetation that experiences tidal changes and suffers from human activities that include small-scale fishing and gleaning. The researchers chose this location for their study because it accurately shows how community-managed mangrove areas operate while also providing easy access to ecological and socio-economic research needs.

Sampling design and vegetation assessment

The researchers conducted a structural assessment of the mangrove forest through the application of a strip transect–quadrat method, which followed established protocols for tropical coastal ecosystem studies (English et al., 1997; Alongi, 2009). The researchers established three (3) transect lines, which extended from the seaward edge of the mangrove stand to landward for 30 meters. The researchers designed the transects to study intertidal zone patterns that would result from their placement across different tidal zones.

The researchers established contiguous quadrats that measured 10 m x 10 m (100 m²) along each transect line. The quadrats were placed next to each other because the mangrove area covered only a small space, which resulted in continuous strip sampling. The researchers used standard taxonomic references for Philippine mangroves to identify all mangrove trees within each quadrat that had a diameter at breast height (DBH) of 2.5 centimeters or higher. The data on height, crown diameter, and basal diameter measurements were collected for each tree that was identified. The researchers estimated tree height through two (2) methods, which included a measuring pole and visual approximation methods that had been calibrated before conducting fieldwork. The crown diameter was measured through two (2) perpendicular axes, and the average diameter was calculated. A diameter tape was used to measure the basal diameter at a height of 1.3 meters above ground level. The data were recorded on these parameters to measure forest structure, species composition, and growth performance.

Regeneration assessment

Natural regeneration within the mangrove ecosystem was assessed by establishing three (3) 1 m x 1 m sub-

quadrats within each 10 m x 10 m plot. These smaller plots were distributed systematically within the larger quadrat to ensure spatial representation and to minimize sampling bias. Within each sub-quadrat, all juvenile mangrove individuals were counted and identified to species level. Individuals were classified as seedlings if they measured less than one meter in height and as saplings if they were at least one meter tall but had a DBH of less than 2.5 cm. This classification allowed for the evaluation of recruitment dynamics and regeneration potential within the study area, following approaches described in mangrove ecological studies (Dahdouh-Guebas and Koedam, 2006).

Faunal assessment

The researchers conducted a faunal assessment to study the macroinvertebrate population, which included their assessment of gastropod species that inhabit mangrove ecosystems. A 1m x 1m quadrat was established at the center of each 10m x 10m plot to conduct their sampling activity. The researchers selected low tide periods for their sampling work because those times provided the best conditions to observe and reach the target organisms.

The manual collection method was used to gather all visible invertebrates from the quadrat area, which they then stored in sterile ziplock bags. Gastropods were collected from mangrove tree trunks, prop roots, and leaves through direct inspection and hand picking. The collected specimens were identified to species level using standard taxonomic keys and reference materials, including the FAO species identification guides (Carpenter and Niem, 1998), supplemented with updated taxonomic verification from online databases such as the World Register of Marine Species (WoRMS Editorial Board, 2024) and SeaLifeBase (Froese and Pauly, 2024) to ensure current nomenclature and classification.

Socio-economic survey and selection of respondents

For the socio-economic part of the study, the researcher employed an adapted questionnaire from Walters (2004), which is a recognized survey format used in analyzing the dependence of the community in relation to the mangrove ecosystem. Purposive sampling was used in selecting respondents, wherein

those who are involved with the utilization of the mangrove ecosystems for their livelihood purposes were targeted. Fisherfolk and other coastal residents involved in fishing and gleaning were among those identified.

Thirty-two respondents were chosen based on the recommendation from barangay officials and community leaders to ensure that respondents are knowledgeable about the mangrove ecosystem. Requirements of being an active or retired fisherfolk from Barangay Abucayan Sur with one year or more experience living in the coastal areas were considered in choosing respondents. Prior to the conduct of interviews, respondents were approached individually and informed about the objectives and scope of the study.

The researchers provided clear and accessible explanations regarding the purpose of the research, the nature of participation, the types of questions to be asked, and any potential risks or benefits associated with the study. Informed consent was obtained from all participants before proceeding with the interviews. Data collection was carried out through face-to-face interviews using the structured questionnaire, with additional probing questions asked when necessary to clarify responses. All information gathered was recorded systematically and treated with confidentiality.

Results and Discussion

In the present study, species diversity and abundance were assessed five years after restoration efforts in the mangrove ecosystem of Abucayan Sur, Calape, Bohol, Philippines, to determine patterns of structural recovery and species establishment. A total of seven (7) mangrove species belonging to four (4) families were recorded across the assessment area, as shown in Table 1. The total number of mangrove individuals increased substantially from 71 individuals during the pre-restoration phase to 278 individuals after restoration, indicating a marked improvement in vegetation establishment and stand development. Among the species documented, *Rhizophora apiculata* exhibited the highest post-restoration abundance with 108 individuals, accounting for 38.8% relative abundance.

Table 1. Species diversity of mangroves in Abucayan Sur, Calape, Bohol (ordered by quantity).

Family Name	Scientific Name	Number of Individuals (Pre-restoration)	Number of Individuals (Post-restoration)	Relative Abundance (%)
Rhizophoraceae	<i>Rhizophora apiculata</i>	2	108	38.8
Rhizophoraceae	<i>Ceriops decandra</i>	30	62	22.3
Acanthaceae	<i>Avicennia marina</i>	0	38	13.7
Sonneratiaceae	<i>Sonneratia alba</i>	5	28	10.1
Acanthaceae	<i>Avicennia alba</i>	15	15	5.4
Rhizophoraceae	<i>Kandelia candel</i>	15	15	5.4
Myrsinaceae	<i>Aegiceras corniculatum</i>	4	4	1.4
Total	7 species	71	278	100.0

This was followed by *Ceriops decandra* with 62 individuals (22.3%) and *Avicennia marina* with 38 individuals (13.7%). Meanwhile, *Sonneratia alba*, *Avicennia alba*, *Kandelia candel*, and *Aegiceras corniculatum* were observed at comparatively lower abundances. The increase in species occurrence and overall stand density suggests that restoration interventions facilitated favorable conditions for mangrove recruitment, establishment, and survival within the rehabilitated coastal zone.

The dominance of *R. apiculata* observed in the study is consistent with restoration trends reported across Southeast Asia, where *Rhizophora* species are commonly utilized because of their high propagule viability, rapid establishment, and tolerance to fluctuating tidal conditions (Salmo et al., 2023). A global meta-analysis by Worthington and Spalding (2018) identified *Rhizophora apiculata* and *Avicennia marina* among the most frequently used and successful species in mangrove rehabilitation programs. Similarly, recent assessments of restored

mangrove ecosystems demonstrated that *Rhizophora* species often exhibit higher survival and structural dominance under restored intertidal conditions due to their adaptability to unstable sediments and saline environments (Djamaluddin et al., 2024). The observed increase in mangrove abundance and species representation indicates progressive structural recovery of the restored ecosystem five years after intervention. Species heterogeneity within restored mangrove stands is ecologically significant because mixed-species assemblages contribute to greater ecosystem resilience, productivity, and resistance to environmental stressors such as storm surges, erosion, and climate-related disturbances.

The rehabilitation efforts have resulted in significant improvements in the growth and structural development of mangrove ecosystems over the past five (5) years (Figure 1). Key indicators, such as basal area, canopy diameter, and tree height, have shown consistent increases, demonstrating the success of the restoration initiatives.

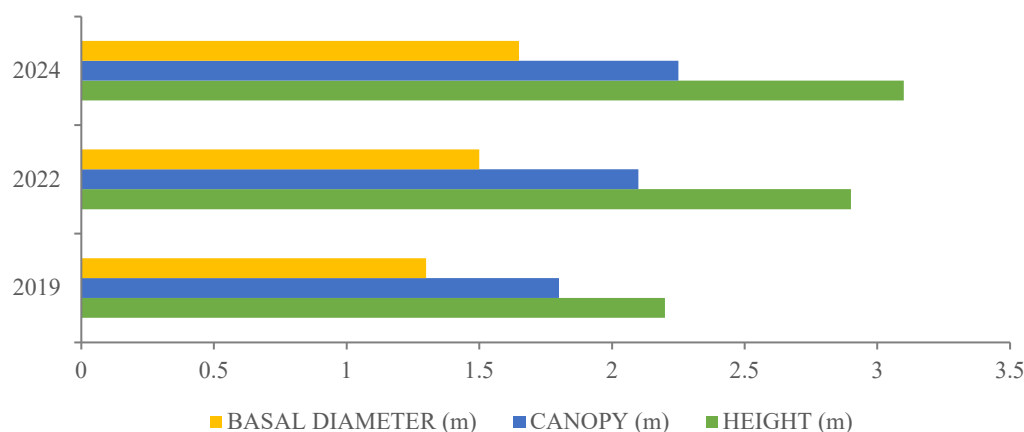


Figure 1. Structural metrics of mangroves.

Basal area, which represents the cross-sectional area of tree trunks at breast height, has steadily increased since 2019. In 2019, the average basal area was 1.3 m, which grew to 1.5 m in 2022 and further increased to 2.65 m by 2024. This expansion in basal area indicates that the mangrove trees have been actively increasing in girth, reflecting healthy stand development and improved structural stability of the rehabilitated forest. Increasing basal area is commonly associated with enhanced biomass accumulation and carbon storage capacity in restored mangrove ecosystems (Adame et al., 2021). Similarly, Macera et al. (2024) emphasized that increasing stand structure and vegetation development are important indicators of ecological recovery and maturation in rehabilitated mangrove ecosystems.

The average diameter of mangrove canopies has also shown a positive trend over the years. In 2019, the mean canopy diameter was 1.83 m, which increased to 2.11 m in 2022 and reached 2.25 m by 2024. The expansion of canopy diameter suggests that the trees

are continuously developing broader crowns and denser vegetation cover, contributing to improved habitat complexity and ecological functioning. Canopy expansion in mangrove ecosystems is strongly linked to increased primary productivity, sediment trapping efficiency, and shoreline stabilization (Camacho et al., 2020; Macreadie et al., 2022). Furthermore, denser canopies help regulate microclimatic conditions and provide shelter for associated faunal communities, thereby enhancing biodiversity within restored coastal habitats.

Moreover, the height of mangrove trees is another crucial indicator of ecosystem recovery. In 2019, the average tree height was 2.23 m, which increased to 2.92 m in 2022 and further grew to 3.12 m by 2024. The steady increase in tree height demonstrates that the mangroves are actively growing and progressing toward greater ecological maturity, enabling them to provide more effective coastal protection and habitat functions. Taller mangrove stands are known to improve wave attenuation

capacity and increase resilience against storm surges and coastal erosion (Menendez et al., 2020). Supporting these findings, Primavera and Esteban (2008) reported that mangrove replanting initiatives in the Philippines resulted in substantial increases in tree height and canopy cover over a five-year monitoring period, highlighting the effectiveness of restoration programs in improving forest structure and ecological complexity. The observed structural improvements in the present study, therefore, suggest that the restoration initiatives implemented in Abucayan Sur have contributed positively to the recovery and long-term resilience of the mangrove ecosystem.

Statistically, linear regression revealed a significant positive trend in basal area from 2019 to 2024 ($R^2 = 0.97$, $p < 0.01$). The average basal area increased from 1.3 m² in 2019 to 2.65 m² in 2024, indicating consistent and robust girth growth among mangrove trees. A significant upward trend was also observed for canopy diameter ($R^2 = 0.96$, $p < 0.01$), with mean values rising from 1.83 m in 2019 to 2.25 m in 2024. This suggests that the mangrove canopy has expanded substantially, contributing to greater habitat complexity. Tree height demonstrated a significant linear increase over the study period ($R^2 = 0.99$, $p < 0.001$), with average height growing from 2.23 m in 2019 to 3.12 m in 2024. This indicates that the mangroves are not only surviving but thriving, reaching higher levels of maturity.

One-way ANOVA was conducted to compare the means of each structural metric across the three (3) time points (2019, 2022, 2024), and the results indicate statistically significant differences in all metrics across the years. Tukey's HSD tests were

performed for pairwise comparisons between years. For all three (3) metrics, significant differences ($p < 0.05$) were found between 2019 and 2022, and between 2019 and 2024. The differences between 2022 and 2024 were also significant for basal area and tree height, but not for canopy diameter, suggesting that most canopy expansion occurred earlier in the rehabilitation period. These analyses demonstrate a clear, statistically significant upward trend in the structural development of the rehabilitated mangrove forest. The consistent increases in basal area, canopy diameter, and tree height over time reflect the success of restoration efforts and the ability of the rehabilitated mangroves to recover and mature. The significant pairwise differences between years further confirm that growth improvements are not due to random variation but are a result of effective management and rehabilitation strategies.

The assessment of mangrove ecosystems post-rehabilitation has also revealed a notable increase in the number of mangrove-associated macroinvertebrates over the years (Figure 2). Razor shell (*Ensis arcuatus*) shows a significant increase in number, which corresponds with the development of the mangrove structure.

Mangrove-associated bivalves and intertidal macroinvertebrates are commonly observed in high abundance within rehabilitated mangrove areas because of improved sediment conditions and habitat complexity (Hamza et al., 2024). This increase is significant as it reflects the overall health and recovery of the mangrove habitat, which is crucial for maintaining biodiversity and supporting ecosystem functions.

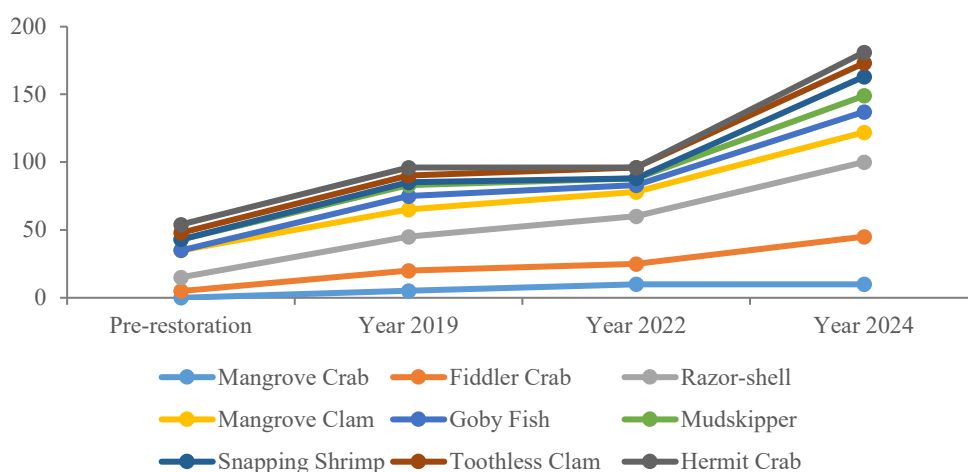


Figure 2. Abundance of mangrove-associated macro-invertebrates.

The graph illustrates a clear upward trend in the abundance of various macroinvertebrate species in the mangrove area from pre-restoration to 2024. All species, including mangrove crab, fiddler crab, razor-shell, and others, show marked increases over time, with the most significant surge occurring between

2022 and 2024. This overall growth in population numbers strongly suggests that the mangrove restoration efforts have been highly effective, leading to improved habitat quality and greater biodiversity within the ecosystem. Some species, such as mangrove clam, muskipper, goby fish, snapping

shrimp, and hermit crab, show noticeable decline in 2022 mainly due to the recent typhoon Odette, which affects their ecosystem, and recovery is still underway.

In terms of its socio-economic impact, the survey revealed that the dominant age groups among respondents were 31-40 years and 41-50 years, representing the core working-age population actively engaged in coastal resource utilization. The majority of respondents were male, reflecting the gender dynamics typical of fishing communities in the region. Educational attainment was primarily at the primary level, followed by secondary education, indicating moderate literacy levels that may influence livelihood opportunities and awareness of environmental issues.

The average family size was 5 members, suggesting typical household compositions in rural coastal communities. Similar demographic characteristics have been documented in coastal fishing communities in the Philippines, where middle-aged male household heads predominantly participate in fisheries and mangrove-related livelihoods, while limited educational attainment often influences adaptive capacity and resource management participation (Israel and Adan, 2021).

Fishing emerged as the primary source of income, with respondents having resided in the area for more than 10 years, highlighting a long-term dependence on coastal resources. Among fishing activities, gleaning was the most common, followed by coastal fishing. Most respondents reported fishing on a daily basis, demonstrating the reliance on consistent harvests for subsistence and income. While respondents noted a slight increase in catch, the average monthly income remained modest at around 5,000 PHP, with only a slight upward trend over the study period.

Awareness of mangrove rehabilitation efforts was high among respondents, with the majority acknowledging the positive impacts, such as reduced shoreline erosion and storm damage, and improved fish catch due to better breeding grounds. These perceptions underscore the ecological benefits of mangrove restoration and its importance to the community's livelihood security. The respondents strongly agreed on the critical role of mangroves in coastal protection and resource sustainability. Similar findings were reported by Friess et al. (2020), who emphasized that coastal communities with high dependence on small-scale fisheries commonly perceive mangrove restoration as beneficial for fishery productivity, shoreline stabilization, and long-term livelihood resilience.

Approximately 70% of respondents participated in mangrove rehabilitation activities, reflecting active community engagement. Community participation is considered a critical factor in the long-term success of mangrove restoration because local stewardship enhances resource protection, monitoring, and sustainability outcomes (Friess et al., 2022). However, challenges remain, notably a lack of financial support

or resources for fishing equipment, which limits the ability of fishers and gleaners to maximize their livelihoods sustainably.

Respondents expressed the need for financial and technical support, including capital for livelihood diversification and capacity-building initiatives, to enhance resilience and reduce pressure on mangrove resources. The community recommended extending restoration efforts to include *Nypa* palm areas, recognizing their ecological and economic significance.

Despite the slight increase in catch and income, overall household income has remained largely unchanged due to the rising number of gleaners and increasing commodity costs. Additionally, there have been no significant new livelihood opportunities introduced, which constrains economic growth. Nonetheless, respondents reported a slight improvement in household quality of life, likely attributable to enhanced coastal protection and resource availability from mangrove rehabilitation. This suggests that while economic gains are modest, the social and environmental benefits contribute positively to community well-being. Similar observations were reported by Romañach et al. (2021), who noted that restored mangrove ecosystems often provide immediate ecological and protective benefits to coastal communities even when direct economic improvements remain gradual and limited during the early years of restoration.

Conclusion

The significant increases in basal area, canopy diameter, and tree height over the past five (5) years demonstrate the successful recovery of mangrove ecosystems in the rehabilitated areas. These structural developments indicate that the mangroves are thriving and providing essential ecosystem services, such as coastal protection, carbon sequestration, and habitat provision. Continued monitoring and maintenance will be crucial to ensure the long-term sustainability of these rehabilitated mangrove forests. Moreover, the increase in the number of mangrove-associated macroinvertebrates following rehabilitation efforts is a promising indicator of ecosystem recovery and health. This growth reflects improved environmental conditions and highlights the importance of mangroves as critical habitats for biodiversity.

Overall, while the socio-economic improvements are incremental, the combined ecological and social benefits of mangrove rehabilitation contribute to enhancing community resilience and quality of life. Continued support and adaptive management are essential to sustain these gains and promote long-term sustainability. Continued research and monitoring will be essential to further understand the dynamics of these communities and to ensure the sustainability of mangrove ecosystems in the face of ongoing environmental challenges.

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