Typhoon-induced mangrove changes and its impacts on livelihood resources in Palawan, Philippines

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ABSTRACT

Raising global climate change has increased the frequency and severity of typhoons, posing a serious threat to mangroves and the well-being of coastal communities. These typhoons contribute to a loss of 10% of the mangrove cover each year, but little attention has been paid to the impact of typhoons on mangroves in Southeast Asia. This study fills this knowledge gap by assessing the aftermath of Typhoon Rai and its impact on mangroves and livelihoods in Palawan, Philippines. Sentinel-2 satellite images were utilized to conduct a normalized difference vegetation index analysis and compare vegetation conditions before (2021) and after the typhoon (2022). In addition, household survey interviews involving 266 household heads and key informant interviews with 12 entities responsible for mangrove management were conducted to assess their impact on livelihood. Focus group discussions and field visits were conducted to validate and supplement the collected data. The results showed significant changes in mangrove cover between the pre-typhoon and post-typhoon periods. Dense mangrove areas have experienced a decline of about -96% (-15,091.1 hectares), while sparse and bare mangrove areas have declined by 1,650 % (13,605.1 hectares) and 192% (1,485.8 hectares), respectively. Following mangrove changes, ecosystem goods and services have also changed. Mangrove-dependent households experienced a decline in the yields of shrimp, crabs, mangrove clams/clams, mangrove snails, sea cucumbers, and nipa (*Nypa fruiticans*), and a decline in ecotourism businesses. In particular, there was an increase in the yield of woodworms (tamilok), the felling and collection of mangrove wood/poles, recreational/tourism activities, and research initiatives. Nevertheless, total revenue from mangrove resources decreased by about 50%, a loss of PHP 77,8560 (USD 1,406) compared to pre-typhoon levels in 2021, amounting to PHP 154,886.90 (US$2,796.15) on average. Although some communities recognize typhoon-related mangrove operations, household participation remains low. This study highlights the need for targeted mangrove interventions, particularly in denuded areas, to accelerate recovery and mitigate losses to mangrove ecosystems and livelihoods. Additionally, providing livelihood support to households that lack coping strategies can help stabilize their income until mangrove ecosystem services are restored.

INTRODUCTION

Mangroves are considered to be the backbone of tropical coastal communities. It provides livelihoods to predominantly low-income fishing communities (Lee et al. 2014). Valuable resources ranging from non-timber forest products, including nipa materials (*Nypa fruiticans*), honey, and medicinal plants, to fisheries, firewood, timber, and mangrove fruits, are few to

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KEYWORDS

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many commodities derived from mangroves (Hutchison et al. 2014). Its aesthetics and beauty are used to grow tourism and create local employment opportunities (Samonte-Tan et al. 2007). It is also home to a diverse range of terrestrial and marine flora and fauna, and is highly valued for its critical role in climate regulation, nutrient cycling, carbon sequestration, and bio-shielding from extreme weather events.

Mangroves play a crucial role in the marine fishery industry. In the Asia-Pacific region, approximately 200 million people depend on the marine ecosystem for sustenance and livelihood (UNDP 2019). Approximately 80% of global fishery-related employment was comprised of small-scale artisanal fishers and aquaculture farmers (FAO 2022). Mangrove ecosystem services (MES) were estimated to provide an average global value of 9,900 USD per hectare (Costanza et al. 1997). In Aborlan, Palawan, Philippines, mangroves were estimated to provide an annual household harvest of PHP 321,200.00 (5,798.57 USD) from fishing and gleaning activities as coastal livelihood (Buncag and Lubrico 2016). Following Typhoon Haiyan, there is a growing recognition of the protection and conservation of mangroves in coastal greenbelt zones (Reyes 2020). In addition, mangroves are four times better at sequestering carbon than terrestrial forests (Spalding and Leal 2021). Under the changing climate, safeguarding mangroves is perceived as a strategic action in climate mitigation through carbon sequestration and enhancing carbon sinks (Quevedo et al. 2022).

Over the years, typhoons have impacted the livelihoods of mangroves and communities. In 2008, Typhoon Chan-hom affected the Lingayen Gulf, northwestern Philippines, by changing soil properties in the mangroves, reducing tree densities, disturbing the fauna, and inducing mangrove mortality (Salmo et al. 2013). In addition, Typhoon Haiyan in 2013 destroyed at least 83% of the mangroves in Lawaan-Balanggiga, Eastern Samar (Cabello et al. 2021). Fish kills and a decline in the quality and quantity of fish and crab harvest in the aftermath of Typhoon Haiyan on Caluit Island, Palawan, Philippines, were observed following mangrove disturbances (Malabrigo et al. 2016).

Under climate crisis, typhoon events are intensifying and more frequent, making mangroves more susceptible to damage and loss. It has been recognized that mangroves have the qualities of self-repair and self-maintenance (Moberg and Rönnbäck 2003; Costanza et al. 2008). However, aggravated by various anthropogenic disturbances extending beyond its limits, it disrupts the essential functions and services of mangroves, potentially leading to mortality, extinction, and peat collapse (Krauss and Osland 2020). The United Nations Intergovernmental Panel on Climate Change (2022) predicted that storm events under Category 4-5 would increase worldwide with increasing global warming. Sippo et al. (2018) reported that since the 1960s, 36,000 hectares of mangroves have died due to storm events, equivalent to approximately 10% of the annual mangrove loss. In a favorable environment and without any disturbances, mangroves disturbed by typhoon events require 10-25 years for recovery. However, frequent exposure can delay recovery (Salmo and Gianan 2019). A delay in recovery has consequences for the mangrove's delivery of various goods and services, and can directly impact the subsistence and livelihoods of the dependent community. Asia is home to the world's leading mangrove forests (Spalding and Leal 2021). Similarly, the region was geographically favorable to storm events, but few studies have attempted to understand the impact of tropical cyclones on mangroves (Salmo 2021). Post-typhoon assessments were mainly conducted in the Caribbean and Australia (Sippo et al. 2018). In the Asia-Pacific region, marine ecosystems support the food and livelihoods of 200 million people (UNDP 2019). Anthropogenic drivers combined with extreme climatic events pose a threat to mangrove dynamics. Despite the growing issue of mangrove damage and losses due to extreme weather events, the disaster losses related to mangrove ecosystems and ecosystem services are not well understood (Hinzpeter and Sandholz 2018; Walz et al. 2021).

In the Philippines, increasing typhoons have become an emerging threat to mangroves (Buitre et al. 2019). The country is considered to be an extremely diverse and carbon-rich mangrove forest. It is home to approximately 29 mangrove species (Garcia et al. 2014) and stores seven percent of the global carbon stocks (Chatting et al. 2022). The possibility of mangrove loss and post-typhoon mangrove assessment is an invaluable study that sheds light on the impact of typhoon events on mangroves. This could provide critical insights into the vulnerability of mangrove-dependent households and serve as a basis for enforcing conservation measures and mitigating environmental and economic impacts. Furthermore, sustainable mangrove management is viewed as contributing to achieving the multiple goals and targets of global initiatives, including SDG 13 (Climate Action), SDG 15 (Life on Land), and many other SDGs.

The aim of this study was to assess the mangrove status following Typhoon Rai and the extent of its impact on coastal livelihoods in Palawan, Philippines. It focuses on examining mangrove vegetation changes, resource changes, impacts on livelihood conditions following vegetation changes, and relevant interventions on mangroves in response to typhoons.

MATERIALS AND METHODS

Study Area

The study was conducted in Palawan, Philippines, located to the west of the Pacific Ocean (PCSDS, 2015). It is geographically situated at 9° 44' 26.5056" North and 118° 43' 48.2592" East (Figure 1). Mangrove forests covered approximately 56,261 hectares or 22.23% of the 256,185 hectares Philippines' total mangrove cover in 2000 (Long & Giri, 2011). The agriculture, farming, and fishery sectors share 58% of the employment sources in the province (PCSDS 2015).

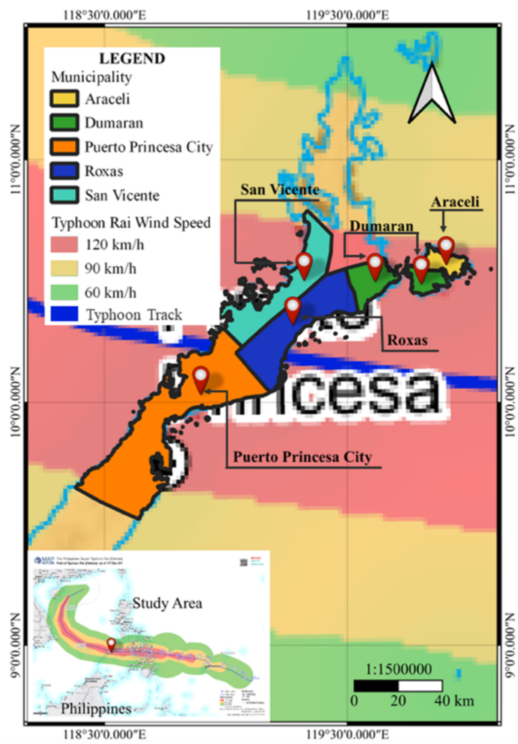

Figure 1: Location of the Study Area

On December 14, 2021, Typhoon Rai hit the Philippines, including the Province of Palawan, which was recorded as one of the strongest in the country (Gerretsen 2022). Typhoon Rai rapidly intensified from Categories 1 to 5 within a day, making people less capable of evacuating easily. (Center for Disaster Philanthropy 2022). The United Nations Office for the Coordination of Humanitarian Affairs (2021) reported that typhoons affected 8 million people (OCHA 2021). It took 400 people's lives, and caused economic loss and damages of at least half a billion dollars (Gerretsen 2022). In the aftermath, Typhoon Rai's post-damage assessment focused on damages to built-in infrastructures, such as commercial buildings and schools (Meneses and Blanco 2022). Thus, this study was initiated to assess the losses and damage to mangrove vegetation and the livelihood of the coastal community following Typhoon Rai. The study covers the five municipalities in Palawan which were heavily affected by Typhoon Rai, specifically Puerto Princesa City, San Vicente, Roxas, and Dumaran Araceli, which cover mangrove areas of 6,000 hectares, 941 hectares, 3 485 hectares, 4,160 hectares, and 2,723 hectares, respectively (Figure 1). Overall, these municipalities constitute approximately 31% of the mangrove area in the province. In terms of mangrove ratio to land cover, Araceli has the highest portion of mangroves (15.4%), Dumaran (7.5%), Roxas (2.8%), Puerto Princesa (2.7%), and San Vicente (0.6%). Araceli and Dumaran are island municipalities that are geographically favorable for the growth and development of mangroves, and human disturbances are not widespread. Consequently, Roxas, Puerto Princesa City, and San Vicente are on the mainland and are geographically more exposed to human threats, including mangrove encroachment due to lack of space for settlement, mangrove deforestation for fuelwood and charcoal, unregulated mangrove conversion for commercial and tourism purposes, and siltation caused by road construction.

Data Collection

The overall research methodology of this study is illustrated in Figure 2. This study collected both remotely sensed and primary data. Remote sensing data included Sentinel-2 high-resolution (10 m) images available from open-source for two time periods: 2021 for the pre-typhoon period (March, June, and December) and 2022 (February, May, and September) for the post-typhoon period. Images with less than 10% cloud cover were carefully selected and pre-processed before analysis. The mangrove boundary from DENR-CENRO Palawan, which was produced by the National Mapping and Resource Information Authority, was collected as input for data processing to minimize the effects of noise during image processing (DENR-NAMRIA 2020). For conducting household surveys from a total of 117,028 households (Philipine Statistics Authority 2020), the sample size was determined using the Slovin sample formula with a margin of error of ± 0.07 and a confidence level of 93 % (see Equation 3.1), and an additional 10% of the total sample size of 224 was suggested. Hence, a total of 266 households were interviewed using a questionnaire on mangrove-related livelihood activities. The number of surveyed households was 89, 68, 68, and 28 from Puerto Princesa, Roxas, Dumaran, San Vicente and Araceli, respectively.

$$n = \frac{N}{1 + N\,(e^2)} \quad (Equation\ 1)$$

where n is the sample size, N is the total population and e is the margin of error

The semi-structured survey questionnaire, consisting of four sections, was primarily used to collect data on household livelihood resources, income, and mangrove management strategies. This section consists of four sections: the first part contains the demographic profile (age, sex, education, and home distance from the mangroves), the second section is related to the mangrove resources and services utilized for household sustenance and livelihood, the third section covers the changes in mangrove resources before and after the typhoon, and for the last section, the details about mangrove management and historical participations were collected. To augment the information from the remotely sensed data and primary data collection, KII and FGD were conducted. Selected entities who were responsible for and actively engaged in mangrove-related programs in the community were invited to key informant interviews. For each municipality, five community leaders were interviewed, one community-based organization, four local government unit representatives (Roxas, San Vicente, Dumaran, and Araceli) and two representatives of the Department of Environment and Natural Resources (CENRO-Roxas and CENRO-Puerto Princesa City) participated. Additionally, two focus group discussions involving the local community were conducted in Puerto Princesa (four women and eight men) and Araceli (one woman and seven men). These two sites were purposively selected, Puerto Princesa City, representing mainland municipalities including Roxas and San Vicente, and the Araceli as the island municipalities, including the Dumaran.

Data Analysis

The Normalized Difference Vegetation Index (NDVI) is one of the most common approach in mapping and assessing the likely health of mangrove vegetation (Ruan et al. 2022; Valderrama-Landros et al. 2018). Studies on post-typhoon mangrove assessment were able to produced optimized mangrove vegetation analysis using NDVI (Cabello et al. 2021; Farzanmanesh et al. 2021; Nesperos et al. 2021; Raynaldo et al. 2020; Razali et al. 2019).

First, Sentinel-2 images were collected from the Copernicus Sci Hub (https://scihub.copernicus.eu/apihub), pre-processed, and downloaded using the Semi-Automatic Classification Plugin in the QGIS 2.28.2 platform (Luca 2021). To quantify the changes in mangrove vegetation, the Normalized Difference Vegetation Index (NDVI) was calculated by applying the NDVI equation to the pre-processed sentinel-2 images (Equation 2).

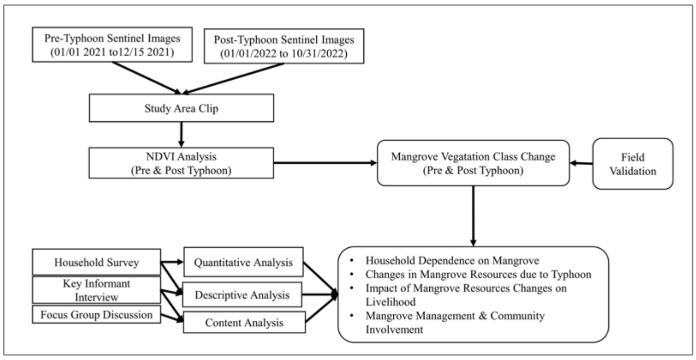

Figure 2: Overview of Methods used for Assessing the Mangrove Changes and the Impacts on Livelihood Before and After the Typhoon

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (Equation\ 2)$$

To categorize the mangrove vegetation based on the NDVI values, a classification system suggested by Nesperos et al. (2021) was adopted, specifically dense (NDVI 0.5–1.0, indicating that mangroves are intact and characterized by a closed canopy), sparse (NDVI 0.11–0.5, indicating sparse low-density forest cover and a relatively open canopy), and bare (NDVI, 0-0.11, indicates a barren area in which mangrove trees are almost absent or dead). The Wilcoxon signed-rank test was used to determine whether there were significant differences in the vegetation index before and after the typhoon, as Jiménez-Rodríguez et al. (2022) described.

Second, to assess the impacts on household livelihoods, descriptive statistics and inferential statistics, particularly the paired sample t-test and Wilcoxon Signed Rank Test, were used to assess the significant changes in livelihoods before and after the typhoon event (Ken et al. 2020). Pearson correlation and chi-square independent tests were used to assess the association between household recovery, mangrove recovery, and mangrove utilization. Content analysis of the qualitative data collected from focus group discussions and key informant interviews was conducted to collectively capture relevant information and triangulate the responses collected through interviews and remotely sensed data.

Finally, a field validation was conducted at selected mangrove sites in five municipalities by visiting the sites from October to December 2022 for photo documentation and collecting Global Positioning Points (GPS) coordinates. A total of 50 GPS coordinates (10 points per municipality) were collected after the typhoon and used to visually validate selected mangrove sites. Figure 3 shows the comparison of mangroves NDVI during pre-typhoon and post-typhoon. While the field validation was limited to the post-typhoon period, reports from the key informant interviews and focus group discussions were conducted to supplement information related to mangrove conditions prior to Typhoon Rai.

Some limitations of the analysis include cloud cover and edge effects, income bias, and reliance on post-typhoon field visits. It is recommended that the results be carefully generalized, as the study area may not cover all mangroves in Palawan, Philippines. Also, the study only captures the number of households adopting changes in mangrove resources, but not the perceived effectiveness. Lastly, the study did not cover in-depth research on which mangrove species have faster regeneration or survival rates after a typhoon.

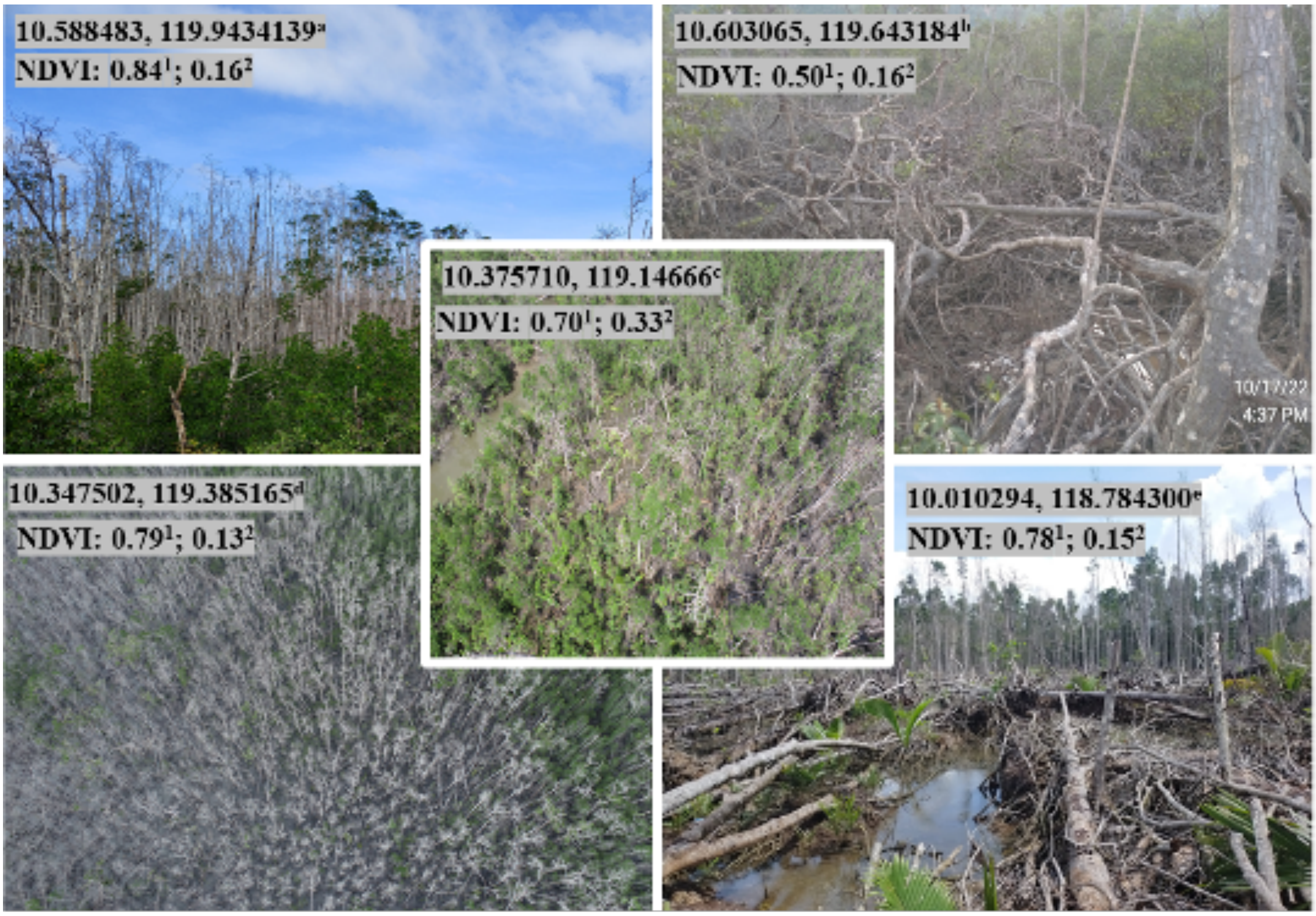

Figure 3: Photos were taken during the field site validation after Typhoon Rai in 2022, representing the post-typhoon (2022) NDVI values. [a]Araceli; [b]Dumaran; [c]Port Barton; [d]Roxas; [e]Puerto Princesa City; [1]Pre-typhoon (2021) NDVI Values; [2]Post-typhoon (2022) NDVI Values

RESULTS AND DISCUSSION

Mangrove Vegetation Changes

There is an observed difference between the pre-typhoon and post-typhoon NDVI values in the mangroves. In 2021, the average mean NDVI value across the sites was 0.73 (dense mangroves), while the average mean NDVI value in 2022 changed to 0.30 (sparse mangroves) The highest decline was observed in Roxas and Duman, from 0.74 (dense mangroves) and 0.71 (dense mangroves) to 0.23 (sparse mangroves) and 0.26 (sparse mangroves), respectively (Figure 4). The Wilcoxon signed-rank tests revealed a statistically significant difference in mangrove vegetation before and after the typhoon, with a p-value < 0.001. The decrease in the average mean NDVI value across the sites indicated a widespread change in the mangrove vegetation from one year to the next. The mangroves, which were once dense and had closed canopies, shifted to sparse and became partially open forests. This implies the need for

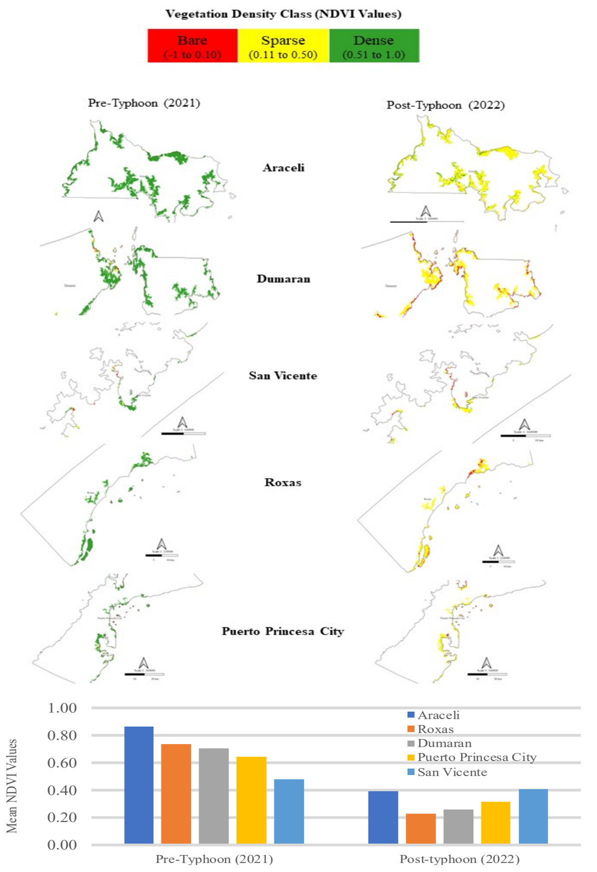

Figure 4: NDVI Map in pre-typhoon (2021) and post-typhoon (2022)

proactive measures to promote mangrove recovery and ensure their long-term sustainability if another typhoon event would landfall, ensuring continuous delivery of mangrove ecosystem services. The observed dropped in NDVI values has been recognized in previous post-typhoon studies as indicative of damages incurred to mangroves after a typhoon (Cabello et al. 2021). These were validated during the field site visit after Typhoon Rai. The community reported that the mangroves were green, intact, had a closed canopy, and were stable in the pre-typhoon stage. After typhoon, the mangroves have suffered to stem and trunk breakage, uprooted, and standing dead due to strong winds, torrential rain, and lightning strikes. A week after the typhoon, many of the standing mangroves have defoliated, leading to mortality for others. The typhoon impacts the fragmented mangrove areas more than the intact ones. In the northwestern part of the city of Puerto Princesa, some bare mangrove forests already existed before the typhoon as the settlement continued to develop. In Dumaran, mangroves have been poached for firewood and charcoal, increasing the bare mangrove areas. Compared to other stable mangrove forests, these areas suffered more from the typhoon due to the compounded effects of unregulated human activities and stress caused by the typhoon. Based on the collected report and published articles, 35 mangrove species were found in the study area. Mangrove species were family of *Acanthaceae, Arecaceae, Avicenniaceae, Bombacaceae, Euphorbiaceae, Lythraceae, Malvaceae, Meliaceae, Myrsinaceae, Pteridaceae, Rhizophoraceae, and Sterculiaceae.* Mangrove species including *Sonneratia alba* (Pagatpat), *Bruguiera gymnorrhiza* (Pototan), *Ceriops tagal* (Tangal), *Rhizophora apiculata* (Bakhaw lalaki), and *Rhizophora mucronata* (Bakhaw babae) dominated the study area. In terms of dominance per municipality, *Rhizophora apiculata* was dominated in Puerto Princesa City, Roxas, San Vicente and Dumaran, while *Rhizophora mucronata* was prevalent in Roxas and Araceli (The ECAN Board of Municipality of Dumaran, 2017; ECAN Resource Management Plan of the Municipality of Roxas, Palawan, 2015; PCSDS, 2006, Abino et al., 2014; PCSDS, 2005). According to the KII and FGDs following the typhoon incidence, many *Avicennia sp.* were found standing dead, *Rhizophora sp.* suffered defoliation, trunk breakage, and uprooted. Many of the tall and old-growth mangroves positioned at the interior of the mangroves suffered and were damaged, while that young mangrove usually in the boundary experienced only minor changes. Typhoon Rai runs across the northeast to northwest of Palawan and, therefore, has the least impact on San Vicente compared to other municipalities. Overall, mangrove species composition, age threshold, undertakings of unregulated human activities, and distance to the typhoon tracks were the determining factors of the extent of typhoon impacts on mangroves.

Table 1 shows the proportions in the area and the differences between the areas before and after the typhoon. There is a decline of the dense class while an expansion of sparse and bare classes. In 2021, dense mangrove was approximately 15711 hectares (91%), while 825 hectares (5%) and 774 hectares (4%) were sparse and bare, respectively. After the typhoon, dense changes to 620 hectares (4%) while sparse and bare increased to 14,430 hectares (83%) and 774 hectares (13%), respectively. The highest decline of dense vegetation occurred in Roxas, Dumaran and Puerto Princesa. Meanwhile, Dumaran and Roxas experienced the highest increase in bare areas after the typhoon. In contrast to Typhoon Haiyan impacts (7705.95 hectares) in 2013, the increase in bare mangroves is less (Villamayor et al., 2016). While the study of Sharma et al. (2022) following Cyclone Amphan (Category 4) impact on Bay of Bengal, reported that 11.5% (55,010 hectares) mangrove loss that is comparable. The mangrove species *Rhizophora apiculata* (Bakhaw lalaki), and *Rhizophora mucronata* (Bakhaw babae),

Table 1: Mangrove Area in Pre-typhoon (2021) and Post-typhoon (2022)

Mangrove Class	2021	2022	Changes 2021-2022	
	Area		Area Difference	Change (%)
	hectare			
Total study area				
Dense	15711	620	-15091	-96
Sparse	825	14430	13605	1649
Bare	774	2260	1486	192
Total	17310	17310		
	Araceli			
Dense	2681	373	-2308	-86
Sparse	29	2313	2283	7783
Bare	13	37	25	193
	Dumaran			
Dense	3863	31	-3832	-99
Sparse	226	3391	3165	1400
Bare	71	738	667	936
	San Vicente			
Dense	720	125	-595	-83
Sparse	144	673	529	368
Bare	77	143	66	85
	Roxas			
Dense	3369	0	-3369	-100
Sparse	101	3068	2967	2938
Bare	15	417	402	2735
	Puerto Princesa City			
Dense	5077	91	-4987	-98
Sparse	324	4984	4660	1437
Bare	598	925	327	55

Ceriops tagal (Tangal), *Bruguiera gymnorrhiza* (Pototan), and *Avicennia officialis L.* (Api-Api) suffered more from typhoon. This is similar to the findings of Carlos et al. (2015), Salmo et al. (2013), and Villamayor et al. (2016) following Typhoon Haiyan in 2013, from which *Rhizophora* species, particularly the old growth stands, suffered the most.

Furthermore, the changes in vegetation have disturbed the mangroves and impacted the fauna that live in the area. For example, in Roxas many of the monkeys were found dead under the mangrove canopy, and in Araceli, fish and mangrove shells were found dead and decaying. These were also observed as the aftermath of Typhoon Haiyan in 2013, where fish kills lasted for almost three weeks, resulting in a significant decline in fishery resources (Malabrigo et al. 2016).

Household Profile

Of the 266 households surveyed, 53% were engaged in fishing-related activities. Most of these are small-scale fishers, using fishing vessels weighing 3 gross tonnes or less, or where no such vessel is used when fishing. Other occupations related to fisheries and mangroves include seaweed farmers, nipa artisans, crab collectors, and fish keepers, accounting for 5.4%, 0.8%, 0.4%, and 0.8%, respectively (Figure 5). Meanwhile, 47% of respondents have a primary income unrelated to fishing or mangrove-related employment. These types of employment include agriculture (8.5%) and other occupations (43.9%), such as government employees, employees in private organizations, tourism services, vendors, buying and selling, and day laborers. Only a few households receive monthly living allowances from their children. As for secondary sources of income, 41% of respondents have additional sources of income. 55% of respondents were in employment unrelated to fishing, such as part-time workers in government or private organizations, day laborers, salespeople, and buying and selling activities. 25.2% are small-scale fishermen, 13.1% are farmers, about 5.5% collect resources from mangroves, and only 0.9% rely on grants or remittances. The result shows that households are highly dependent on fishery resources directly associated with mangrove goods and services. There were at least two household members engaged in fishing activities to support household needs. The average annual income of households was estimated at about PHP 100,000 and less (USD 1,823.34 and less), with 76% to 100% of household income coming from fishing. Income was mainly allocated to food, education, house rental, and health care. In comparison to the annual income in the MIMAROPA Region, which is PHP 258,000.00 (USD 4,657.63), the majority of the households that participated in this study belong to a household with an average income below the national average (PSA 2018). Household average annual income is not high in the study area since portions of their harvest and catch are intended for household consumption. The household dependence on fishery and agriculture aligns with the 2015 Updates of the State of the Environment of Palawan (PCSD 2015), which emphasized the substantial reliance of households in Palawan on fishery and agriculture. It reflected the significant contribution of natural capital and ecosystems in sustaining household occupations in the province.

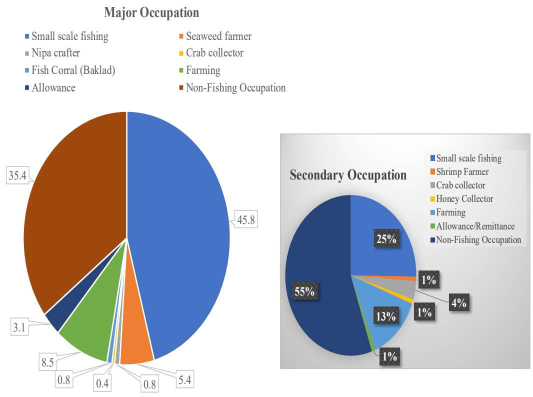

Figure 5: Household Head Occupation

Impact on Livelihood due to Mangrove Changes

Mangroves offer an array of resources and services. Majority of the households directly derived fishery resources, including a variety of fish, mangrove snails, mangrove crabs, mangrove clam, shrimp, *tamilok* or woodworm or worm-like mollusk (*Teredo navalis*), and sea cucumber. Few households reported harvesting octopus, sea grapes and lobster in the nearby mangroves. Mangrove stands were also collected and utilized for firewood, charcoal, and housing materials. However, it is exclusively for personal use due to the province's mangrove-cutting ban. Nipa palms (*Nypa fruitican*s) were also collected for roof and hat making. Majority of the households in Dumaran and Roxas engaged in nipa mat making while in Puerto Princesa City engaged in nipa roof making. Households also benefited from mangroves through access to navigation and transportation, recreation sites, tourism opportunities, research, and a venue for special occasions like weddings. Utilization of the mangrove resources slightly varies across the sites. The direct utilization of mangrove stands and access to transportation, navigation, and recreational use are only observed in Dumaran, Roxas, and Puerto Princesa City. Tourism-related activities are operated only in Puerto Princesa City.

After the typhoon, there was a change in the delivery of mangrove goods and services. The yields of shrimp, crab, mangrove clam/bivalve, mangrove snails, sea cucumber, nipa, and ecotourism activities declined. The harvest of woodworm (*tamilok*) increased, more mangrove wood and poles were cut down and collected, more recreational activities were facilitated, and several research projects were launched. As illustrated in Figure 6, the changes led to an alteration in the way mangrove-based resources and services were utilized, with a rise in use solely for domestic and a fall in selling and marketing. The impact of Typhoon Rai on the changes in utilization patterns was highlighted by Pearson's chi-squared test that found a significant difference between the means of mangrove utilization before and after the typhoon event (χ^2= (4, N=266) = 232.88, $p<0.001$).

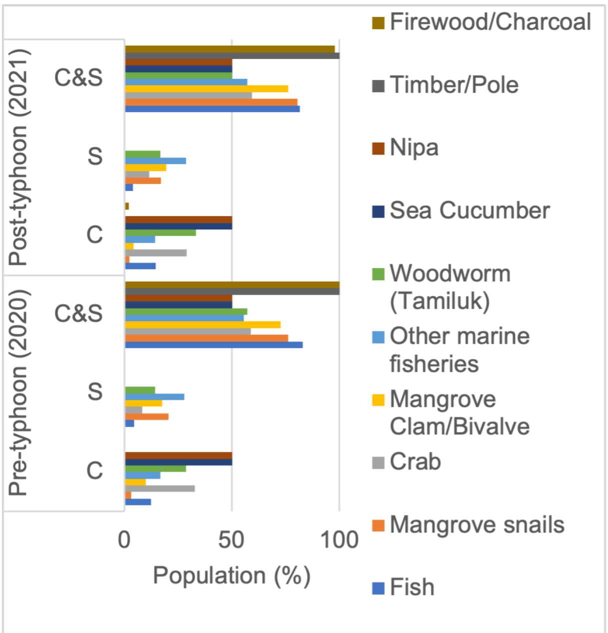

Figure 6: Utilization Pattern of the Household in Pre-typhoon and Post-typhoon

The water and soil quality of the mangroves was altered by massive defoliation and uprooting after the typhoon. The fallen mangrove leaves increase the concentration of carbon dioxide in the water and prevent the production of dissolved oxygen. In addition, the uprooted trees clogged waterways and accumulated excessive organic material that was harmful to aquatic organisms. Affected aquatic life included fish, mangrove snails and crabs. A similar event occurred in Caluit Island, Palawan after Typhoon Haiyan in 2014. After the typhoon, the abundance of fish and crabs decreased due to mangrove defoliation, which affected the fishing activities of the local community (Malabrigo et al. 2016). The changes in the water and soil properties intolerable for the thriving species resulting in the discontinuation of fishery activities. The situation for mangrove collectors is now reversed. During the pre-typhoon (2021), a small number of households were collecting mangrove stands for charcoal-making and housing materials. However, following the typhoon, due to limited alternative options, more households began to engage as mangrove collectors. Despite the prohibition policy in mangrove forests, some households have poached the uprooted trees, and others have cut down mangroves to meet the high demand for wood to rebuild their homes. There were also households that were not engaged in charcoal production before the typhoon but chose to engage in charcoal production after the typhoon because it provided easy money to meet household needs. The unregulated mangrove cutting driven by the declining incomes and the desire to recover from the damages incurred by the typhoon pose a threat to the remaining mangrove stands. Most households had difficulty producing building materials to rebuild their damaged homes. However, dead mangroves cannot be used as prohibited by the law. Policies for the fallen mangrove stands should be considered to help the community minimize the cost of restoring the houses during such challenging times, especially if the typhoon destroyed these houses, and to maximize the benefits of the dead mangroves. Alternative livelihoods should be created to support the community while preventing the destruction of mangrove forests.

Overall, the changes in mangrove resources significantly affected the average annual household income from mangrove resources. Shown in Table 2, the average annual income decreased by 50.27%, resulting in a loss of PHP 77,859.59 (US$1,405.57) from PHP 232,745.50 (US$4,201.71) in 2021 to PHP 154,886.90 (US$2,796.15) in 2022. This corresponds to the shifts of vegetation conditions from dense to sparse and bare that disturbed and reduced the productivity of mangrove-based resources, with implications for the decline in harvested/collected fisheries products, cessation of fishing activities, and shift to alternative livelihoods, consistent with the finding of Quevedo et al. (2022). The estimated annual income from gleaning and fishing activities in pre-typhoon (2021) is not high as compared to other studies. Specifically, Buncag and Lubrico (2016) study in Aborlan, Palawan, reported an annual harvest per household of PHP 321,200.00 (5,798.57 USD). Meanwhile, the study by Carandang et al. (2013) found that the average annual revenue per household in Kamuning Puerto Princesa City, Palawan, was significantly higher, amounting to PHP 25,521,700 (567,100 USD). For this study, the annual household income solely consisted of revenue generated from mangrove resources harvested for sale. Market prices of the mangrove resources utilized only for subsistence and housing materials were not factored into the estimation, resulting in substantial differences observed when compared to other studies.

Table 2: Changes in Income from Mangrove-Based Livelihood

Municipality	Mean Annual Income (SD)		
	Pre-Typhoon (2021)	Post-typhoon (2022)	% Change
	PHP ('000)		
Araceli	279.4	247.8	-31.6
	(± 215.8)	(± 201.1)	(± 14.8)
Dumaran	300.1	188.0	-112.1
	(± 207.8)	(± 156.9)	(± 190.4)
Puerto Princesa City	129.8	112.9	-16.9
	(± 108.8)	(± 105.7)	(± 75.0)
Roxas	194754.0	122769.0	-72.0
	(± 15.34)	(± 102.64)	(8± 5.46)
San Vicente	718.4	399.3	-319.1
	(± 512.5)	(± 317.3)	(± 382.1)
Average	232.8	154.9	-77.9
	(± 230.2)	(± 152.4)	(± 161.1)

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Household perceptions of recovery from Typhoon Rai revealed that about 90% of households have recovered and 77% of households felt that mangroves were still not recovering. Although the majority of households have recovered, the slow recovery of mangroves is affecting their food and livelihoods. The household recovery was attributed to the typhoon relief, government support, and other charitable initiatives after the typhoon. However, this support is limited, and the services derived from the mangrove are their lifeblood. To ensure the continuous flow of the mangrove ecosystem services, actions should be taken. Most households (33%) perceived that mangrove has recovered in just one month, and about 32% of them perceived that it would take 8 months to one year for the mangrove to completely recover. The largest portion of households from Roxas and Puerto Princesa City agreed it would require 8 months to one year before mangrove recovers due to noticeable changes in the mangroves. Recovery is critical for the community with high dependence on mangrove resources. If mangroves do not recover, goods and services will not be sufficient to meet household needs. There is a positive association between the household not recovering and the mangrove not recovering, as revealed by the Chi-square independent test (χ^2 = 40.221; df=1; p<0.001). The mangrove recovery is positively associated with livelihood recovery. The reduction in the ecosystem goods and services exposes the community to environmental shocks, especially in households that lack coping strategies (Depietri 2020).

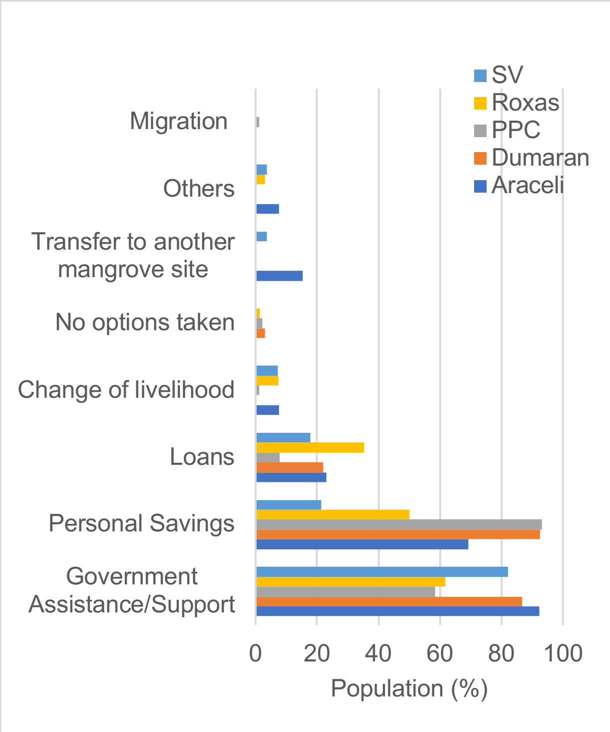

Figure 7: Household Coping Strategies with Changes in Mangrove Resources

It is worth knowing that households used multiple coping strategies following the typhoon. As shown in Figure 7, government support, personal savings and credit were the main coping strategies in the five municipalities. The results reflected the importance of having a supportive government capable of meeting household needs during crisis. Household in Araceli heavily relies on government support, providing them with cash, food packages and even fishing equipment. Personal savings helped most of the households in Dumaran, Roxas, and Puerto Princesa City, which supported fishing activities that were stopped due to disturbances in the mangroves after the typhoon. However, their savings did not last long, and the government support they received helped them all through the recovery period. Meanwhile, in San Vicente, most households shifted to a different livelihood, such as construction worker and day laborer, because their mangrove harvest is not enough to meet household needs. About 5% of the households across the five municipalities had limited or no savings. Access to credit was their alternative option. This portion of the population relies only on restoring mangrove forests and exploiting the remaining mangrove ecosystem services to meet at least the bare minimum of their household needs. However, despite the fact that the study did not capture the perceived effectiveness of the identified coping strategies, it still provided helpful information to prepare households for when another disaster occurred. The findings highlighted the importance of coping strategies employed by the households to address negative impacts of natural disasters when livelihood resources change. Further enhancing and improving these coping strategies and diversifying them across the municipalities potentially equipped them from the adverse impacts when another disaster occurred (Israel and Briones 2014).

Mangrove Interventions Relevant to the typhoon event

Mangrove management strategies are crucial to ensure mangrove sustainability, especially under the threat of natural disturbances and human activities. About 93% of the households are aware of the various mangrove management undertakings in the municipality. The presence of mangrove management is a positive indicator of willingness to conserve and protect the mangroves from threats. The top mangrove management strategies, including mangrove tree planting, community-based management, and prohibiting cutting mangroves. Households have a high level of agreement that these strategies were effectively implemented in the study area.

Mangrove tree planting is one of the dominant projects in the mangroves, which is often initiated by the local government units and conducted four times a year on average. To improve the welfare of the local community, the DENR implemented Administrative Order No. 2004-29, which ensures the sustainable use of forest resources through collaboration and active participation with government and private agencies. To achieve this, a Community-Based Forest Management Strategy is adopted. In Palawan, 37 active CBFMs are involved in various programs under the DENR, with the primary objective of sustainably managing forest resources while providing local livelihood opportunities. These CBFMs are engaged in several environmental initiatives, including mangrove planting, establishing and maintaining mangrove nurseries, forest apprehension, forest patrolling, and many other activities that are instrumental in enhancing and safeguarding both coastal and forest areas.

In addition, the Strategic Environmental Plan for Palawan Act or the RA 7611 declares mangroves as protected areas that restrict high impact activity and limit only to low-impact activity unless authorized and approved by the government (Strategic Environmental Plan for Palawan Act 1992). This policy is widely recognized in the province and prohibits mangrove cutting in all areas. However, despite the high awareness, enforcement is weak. In San Vicente, for instance, mangroves were encroached for settlement and tourism purposes. Some households in Dumaran cut mangroves for firewood and charcoal. In Puerto Princesa City, mangroves were converted for housing. Government agencies responsible for mangrove management were challenged to enforce the law due to limited local staff to oversee the mangroves. Mangrove intervention designed to address typhoon-related damages is unavailable in the area. Previous typhoons that hit the province were weak; thus, there was no necessity to design and develop policies relevant to typhoon-induced mangrove changes. Moreover, households perceived that mangrove planting (67%), community-based management (63%) and prohibition of mangrove cutting (76%), were among the strategies implemented at the local level that were considered relevant to those typhoon-induced mangrove losses and damages.

In contrast to the high recognition of mangrove management, the participation of about 58% of households in these strategies is low. Households indicated that they were willing to participate, but in some situations, their participation jeopardized their livelihood engagements, so they preferred to work to earn money rather than participate. Thus, it is important to provide a deeper understanding among the households about the importance of their mangrove participation, which could contribute to increasing the household participation level (Costanza et al. 2008).

Mangroves in the study area are widely known for their provision, support, and regulation of services (Figure 8). These services are critical for the local community to sustain their livelihoods, put enough food on the table, and ensure the continued supply of resources valuable to their households. Mangroves are also seen as part of the solution to the climate crisis. It also buffers coastal areas against typhoons, erosion, and tsunamis. However, only a few households recognized this mangrove's ability. Increasing household awareness of the role of mangroves, especially in the current climate crisis, can increase households' appreciation of mangroves and influence them to increase their participation.

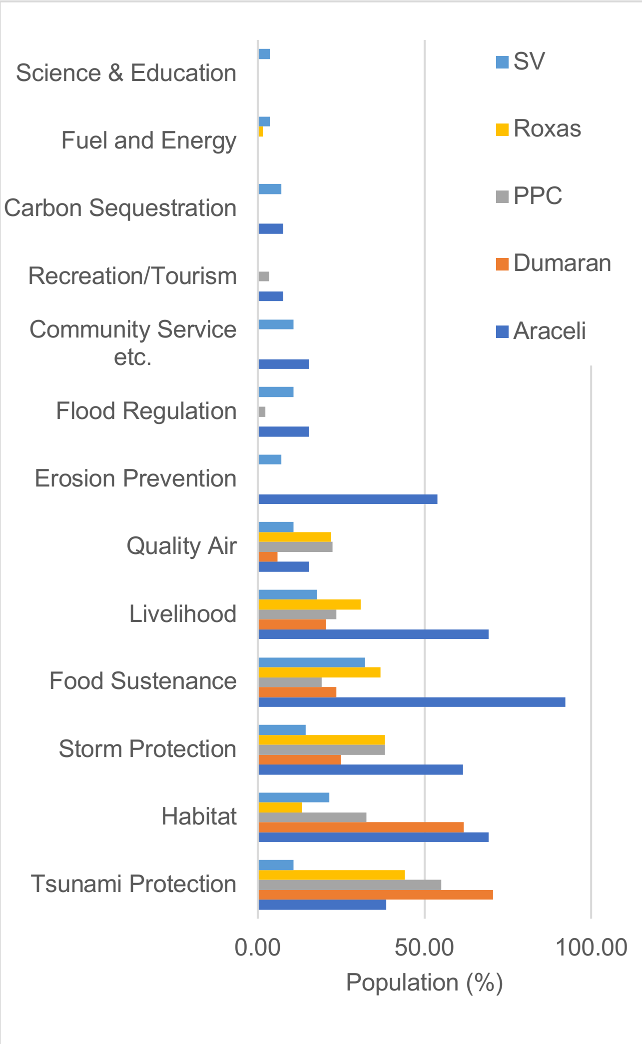

Figure 8: Mangrove Ecosystem Services Recognized by the Community

CONCLUSION

This study sheds light on the impact of extreme typhoons on the mangroves in Palawan, Philippines. Following Typhoon Rai in 2022, the mangrove vegetation in Puerto Princesa City, Roxas, Dumaran, Araceli, and San Vicente shifted from dense vegetation to sparse and bare. Typhoon-induced mangrove changes following Typhoon Rai resulted in unavoidable ecosystem damages, which threatened various mangrove resources, affecting the livelihood of the dependent households. The households experienced a decline in shrimps, crabs, mangrove snails, cucumber, and nipa yields and a decline in tourism operations. Meanwhile, increased woodworm harvesting has been reported after Typhoon Rai due to several fallen mangroves that serve as an ideal habitat for woodworms. On the contrary, the demand for wood and alternative means of livelihood promoted the harvesting and cutting of mangrove stands for building materials and charcoal production, posing a threat to the remaining mangroves and hindering their recovery. Mangrove intervention to assist recovery is critical in heavily affected areas, particularly in Dumaran, Roxas, and Puerto Princesa City, to ensure rapid recovery and minimize economic losses. Providing livelihood opportunities to prevent overexploitation of the mangrove resources and mangrove degradation is needed, especially in Dumaran, Puerto Princesa, and Roxas, where many households are engaged in mangrove cutting and charcoal making. Diversified coping strategies should be introduced across the municipalities to lessen the adverse impact of scarcity on livelihood resources due to the typhoon-induced mangrove changes. Policies that ensure the long-term productivity of mangroves against extreme typhoons should be implemented for biodiversity conservation and the community's welfare. Future research should investigate effective mangrove strategies relevant to typhoon-induced mangrove changes and assess their long-term impacts.

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CONFLICT OF INTEREST

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CONTRIBUTIONS OF INDIVIDUAL AUTHORS

PC Montoya conceptualized the study, conducted a comprehensive review of relevant literature, and assessed the changes in mangrove ecosystems induced by typhoons and their implications for livelihood resources in Palawan, Philippines. Montoya also writes the original draft of the paper. RP Shrestha contributed to the conceptual framework, analysis, and provided critical comments, reviews, and editing throughout the writing process.

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