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Morphometric Variation, Growth Patterns, and Interpopulation Comparisons of *Thalamita crenata* (Rüppell, 1830) in Surigao del Norte and Agusan del Norte, Philippines

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ABSTRACT

Thalamita crenata is a commercially and ecologically important crab species, yet comprehensive biological data on its populations in the Philippines remain limited. This study aimed to provide an initial assessment of *T. crenata* populations in Surigao City, Surigao del Norte and Buenavista, Agusan del Norte, Philippines. A total of 104 individuals were sampled and measured at each site. The maturity of the collected individuals was inferred from the mean values of their morphometric indices and the presence of ovigerous females. Descriptive comparisons of morphometric values between the two sites suggested potential variations in growth conditions. Mann-Whitney U tests revealed significant differences in cheliped dactylus length (CDL) between the two populations, with individuals from Buenavista exhibiting larger chelipeds (males: U = 387.5, z = 4.38, $p < 0.0001$; females: U = 639, z = -6.11, $p < 0.0001$). Strong positive Pearson's r correlations between carapace dimensions (width and length) and body weight were observed in both areas (Surigao City: r = 0.677-0.695; Buenavista: r = 0.923-0.834) highlighting the utility of carapace size measurements for monitoring growth patterns. These findings provide valuable baseline data for future assessments of mangrove health, fisheries production, and environmental suitability for *T. crenata*. Future investigations should examine environmental factors influencing growth variations and assess potential threats to these populations. Such efforts will be crucial for developing effective strategies for more proactive environmental management among related marine ecosystems.

Keywords: *Morphometrics, allometry, breeding capacity, crabs, mangrove ecosystem*

1 Introduction

Crabs are a diverse group with numerous species holding significant economic value, driving the need for comprehensive research on their biology (Noori et al. 2015). The Portunidae family, a prominent and diverse group, includes commercially important crabs like the European shore crab (*Carcinus maenas*), mud crabs (*Scylla* spp.), and swimming crabs (*Portunus* spp.)

(Davie 2021). This family comprises approximately 38 genera and over 300 recognized species, identified by a flattened dactyl on their fifth leg (Huang & Shih 2021, Koch et al. 2023). Despite this diversity, taxonomic uncertainties persist at both the family and subfamily levels within the superfamily Portunoidea (Martin et al. 2016). An economically valuable member of the Portunidae family is *Thalamita crenata* (Rüppell, 1830), also known as the crenate swimming crab or spiny rock crab. This species is a common inhabitant of mangrove communities (Muhd-Farouk et al. 2017). Typically, small in size, *T. crenata* are collected by artisanal fishers for local consumption using baby trawlers, skimming nets, or crab traps within bays and mangrove creeks (Pratiwi & Dewi Elfidasari 2020, Subang et al. 2020). Similar to mud crabs, *T. crenata* inhabits mangrove ecosystems and may even be discarded as bycatch in mud crab fisheries alongside menippid crabs and hermit crabs (Li et al. 2021).

Beyond their economic value, mangrove crabs like *T. crenata* play a crucial role as ecosystem engineers. Their burrowing activities, or bioturbation, influence sediment formation by reshaping burrows, creating ventilation outlets, constructing flow channels, and building protective walls (Al-Khayat & Giraldes 2020, Xie et al. 2022). These crabs also contribute to nutrient cycling within mangrove communities, and their abundance serves as a potential indicator of threats to the health of the mangrove ecosystem itself (Susanto & Irnawati 2014, Chen et al. 2016, Hamid et al. 2019). Such studies are particularly important in the Philippines, where the expanding fisheries sector has impacted mangrove protection, jeopardizing coastal communities' natural defense against tsunamis and storm surges (Buitreet al. 2019).

Despite its ecological and economic significance, research on freshwater and estuarine crabs in Mindanao Island, Philippines, has been limited over the last decade (Jumawan et al. 2022). The information on *T. crenata*'s biology and distribution remains scarce. Existing records of the species are limited, with Subang et al. (2020) reporting its widespread distribution in Palawan and harvesting through crab pots or fishing nets. Additionally, the species has been documented in the Santiago Dive Point (Camotes Islands) and Pacijan Island (Santiago Bay) (Marine Iconography of the Philippine Archipelago 2004).

To address this knowledge gap and contribute valuable baseline data for future assessments, this study examined the morphometric characteristics and breeding capacity of *T. crenata* populations in Surigao City, Surigao del Norte, and Buenavista, Agusan del Norte. The study also compared these populations and analyzed their morphometric relationships to explore potential growth patterns and environmental suitability. This initial assessment aims to shed light on the role of *T. crenata* in the Philippine mangrove ecosystem, paving the way for future research on their potential as a bioindicator species, and developing effective management strategies for their sustainable harvest and conservation.

2 Materials and Methods

Study Sites

The sample sites were located in Surigao City, Surigao del Norte and Buenavista, Agusan del Norte, with coordinates 9.7571° N, 125.5138° E and 8.7859° N, 125.3686° E, respectively (Figure 1). Sampling was conducted randomly and guided by resource availability, ensuring a representative population selection. Crab samples of several size ranges were kept inside the coolers and transported to the laboratory for proper storage. Identification of crab samples were done using the field guide summary from SeaLifeBase (Ng 1998). Sampling in Surigao del Norte was conducted on 11 April 2021 while sampling in Buenavista, Agusan del Norte was conducted on 21 April 2021.

Crab Species and Habitat Description

Thalamita crenata is characterized by six rounded lobes of nearly equal size along the front margin of the carapace between the eyes, as well as five sharp spines on the antero-lateral margins — key features defining the genus *Thalamita* (Figure 2). Its chelipeds, or pincers, are notably large and strong, adapted for grasping and defense. The carapace surface is smooth, with low but distinct ridges. The overall coloration ranges from dark to olive green, providing effective camouflage in its natural habitat.

The collected species were observed in shallow,

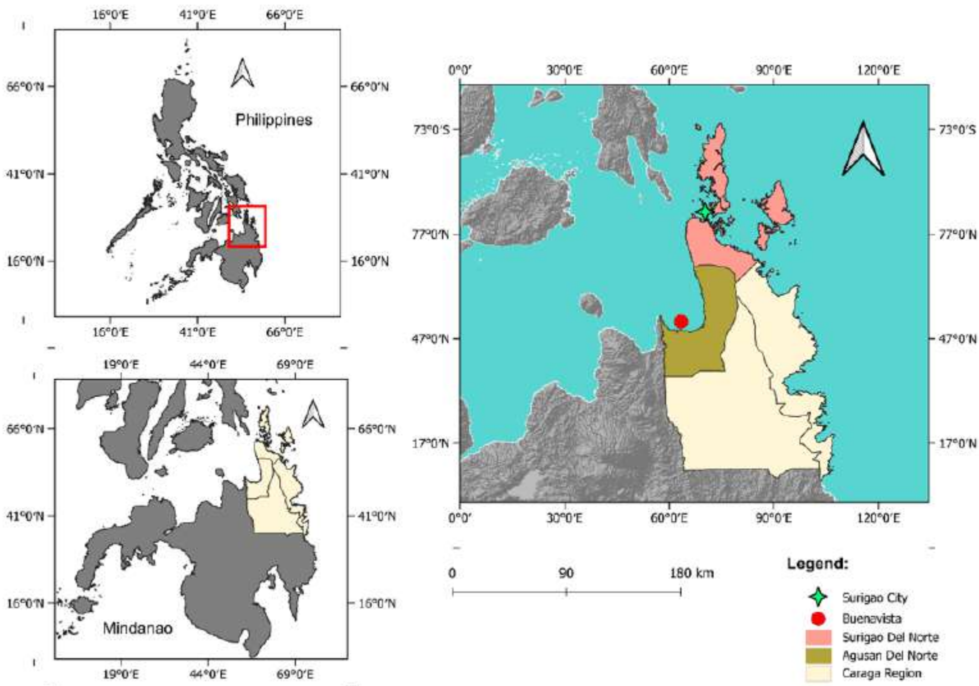

Figure 1. Map showing the sampling site for Surigao City, Surigao del Norte, and Buenavista, Agusan del Norte. Aerial view of both sites and the established coordinates were processed through QGIS v3.36.0.

non-reef habitats with soft substrates, such as intertidal mudflats, estuaries, and river mouths. It favors brackish waters and is especially common in mangrove areas, including muddy or muddy-rocky substrates on intertidal platforms. While less frequently encountered on coral reefs, it can occasionally be found in reef-associated zones. *T. crenata*, a free-living predatory carnivore, primarily preys on slow-moving invertebrates that inhabit mangrove swamps and also acts as a scavenger, helping to maintain ecosystem balance.

Morphometric Measurements

A vernier caliper and a digital weighing scale were used to measure lengths (mm) and the total weight (g) of crabs, respectively. Maximum carapace width (CW), maximum carapace length (CL), frontal width (FW), natatory leg dactylus length (NDL), natatory dactylus width (NDW), cheliped dactylus length (CDL), palm cutting edge (CE), maximum palm length (PL), and maximum palm width (PW) were measured (Figure 3) (Asaduzzaman et al. 2021, Shahdadi et al. 2018). Identification of sexes (Figure 2) were based on abdominal shape: male crabs have a V-shaped abdomen, while females have rather round-shaped (Ng 1992). Females harboring visible eggs (ovigerous) in the abdomen were also noted.

Data Analysis

Descriptive statistics of the morphometric and weight values were used to assess the developmental stages of the populations. The sex ratio of each *T. crenata* was defined as the ratio of the total number of females divided by the total number of males calculated (Wardiatno & Hamid 2015). Distribution of sex were identified through percentage of abundance in each site. Pearson's correlation coefficient (r) was used to analyze the relationships between maximum carapace width (CW), and maximum carapace length (CL) to their respective body weights (BW). Comparative analysis was done by comparing the mean values of the morphometric indices and the body weights and Mann-Whitney U was performed for comparison of Cheliped Dactylus Length (CDL). Statistical analysis was done through the software JASP version 0.14.1.0, and formulation of graphs were done through Microsoft Excel version 2016.

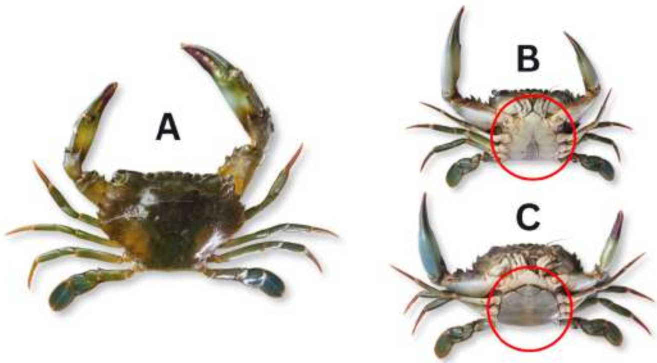

Figure 2. Habitus of *T. crenata*. A) Dorsal view; Ventral view, B) Male showing the distinct V-shaped abdomen; C) Female showing the distinct round-shaped abdomen.

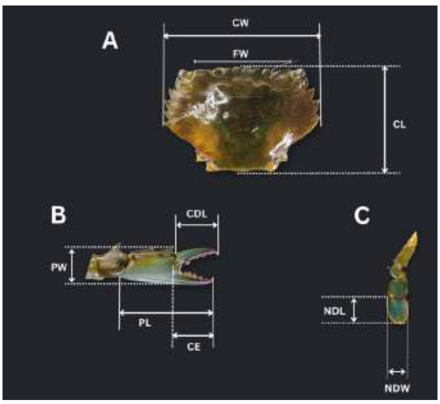

Figure 3. Morphometric indices of *T. crenata.* A) Frontal width (FW) carapace width (CW), and carapace length (CL); B) maximum palm width (PW), maximum palm length (PL), palm cutting edge (CE), and cheliped dactylus length (CDL); C) natatory leg dactylus length (NDL) and natatory leg dactylus width (NDW).

3 Results and Discussion

Proportion and Sex Ratio

A total of 104 specimens of *T. crenata* were collected and measured at each site, resulting in a balanced sex ratio (1:1) in Surigao City (n = 104, 52 males, 52 females) (Figure 4). This suggests a potentially stable population structure at this location, which could be beneficial for long-term recruitment success. Interestingly, in Buenavista (Figure 5), the collected individuals (n = 104) displayed a female-biased sex ratio (1:2.06). The dominance of females (34 males, 70 females) might indicate factors influencing sex determination or differential mortality rates between the sexes in this specific habitat (Ewers-Saucedo 2019). Notably, the observed proportion of ovigerous females was also higher in Surigao City (44%) than Buenavista (24%). This difference could be linked to the observed sex ratio disparity, with a higher proportion of females in Buenavista potentially leading to increased competition for mates, and consequently, a lower proportion of successfully reproducing females. However, statistical analysis using a chi-square test ($\chi 2$) revealed no significant difference ($p > 0.05$) between the sex ratios of *T. crenata* populations in Surigao City and Buenavista (Table 1). This suggests that despite the observed female bias in Buenavista, the overall sex ratio disparity might not be statistically robust. Hence, further investigation is needed to explore the underlying ecological drivers behind these observations.

Table 1. Proportion and sex ratio of male and female of *T. crenata* in two study sites.

Study Sites	Number (*ind.*)		Proportion (*%*)		Sex Ratio
	Male	Female	Male	Female	Male:Female
Surigao City, Surigao del Norte	52	52	50	50	$1:1^{ns}$
Buenavista, Agusan del Norte	34	70	32.69	67.31	$1:2.06^{ns}$

** Significant ($p < 0.05$); ns = not significant ($p > 0.05$).*

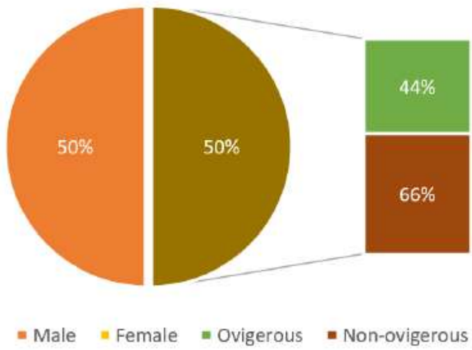

Figure 4. Percentage of sex distribution of *T. crenata* from Surigao City, Surigao del Norte with notes on ovigerous females.

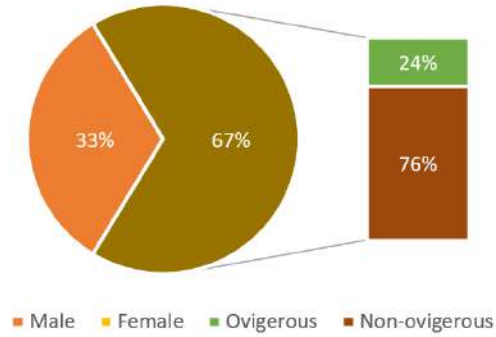

Figure 5. Percentage of sex distribution of *T. crenata* from Buenavista, Agusan del Norte with notes on ovigerous females.

The descriptive statistics for morphometric measurements and body weight in both Surigao City and Buenavista populations (Table 2) reveal a relatively homogenous distribution around the mean values within each location. This observation suggests a high degree of similarity in developmental stages among individuals within each population. The mean maximum carapace width (CW) for males in Surigao City (56.90 mm) and Buenavista (51.18 mm), with the maximum values reaching 67 mm and 70 mm. respectively. This finding aligns with the results of Muhd-Farouk et al. (2017) indicating certain size range as indicative of mature male *T. crenata*. The presence of ovigerous females in both locations strengthens the evidence that the sampled populations consisted primarily of reproductively mature individuals, as supported by Hamid et al. (2019).

While climate can influence breeding patterns, the findings suggest that *T. crenata* populations in Surigao City and Buenavista may exhibit continuous breeding throughout the year. This observation, supported by the presence of ovigerous females and the overall homogeneity of morphometric measurements, aligns with the findings of Hamid et al. (2019). This finding is similar to the observations of Sigana (2002) in Kenya, who reported year-round breeding activity for *T. crenata*. The presence of ovigerous females in Surigao City and Buenavista during April provides further support for this notion, suggesting that *T. crenata* populations in these Philippine locations might also exhibit continuous breeding patterns. The observed homogeneity in developmental stages within each population suggests successful recruitment, potentially

Table 2. Summary of descriptive statistics of identified *T. crenata* from Surigao City, Surigao del Norte and Buenavista, Agusan del Norte.

Morphometrics (mm)	Surigao City				Buenavista			
	Females		Males		Females		Males	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
n	52		52		70		34	
Body Weight (g)	30.96	7.80	37.04	9.90	22.77	9.12	29.15	15.87
PW	10.87	1.28	13.14	2.61	12.23	3.74	13.68	3.84
PL	37.85	4.06	44.96	7.49	33.89	6.41	39.59	9.28
CE	15.33	1.92	18.60	4.56	13.71	3.41	16.00	5.25
CDL	18.58	2.30	21.52	2.82	15.17	2.77	17.68	3.74
NDW	8.27	2.01	9.39	2.46	7.11	1.40	8.47	2.55
NDL	12.12	1.89	13.35	2.11	11.96	2.47	13.06	2.61
FW	32.75	3.00	34.31	4.16	30.96	5.43	31.82	6.72
CL	37.44	3.51	39.67	4.34	31.41	4.62	33.06	6.42
CW	52.92	5.69	56.90	6.10	48.24	6.50	51.18	9.38

indicating stable population structures. The presence of ovigerous females, along with parallels to findings by Sigana (2002) on year-round breeding in Kenya, point towards the possibility of continuous breeding in Surigao City and Buenavista. This information could be valuable for fisheries management strategies, particularly if continuous breeding is confirmed through further studies. However, the current analysis has limitations. Descriptive statistics alone may not definitively pinpoint maturity stages for all individuals. Future research incorporating additional maturity indicators, like gonad weight or histological examination, could provide a more robust assessment of reproductive maturity across the population. Furthermore, while Sigana (2002) reported a brief pause in breeding activity in Kenya, investigations are needed to determine if environmental variations in the Philippines might influence any temporary reproductive hiatuses for *T. crenata* populations in these locations.

Morphometric Patterns and Potential Threats

The analysis of body weight and morphometric measurements revealed notable patterns between *T. crenata* populations in Surigao City and Buenavista (Figure 6). Females and males from Surigao City exhibited larger body size and weight compared to their counterparts in Buenavista. This difference could be attributed to several factors including warmer water temperatures in Surigao City. Crustacean growth rates are positively correlated with temperature, as warmer conditions can accelerate growth by shortening molting intervals or increasing growth increments during molting (Green et al. 2014, Tropea et al. 2015, Shields 2019). Surigao City is situated on the northern coast of Mindanao, closer to the equator. This means it receives more direct sunlight and heat from the sun, leading to warmer water temperatures (Smithson et al. 2013). The smaller size of *T. crenata* in Buenavista might suggest potential suboptimal growth conditions. This could be due to cooler temperatures or other environmental factors like water quality or food availability (Rouf et al. 2021).

Interestingly, despite their overall smaller size, individuals in Buenavista exhibited larger maximum palm widths (cheliped size) compared to those in Surigao City, for both males and females. Mann-Whitney U test revealed a significant difference in cheliped size for both males ($U = 387.5$, $z = 4.38$, $p < 0.0001$) and females ($U = 639$, $z = -6.11$, $p < 0.0001$). These findings provide strong statistical support for the initial observation of larger chelipeds in Buenavista. Larger chelipeds, specifically the cheliped dactylus length, can provide advantages in several ways: increased success in capturing and consuming a wider variety of prey sizes, and enhanced dominance in competition for mates and interactions involving aggression within the species (Masunari et al. 2015, 2020). The larger cheliped size in Buenavista could be a compensatory adaptation to potentially lower food availability or quality in this habitat. Individuals with larger chelipeds might be more efficient at foraging and surviving in such conditions. Alternatively, the increased cheliped size could be result from stronger intraspecific competition for mates or resources in Buenavista, where selection might favor individuals with a competitive advantage in cheliped size.

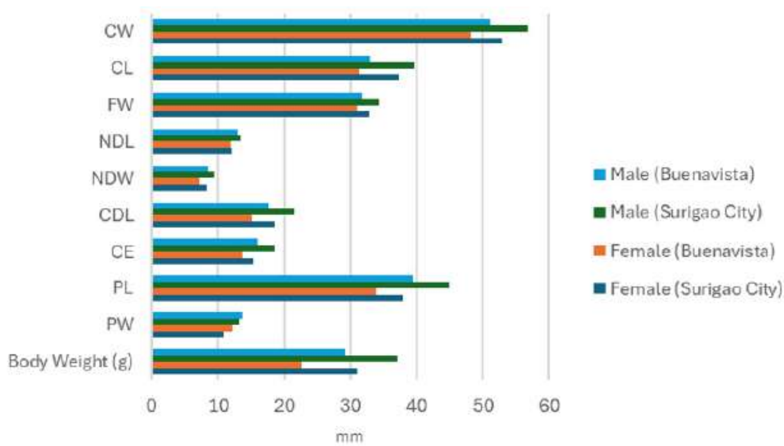

Figure 6. Graph showing the comparison of mean values of *T. crenata* between both sites.

The observed size disparity between the two populations could be further influenced by environmental contamination. Exposure to such contamination could affect oxygen consumption among crustaceans, potentially altering metabolic processes and affecting overall fitness (Capparelli et al. 2016). Aquaculture farmers in Surigao del Norte are practicing mud crab fattening methods for increasing production yield, potentially affecting the quality of other species within the mangrove communities (Sulima 2017). The province is also known to be the location of several mining corporations wherein records of metal concentration on marine sediments revealed high metal enrichment specifically in Pb and Cu (Tomaquin 2014, Capangpangan et al. 2015).

In Agusan del Norte, sediment analyses within the selected mangrove communities along the Butuan Bay area showed contaminations of Hg, Ni, and Cr at the level above the standard for sediments, and contamination of Pb in the muscles of mud clams are also above the standard level (Elvira et al. 2018). Although the current study did not directly measure heavy metal levels in *T. crenata* tissues, the documented presence of heavy metal contamination in sediments and mud clams from Buenavista raises significant concerns. As benthic scavengers and omnivores, *T. crenata* are likely exposed to these contaminants through their diet or by filtering contaminated water (Chen et al. 2016). Bioaccumulation of heavy metals can negatively impact growth, development, and reproductive success (Ebol et al. 2020). The potential for heavy metal bioaccumulation in Buenavista could contribute to the observed smaller size of *T. crenata*. While this size disparity relative to Surigao City might be linked to reduced growth rates due to heavy metal exposure, further scientific investigation is required to determine a causal relationship.

Carapace Width and Carapace Length to the Body Weight Relationship

The relationships between carapace dimensions (width and length) and body weight in *T. crenata* populations from Surigao City and Buenavista were analyzed. The findings revealed a strong positive correlation between both carapace width (CW) and carapace length (CL) with body weight (BW) in both locations (Figures 7 & 8). This positive

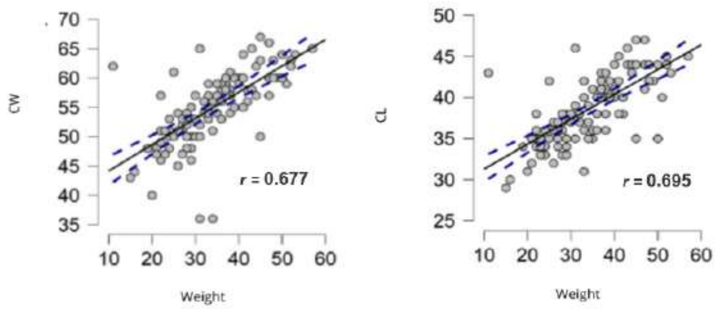

Figure 7. Scatter Plot showing the relationship of the maximum carapace width (CW) and maximum carapace length (CL) *T. crenata* to its body weight from Surigao City, Surigao del Norte, Philippines.

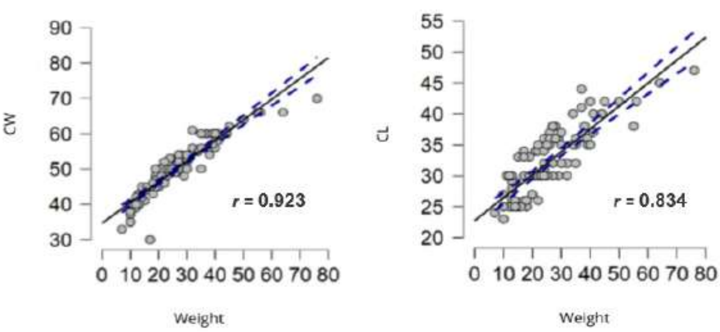

Figure 8. Scatter Plot showing the relationship of the maximum carapace width (CW) and maximum carapace length (CL) *T. crenata* to its body weight from Buenavista, Agusan del Norte, Philippines.

correlation is statistically supported by Pearson's r values, which were 0.677 and 0.695 for CW-BW and CL-BW in Surigao City, respectively. Notably, the correlations were even stronger in Buenavista, with Pearson's r values reaching 0.923 and 0.834 for CW-BW and CL-BW, respectively. The positive correlation between carapace size and body weight in *T. crenata* aligns with crustacean biology principles (Widigdo et al. 2017). As these crabs grow, they molt, requiring a larger exoskeleton.

Carapace width and length, commonly used to measure size, increase proportionally with body weight (Johnston & Yeoh 2020). This reflects the relationship between structural size and overall biomass. Larger individuals have more muscle tissue, organs, and other components, leading to greater weight. Allometry, where body parts grow at different rates, explains this connection (Bezerra Ribeiro et al. 2017). In crustaceans, carapace dimensions are isometrically related to body weight, meaning they increase proportionally to accommodate the growing body (Taylor 2018). Additionally, the growth of muscle mass, crucial for movement and feeding, significantly impacts body weight (Pescinelli et al. 2015), as does the development of internal organs as individual grows larger (Wu et al. 2020).

The strong positive correlations observed in this study offer valuable insights for understanding T. crenata populations. Carapace size measurements can be used as a non-lethal method to estimate body weight and monitor growth patterns, which is crucial for fisheries management and stock assessment (Viswanathan et al. 2016, Vermeiren et al. 2021). Furthermore, these relationships can be used to assess habitat suitability. Stronger correlations, like those seen in Buenavista, might suggest a more favorable environment with ample food resources that allow individuals to attain larger sizes. Finally, the CW-BW and CL-BW relationship data can be compared to existing studies of other crab species to identify potential differences in growth patterns or ecological adaptations among brachyurans (Bezerra Ribeiro et al. 2017, Hamid et al. 2018, Redjeki et al. 2020, Pescinelli et al. 2023).

4 Conclusion and Recommendations

This study of *T. crenata* populations in Surigao City and Buenavista revealed notable morphometric variations, potentially influenced by environmental factors such as warmer water temperatures. Further research is necessary to investigate specific factors, including food availability, water quality, and heavy metal bioaccumulation. This would help better understand population dynamics, mangrove community health and potential health risks associated with human consumption. The findings provide a valuable baseline for future studies, enabling comparisons across time and locations. Investigating environmental factors will contribute to assessments of fisheries production and environmental suitability of the species.

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Statement of Conflict of Interest

To maintain impartiality in the article's evaluation, Jess Jumawan, who serves as the member of the editorial board of JESEG refrained from involvement in the review process of this article. Also, the authors declare that there is no conflict of interest associated with the conduct of this research and the publication of this manuscript.

Author Contribution

PJB Pastor *led the research, conducting field sampling, analyzing data, and drafting the manuscript*. AB Goloran, GL Betco, and CA Salanatin *all made equal contributions to sampling and data analysis*. JH Jumawan *served as a mentor, providing the team with essential skills and shaping the study design.* Dr. Jumawan also *approved the manuscript for submission and waived the review process of this paper* due to his position as a member of the journal's editorial board.

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Diet analysis of Philippine Crocodile *Crocodylus mindorensis* (Schmidt 1935) in Paghungawan Marsh, Barangay Jaboy Pilar, Surigao del Norte, Philippines

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ABSTRACT

Siargao Islands in Surigao del Norte have not been part of the historical range of the Philippine Crocodile (*Crocodylus mindorensis*). However, 36 juvenile F2 progeny of this species were successfully introduced in Paghungawan Marsh in 2013, with a supplemental release of eight yearlings and 21 juvenile crocodiles in 2017. To supplement the current knowledge of this species' biology with essential information on its success in thriving Paghungawan Marsh since its introduction, a study on the diet analysis of this crocodile species was conducted in the area. Through stomach flushing of three *C. mindorensis* individuals captured in the study area, the stomach contents were collected and grouped into four categories: vertebrates (50%), invertebrates (33.33%), inorganic and organic materials (12%), and plant materials (5%). Diet of the three *C. mindorensis* individuals showed food items that vary from Cichliformes (40%), Architaenioglossa (11.67%), Chiroptera (10%), Coleoptera (5%), Decapoda (8.33%), and Hymenoptera (8.33%) which indicates that fishes are their dominant prey. These findings suggest that *C. mindorensis* is a generalist species and seemingly opportunistic. Their diet reflects habitat variability and the available prey items of the established stations. This study highlighted the adaptive capacities of *C. mindorensis* and suggests that if protected and with sufficient prey availability, the population of this endangered species will recover. More dietary composition studies should be done to understand better how this species participates in varied communities.

Keywords: *food items, stomach flushing, carnivorous predator, endemic crocodile*

1 Introduction

Two crocodilian species are found in the Philippines: the Estuarine Crocodile, *Crocodylus porosus*, and the Philippine Crocodile, *Crocodylus mindorensis*. Endemic to the Philippine Islands, *C. mindorensis* was historically distributed in the Visayan Islands and southern and central Luzon but has been locally extinct (Ross and Alcala 1983). Remnant populations are found in inland freshwater habitats in northeastern Luzon and central to southern Mindanao (Pontillas 2000, van Weerd 2010, and Pomares et al. 2008). These records indicate that the species exist in isolated populations on small islands with minimal habitats (Manalo 2008).

Historically, the Philippine crocodile has not been known to occur in the Siargao Islands, Surigao del Norte. In March 2013, 36 juvenile F2 progeny from the Pag-asa Farm semi-wild facility of J.K. Mercado & Sons Agricultural Enterprises Inc. (JKMSAEI) in Kapalong, Davao del Norte, were successfully introduced in Paghungawan Marsh in Siargao Islands initiated by the Philippine Government in partnership with the Non-Government Organization, Crocodylus Porosus Philippines Inc. (CPPI) (Manalo et al. 2013). This semi-wild facility was conceived as part of a tripartite crocodile conservation partnership among DENR, Siliman University, and JKMSAEI. The habitat suitability survey on the release site indicated that Paghungawan Marsh was ideal for Philippine crocodiles. Critical resources such as food and microhabitats are naturally available (Bucol et al. 2013). The release aims to repopulate the species in the wild, enhance the current knowledge of the species biology, and contribute to the island's tourism industry, making it a Community-based Sustainable Tourism (CBST) site featuring the natural and rich biodiversity of Paghungawan Marsh and Crocodile Night Watch as a significant attraction. After the release, monitoring showed a decrease in the number of crocodile sightings, primarily attributed to the natural dispersal movement of the crocodiles to areas inaccessible to humans and the presence of heavy infrastructure development, such as the upgrading of provincial roads, caused the juvenile crocodiles to move away to adjacent waterlogged areas. With this, the local government of Pilar requested a supplemental release of eight yearlings and 21 juvenile crocodiles in 2017 to enhance their community-based sustainable ecotourism and continuously increase the wild population in the southern Philippines (Manolis 2017).

Crocodiles are carnivorous predators that prey on small fishes, frogs, crustaceans, insects, and small aquatic invertebrates (Fergusson 2010). They are ambush hunters, waiting for fish or land animals to come close, then rushing out to attack (Gurjwar and Rao 2018). Nile crocodiles prey on waterfowl and kingfishers by snatching and consuming dead animals that would otherwise pollute the waters (Wallace and Leslie 2008). Crocodiles cannot masticate, and their inflexible tongues cannot assist swallowing. Instead, they rely on mechanical and chemical breakdown further along the digestive tract for food digestion (Avila-Cervantes et al. 2017). According to Gurjwar and Rao (2018), crocodiles have a very slow metabolism and can survive long periods without food. Despite their appearance of being slow, these cold-blooded predators are on top of their environment, and various species have been observed attacking and killing animals.

Based on the study conducted by Isberg (2007), crocodilians are carnivorous reptiles, and their diets consist mainly of proteins and fats. The fat composition in the crocodile's tail is essential because it is a source of energy during low food availability or hibernation periods. Therefore, the tail of a crocodile is adapted for fat storage and plays a vital role in providing energy for the crocodile during times of scarcity (Isberg 2007). The study of Luthada-Rawiswi et al. (2019) on Nile crocodiles revealed that fats are high-energy nutrients that can be utilized to partially spare protein, and fats supply about twice the energy of proteins and carbohydrates.

Studies have shown that the composition of crocodile diet changes distinctly through different life stages (Isberg 2007). As crocodiles grow, they develop strategies to hunt in deeper water (e.g., fish, turtles, and mud crabs) and along the shore (e.g., dingoes, wallabies, and birds). Previous dietary studies reported aquatic and terrestrial insects, arachnids, aquatic gastropods, crustaceans, fish, amphibians, reptiles, birds, and terrestrial mammals (Cedeño-Vazquez et al. 2014). The ontogenetic trends of the crocodilian diet are similar for the different species, although different to compare statistically because of seasons, size classes, and types of analyses (Wallace and Leslie 2008).

More information on the ecology, feeding behavior, and life history of *C. mindorensis* needs to be provided. Most of the early works, mainly on breeding factors and behavior in captivity, were gathered from captive populations at the Crocodile Farming Institute (CFI), which was later renamed to Palawan Wildlife Rescue and Conservation Center (PWRCC) (Ortega 1998), and at a small captive breeding center at Silliman University in Negros Island (Alcala et al. 1987). On the feeding biology of *C. mindorensis,* the only available data is the study of Brown et al. (2021), which reflected the dominance of snails in the food prey items, suggesting its association in rice paddies being their microhabitat. Hence, this study analyzed the stomach contents of

C. mindorensis in Paghungawan Marsh and determined the patterns of prey availability to know the foraging behavior and diet of the said species in the wild. With a better understanding of the feeding biology of *C. mindorensis*, conservation planners can identify more suitable release sites with suitable prey items.

2 Materials and Methods

Study site

The Paghungawan Marsh, covering an area of 18.5 ha, is in the north-central region on the island of Siargao. It is included in the Siargao and Bucas Grande group of islands that were formally gazette as part of the protected area under Presidential Proclamation No. 902 on 10 Oct 1996, under the Republic Act 7586, otherwise known as the National Integrated Protected Areas System (NIPAS) Act of 1992. Formed by a geological limestone depression, the Paghungawan Marsh – a freshwater marsh, lies within the jurisdictional boundaries of Barangay Jaboy in the Municipality of Pilar. The marsh is dominantly covered by typical swamp-associated species such as the cheesewood tree *Nauclea orientalis* (locally called "bangkal") and the herbaceous *Hypolytrum nemorum*. Mudfish, tilapia, and carp are fish species thriving in the area. This habitat maintains its resiliency to changing climate and is known to host diverse terrestrial species.

The sampling site has several natural limestone depressions and shallow caves. These limestone caves become partly submerged underwater during the wetter months. They also serve as the habitat for several fruit-eating bats, swiftlets, and other invertebrate species vital in maintaining ecological processes in the adjacent forest ecosystem. Figure 1 shows the stations where the three crocodiles were captured.

This study was granted with the gratuitous permit number R13-2021-08 issued by DENR Region XIII Butuan City. The study was also presented in the Protected Area Management Board (PAMB) with a resolution number 2021-90.

Crocodiles were captured during the dry season in June 2021 and April 2022. The locations where the traps were set were determined based on previous reports from the quarterly spotlight surveys conducted by CPPI. Baited snare traps were deployed overnight in three sampling stations (Table 1).

The snares were not used in the area for wildlife hunting but were only deployed solely for

Figure 1. Map showing the established station to capture the Philippine crocodiles in Paghungawan Marsh, Philippines.

Table 1. The coordinates of the three sampling stations that were established overnight in Paghungawan Marsh, Philippines.

Stations	Coordinates	Description of Habitat
1	9°53’39.12”N; 126°4’51.6”E	near the access drainage culvert along the edge of marsh dominated with herbaceous plant Hypolytrum nemorum
2	9°53’52.8”N; 126°4’43.32”E	inside a slightly elevated limestone cave
3	9°53’39.12”N; 126°4’51.6”E	near the watch tower within the rock crevices

the study and removed upon sampling completion. Before collecting samples, physicochemical parameters were determined using Onset® HOBO® Data Loggers U-12 for temperature, humidity, and light intensity, together with Horiba Portable meter for pH and dissolved oxygen deployed in the three identified sampling stations.

Capture Method and Stomach Flushing

The three adult Philippine crocodiles that were captured using the baited funnel-type fence snare trap were securely immobilized to measure their SVL and determine sex through cloacal sexing. Stomach contents were obtained within a few hours from the time of capture by stomach flushing with brine solution using the “scoop and pump” method (Taylor et al. 1977) as modified by Webb et al. (1982) until further flushes consisting of water only. Stomach flushing is a non-destructive technique that is demonstrated to recover >95% of contents in crocodilian stomachs (Rice et al. 2005). In performing the procedure, it was made sure that no crocodile was harmed. The subject species was put aside to rest before releasing it carefully back into the wild. Likewise, it was ensured that there was minimum disturbance to the habitat and wildlife resources during the collection process.

Dietary analysis

Stomach samples were sorted and preserved using 70% denatured alcohol for transport to the Caraga State University (CSU) laboratory for further analysis. Each prey item was examined under a stereomicroscope to identify up to the lowest possible taxon. Food items were classified based on existing taxonomic guides (Brown et al. 2021), and the stomach contents were categorized into the following: invertebrate, vertebrate, plant materials, and organic and inorganic materials (Solania et al. 2019). To assess the importance of each prey item in the diet of the three crocodiles, the frequency of occurrence (FOO) was calculated, which is the number of times a category is present in one or more stomachs expressed as a percentage of the total number of stomachs contents (Torralba et al. 2022).

3 Results and Discussion

Prey Preferences of Philippine Crocodiles

Each crocodile captured in Paghungawan Marsh, Siargao Islands, was identified by a unique tail cut number and its sex and snout-to-vent length (SVL) in centimeters. The female had SVL measurements of 95 cm, and the two males had 105 cm and 110 cm, respectively. The stomach content of these three crocodiles was examined, revealing prey items that included fish, snails, ants, bees, wasps, beetles, crustaceans, and plant material, all of which were consistently present across individuals (Table 2). The two male crocodiles’ stomachs contained bats, gastroliths, and wood, suggesting a broader ingestion of materials possibly linked to dietary or digestive behaviors.

As observed, crocodiles 3/1/1 and 2/0/37 captured inside the cave have similar food intake with more diverse prey items compared to crocodile number 3/0/36, captured in Station 1. These findings indicate that crocodiles are opportunistic predators in the habitats they thrive in.

Categorization of food consumed by each individual

The stomach contents found in the three individuals of crocodiles captured in the sampling site were grouped according to their categories based on the previous studies of Torralba et al. (2022) and Solania et al. (2019). As shown in Figure 2, the contents were categorized as invertebrate, like beetles, snails, and crustaceans, and vertebrate prey, which includes its bones and other remnants of its body parts. Plant fragments such as leaves, fruits, and twigs were plant matter. Stones and wood debris were categorized as inorganic and organic materials. Intricate structures from both invertebrates and vertebrates, like shells, chitinous covering of crustaceans, fish scales, and bones, were frequently observed and

Table 2. The stomach contents retrieved from the three captured crocodiles in Paghungawan Marsh, Siargao Islands, Philippines.

Tail Cut Number	Sex	Snout-to-vent Length (SVL) in cm	Stomach Contents
3/0/36	Female	95	fish, snails, ants, bees, wasps, beetle, crustaceans, and plant material
3/1/1	Male	105	fish, snails, ants, bees, wasps, beetle, crustaceans, bats, gastroliths, wood and plant material
2/0/37	Male	110	fish, snails, ants, bees, wasps, beetle, crustaceans, bats, gastroliths, wood and plant material

Figure 2. Stomach contents retrieved from the captured crocodiles: (A) invertebrates; (B) vertebrates; (C) plant material; (D) organic and inorganic material.

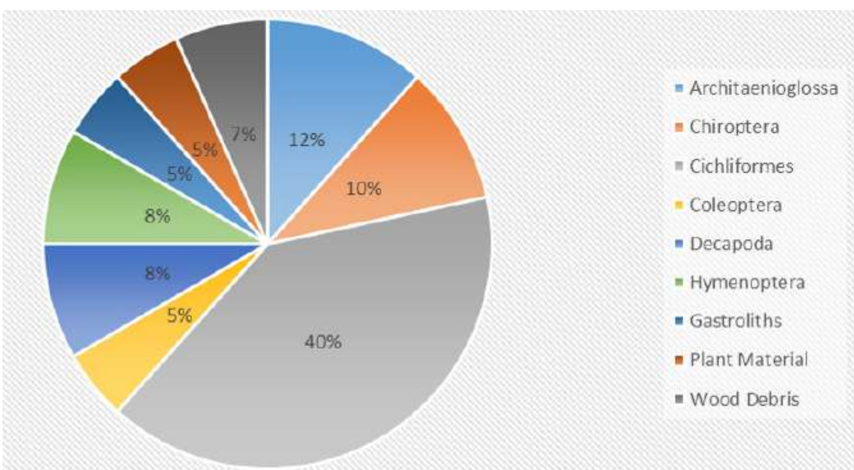

Figure 3. Comparison of percentage composition of each stomach content observed from all sampled individuals of *Crocodylus mindorensis.*

could be overrepresented due to slower digestion and gut retention in crocodiles (Platt et al. 2013).

Figure 3 shows the percentage composition of the different stomach contents in every individual of *C. mindorensis*. Of the stomach contents, Cichliformes had the highest percentage occurrence (Mean=40%) in the three crocodiles followed by Architaenioglossa (Mean=12%). The samples could only be identified up to the Order level and could not be classified to the lowest taxonomic rank.

Percentage of Diet Categories of C. mindorensis

Vertebrates were frequently found in the guts of the examined crocodiles, which comprised 50% of the gut content. *C. mindorensis* consumed food items varying from Chiroptera (FOO=10%) and Cichliformes (FOO=40%) followed by the invertebrates (33.33%) that consisted of Architaenioglossa (FOO=11.67%), Coleoptera (FOO=5%), Decapoda (FOO=8.33%), and Hymenoptera (FOO=8.33%). Inorganic and organic materials ranked third, comprising 12% of the total, while plant material was the least food group recorded (5%). Crocodiles are expected to be known as carnivorous predators (Fergusson 2010).

Environmental parameters were also obtained to discuss its potential effect on prey item availability. As observed in the different sampling plots, the average water temperature and light intensity were highest at Station 3, which is more exposed to the sun (near the watchtower), and lowest at Station 2 (near the cave). Humidity, pH, and dissolved oxygen were highest in Station 2 and lowest in Station 3. These parameters are inversely proportional to temperature.

According to Horne and Goldman (1994), as water temperature increases, the solubility of oxygen decreases, increasing water pollution and negatively affecting aquatic organisms. Low dissolved oxygen levels from increased water temperatures also affect the solubility and availability of essential nutrients. Healthy water should generally have dissolved oxygen concentrations above 6.5-8 mg/L. The occurrence of *C. mindorensis* in cliffs and caves is likely due to the decreasing water level and temperature change in the marsh. Crocodilians have a preferred body temperature of around 30-33℃, and to achieve such temperatures, they move back and forth between warm and remarkable parts of their environment. In cold weather, they bask in the sun to heat; in hot weather, they seek shaded, cool areas to avoid overheating (Webb 2014). During the dry season and the water level in the marsh is shallower, *C. mindorensis* was observed to hide in caves, grottos, and crevices within the secondary-growth karst forest on the eastern side of the marsh as seasonal shelter (Binaday et al. 2020).

Cedeño-Vazquez et al. (2014) reported that it is the first time they observed near the shore of a freshwater wetland in Rio Hondo that a bat is part of the diet of *C. moreletii*. Crocodiles 3/1/1 and 2/0/37 were captured inside the cave; bats represent 10% and 20% of their total stomach contents. Binaday et al. (2020) revealed that three sub-adult crocodiles were found in cliff crevices across a road bordering the marsh. Although several species of crocodiles are known to utilize crevices and caves, like Nile crocodiles (*C. niloticus*) (Fergusson 2010), Australian freshwater crocodiles (*C. johnstoni*) (Somaweera et al. 2014) and African dwarf crocodiles (*O. tetraspis*) (Shirley et al. 2017). According to Binaday et al. (2020), this is the first observation of *C. mindorensis* utilizing elevated limestone crevices and caverns on steep slopes, suggesting that more work is needed to understand its movement patterns and the duration of cave utilization. The findings of this study in Paghungawan Marsh indicate that Philippine crocodiles in the marsh may be exploiting the abundant fish population opportunistically compared to other prey types that are less available in the area.

Since crocodiles are carnivores, gastroliths (stones), wood, plant material, and seeds can be considered accidental ingestion during prey capture (Eaton and Barr 2005). However, Huchzermeyer (2003) mentioned that crocodilians are known to swallow stones as gastroliths, which help digest their prey. Most gastroliths, especially intentionally ingested stones, are generally restricted to the stomach, and the entire digestive tract of vertebrates can contain gastroliths (Wings 2007). Hardwood sticks and seeds could also serve as gastroliths (Eaton and Barr 2005).

Even though percent occurrence has proven to be an efficient method to examine prey items (Platt et al. 2013), digestion rates can produce biased stomach content data and have been shown to inflate the observation of hard chitinous remains due to longer digestion time (e.g., fish scales and bones, snail opercula, and hair) which emphasizes the need for a standardized method to quantify crocodile prey items, allowing for a better understanding of dietary dynamics and inter-individual diet variation.

Comprehensive dietary analyses in crocodiles are difficult to achieve mainly because of the need for methods to determine the lowest taxonomic level and the number of prey consumed with high certainty (Balaguera-Reina et al. 2018). In the study of Wallace and Leslie (2008) involving *C. niloticus*, fishes were found more frequently with increased crocodile size and constituted a higher percentage of the total dietary mass. There was no observed difference between the frequencies of stomach contents between the sexes. In the fishery assessment conducted by Manalo et al. (2015) in Paghungawan Marsh, six fish species were in the marsh. Of a total of 245 fishes sampled, 81% were Nile Tilapia (*Oreochromis niloticus*). The highest total catch (in one hour of fishing) was recorded in the release site in Paghungawan Marsh with a mean catch-per-unit effort (CPUE) of 9.44±7.62 kg/net/hour. The abundance of fish in the marsh could be attributed to its dominance in the observed prey samples.

As shown in Table 3, crocodiles prey on various species. These existing studies on diets subjected three different crocodilian species: 49 American crocodiles (*Crocodylus acutus*) in 10 months (Balaguera-Reina et al. 2018); 286 Nile crocodiles (*Crocodylus niloticus*) in two year-period (Wallace and Leslie 2008); and 30 Philippine crocodiles (*Crocodylus mindorensis*) in nine months (Brown et al. 2021). Considering that more crocodiles were sampled in the previous studies for a longer duration of their studies, they were able to discover a diverse selection of prey items. However, this study in Paghungawan Marsh examined only three crocodiles, revealing five prey groups from six different taxonomic Orders in their stomach contents. Because of the observed low abundance of other potential prey items of Philippine crocodiles in Paghungawan Marsh, such as wading birds, reptiles, and frogs, compared with the high abundance of fish in the marsh (Bucol et al. 2013), the captured individuals showed a dominance of fish in their food intake and less diverse prey items. The low occurrence of some food items could also indicate the low or non-availability of these prey items in certain stations (Balaguera-Reina et al. 2018).

Dietary differences among locations, sex, and size may be related to differences in foraging behavior and variation in prey species encountered in different habitat types (Platt and Brantly 1991). The variety of prey consumed by crocodiles and the transition from invertebrate to vertebrate foods with an increase in size was consistent with other studies. It showed that the composition of their diets changed distinctly through different life stages (Wallace and Leslie 2008, Balaguera-Reina et al. 2018, Platt et al. 2013, and Brown et al. 2021). Crocodiles are considered generalists with a broad spectrum of prey inhabiting all habitats (e.g., terrestrial, aquatic, and aerial) (Balaguera-Reina et al. 2018). There are several similarities in the food preference of the three species of crocodiles, only that Annelida was only

Table 3. Comparison of prey groups observed in the stomach contents of crocodiles based on existing diet studies on different species of crocodiles.

Prey group	*C. niloticus*	*C. acutus*	*C. mindorensis*	*C. mindorensis*
	Balaguera-Reina et al., 2018 (Central America)	Wallace & Leslie, 2008 (Botswana)	Brown et al., 2021 (Philippines)	This study
Amphibians	/	/	/	
Annelida	/			
Arachnids	/	/		
Birds	/		/	
Crustaceans	/	/	/	/
Fish	/	/	/	/
Insects	/	/	/	/
Mammals	/	/	/	/
Reptiles	/	/	/	
Snails			/	/

found in American crocodiles, and snails are only present in Philippine crocodiles, based on the existing dietary studies on crocodiles.

Cichliformes were the most frequently recovered prey, consistent with other crocodilians (Rice et al. 2005 and Wallace and Leslie 2008). Our data showed similarities in prey composition with the study of Brown et al. (2021) in the municipalities within Isabela Province on *C. mindorensis* diet. However, in their study, the dominant prey is a snail, greatly influenced by its study site, whose landscape is intensely dominated by agriculture, interspersed corn and rice fields in the foothills of the Sierra Madre, to networks of small creeks and canals running between agricultural plots with high presence of snails. Despite general expectations of crocodilian ontogenetic dietary trends, snails were prominent in their study's diet of *C. mindorensis*. Reliance on the invertebrate prey base has been previously hypothesized to result from their high abundance and diversity in the environment and net energetic value (Balaguera-Reina et al. 2018).

4 Conclusion and Recommendations

This study found that *C. mindorensis* is a generalist species, as reflected by their diet, the available prey items, and the habitat variability of the established stations. The dietary data showed that it has a varied and seemingly opportunistic diet, and though it is highly dependent on aquatic prey, it still hunts on land as well. It may have similarities with other crocodilians, but there is a local variation within the diet of the said species. This finding highlights the importance of using the context of predator population and prey abundance. Since the present study identified the prey items only up to the Order level, this emphasizes the need for a standardized method to quantify crocodiles' prey items accurately.

Owing to the limited sample size of *C.mindorensis*, it is necessary to allocate a longer sampling duration to capture more individuals of crocodiles to be subjected to stomach lavage, which could result in the observation of a wider variety of prey items. There is a need for additional field observations of foraging crocodiles to complement dietary studies based on the analysis of stomach contents. Further studies should be conducted for greater insight into the confounding factors potentially influencing its diet. This study highlights the adaptive capacities of crocodilians. It suggests that if protected from hunting and with sufficient prey availability, *C. mindorensis* can survive in heavily degraded habitats. Therefore, conservation efforts must be directed to maintain habitats in good conditions with minimum human intervention that allows the population of this endangered species to recover. Also, more studies that quantify dietary composition should be done to understand better how this species fits and participates in the varied communities in which it is found.

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Statement of Conflict of Interest

To ensure impartiality, EF Gamalinda, a member of the JESEG Editorial Board, was excluded from the review process of this article. The authors confirm that there are no conflicts of interest related to the publication of this paper.

Author Contribution

Conceptualization: CJ Baltazar, LA Ombat, ARV Galolo, EF Gamalinda, P Baltazar, and RI Manalo; *Data Collection:* CJ Baltazar, P Baltazar, RI Manalo, and F Magallanes; *Interpretation of Data:* CJ Baltazar; *Manuscript Writing and Revision:* CJ Baltazar, LA Ombat, ARV Galolo, EF Gamalinda, and RI Manalo.

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Beetles (Insecta: Coleoptera) in Andanan Watershed Forest Reserve, Mindanao, Philippines

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ABSTRACT

Beetles (Insecta, Coleoptera) fauna play a crucial role in the food web and serve as a valuable bioindicator of the ecosystem health. In the riparian forest zone of Andanan Watershed Forest Reserve, 52 species from 45 genera and 24 subfamilies were recorded. Scarab beetles (family Scarabaeidae) had the highest species richness, with eleven species, including the largest species, *Chalcosoma atlas*. Other phytophagous groups, such as longhorn beetles (Cerambycidae: 8 species) and weevils (Curculionidae: 7 species), were also documented. Additional families observed include Cantharidae, Carabidae, Chrysomelidae, Cicindelidae, Coccinellidae, Elateridae, Endomychidae, Lampyridae, Lucanidae, Lycidae, Meloidae, Passalidae, and Prionoceridae. Notably, the endemic tiger beetle *Calomera mindanaoensis*, found only in Mindanao, was recorded, along with the recently discovered species of scarab beetles – *Engertia lii* and *Philacelota leucothea*, reported in 2006 and 2019, respectively, and considered endemic to the Philippines. Additionally, the records of two cantharid beetles (*Cordylocera* and *Paradiscodon*), two elaterid beetles (*Lanelater* and *Paracalais*), and a blister beetle (*Zonitoschema*) may represent the first documentation of these groups in Mindanao.

Keywords: *Adephaga, Polyphaga, checklist, new records, watershed beetles*

1 Introduction

A key factor contributing to the remarkable success of beetles (Insecta, Coleoptera) lies in their distinct sclerotized body and modified forewings, which have evolved into rigid elytra that serve as protective sheaths for their delicate hindwings (Sharma et al. 2013). The intricate adaptation of their transformative life cycle to the specialized characteristics of their adult form also exemplifies the evolutionary prowess that has propelled beetles to unparalleled success in diverse ecosystems. Coleoptera, one of the largest insect orders, stands out as a pinnacle of biodiversity, encompassing an extraordinary number of species (Wankhade et al. 2014). Ubiquitous across various habitats, they play a pivotal role in maintaining environmental health and serve as effective bioindicators. Research highlights their sensitivity to changes in forest types and habitat microenvironments, underscoring their importance in assessing ecological conditions (Li et al. 2017).

The extensive diversity of beetles, marked by their adaptability to various habitats and prolonged lifespans, positions them as ideal biological indicators. Their multifaceted roles within ecosystems include significant contributions to ecological food webs, providing protein sustenance for species at higher trophic levels (Sushko 2017). Across beetle families, a wide range of ecological functions emerges – some species act as predators and decomposers of organic material (Rizal et al. 2019), while others are recognized as potential pests. Despite the potential for certain beetle species to be pests, their overall impact on ecosystems is nuanced and often beneficial. For example, ladybird beetles from the family Coccinellidae serve as valuable allies in pest control, with both larvae and adults feeding on aphid colonies and mealy bugs (Brown et al. 2010). Similarly, ground beetles from the family Carabidae function as common predators, preying on various insects and arthropods. Dung beetles and other predatory terrestrial beetles from the Scarabaeiformia and Staphyliniformia groups contribute to pest reduction by efficiently managing populations in mammal dung (Brown et al. 2010). This complex interplay of beetles within ecosystems underscores their dual role as potential pests and indispensable contributors to ecological balance. Understanding these intricate relationships is crucial for appreciating the broader ecological significance of Coleoptera in maintaining the health and equilibrium of various ecosystems.

Studying beetle communities in specific habitats or restricted areas, such as oceanic islands, provides valuable insights into their biodiversity. Comprehensive species lists offer current assessments of ecosystem health and facilitate comparisons with historical data, enabling monitoring changes over time (Howden & Howden 2001). Mindanao, the second-largest island in the Philippines, contains various protected sanctuaries and is recognized as an important hotspot for biodiversity and a center for endemism. However, little is known about the diversity of Coleoptera, particularly in the Caraga region.

The Andanan Watershed Forest Reserve, located in Sibagat and Bayugan, Agusan del Sur, is home to a diverse range of endemic entomofauna across different habitat types (Domine & dela Cruz 2020, Guerzon et al. 2023, Sabuero et al. 2024). However, there is a lack of information on other entomofaunal records, particularly beetles, despite their potential value in forest management and conservation. The results of this study may provide significant insights, such as compiling a checklist of various taxa useful for monitoring coleopteran diversity, establishing a baseline for future research, and contributing to management practices aimed at protecting and conserving this insect group present in the Andanan Watershed Forest Reserve.

2 Materials and Methods

This study follows the entomofaunal survey (Domine & dela Cruz 2020, Guerzon et al. 2023, Sabuero et al. 2024) conducted in the Andanan Watershed Forest Reserve (AWFR) from the following dates: July 13–14; August 24–25; September 21–22 and 28–29, 2019. The collection adhered to the legal requirements outlined in R.A 9147, the Wildlife Resources Conservation and Protection Act, with a Gratuitous Permit (R13-2021-32) from the Protected Area Management Board of the DENR Caraga Region. A preliminary survey, documented through digital media and GPS coordinates, was conducted before the actual fieldwork. The collection is limited to terrestrial and above-ground habitats. Collection methods include opportunistic searching using hand and net-based techniques such as sweep-netting and beating. Collected specimens were initially sorted. A killing jar with phenol was used for large-sized specimens, while small beetles were placed into vials with 85% ethanol. Specimens were relaxed using phenol, then pinned and photo-documented. Coleopterists and other colleague experts validated identifications.

3 Results and Discussion

The Andanan Watershed Forest Reserve (AWFR) (Fig. 1) spans the provinces of Bayugan and Sibagat in Agusan del Sur. The watershed comprises both cultivated and secondary-growth forests, supporting a diverse array of flora and fauna. Three different collections sites were explored: Calaitan (8.7927°N, 125.7789°E), Berseba (8.8552°N, 125.8007°E), and Santo Niño (8.8451°N, 125.7871°E). No collections were conducted within the primary forest of the AWFR, as the secondary forest was more accessible during the sampling period. Beetle fauna were collected in riparian and lowland ecosystems, featuring mixed agricultural vegetation and patches of remaining secondary forests. Cultivated plantations of falcata (*Paraserianthes falcataria*), coconut trees (*Cocos nucifera*), corn (*Zea mays*), banana (*Musa paradisiaca*), cassava (*Manihot esculenta*), and various other root crops were observed in several areas, mostly upland. Fruit-bearing trees such as lanzones (*Lansium parasiticum)* and durian (*Durio zibethinus*) were also noted. Riparian zones, known for their high plant diversity and productivity, provide abundant habitats for animals. The canopy and shade from forest trees contribute to maintaining the pristine quality of water and supporting other vegetation growth (Cayasan et al. 2013).

A total of 45 genera of beetles were recorded in Andanan Watershed Forest Reserve. The majority of the composition belongs to the superfamilies Chrysomeloidea and Curculionoidea, which consist primarily of phytophagous beetles that depend heavily on plants and vegetation. Among the recorded groups, scarab beetles (Scarabaeidae: 11 species) had the highest species count, followed by longhorn beetles (Cerambycidae: 8), weevils (Curculionidae: 7), leaf-beetles (Chrysomelidae: 5), tiger beetles (Cicindelidae: 4) and click beetles (Elateridae: 4). The groups with the fewest species collected were Carabidae, Lucanidae, Coccinellidae, Cantharidae, Prionoceridae, Endomychidae, Lampyridae, Lycidae, Passalidae and Meloidae (Table. 1).

Coleopteran Fauna in Andanan Watershed Forest Reserve

Eight superfamilies (Tables 1 and 2) of beetles were identified in Andanan Watershed Forest Reserve, including the most diverse Chrysomeloidea (25%) and Curculionoidea (13.46%). Scarabaeoidea (26.92%) and

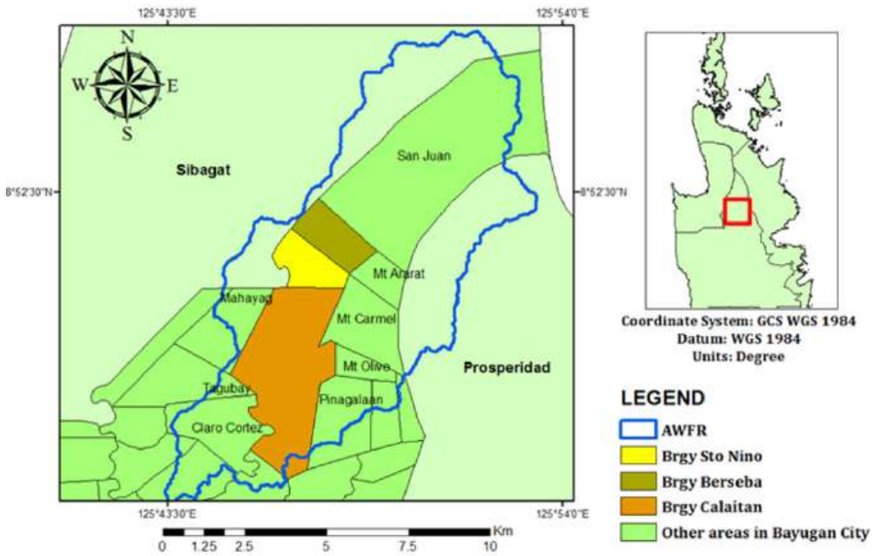

Figure 1. Location map showing the Andanan Watershed Forest Reserve (blue line) and the three collection sites of the study (Calaitan, Berseba, and Sto. Niño).

Table 1. Percent diversity of superfamilies and number of species from different family groups of beetles found in Andanan Watershed Forest Reserve.

Superfamily (% Diversity)	Family (Number of Species)
Caraboidea (9.62%)	Cicindelidae (4) Carabidae (1)
Chrysomeloidea (25%)	Cerambycidae (8) Chrysomelidae (5)
Cleroidea (1.92%)	Prionoceridae (1)
Cucujoidea (5.77%)	Coccinellidae (2) Endomychidae (1)
Curculionoidea (13.46%)	Curculionidae (7)
Elateroidea (15.38%)	Cantharidae (2) Elateridae (4) Lampyridae (1) Lycidae (1)
Scarabaeoidea (26.92%)	Lucanidae (2) Passalidae (1) Scarabaeidae (11)
Tenebrionoidea (1.92%)	Meloidae (1)

Caraboidea (9.62%) were also observed, along with representatives of Elateroidea (15.38%), Cucujoidea (5.77%), Cleroidea (1.92%), and Tenebrionoidea (1.92%) (Table 1).

Ground beetles from the family Carabidae are the only adephagan beetles found in Andanan Watershed Forest Reserve, represented by two subfamilies – Cicindelinae, commonly referred to as tiger beetles, noted for their aggressive predatory behavior and speed, and the genus *Chlaenius* (Fig. 2E) of subfamily Licininae. Three genera of tiger beetles were identified: *Calomera* (Fig. 2D), *Therates* (Figs 2A, 2B) and *Tricondyla* (Fig. 2C). *Tricondyla aptera* (Fig. 2C) is native to the Indo-Australian archipelago (Trautner & Schwaller 1994), as are most species of *Therates* (Figs 2A, 2B) (Santos 2014, Cabras et al. 2016). Additionally, species like *Calomera mindanaoensis* (Fig. 2D) are endemic to Mindanao island (Cassola 2011).

Several groups from the large families of Chrysomeloidea were recorded, including Cerambycidae (longhorn beetles) and Chrysomelidae (leaf beetles). Longhorn beetles were generally observed in woodlands, camouflaging against tree bark, while some species are known to mimic chrysomelids. Seven genera were identified: *Astathes* (Fig. 3H), *Choeromorpha* (Fig. 3G), *Glenea* (Fig. 3A), *Eustathes* (Fig. 3I), *Epepeotes* (Figs 3B, 3D), *Prosoplus* (Fig. 3E), and *Pterolophia* (Fig. 3F), which are also found in other regions of the Indo-Australian Archipelago (Vives 2015, Chemin 2011, Saha et al. 2013). Chrysomelid leaf beetles are closely associated with flowering plants, as they are primarily angiosperm feeders. In Andanan Watershed Forest Reserve, two subfamilies were identified – Cassidinae and Galerucinae. Cassidinae, commonly known as tortoise beetles, were represented by the genus *Aspidimorpha* (Fig. 4A). Meanwhile, Galerucinae was identified with three genera: *Aplosonyx* (Figs 4B, 4E), *Cassena* (Fig. 4D) and *Coeligetes* (Fig. 4C).

Families Coccinellidae and Endomychidae, belonging to the superfamily Cucujoidea, were found in the area. Coccinelid beetles, or ladybirds, were represented by two genera – *Coccinella* (Fig. 4G) and *Henosepilachna* (Fig. 4H) – noted for their predatory ability against aphids. Endomychidae, typically associated with feeding on fungal matter, was represented by the genus *Indalmus* (Fig. 4F). This genus was also included in the study of Shockley et al. (2009), which examined its distribution across various parts of Asia, including the Philippines.

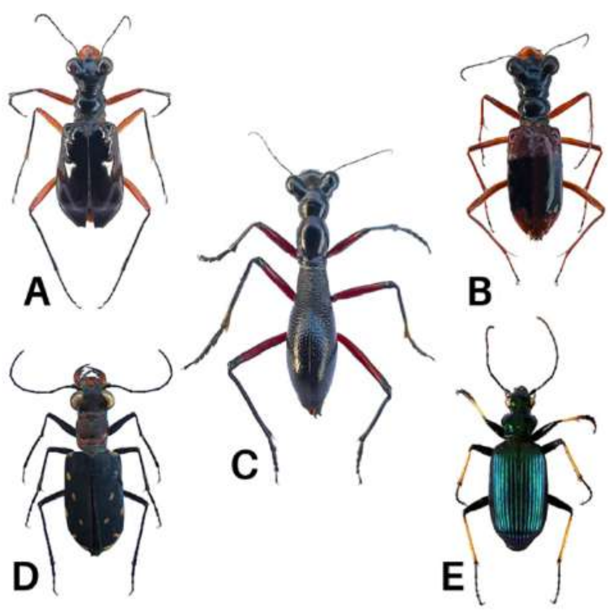

Figure 2. Tiger beetles [Cicindelidae] (A) *Therates coracinus*; (B) *Therates fulvipennis*; (C) *Tricondyla aptera*; (D) *Calomera mindanaoensis*; and a ground beetle [Carabidae] (E) *Chlaenius* sp.

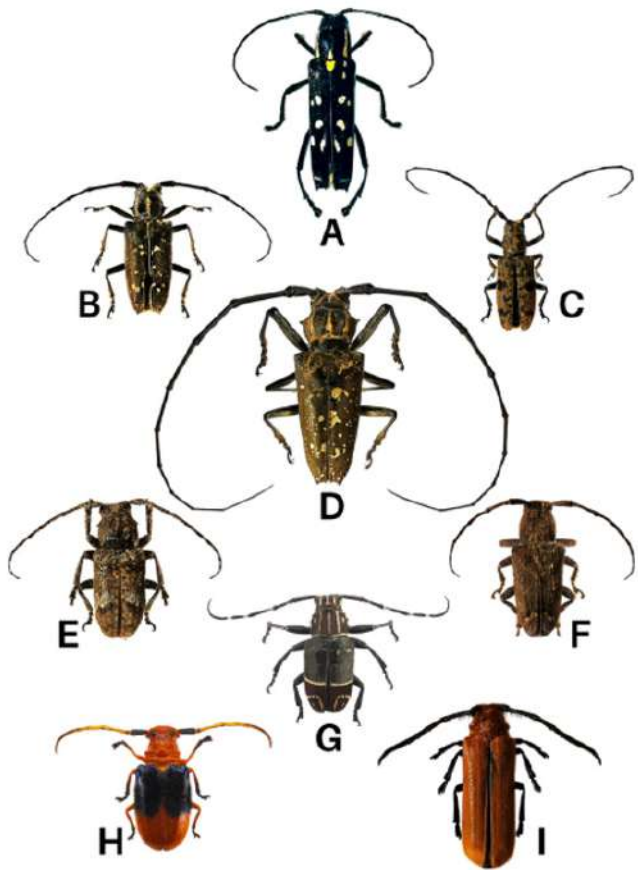

Figure 3. Longhorn beetles [Cerambycidae] (A) *Glenea beatrix*; (B) *Epepeotes desertus* ♀; (C) *Epepeotes plorator*; (D) *Epepeotes desertus* ♂; (E) *Prosoplus bankii;* (F) *Pterolophia jacta*; (G) *Choeromorpha mystica*; (H) *Astathes levis*; and (I) *Eustathes flava*.

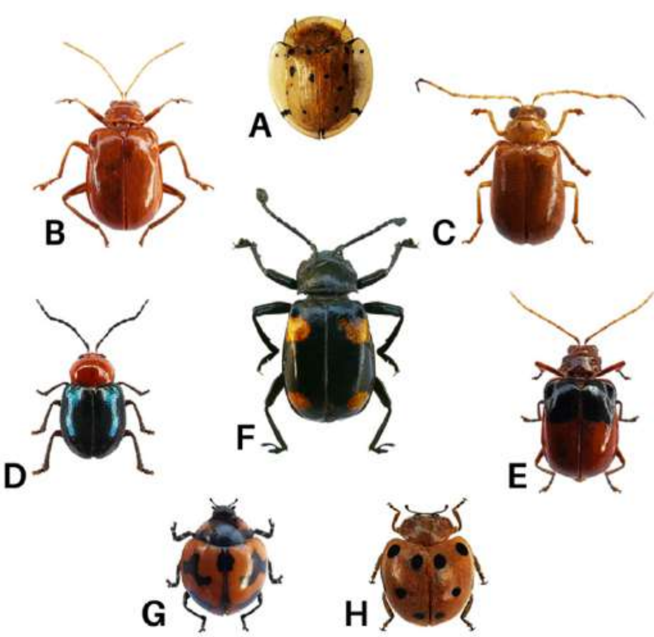

Figure 4. Leaf beetles [Chrysomelidae] (A) *Aspidimorpha miliaris*; (B) *Aplosonyx* sp. 1; (C) *Coeligetes* sp.; (D) *Cassena* sp.; (E) *Aplosonyx* sp. 2, a fungus beetle [Endomychidae]; (F) *Indalmus* sp., and ladybird beetles [Coccinellidae]; (G) *Cocinella transversalis*; (H) *Henosepilachna* sp.

Curculionoidea, one of the most megadiverse superfamilies, was represented by three subfamilies in the Andanan Watershed Forest Reserve: Dryophthorinae, Entiminae, and Molytinae. Members of the genus *Rhynchophorus* (Figs 5E, 5F) (palm weevils) from Dryophthorinae have been reported as a major pest affecting sago palms in Agusan del Sur, Mindanao (Abad 1983). Species from the genera *Calidiopsis* (Fig. 5A) and *Metapocyrtus* (Figs 5B, 5C) (Entiminae) are known for their diversity and endemism in Mindanao (Ballentes et al. 2006, Yap & Gapud 2007). Additionally, representatives of Molytinae, including the genera *Aclees* (Fig. 5G) and *Merus* (Fig. 5D), were also observed.

Four families of Elateroidea were identified in Andanan Watershed Forest Reserve: Cantharidae (soldier beetles), Elateridae (click beetles), Lampyridae (fireflies), and Lycidae (net-winged or trilobite beetles). The cantharid soldier beetles *Paradiscodon* (Fig. 6A) and *Cordylocera* (Fig. 6B) were previously reported in Borneo and other parts of the Oriental region (Aoki & Harada 1982, Geiser 2013), and their presence here may represent the first records in the Philippine archipelago. Similarly, *Lanelater* (Figs 6C, 6D) and *Paracalais* (Fig. 6F), two genera of click beetles, were recorded for the first time on Mindanao island. Also, a large and relatively common species, *Oxynopterus mucronatus* (Fig. 6E), was observed. A firefly from the genus *Vesta* (Fig. 6I), distributed in Taiwan and Continental China (Jeng et al. 2007), was collected as well. The larviform stage of a female lycid beetle *Platerodrilus* (Fig. 6H) was documented. Moreover, a single genus of Prionoceridae from Cleroidea, *Prionocerus* (Fig. 6J), was found and distributed throughout the Oriental Region.

In the superfamily Scarabaeoidea, three families were identified: Lucanidae (stag beetles), Passalidae (bess beetles), and Scarabaeidae (scarab beetles). Stag beetles from the genera *Prosopocoilus* (Fig. 7E) and *Odontolabis* (Fig. 7F), as well as *Leptaulax* (Fig. 7G) of the family Passalidae, were recorded. A study by Cruz et al. (2007) highlighted that these stag beetles are considered wildlife hotspots in southern Palawan and are vulnerable to illegal trade. Additionally, Iwase (1996) described several species of *Leptaulax* collected from various regions in the Philippines, including Mindoro, Ifugao, Negros and Mindanao.

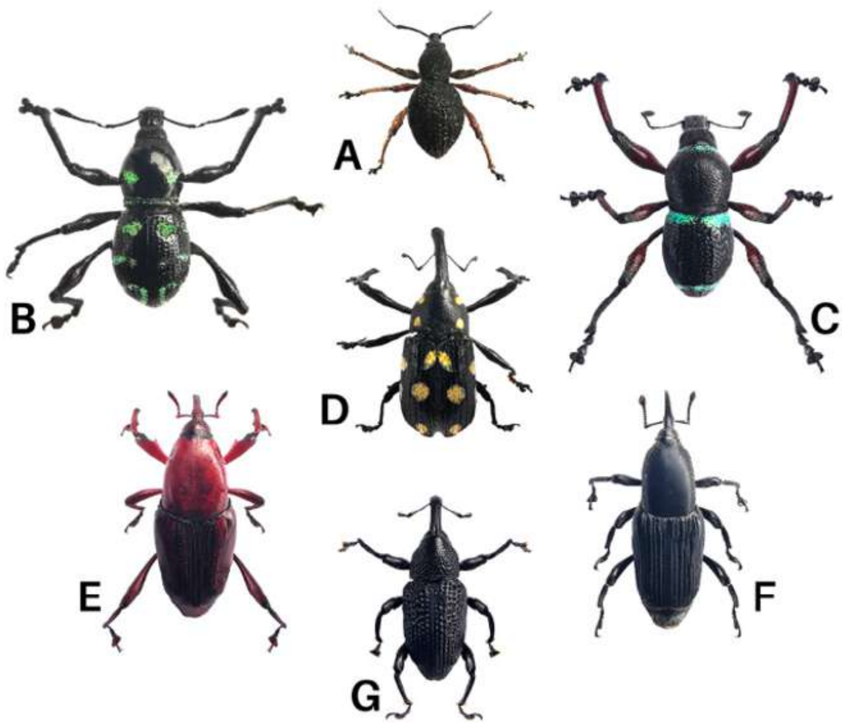

Figure 5. Weevils [Curculionidae] (A) *Calidiopsis* sp.; (B) *Metapocyrtus* sp. 1; (C) *Metapocyrtus* sp. 2; (D) *Merus* sp.; (E) *Rhynchophorus* sp. 1; (F) *Rhynchophorus* sp. 2; and (G) *Aclees hirayamai.*

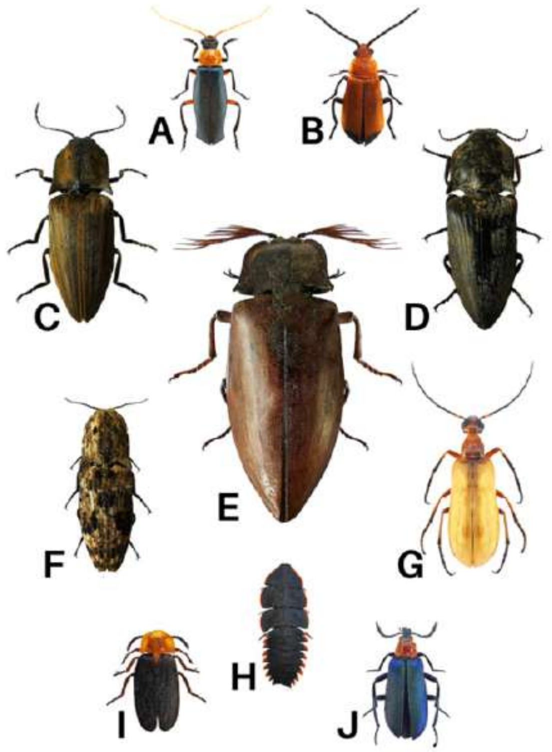

Figure 6. Soldier beetles [Cantharidae] (A) *Paradiscodon* sp.; (B) *Cordylocera atricornis*, click beetles [Elateridae]; (C) *Lanelater* sp. 1; (D) *Lanelater* sp. 2; (E) *Oxynopterus mucronatus*; (F) *Paracalais* sp., a blister beetle [Meloidae]; (G) *Zonitoschema* sp., a trilobite beetle [Lycidae]; (H) *Platerodrilus ruficollis* ♀, a firefly [Lampyridae]; (I) *Vesta* sp., and a small cleroid beetle [Prionoceridae]; (J) *Prionocerus coeruleipennis*.

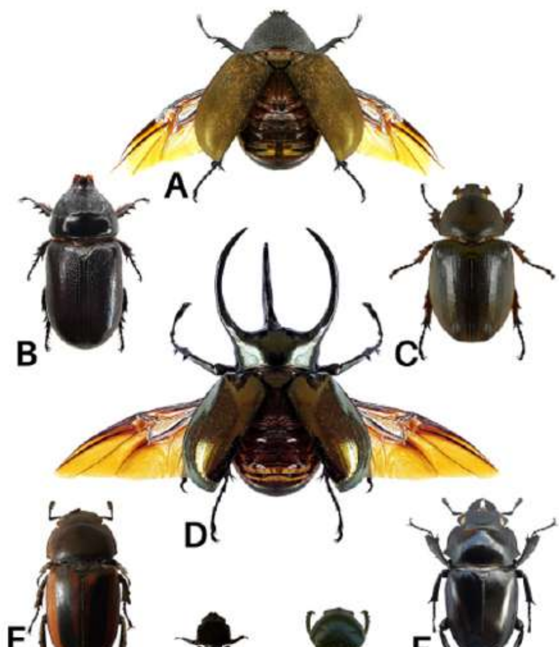

Figure 7. Rhinoceros beetles [Scarabaeidae] (A) *Chalcosoma atlas* ♀; (B) *Oryctes rhinocerus*, (C) *Xylotrupes pubescens*; (D) *Chalcosoma atlas* ♂, stag beetles [Lucanidae]; (E) *Prosopocoilus zebra*; (F) *Odontolabis* sp., a bess beetle [Passalidae]; (G) *Leptaulax* sp., and a dung beetle [Scarabaeidae]; (H) *Onitis falcatus*.

Scarabaeidae, the most diverse group within Scarabaeoidea, included eleven genera across five subfamilies. Among these, *Protaetia* (Fig. 8D) from Cetoniinae and the rhinoceros beetles from the genus *Chalcosoma* (Figs 7A, 7D), *Oryctes* (Fig. 7B), and *Xylotrupes* (Fig. 7C) were identified. Both male and female specimens of *Chalcosoma atlas* (Figs 7A, 7D) were collected in Andanan Watershed Forest Reserve. This large species, known for the prominent horns of the males, is common in Mindanao, with previous records from Mt. Apo (Kawano 1995). Several studies have reported significant damage to palm trees caused by *Oryctes* in Southeast Asia, particularly in the Philippines (Hinckley 1973, Zelazny & Alfiler 1987, Winotai 2014).

The subfamily Melolonthinae, commonly known as June beetles, includes three genera: *Engertia* (Fig. 8F), *Leucopholis* (Fig. 8G) and *Philacelota* (Fig. 8E). *Engertia lii* (Fig. 8F) and *Philacelota leucothea* (Fig. 8E) were first described in the Philippines by Keith (2006) and Prokofiev (2019), respectively, while *Leucopholis* species are widespread and notorious for causing damage to crops in the Philippines (Calcetas & Adorada 2017). Dung beetle *Onitis* (Fig. 7H) from the subfamily Scarabaeinae, which are entirely coprophagous, have distributions extending beyond Africa into the Palearctic and Oriental regions (Gupta et al. 2015). According to Cheung et al. (2018), *O. falcatus* (Fig. 7H) is the only dung beetle species found in the Philippines and was likely collected in this study area. Rutelinae, commonly called leaf chafers, were also recorded, with two genera represented: *Adoretus* (Fig. 8A) and *Anomala* (Figs 8B, 8C). Lastly, a single species of blister beetle from the family Meloidae, *Zonitoschema* (Fig. 6G), was also collected. In a 1982 paper by Mohamedsaid, four species of this genus were documented in Malaysia, suggesting that this might be the first record of this group in the Philippines.

According to Bouchard et al. (2017), among the six megadiverse families of beetles, five were collected in Andanan Watershed Forest Reserve – Curculionidae, Carabidae, Chrysomelidae, Cerambycidae and Scarabaeidae. However, the family Staphylinidae (rove beetles) was not reported during the expedition due to the unsuitable collection methods used. Rove beetles and other members of Staphyliniformia are relatively small

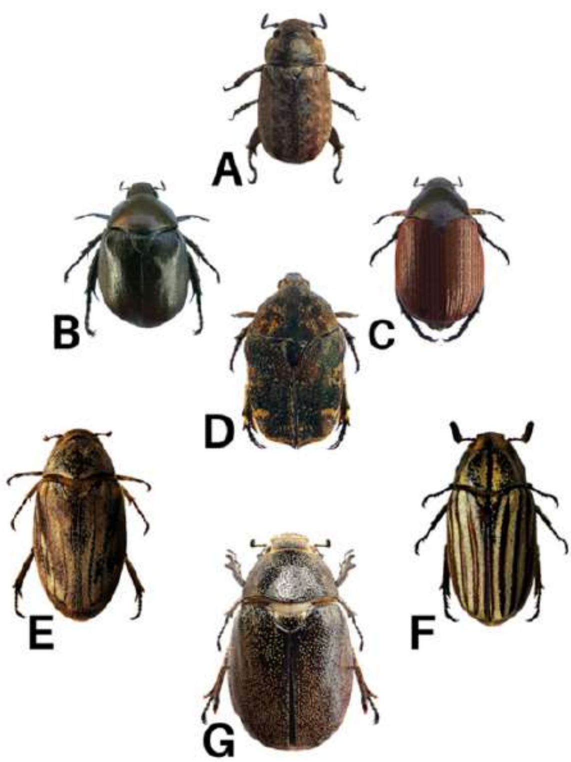

Figure 8. Leaf chafers [Scarabaeidae] (A) *Adoretus* sp.; (B) *Anomala* sp. 1; (C) *Anomala* sp. 2, a flower chafer [Scarabaeidae]; (D) *Protaetia fusca*, and scarab beetles [Scarabaeidae]; (E) *Philacelota leucothea*; (F) *Engertia lii*; (G) *Leucopholis* sp.

Table 2. Inventory checklist of beetles (Coleoptera) collected in Andanan Watershed Forest Reserve, showing various species from different taxa groups.

Suborder	Superfamily	Family	Subfamily	Genus	Species
Adephaga	Caraboidea	Cicindelidae	Cicindelinae	*Calomera* Motschulsky, 1862 *Therates* Latreille, 1816 *Tricondyla* Latreille, 1822	*C. mindanaoensis* Cassola, 2000 *T. coracinus* Erichson, 1834 *T. fulvipennis* Bates, 1878 *T. aptera* Chevrolat, 1841
		Carabidae	Licininae	*Chlaenius* Bonelli, 1810	*Chlaenius* sp.
Polyphaga	Chrysomeloidea	Cerambycidae	Lamiinae	*Astathes* Newman, 1842 *Choeromorpha* Chevrolat, 1849 *Glenea* Newman, 1842 *Epepeotes* Pascoe, 1866 *Eustathes* Newman, 1842 *Prosoplus* Blanchard, 1853 *Pterolophia* Newman, 1842	*A. levis* Newman, 1842 *C. mystica* Pascoe, 1869 *G. beatrix* Thomson, 1879 *E. desertus* Linnaeus, 1758 *E. plorator* Newman, 1842 *E. flava* Newman, 1842 *P. bankii* Fabricius, 1775 *P. jacta* Newman, 1842
		Chrysomelidae	Cassidinae	*Aspidimorpha* Hope, 1840	*A. miliaris* Fabricius, 1775
			Galerucinae	*Aplosonyx* Chevrolat, 1837 *Cassena* Weise, 1892 *Coeligetes* Jacoby, 1884	*Aplosonyx* sp. 1 *Aplosonyx* sp. 2 *Cassena* sp. *Coeligetes* sp.
	Cleroidea	Prionoceridae	Prionoceridae	*Prionocerus* Perty, 1831	*P. coeruleipennis* Perty. 1831
	Cucujoidea	Coccinellidae	Coccinellinae	*Coccinella* Linnaeus, 1758 *Henosepilachna* Li, 1961	*C. transversalis* Fabricius, 1781 *Henosepilachna* sp.
		Endomychidae	Lycoperdininae	*Indalmus* Gerstaecker, 1858	*Indalmus* sp.
	Curculionoidea	Curculionidae	Dryophthorinae	*Rhynchophorus* Herbst, 1795	*Rhynchophorus* sp. 1 *Rhynchophorus* sp. 2
			Entiminae	*Calidiopsis* Heller, 1913 *Metapocyrtus* Heller, 1912	*Calidiopsis* sp. *Metapocyrtus* sp. 1 *Metapocyrtus* sp. 2
			Molytinae	*Aclees* Schönherr, 1833 *Merus* Gistel, 1857	*A. hirayamai* Kono, 1933 *Merus* sp.
	Elateroidea	Cantharidae	Silinae	*Cordylocera* Guerin-Meneville, 1830 *Paradiscodon* Wittmer, 1954	*C. atricornis* Guerin-Meneville, 1838 *Paradiscodon* sp.
		Elateridae	Agrypninae	*Lanelater* Arnett, 1952 *Paracalais* Neboiss, 1967	*Lanelater* sp. 1 *Lanelater* sp. 2 *Paracalais* sp.
			Oxynopterinae	*Oxynopterus* Hope, 1842	*O. mucronatus* Olivier, 1792
		Lampyridae	Amydetinae	*Vesta* de Castelnau, 1833	*Vesta* sp.
		Lycidae	Leptolycinae	*Platerodrilus* Pic, 1921	*P. ruficollis* Pic, 1942
	Scarabaeoidea	Lucanidae	Lucaninae	*Prosopocoilus* Westwood, 1845 *Odontolabis* Hope, 1842	*P. zebra* Olivier, 1789 *Odontolabis* sp.
		Passalidae	Passalinae	*Leptaulax* Kaup, 1868	*Leptaulax* sp.
		Scarabaeidae	Cetoniinae	*Protaetia* Burmeister, 1842	*P. fusca* Herbst, 1790
			Dynastinae	*Chalcosoma* Hope, 1837 *Oryctes* Hellwig, 1798 *Xylotrupes* Hope, 1837	*C. atlas* Linnaeus, 1758 *O. rhinoceros* Linnaeus, 1758 *X. pubescens* Waterhouse, 1841
			Melolonthinae	*Engertia* Dalla Torre, 1913 *Leucopholis* Dejean, 1833 *Philacelota* Heller, 1900	*E. lii* Keith, 2006 *Leucopholis* sp. *P. leucothea* Prokofiev, 2019
			Scarabaeinae	*Onitis* Fabricius, 1798	*Onitis falcatus* Wulfen, 1786
			Rutelinae	*Adoretus* Laporte, 1840 *Anomala* Samouelle, 1819	*Adoretus* sp. *Anomala* sp. 1 *Anomala* sp. 2
	Tenebrionoidea	Meloidae	Nemognathinae	*Zonitoschema* Peringuey, 1909	*Zonitoschema* sp.

in size, mycophagous, saprophagous, algal feeders, and even predators of smaller insects, typically inhabiting heterotrophic niches. Despite this, plant-feeding beetles, such as weevils, leaf beetles, and longhorn beetles, were frequently observed. These groups, closely associated with flowering plants, demonstrate a remarkable diversity driven by this ecological relationship (Bouchard et al. 2017). Another diverse family collected were the scarab beetles, most of which are phytophagous, relying on plants and plant structures for feeding. Several scarab species, particularly dung beetles, are saprophagous, feeding on decaying organic matter.

Scarab beetles were the largest specimens found among the collected beetles, particularly the atlas beetle *Chalcosoma atlas,* a common species in which both male and female individuals were collected. Other large specimens include members of the subfamily Dynastinae and family Lucanidae (stag beetles). A large elaterid beetle, *Oxynopterus mucronatus,* was also documented. However, smaller-sized beetle groups were not well represented due to the collection methods being biased towards more extensive, more conspicuous individuals, with a primary reliance on sweep net collection.

Most beetles found in Andanan Watershed Forest Reserve are native to the Oriental region or endemic to the Philippine archipelago. Some species are newly described or recently reported in the Philippines, such as the tiger beetle *Calomera mindanaoensis,* described in 2000 and endemic to Mindanao, and the scarab beetles *Engertia lii* (described in 2006) and *Philacelota leucothea* (discovered in 2019), both believed to be endemic to the Philippines. While all collected specimens were identified to the generic level, almost 50% remain unidentified at the species level, particularly among the weevils and leaf beetles.

The landscape and structure of the stream ecosystem play a crucial role in shaping the beetle diversity in Andanan Watershed Forest Reserve. This diversity may be influenced by the area's riparian forest, consisting of forest patches, moist ground, thick layers of leaf litter, and lowland areas, including agricultural lands. Beetles in the reserve display a wide range of habitat preferences (Banerjee, 2014), suggesting that they have developed ecological and biological adaptations suited to varying habitats and diets. Additionally, beetles are known to thrive in almost every type of habitat, with their diversity being particularly pronounced in tropical regions. It is also worth mentioning that Varela and Degamo (2016) reported several species of aquatic beetles in the nearby Agusan Marsh, possibly found also in the aquatic habitats of the Andanan Watershed.

4 Conclusion and Recommendations

Megadiverse phytophagous beetles have shown a significant number in Andanan Watershed Forest Reserve, such as weevils, leaf beetles, longhorn beetles, and scarab beetles, exhibiting that the vegetation structure of the area's riparian forest establishes a hospitable matrix for this beetle fauna. The island of Mindanao houses both mountainous regions and sanctuaries that are considered an essential hotspot for the biodiversity of endemic flora and fauna, while other forests are still not fully explored yet, possibly leading to new species and more new records of other insect fauna in the region.

This preliminary study focuses on the checklist of coleopteran fauna using basic and limited collection resources. Thus, it is recommended that other collecting techniques, such as several trapping collections (Malaise, light, flight-intercept, pitfall, and bait), be utilized to improve the assessment of beetle biodiversity in the area. The study also suggests conducting a survey and collection within the primary forest.

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Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

Author Contribution

MCC Gultiano contributed to the collection of specimen materials from the field and the initial drafting of the manuscript. NAR Burias assisted in processing the materials through imaging and helped in reviewing and editing the manuscript. INB dela Cruz led the conceptualization of the study, and provided overall supervision, including collection of materials and revision of the paper.

All authors approved the final version of the manuscript.

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POLICY BRIEF

Envisioning a Sustainable Water Resource Governance in the Sambunotan Watershed: Integrating GIS, Hydrology, Geology, and Water Quality Insights

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KEY POINTS

- The Sambunotan Watershed is essential for water supply, agriculture, and biodiversity in northern Dinagat. However, it faces natural and man-made disruptions that include deforestation, mining, unsustainable farming, and climate variability, putting ecosystem services and the community well-being at risk.
- A revised watershed boundary corrected discrepancies in earlier delineations and revealed that the Sambunotan River is not its primary tributary.
- With approximately 70% of the watershed classified as Alienable and Disposable (A&D), 30% as timberland, and no protected areas, combined with mining tenements covering more than 75% of its area, the watershed is highly vulnerable to environmental degradation.
- Hydrological modeling highlighted seasonal water dynamics, with a total baseflow of 71.60 million cubic meters (MCM), while water quality analysis linked land use, particularly tree cover, to improved water parameters, underscoring the need for sustainable land-use practices.
- Key recommendations include designating protected areas or local conservation areas, regulating mining and land use in A&D zones, improving water and sediment monitoring, enhancing reforestation in riparian zones, and renaming the watershed to align governance with its true ecological and hydrological features.

Keywords: *Sustainable Water, Watershed Governance, Sambunotan Watershed, GIS, Hydrological Analysis, Geological Mapping, Water Quality Assessment, Watershed Management*

1 Introduction

Governance to manage water resources is crucial for preserving ecological balance and supporting the livelihoods of communities that depend on them (Annisa et al. 2023). The Sambunotan Watershed, located in northern Dinagat, Mindanao, Philippines, is a critical resource by providing clean water and sustaining agriculture and biodiversity (Crismundo 2020, Naïve et al. 2019). In recent years, the environmental conditions of the watershed have deteriorated (Crismundo

2020), with the most pressing threats being timber poaching, charcoal production, grass fires, and other unsustainable practices (Bagayas 2020). Moreover, the watershed is increasingly threatened by deforestation, agricultural expansion, mining activities, and the impacts of climate variability. If not addressed, these stressors could jeopardize the watershed's ability to provide essential ecosystem services, with potentially severe long-term consequences for the environment and local communities. Without immediate and coordinated action, the watershed's capacity to support biodiversity, agriculture, and water resources will continue to decline. This concern underscores the importance of achieving Sustainable Development Goals (SDGs) such as SDG 6 (Clean Water and Sanitation) to ensure sustainable water resource management, SDG 11 (Sustainable Cities and Communities) to enhance resilience and sustainability in human settlements that depend on the watershed, SDG 13 (Climate Action) to address climate-related impacts, SDG 15 (Life on Land) to protect and restore terrestrial ecosystems, and SDG 12 (Responsible Consumption and Production) to promote sustainable practices. A comprehensive and sustainable watershed management plan is urgently needed to integrate these SDGs into actionable governance interventions.

In this context, a collaborative effort between Caraga State University and KAISAHAN, Inc.,[1] a non-governmental organization, was initiated in 2021 to conduct a baseline study supporting the development of the Sambunotan Watershed Management Plan (SWMP). This policy brief highlights key findings from the study, which combined hydrological modeling, geological mapping, water quality analysis, GIS tools, advanced analytical techniques, and field surveys. Together, these approaches aided to comprehensively understand the Sambunotan Watershed's dynamics and vulnerabilities.

The following sections detail these findings, drawn from the terminal report (Makinano-Santillan et al. 2022) and related publications (Makinano-Santillan et al. 2024a; Makinano-Santillan et al. 2024b; Salcedo-Albores et al. 2023). Building on these findings, we explore policy implications and recommendations to address key risks and opportunities for intervention. This scientific foundation provides a basis for designing governance frameworks that tackle resource management challenges while fostering ecological conservation and community resilience. By adopting this collaborative, science-driven approach, we can support the long-term sustainability of the Sambunotan Watershed and its essential ecosystem services.

2 Major Findings and Insights from the Sambunotan Watershed Study

2.1 (Re)Defining the Sambunotan Watershed Boundary for Informed Policy and Management

The Sambunotan Watershed, delineated by the Department of Environment and Natural Resources (DENR)[2], covers approximately 2,819.59 hectares in the northern part of Dinagat Islands province, Caraga Region, Mindanao, Philippines (Figure 1). This estimate closely matches the 2,819 hectares reported by Crismundo (2020) but slightly differs from the 2,820.99 hectares cited by Bagayas (2020).

Recognizing the need to address discrepancies in reported watershed areas, enhance physical characterization, and support hydrological modeling and analysis, a precise delineation of the Sambunotan Watershed boundary was conducted. Using a 5-meter spatial resolution Digital Terrain Model (DTM)[3] and advanced GIS-based watershed delineation techniques (Makinano-Santillan et al. 2022), the refined boundary (Figure 1b) adheres to the definition outlined in Presidential Decree No. 705: "a land area drained by a stream or fixed body of water and its tributaries having a common outlet for surface run-off" (The LAWPhil Project 2022).

The refined delineation reveals a total surface area of 2,823.96 hectares[4] — substantially more extensive than previously reported estimates. This increase is attributed to the use of high-resolution topographic data, which allowed for a

[1] Kaisahan Tungo sa Kaunlaran ng Kanayunan at Repormang Pansakahan, Inc.

[2] The watershed boundaries, obtained from the DENR and provided as a GIS shapefile, were supplied to the project by KAISAHAN, Inc.

[3] A DTM is a type of a Digital Elevation Model (DEM). It is a representation of the Earth's bare surface topography, devoid of vegetation, buildings, and other surface objects. The Interferometric Synthetic Aperture Radar (IfSAR) DTM from the National Mapping and Resource Information Authority (NAMRIA) was utilized in the refined watershed boundary delineation.

[4] GIS-computed area, with the Universal Transverse Mercator (UTM) Zone 52, World Geodetic System 1984 coordinate reference system.

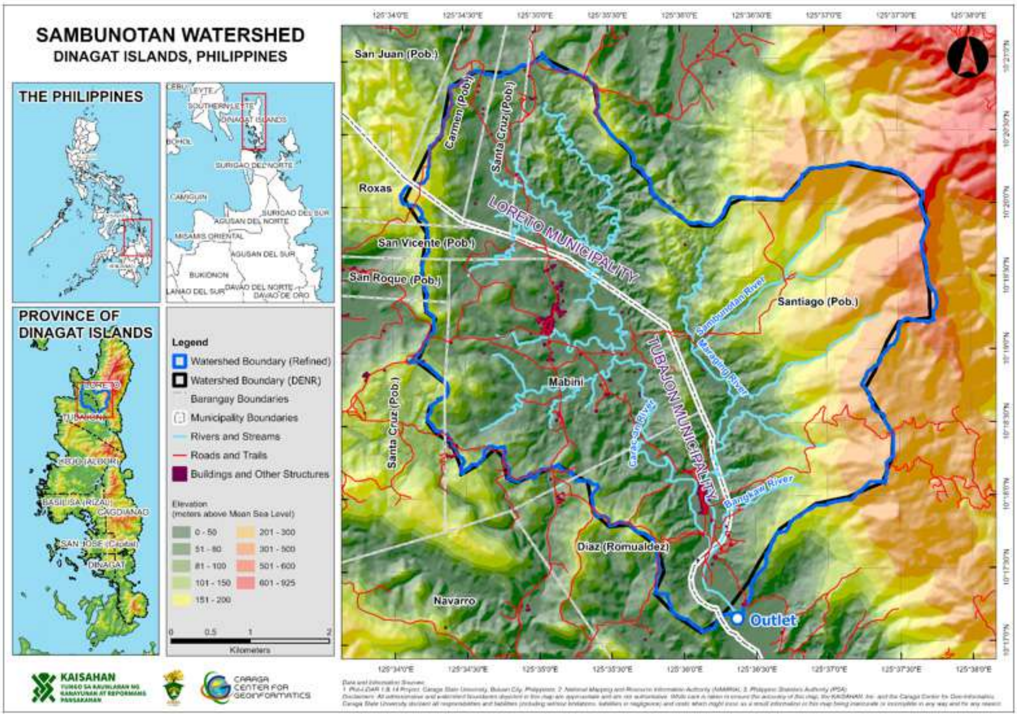


Figure 1. Map showing the boundaries of the Sambunotan Watershed. The black line represents the boundary delineation provided by the DENR, while the blue line indicates the refined boundary derived from a 5-meter spatial resolution Digital Terrain Model (DTM).

more accurate identification of natural watershed boundaries. Based on the refined boundary, approximately 63% of the watershed is within the Loreto municipality, while the remaining 37% is within Tubajon. Three barangays of Loreto and six barangays of Tubajon have boundaries within the watershed[5]. This refined understanding of the boundary provides a stronger foundation for the watershed's policy development, resource management, and sustainable planning efforts.

2.2 Hydrological and Geographical Features of the Sambunotan Watershed

The Sambunotan Watershed constitutes a significant portion of the Malinao Inlet Basin (Figure 2), covering approximately 23% of its total area of ~12,277 hectares (Makinano-Santillan et al. 2022). All water from the Sambunotan Watershed flows downstream into the middle part of the Malinao Inlet Basin, ultimately discharging into the Malinao Inlet, which highlights the watershed's critical role in sustaining downstream water resources, influencing the basin's sediment transport, water quality, and ecological health.

A GIS analysis of the watershed's drainage network reveals a total length of rivers and streams measuring approximately 67 kilometers, corresponding to a drainage density of 2.38 km/km^2. Elevation within the watershed varies from 0 meters near the main outlet to 665 meters above mean sea level (MSL), with an average elevation of 111 meters above MSL (Figure 3a). The average slope of 23% reflects predominantly rolling to moderately steep terrain. Notably, areas with steep slopes exceeding 30% are concentrated in the eastern part of the watershed (Figure 3b).

A further subwatershed delineation identified three major river systems and their corresponding subwatersheds (SW) within the Sambunotan Watershed (Figure 4): the Carac-an River SW, Maraging River SW, and Bangkaw River SW.

[5] These barangays are Santiago, Santa Cruz, and Carmen in Loreto, and Diaz, Mabini, Santa Cruz, San Roque, San Vicente, and Roxas in Tubajon.

Figure 2. Map showing the Sambunotan Watershed within the Malinao Inlet Basin, which spans the municipalities of Loreto, Tubajon, and Libjo.

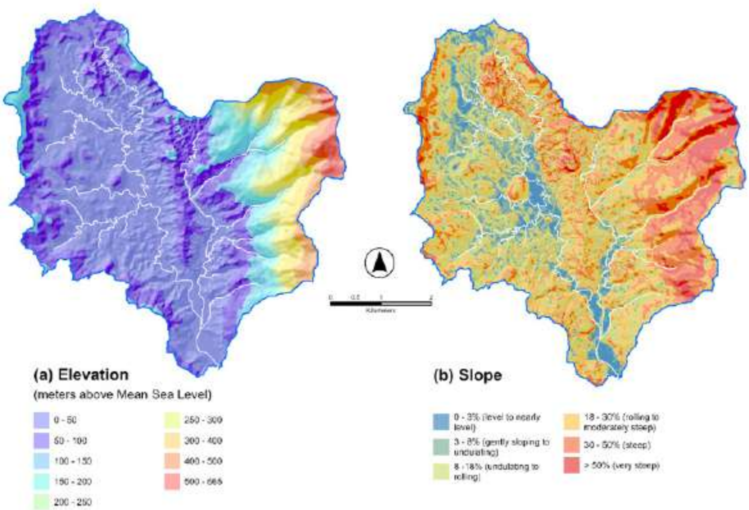


Figure 3. Elevation and slope maps of Sambunotan Watershed.

Among these, the Carac-an River SW is the largest, covering 1,527.44 hectares (54%), followed by the Maraging River SW with 1,064.94 hectares (38%). The Bangkaw River SW and other minor areas account for the remaining 8%.

Beyond identifying the major river systems and sub-watersheds, the delineation provided valuable insights to support better and more effective water resource governance within the watershed:

● The Sambunotan River's Role and Location: The Sambunotan River is not the major tributary of the watershed. Instead, it is an upstream river with its own drainage area within the Maraging River

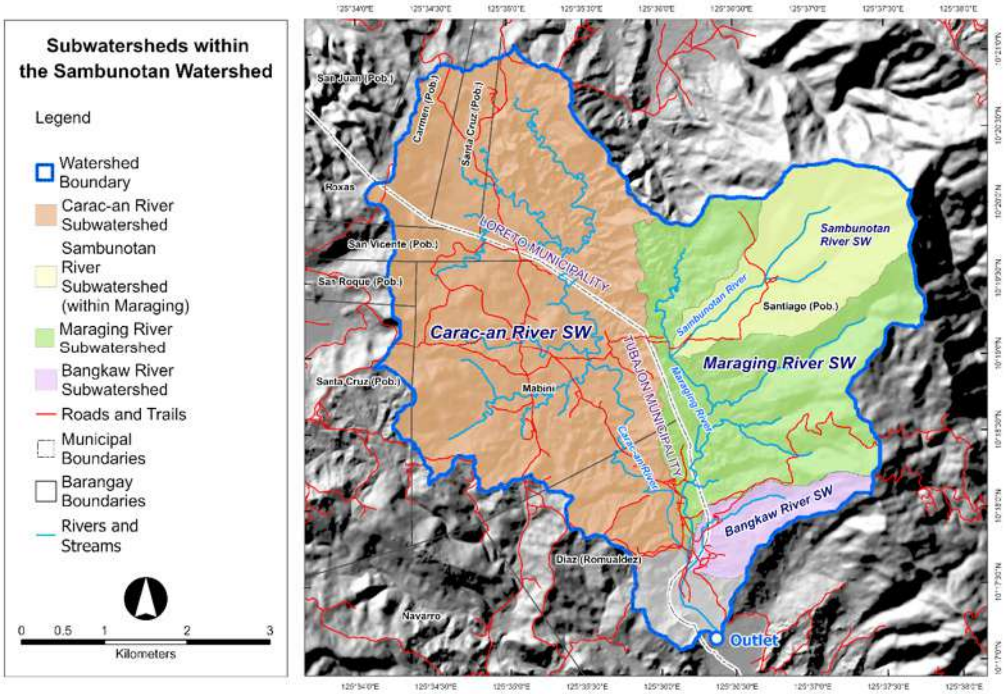


Figure 4. Subwatersheds within the Sambunotan Watershed.

SW, covering approximately 374.37 hectares. The Sambunotan River lies upstream of the Maraging River in Loreto municipality and is several kilometers from the watershed's primary outlet.

- Absence of a Dominant Tributary: No single river is the major tributary of the so-called Sambunotan Watershed. The Carac-an, Maraging, and Bangkaw rivers have distinct watersheds. Near the downstream portion of the watershed, the Carac-an River and Maraging River converge, further emphasizing the interconnected but distinct nature of the watershed's hydrological systems.

These findings highlight a critical issue with the name "Sambunotan Watershed," which inaccurately implies that the Sambunotan River is the primary tributary of this watershed. This misnomer can lead to confusion in watershed governance, potentially resulting in misaligned priorities and ineffective management plans. To address this, it may be necessary to adopt a more appropriate and representative name for the watershed—one that reflects its actual hydrological composition and the significant roles of the Carac-an, Maraging, and Bangkaw Rivers (e.g., Carac-an-Maraging-Bangkaw Watershed). Renaming the watershed appropriately could improve clarity, enhance stakeholder communication, and ensure management strategies align with the area's hydrological and ecological dynamics. Moreover, identifying the location of the actual Sambunotan River could enable more focused and effective management of its drainage area, should specific attention be required for its conservation or development.

Although we advocate for renaming the watershed, we will continue using the term 'Sambunotan Watershed' in the succeeding section for consistency in the discussion.

2.3 Land Classification and Land-use/Land-cover Dynamics in the Sambunotan Watershed

According to DENR data, approximately 70% of the Sambunotan Watershed is classified as Alienable and Disposable (A&D), while the remaining 30% is classified as timberland (Figure 5a). No part of the watershed is designated as a protected area. Within the watershed, there are about three Mineral Production Sharing Agreements (MPSAs) covering approximately 700 hectares (25% of the watershed), about two Exploration Permit Applications (EXPAs) covering approximately 800 hectares, an Application for

Production Sharing Agreement (APSA) covering about 280 hectares, and two declared Minahang Bayan[6] covering approximately 380 hectares (Mines and Geosciences Bureau Region XIII 2022) (Figure 5b).

The classification and land use activities within the Sambunotan Watershed provide context for understanding its evolving land cover. While significant portions of the area are allocated for mineral agreements and timberland, the dominant land cover remains relatively stable, as shown by our analysis of Esri Land-cover maps (Esri 2022) (Figure 6). From 2018 to 2021, trees consistently covered more than 60% of the watershed yearly, while rangeland accounted for over 20% but never exceeded 30% (Figure 6). Cropland and built-up areas remained the least prevalent, covering less than 10% of the total watershed areas (Makinano-Santillan et al. 2022).

Analysis of land cover changes (Figure 7) reveals that built-up areas in the watershed have not expanded significantly, with the largest extent recorded in 2020 at approximately 30 hectares, equivalent to 1.08% of the total watershed area. Cropland areas showed minor changes, decreasing from 2018 to 2020 and increasing slightly from 2020 to 2021. Rangeland increased from 2018 to 2019 but then decreased from 2019 to 2021. Conversely, tree cover decreased from 2018 to 2019 but recovered and increased from 2019 to 2021. Overall, these changes are relatively minor, and the land cover condition of the watershed can generally be considered stable over the past five years (Makinano-Santillan et al. 2022). These findings are based on Esri land cover maps, which may have accuracy limitations. Interpretations should be made cautiously and, where possible, supported by field validation.

2.4 Baseline Hydrological Data and Modeling

To further support the development of a comprehensive management plan for the watershed, baseline hydrological data was collected to support the hydrological modeling and aid in water management strategies (Makinano-Santillan et al. 2022, Salcedo-Albores et al. 2023). Rainfall, water level, and discharge measurements were

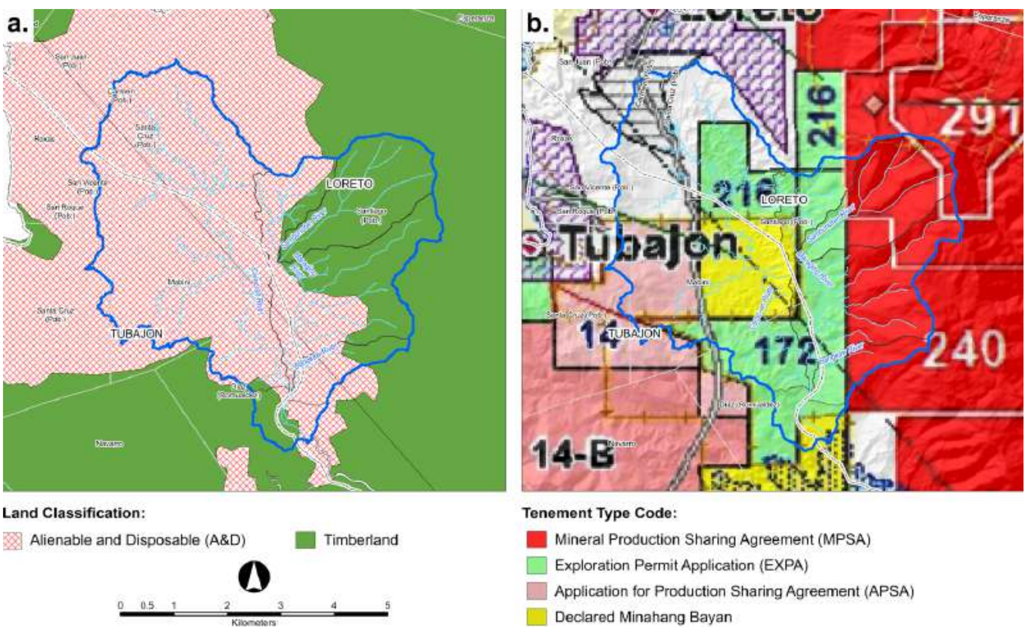


Figure 5. (a) Land classification and (b) mining tenements within the Sambunotan Watershed. The land classification data is sourced from the Department of Environment and Natural Resources (DENR) Caraga Region XIII, while the mining tenements data is based on the Mines and Geosciences Bureau (MGB) Regional Office No. XIII Mining Tenements Control Map as of October 31, 2022.

[6]According to the DENR Administrative Order No, 2015_03, "Minahang Bayan" or "People's Small-Scale Mining Area" refers to the entire area declared as People's Small-Scale Mining Area pursuant to Republic Act No. 7076, otherwise known as the “People’s Small-Scale Mining Act of 1991”.

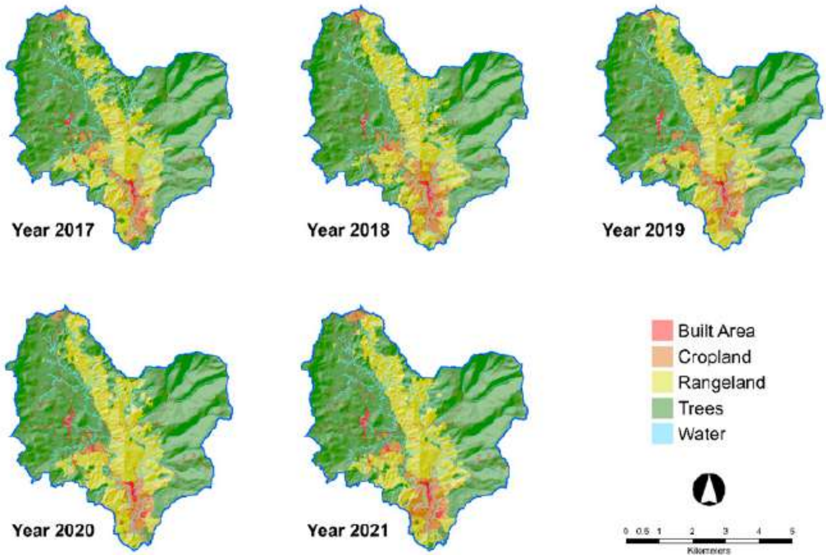
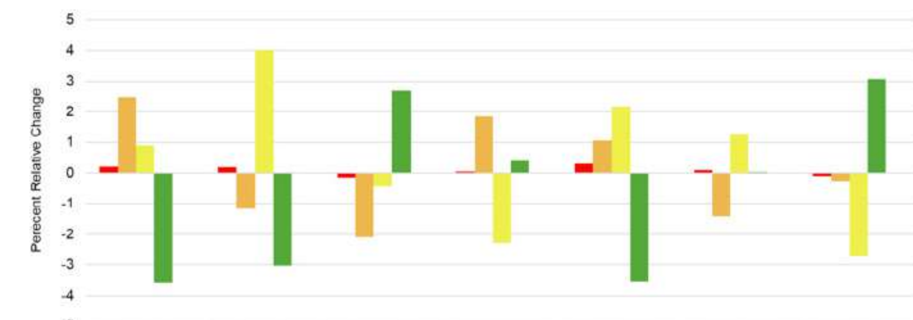


Figure 6. Land cover maps of the Sambunotan Watershed from 2017 to 2021, highlighting the distribution and changes in major land cover classes over time. Source: Esri Land Cover



	2017-2018	2018-2019	2019-2020	2020-2021	2017-2021	2018-2021	2019-2021
Built Area	0.20	0.18	-0.14	0.05	0.30	0.09	-0.09
Cropland	2.48	-1.16	-2.10	1.84	1.06	-1.42	-0.26
Rangeland	0.90	4.01	-0.45	-2.29	2.18	1.28	-2.73
Trees	-3.59	-3.03	2.68	0.39	-3.55	0.04	3.07
Water	0.01	0.00	0.01	0.01	0.02	0.02	0.02

Figure 7. Percentage of land cover changes in the Sambunotan Watershed relative to its total area.

conducted within the watershed, utilizing advanced equipment such as rain gauges, water level loggers, 2D velocity meters, and an Acoustic Doppler Current Profiler (ADCP). These tools captured data on both low and high flows. A rain gauge was strategically installed upstream to synchronize rainfall data with other sensor measurements.

The collected field data served as the foundation for calibrating a hydrological model based on the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) and generating hydrograph results for water balance analysis (Salcedo-Albores et al. 2023). This analysis examines current water resource availability and trends over time, providing valuable insights to strengthen water management decision-making. The model calibration was conducted using a field dataset collected from October 31, 2022, to November 2, 2022. The model's performance was assessed using three statistical measures:

- Nash-Sutcliffe Efficiency (NSE): 0.85, indicating excellent agreement between observed and simulated data.

- Percent Bias (PBIAS): 1.62, showing minimal deviation between observed and simulated data.

- RMSE-Observations Standard Deviation Ratio (RSR): 1.62, reflecting a high level of reliability.

These statistics collectively rated the model as "Very Good."

The study also highlighted the critical role of baseflow in sustaining ecosystems and water supply. The municipality of Tubajon, for instance, relies on water sourced from the Sambunotan Watershed. Using historical annual precipitation data, baseflow for individual subwatersheds was modeled using the calibrated hydrologic model, with the total baseflow volume estimated at 71.60 million cubic meters (MCM) (Table 1). Results indicate that larger subwatersheds, such as Carac-an, exhibit higher baseflow due to longer travel times to the main outlet.

These findings provide essential baseline data for water resource management within the watershed. They can also be used to estimate groundwater exploitation levels across wet and dry seasons, aiding sustainable water resource planning.

2.5 Water Quality Assessment

Water quality within the Sambunotan Watershed was assessed using in-situ measurements conducted in May 2022 using the Biobase Portable Multi-Parameter Water Quality Meter (Makinano-Santillan et al. 2022, Makinano-Santillan et al. 2024b). The spatial distribution of observed water quality parameters is illustrated in the accompanying maps (Figure 8). Key results showed a variability in temperature in both upstream and downstream locations, ranging from 25.6℃ to 27.95℃, as measured. Total Dissolved Solids (TDS) levels across all sampling sites remained below the 500 mg/L limit for Class AA surface waters, as set by DENR Administrative Order 34, series 1990. However, TDS levels varied significantly across sites. For instance, the elevated TDS levels observed in Stations 5 and 11 (Figure 8e) may be attributed to various human activities documented during field measurements. These include quarrying, construction, livestock farming, clothes washing, and garbage dumping along the riverbanks in the vicinity of these stations, which likely contribute to increased dissolved solids in the water.

Dissolved Oxygen (DO) levels were within acceptable limits for Class AA to Class C surface waters, with some upstream stations exceeding the 2 mg/L minimum threshold for Class C water bodies, ensuring the ability to sustain aquatic life. Statistical analysis highlighted the significant influence of land use and vegetation cover on water quality. For example, the tree cover percentage within the contributing area was positively correlated with pH levels, underscoring the importance of tree cover in maintaining water quality parameters.

These findings, derived from field measurements and statistical analysis (Makinano-Santillan et al. 2022, Makinano-Santillan 2023b), demonstrate the critical role of land cover classes—particularly cropland, built-up areas, and tree cover—in influencing water quality across the watershed.

2.6 Geologic Mapping, Potential Mining Impacts, and Erosion Dynamics in the Sambunotan Watershed

Geologic mapping and related field investigations, utilizing the latest modified lithologic map (Santos 2014, UNRFNRE 1993), validated that the significant river networks within the Sambunotan Watershed are structurally controlled, shaped by lineaments cutting through

Table 1. Baseflow volume computed through hydrologic modeling, in millions cubic meters (MCM). Data sourced from Makinano-Santillan et al. (2022).

Subwatershed	Dry Season Baseflow Volume	Wet Season Baseflow Volume	Total
	December to May, 2022	June to November, 2022	
Sambunotan	0.752	4.969	5.720
Maraging	9.938	18.580	28.518
Carac-an	8.086	28.423	36.509
Bangkaw	0.057	0.711	0.769
Others	0.004	0.082	0.085
Total	**18.837**	**52.765**	**71.601**

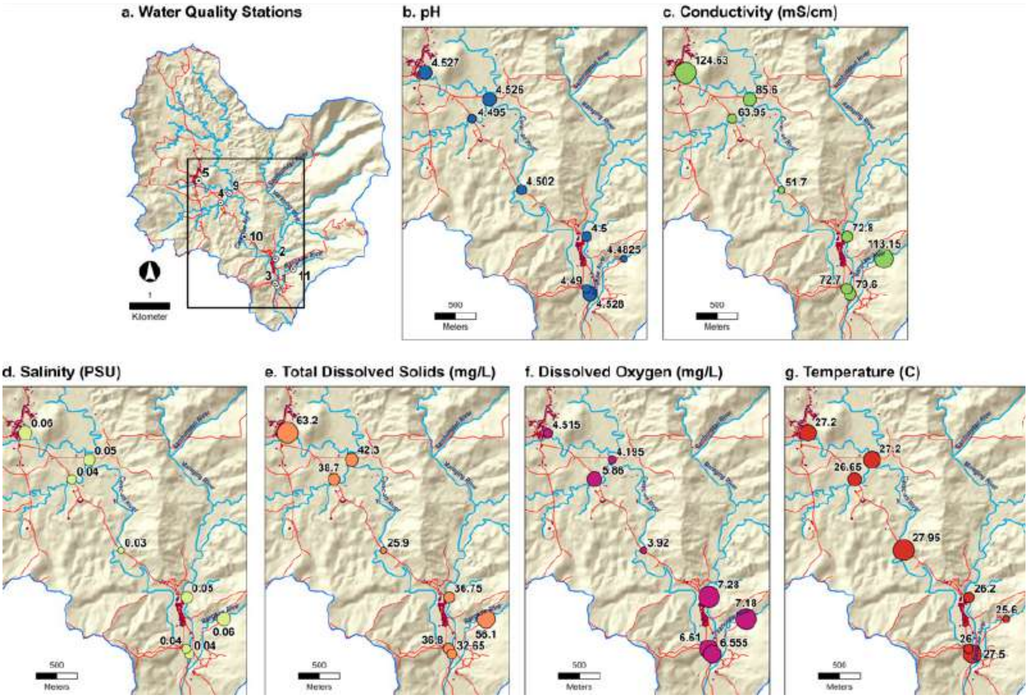


Figure 8. Spatial distribution of observed water quality parameters in the Sambunotan Watershed, May 2022. Data sourced from Makinano-Santillan et al. (2022).

the islands or lithologic contacts between different rock types. These planes of weakness act as pathways for water flow, influencing the watershed's hydrological system. Regions of limestone and clastic sediments, known for their high porosity and permeability, were identified as having the highest potential to serve as aquifers. This finding is supported by the concentration of water resources for the municipalities of Tubajon and Loreto within these rock types. Extending geologic mapping beyond the watershed boundary and overlaying the water resource location map of the two municipalities (i.e., Tubajon and Loreto) can provide clues on the possible groundwater resources in the area. Among the rock types found in northern Dinagat, the regions of the limestone and clastic sediments have the highest potential to become aquifers based on these units' high porosity and permeability. This finding is validated by the concentration of most of the water resources of the two municipalities in these two rock types (Makinano-Santillan et al. 2022, Makinano-Santillan et al. 2024a).

Mining activities within the watershed present significant risks to water quality. A Minahang Bayan and several mining tenements for chromite, nickel, and cobalt exploration, as shown in Figure 5, overlap with critical water sources. These metal resources are commonly associated with mantle rocks like harzburgite and dunite. All the Sambunotan River subwatershed and the headwaters of the Bangkaw River subwatersheds are in the Harzburgite region. These two watersheds are identified as the primary water sources of some barangays in Tubajon (i.e., Mabini and Diaz). All these points highlight that any development within these mining tenements (i.e., MPSA#3; MPSA#240, MPSA#291, EXPA#172; EXPA#216 in Figure 5) will have a significant impact on the overall water quality within the watershed (Makinano-Santillan et al. 2022; Makinano-Santillan et al. 2024a).

Erosion dynamics also vary across the watershed. The upstream portions of the Carac-an Subwatershed exhibit high to critical erosion levels, while downstream areas experience moderate erosion conditions. Correlation analysis (Table 2) indicates that cropland is positively associated with higher soil erodibility, while tree cover has a negative correlation, suggesting its importance in reducing erosion. These findings highlight the potential for significant changes in cropland areas to influence sediment transport within the watershed (Makinano-Santillan et al. 2022; Makinano-Santillan et al. 2024a).

Overall, the geological mapping and analysis results underscore the importance of sustainable land use practices in erosion-prone areas and the need to manage mining activities to preserve water quality carefully. Protecting aquifer-rich regions, such as limestone and clastic sediment areas, and promoting reforestation efforts in erosion hotspots can enhance water resource management and reduce sedimentation risks in the Sambunotan Watershed.

3 Policy Implications and Recommendations

The Sambunotan Watershed faces various challenges, from land use changes and erosion to impacts on mining and water quality degradation. Addressing these issues requires a science-based, collaborative approach to governance that balances development with ecological protection. The following policy implications and recommendations are directed toward local government units (LGUs) of Loreto and Tubajon, regional offices of national agencies such as the Department of Environment and Natural Resources (DENR) and the Mines and Geosciences Bureau (MGB), non-governmental organizations (NGOs), and other stakeholders involved in watershed management and policy formulation. These recommendations guide decision-makers in implementing effective and sustainable watershed management strategies.

3.1 On the Sambunotan Watershed Boundary

Accurately defining the boundaries of the Sambunotan Watershed is a fundamental step toward effective governance and resource management. The refined boundary provides a reliable basis for policy formulation, addressing discrepancies in previous estimates and ensuring that management strategies align with the true extent of the watershed.

Recommendations:

- Officially adopt the refined Sambunotan Watershed boundary to standardize planning and resource management across municipalities.
- Form a joint Watershed Management Board with representatives from Loreto and Tubajon LGUs, DENR, and other stakeholders involved in watershed management to collaboratively manage and govern the watershed, leveraging the updated boundary data to guide decision-making.
- Integrate the refined watershed boundary into local development and land-use plans to ensure alignment with sustainable management objectives.

3.2 On the Naming of the Sambunotan Watershed

The Sambunotan Watershed's name implies that the Sambunotan River is its primary tributary, despite evidence that this river is a minor upstream feature within the Maraging River Subwatershed. Instead, the watershed comprises three distinct river systems: the Carac-an River, Maraging River, and Bangkaw River, each with unique hydrological and ecological roles. This misnomer can confuse governance, leading to misaligned priorities and ineffective management strategies. A more accurate and representative name would reflect the watershed's hydrological composition, improving stakeholder communication and coordination.

Recommendations:

- Conduct consultations with stakeholders, including LGUs, communities, and experts, to discuss the watershed's renaming to reflect better its hydrological composition (i.e., Carac-an-Maraging-

Table 2. Correlation Between Erodibility Index (EI) and Land Cover Distribution in the Sambunotan Watershed. Data sourced from Makinano-Santillan et al. (2022).

	Builtup	Cropland	Rangeland	Trees
Pearson Correlation	0.689	**.899***	0.551	-0.849
Sig. (2-tailed)	0.198	0.038	0.335	0.069
Sum of Squares and Cross-products	4.445	27.717	12.813	-45.046
Covariance	1.111	6.929	3.203	-11.261
N	5	5	5	5

**. Correlation is significant at the 0.05 level (2-tailed).*

Bangkaw Watershed).

- Adopt a new, representative name through an official declaration or resolution to improve clarity and align management strategies with the watershed's dynamics.
- Develop educational campaigns and materials to communicate the rationale behind the name change, ensuring all stakeholders understand its significance for effective governance and resource management.
- Identify and map the Sambunotan River and its drainage area, enabling focused and informed interventions for its conservation or development, if necessary.

3.3 On the Watershed's Hydrology and Geography

The hydrology and geography of the Sambunotan Watershed play a critical role in sustaining downstream ecosystems, influencing sediment transport, and supporting communities reliant on its resources. Targeted management in vulnerable areas, particularly steep slopes and high-drainage regions, is vital to mitigate erosion risks and maintain ecological balance.

Recommendations:

- Implement soil and water conservation measures, such as reforestation and contour farming, in areas with steep slopes and high erosion risks.
- Develop a sediment monitoring program to assess and mitigate sediment transport impacts on downstream water bodies.
- Incorporate hydrological data into disaster risk reduction plans to address flooding and erosion risks.

3.4 On the Watershed's Land-use and Land-cover Dynamics

The land classification and land-use dynamics within the Sambunotan Watershed present opportunities and challenges for sustainable management. While the watershed's land cover has remained relatively stable in recent years, the absence of a protected area designation and extensive Alienable and Disposable (A&D) lands, timberland, and mining tenements expose the watershed to significant risks. A&D areas are particularly vulnerable to unregulated development, while timberland faces pressures from deforestation and unsustainable practices. Furthermore, mining activities in critical zones overlap with key water sources, posing threats to water quality and ecosystem health. These factors highlight the urgent need for targeted policy interventions to protect the watershed's ecological and hydrological functions while supporting sustainable land use.

Recommendations:

- Propose the designation of critical portions of the watershed as protected areas under existing laws, such as the Expanded National Integrated Protected Areas System (E-NIPAS) Act.
- Implement stricter regulations on activities in A&D and timberland areas to ensure land use aligns and adheres to sustainable practices.
- Comprehensive Environmental Impact Assessments (EIAs) are required for all mining tenements, focusing on their effects on water quality, erosion, and biodiversity.
- Strengthen monitoring and enforcement mechanisms to prevent illegal activities, such as timber poaching and land clearing, particularly in timberland areas.
- Promote sustainable land-use practices, such as agroforestry, to balance development needs with conservation goals.

3.5 On the Baseline Hydrological Data and Modeling

The availability of robust baseline hydrological data is crucial for informed decision-making and long-term water resource management. Hydrological models offer predictive insights into water availability, distribution, and seasonal variability, providing a strong foundation for effective planning and intervention. Monitoring water levels in river systems is also essential to tracking changes over time and adapting management strategies accordingly.

Recommendations:

- Use hydrological modeling data to optimize the placement of future water infrastructure, such as reservoirs and irrigation systems.
- Conduct periodic updates to the hydrological model to incorporate new data and improve decision-making accuracy.
- Establish a regular water level monitoring program for the watershed's river systems using automated sensors and manual verification to ensure continuous data collection for trend analysis and

emergency preparedness.

- Integrate water level data into the existing hydrological model to refine predictions and enhance resource planning across dry and wet seasons.

3.6 On the Watershed's Water Quality

Maintaining water quality is a key priority for the Sambunotan Watershed, as it directly impacts biodiversity, agriculture, and human health. Water quality is significantly influenced by land-use practices and human activities, requiring targeted interventions to address point and non-point pollution sources. Trees play a crucial role in maintaining water quality, emphasizing the need for reforestation and conservation. Addressing pollution sources and promoting sustainable land use can mitigate risks and safeguard water resources for future generations.

Recommendations:

- Enforce regulations to control quarrying, garbage dumping, and livestock farming near riverbanks.

- Launch community-based reforestation programs focusing on riparian zones to enhance water filtration and stabilize riverbanks.

- Establish a water quality monitoring network to regularly assess and address pollution hotspots.

3.7 On the Watershed's Geology, Potential Mining Impact, and Erosion Dynamics

The geological characteristics of the Sambunotan Watershed shape its hydrology and groundwater potential while influencing erosion and sediment transport. Geologic features, such as aquifer zones, provide essential water resources but are at risk from mining activities. Erosion in cropland areas threatens soil productivity and increases sedimentation in water bodies. Addressing the impacts of mining and soil erosion requires strategic interventions to protect critical water sources and maintain land stability.

Recommendations:

- Designate limestone and clastic sediment zones as critical aquifer recharge areas and regulate activities that could disrupt these zones.

- Strengthen enforcement of mining regulations to minimize environmental damage, particularly in harzburgite regions supplying critical water sources.

- Promote soil conservation practices in cropland areas, such as cover cropping and no-till farming, to reduce erosion and sedimentation.

4 Concluding Remarks and Further Study

This policy brief synthesizes key findings from scientific analyses and field investigations in the Sambunotan Watershed, offering actionable recommendations to guide decision-makers in addressing these challenges. By adopting the recommendations presented, stakeholders can develop a comprehensive and sustainable watershed management plan that balances ecological preservation with socio-economic development. Such a plan will protect the watershed's ecosystem services and enhance its beneficiaries' well-being, ensuring long-term water security, resilience to climate impacts, and sustainable growth for the region.

While the inclusions of critical maps, such as high erosion zones, recommended protected regions, water quality hotspots, and limestone and clastic sediment zones, are essential for decision-making, unfortunately, this study did not generate them. The generation and development of these maps require additional data and analyses beyond the scope of this research. We recommend their inclusion in future studies to provide a more comprehensive basis for watershed management planning.

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Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

Author Contribution

MM Santillan: *Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review and Editing, Supervision, Project administration, Funding acquisition*. AC Gagula: *Conceptualization, Writing - Original Draft, Writing - Review and Editing*. RP Varela: *Conceptualization, Writing - Original Draft, Writing - Review and Editing*. JR Santillan: *Conceptualization, Formal analysis, Investigation, Writing - Original Draft, Writing - Review and Editing, Visualization.*

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Species Richness of Avifauna in the Agusan Marsh Wildlife Sanctuary, Northeastern Mindanao, Philippines

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A B S T R A C T

The Agusan Marsh Wildlife Sanctuary (AMWS) plays a crucial role in preserving bird biodiversity, with 150 species documented across 18 orders, 54 families, and 115 genera from January 2023 to August 2024 in the nine Biodiversity Monitoring System sites. This avifauna diversity includes richness in the families Ardeidae (n=6), Columbidae (n=13), Rallidae (n=9), and Scolopacidae (n=9), with a 19.05% increase in recorded species since 2014. It also supports 43 endemic species (29%), of which 13 species (9%) are unique to Mindanao. Furthermore, AMWS is a significant stopover for migratory birds, with 35 migratory species (23%) reflecting its role within the East Asian-Australasian Flyway. According to the International Union for Conservation of Nature (IUCN) and the DAO 2019-09, approximately 11% of species are threatened. Specifically, 6% were vulnerable, 2% critically endangered, 1% endangered, near threatened, and Other Threatened Species (OTS). The Caimpugan Peat Swamp Forest has the highest species richness, with 80 bird species (53%). However, areas with high anthropogenic activity have fewer species, particularly in Dinagat-Mambagongon Creek. Anthropogenic activities in AMWS include hunting, timber cutting, rattan harvesting, and agricultural expansion. Effective management strategies are essential to alleviate pressures on AMWS biodiversity and support local communities, such as deputizing park rangers known as Bantay Danao to enhance the enforcement of RA 9174 and RA 11038; imposing penalties to curtail agricultural expansion in AMWS peatlands, riparian zones, and Multiple Use Zones (MUZs); executing the Special Use Agreement in Protected Areas (SAPA) when using resources is unavoidable; exploring alternative livelihoods such as community-based forest management (CBFM) and biodiversity-friendly enterprises (BDFEs); and revising land use maps while proposing legislation with explicit wetlands management guidelines, particularly for peatlands.

Keywords: *Agusan Marsh Wildlife Sanctuary, avifauna, species richness, endemic, protected area*

1 Introduction

The Philippines is identified as one of the world's most biologically rich countries in terms of the diversity of ecosystems, species, and genetics. Avian diversity in the country is among the highest in the world, where more than 7% of the land area is declared as Important Bird Areas

(IBAs) or sites that are significant for the conservation of bird populations on a worldwide scale due to the presence of threatened, endemic, and restricted-range species (Haribon Foundation 2014, Donald et al. 2018, Jensen 2018, Waliczky et al. 2018, Paguntalan et al. 2021). Among the outstanding IBAs is the Agusan Marsh Wildlife Sanctuary (AMWS) (PH085), located in the heart of the Agusan River Basin, one of the country's most ecologically significant inland wetlands.

Agusan Marsh Wildlife Sanctuary comprises a vast complex of freshwater marshes, lakes, and water courses that collectively act as catch basins for floodwaters, which regularly inundate the Agusan Valley during monsoon season and act like a giant sponge where excess water is collected at times of high flow. AMWS has been locally, nationally, and internationally recognized through its inclusion in the ASEAN Heritage Parks Network on November 8, 2018, and its designation as Ramsar Site No. 1009, "Wetland of International Importance," on November 12, 1999 (Orella et al. 2022).

Several threatened avifauna species are known to occur only on the island of Mindanao and nowhere else in the world (Nuñeza et al. 2019, Serrano et al. 2019, Matutes & Densing 2022, Villancio et al. 2022). More than 200 avifauna species are known to spend at least part of the year in the AMWS, thus making it one of Asia's essential transit points for migratory birds (DENR n.d). Despite the high concentration of endemic and restricted-range species, ornithological expeditions were few in the AMWS. These assessments were more focused on mountainous and highland protected areas in Mindanao like Mt. Pantaron (Salolog et al. 2021), Mt. Kitanglad, Mt. Apo, Mt. Hamiguitan, and Mt. Malindang (Mohagan et al. 2015). Published articles about the avifauna of the AMWS are outdated, such as those by Michaelson (1991) during the Wetland Field Survey, Sebastian & Ibañez (2004), and Sucaldito & Nuñeza (2008, 2014). The previous survey of Sucaldito & Nuñeza was on August 2005-January 2006. These are the only available information on the avifaunal community of AMWS. Nonetheless, the Protected Area Management Office of AMWS has been monitoring the population and abundance of the avifauna species consistently in the nine (9) Biodiversity Monitoring System (BMS) sites such as Lake Mihaba, Lake Kelobidan, Lake Mambagongon, Lake Panlabuhan, Lake Tugno, Dinagat – Mambagongon Creek, Sabang Gibong-Sabang – Adgaoan River, Caimpugan Peat Swamp Forest, and Sago Forest.

Recently, the AMWS was included in the tentative lists of UNESCO World Heritage Sites under criteria 9 and 10, respectively (UNESCO n.d.). Knowledge of the current population and species richness of avifauna in the AMWS is significant since updated information, especially on endemic, migratory, and threatened species, is needed in the protected area resource profile for UNESCO application. This study presents the composition and richness of avifauna species and significant new records in the AMWS, providing essential information for identifying critical habitats and species of conservation concern and providing data that will inform effective conservation strategies and management practices for the protected area.

2 Materials and Methods

Site Description and Entry Protocol

Before conducting the surveys, PAMB Resolution No. 2024-16 and prior consent from the target Local Government Units (LGUs) in Agusan del Sur has been obtained. Nine (9) sampling sites were established following the Biodiversity Monitoring System (BMS) sites of AMWS covering the six (6) municipalities such as San Francisco, Rosario, Talacogon, La Paz, Loreto, and Bunawan (Figure 1). Geographic locations were obtained by geotagging using a handheld Global Positioning System (GPS) receiver (DENR-FMB 2013) and were transformed into a digital map using the Quantum Geographic Information System (QGIS) software v3.34.7. Sampling was done from January 2023 to August 2024. The sites were categorized into (a) Lakes (Sites 1, 2, 3, 4, and 6) with open waters; (b) Rivers and creeks (Sites 7 and 8) with a definite riparian ecosystem; and (c) Peat swamp forest (Sites 5 and 9) is determined as vegetation in a peatland area.

Site 1: Lake Mihaba, Brgy. San Marcos, Bunawan, Agusan del Sur (Figure 2A)

Lake Mihaba is characterized as a permanent freshwater lake, S-shaped and elongated. The area is 8°10'41.91"N, 125°54'55.74"E with

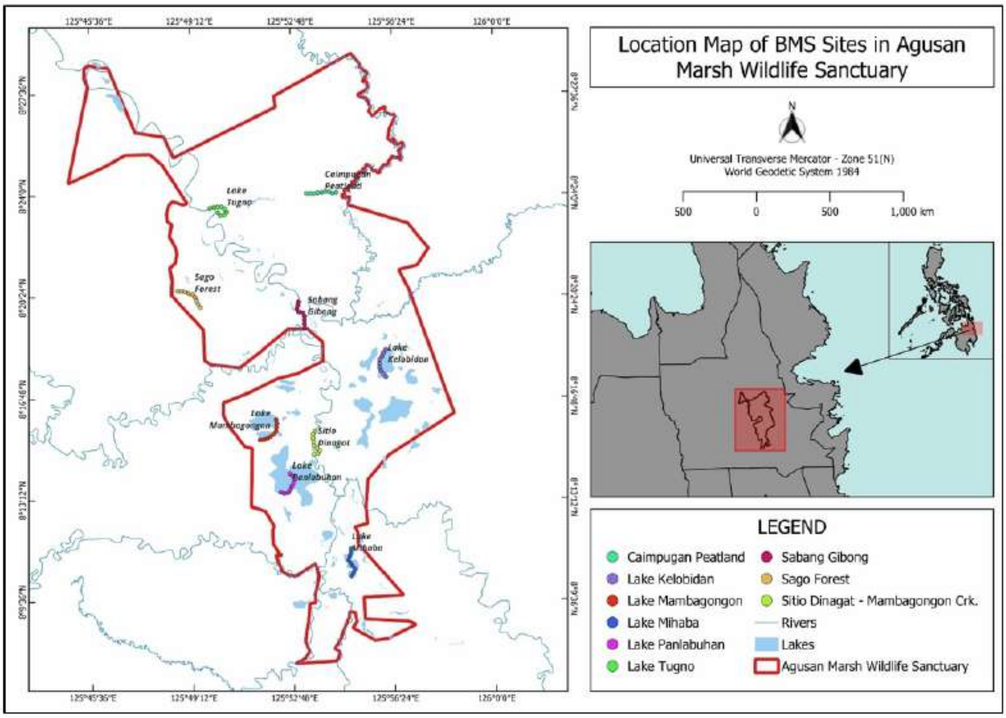

Figure 1. Map showing the BMS Sites and the sampling points within the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

elevations ranging from 16-21 masl. It is 88.16 hectares with a minimum length of 520 m, a width of 500 m, and an average depth of 3 m. *Nauclea orientalis, Milletia elliptica, Mitragyna diversifolia,* and *Dillenia philippinensis* for tree species dominate its vegetation. Macrophytes observed include *Eichhornia crassipes, Phragmites australis, Ipomea aquatica, Pistia stratoites,* and *Scipiodendron gheari.* A few fish traps made with bamboo were also observed, and they were placed by the Indigenous Agusanon Manobo settling in the nearby area (approximately 1 km away). Aside from sustainable fishing, no other anthropogenic activities were inside the lake. Distance to the main population center contributed to the recede of these activities, perhaps because of logistical difficulties that are inherent therein (Gotame 2010).

Site 2: Lake Kelobidan, Brgy. Wasian and Bayugan III, Rosario, Agusan del Sur (Figure 2B)

Lake Kelobidan is characterized as a permanent freshwater lake, pear-shaped, situated at 8°16'19.8"N, 125°56'25.1"E with 21 masl approximate elevation. The lake's total area is 254 hectares and has a width of 1,100 m and a length of 2,900 m with an average depth of 2.8 m. *Nauclea orientalis, Lagerstroemia speciosa, Premna odorata*, and *Barringtonia racemosa* dominate the inundated forest on the lake shoreline, which epiphytic ferns such as *Asplenium nidus, Aglaomorpha quercifolia,* and *Stenocleana palustris* latch in. Some *Terminalia copelandii* and *Dillenia philippinensis* were observed in the outflow and inflow of the lake. *Salvinia molesta, Pistia stratoites*, and *Eichhornia crassipes* increased on the surface, covering 15% of the lake's total area. A few fishermen, Agusanon Manobo, were observed fishing using nets and modified fishing rods. The floating community of Sitio Ticgon is about 3 kilometers from the site, accessible only by a tiny pump boat or canoe. The lake water smells awful, particularly in the outflow, due to decaying plant matter mixed with oil spills from the pump boats. Prunings of naturally grown *Nauclea* and sometimes cuttings were also observed mainly on the cruise trail.

Site 3: Lake Mambagongon, Sitio Mambagongon, Brgy. Poblacion, La Paz, Agusan del Sur (Figure 2C)

Lake Mambagongon is also one of the elongated permanent freshwater lakes in AMWS.

It is situated at 8°16'36.25"N, 125°52'52.46"E, with a total area of 265.92 hectares. Elevation ranges from 16-21 masl. The length is 672 m, a width of 948 m, and an average depth of 2.51 m. Twenty-five floating households are within the lake, mainly Agusanon Manobo. *Nauclea orientalis* and *Mitragyna diversifolia* species had stunted growth near the settlement and almost no canopy. It may also be attributed to the lake's deep waters since floating houses were established in much deeper water for it to be buoyant. Several cuttings of trees were recorded in the inundated forest dominated by *Garcinia rubra, Spondias pinnata, Hibiscus tiliaceus,* and *Syzygium* sp., 1-2 km away from the settlements, indicating anthropogenic disturbance. *Lycopodium squarrosum* also dominated the epiphytes aside from *Stenochleana palustris* and *Aglaomorpha quercifolia.* Observed grasses and herbaceous plants include *Ageratum conyzoides, Scleria scrobiculata,* and *Hyptis brevipes*. *Pistia stratoites, Eichhornia crassipes, Ipomea aquatica,* and *Hydrilla verticillata* were some of the macrophytes observed. Several fishing boats and traditional fish traps made from bamboo called Bobo were also documented. The same is true of other lakes; they also suffer from the proliferation of Eichhornia species blocking several cruise trails.

Site 4: Lake Panlabuhan, Sitio Panlabuhan, Brgy. Poblacion, Loreto, Agusan del Sur (Figure 2D)

Lake Panlabuhan is a circular permanent freshwater lake. It is a lake system in Sitio Panlabuhan in the Loreto municipality composed of Lake Bukogon, Kanimbaylan, Kubasayon, and Dinagat (Apdohan et al. 2021). It is located within the geographic coordinates of 8°13'58.45"N, 125°52'48.30"E, with a total area of 513.3 hectares. It is approximately 34 meters above sea level. The length is 1.63 km, a width of 1.51 km, and an average depth of 4 m. The canoe is the primary transportation method because gas boats are prohibited inside the lake. Thirty-six households of Agusanon Manobo were inside the lake, adapting to life above water. They also strictly conserve the area for their cultural heritage. It is also one of the ecotourism sites of Agusan Marsh Wildlife Sanctuary for its cultural immersion in floating villages. One feature of this lake is its inundated dying forest, which woodpeckers inhabit. *Nauclea orientalis, Hibiscus tiliaceus, Mitragyna diversifolia,* and *Kleinhovia hospital* dominated the tree species. Trees do not have any or a little canopy left, and fern epiphytes such as *Aglaomorpha, Nephrolepis,* and *Stenochleana* latched on their branches. Some macrophytes observed were *Nymphaea lotus, Ipomoea aquatica, Salvinia natans, Salvina molesta,* and *Hydrillia verticillata*. The proliferation of *Salvinia*, along with *Echhornia* and *Pistia*, is also observed.

Site 5: Lake Tugno, Brgy. La Flora, Talacogon, Agusan del Sur (Figure 2E)

Lake Tugno is a horseshoe-shaped oxbow lake. It is a remnant of the bend in the Agusan River. It is also classified as Stillwater Lake because it lacks inflow or outflow and is not nourished by a stream or spring. There is no natural outlet, and it often dries up during summer. It is between 8°23'29.7"N and 125°50'15.1"E with a total area of 15.5 ha, 21 masl approximate elevation. It has a width of 92 meters, a length of 1,400 m, and an average depth of 1.15 m. The water is tea-colored, one of the characteristics of an area forming a peatland. *Nauclea orientalis* and *Mitragyna diversifolia* dominated the lake shore with minimal Ficus species. Herbaceous plants such as *Cyperus compactus, Eleocharis* sp., *Mapania sumatrana, Lepironia articulata,* and *Scleria scrobiculata* also dominated the area. It is also observed that only *Nephrolepis bisserata* is present among the ground pteridophytes, while *Stenochleana palustris* is for the fern epiphytes. Traditional fish traps were also observed mainly for mudfish. Minimal *Echhornia* is present but already dried due to the lowering of the lake's water level.

Site 6: Caimpugan Peat Swamp Forest, Brgy. Caimpugan, San Francisco, Agusan del Sur (Figure 2F)

The Caimpugan Peat Swamp Forest is the sole intact peat swamp forest in the Philippines, encompassing approximately 5,630 hectares at coordinates 8°24'53.16"N, 125°53'5.99"E, with an elevation ranging from 80 to 90 masl. It is situated between the Gibong and Agusan Rivers. This peatland is categorized into various vegetation zones based on the zonal edaphic composition of the peat and height, diameter, and growth form (Orella et al. 2022). Five (5) distinct vegetation zones are recognized: Tall-pole Forest, Short-pole Forest, Stunted Forest zone, Ferns and lycopods vegetation zone, and Sedge vegetation zone. The Tall Pole Forest can be observed around

1.2 km from the Gibong River. Stilted-rooted species characterize this zone, predominantly *Tristianopsis micrantha, Ternstroemia philippinensis, Mangifera caesia,* and *Calophyllum sclerophyllum.* The tree species in this zone reached heights up to 30 m or more (Aribal et al. 2017). The Short-pole Forest is characterized by a gradual decrease in height (5-25 m). *Tristianopsis* and other associated trees primarily dominate it, such as *Calophyllum, Fagraea, Palaquium, Ardisia,* and *Baccaurea*. The Stunded forest zone is characterized by pygmy trees at the center of the peatland, which is permanently inundated with water. The dominant species are still *Tristianopsis*, and the most common constituent trees such as *Calophyllum sclerophyllum, Ilex cymosa, Fagraea racemosa, Syzygium tenuirame,* and *Polyscias aherniana.* The forest was also open enough to allow significantly thick growth of *Pandanus* sp. and the climbing fern *Stechnochlaena palustris*. The forest is also constantly confronted with threats of degradation primarily driven by socio-economic activities and population growth, which include competing land claims, land-use conversion, timber poaching, and establishment of drainage canals. Remnants of peat fire are also recorded.

Site 7: Dinagat- Mambagongon Creek, Sitio Dinagat, Brgy. San Marcos, Bunawan, Agusan del Sur (Figure 2G)

The creek is a rivulet with minimal corn agriculture at 8°16'9"N, 125°53'37"E. Elevation ranges from 83-92 masl. Human settlements were along the creek of at least 20 households. The riparian ecosystem is dominated by *Nauclea orientalis, Ficus* sp., and *Mitragyna diversifolia f*or tree species. Grasses, such as *Apluda, Aristida*, and *Hymenachne*, dominate the ground cover. Shrubs, such as *Melastoma malabathricum, Melicope triphylla, Premna odorata,* and *Leea* sp., were also observed, as well as ground ferns such as *Diplazium esculentum, Lygodium circinnatum, Pteridium aquilinium,* and *Nephrolepis bisserata.* Human disturbance is evident in areas such as solid waste mismanagement, unsanitary disposal of livestock wastes, cutting *Nauclea* for firewood, and clearing the riparian ecosystem for corn agriculture. There are no records for *Echhornia crassipes,* but the abundance of *Salvinia molesta* and *Salvinia natans* increases on the edge of the creek where the current is slow.

Sitio 8: Sabang Gibong-Sabang Adgaoan River, Brgy. Sabang Gibong, Talacogon and Brgy. Sabang Adgawan, La Paz (Figure 2H)

The Sabang Gibong-Sabang Adgaoan River is a segment of the Agusan River, situated at coordinates 8°13'47"N, 125°53'56"E, with an approximate elevation of 18 masl. It is approximately 50-100 meters from the central barangay of Sabang Adgawan, comprising at least sixty (60) households. This segment is identified as a riparian ecosystem that was developed for corn cultivation. The cornfield measures approximately 1.5 km between the opposing riverbanks and is 5 m from the riverbank. There were remaining trees of at most 11 individuals of *Nauclea orientalis* only and no other tree species. Shrubs in the area include *Melastoma malabathricum, Allophyllus cobbe, Stachytarpheta jamaicensis,* and *Sida rhombifolia*. Along with agriculture, high-level anthropogenic disturbances were recorded, such as livestock farming of pigs, chickens, and ducks with unsanitary wastewater disposal, mismanagement of solid waste, construction of electrical posts and wire connections, and minimal oil spills from pumpboats. Due to the strong river water current, no macrophytes were recorded.

Site 9: Sago Forest, Brgy. Desamparados, Talacogon (Figure 2I)

The Sago Forest is identified as a peatland ecosystem within AMWS, encompassing approximately 1,500 hectares. It is located at 8°20'2.68"N, 125°49'31.68"E. The elevation varies from 85 to 98 masl, characterized by a waterlogged peat forest predominantly composed of sago palm (Metroxylon sagu). *Terminalia copelandii*, *Ficus* sp., and *Lagerstroemia speciosa* were observed in the nearby Sitio Bataran, the nearest community in the peatland. Grasses, such as *Hymenache amplexicaulis, Isachne globosa, Ophiuros exaltatus, Paspaslum scrobiculatum,* and *Apluda mutica*, dominated the ground cover. *Hoya myrmecopa, Hoya merrillii,* and *Hoya siariae* are also abundant in the area as epiphytes, together with pteridophytes like *Aglaomorpha quercifolia, Asplenium nidus, Asplenium polyodon, Anthrophyum reticulatum,* and *Pyrrosia piloselloides*. A few animal and fish traps were documented, and minimal tree saplings were cut, primarily in the trails inside the forest. The harvesting of sago palms, one of the food sources of Agusanon Manobo, is also noted. Agricultural expansion for rice agriculture and drainage also disturbs the area, significantly lowering the water level and altering its hydrology.

Field Sampling and Identification of Birds

Birds were listed following the Line-Transect Survey Method, which involves recording all birds seen (flying, singing, or feeding) within 20 m of both sides of at least a 2 km line-transect established at each site (Lador & Seronay 2020). Birds seen and heard calling were recorded during the day in a prepared field datasheet using the 10 x 42 roof prism binoculars, 20 x 60-degree and 80 x 45-degree spotting scopes, and photographed using digital cameras with 800 mm telephoto lenses. The line transect was divided into nine stations at a distance of 250 m each. Geographic locations were recorded using a handheld GPS receiver and geotagging (DENR-FMB 2013). Transect cruises and walks were done early every 5:00-6:00 am when bird activity began to peak and in the late afternoon between 5:00- 6:00 pm. Observations were made for at least eight (8) minutes per station per site (Bibby et al. 2000, Lee & Marsden 2008). A total of nine (9) transects were laid around the protected area. Local guides and/or forest rangers known as Bantay Danao were considered co-researchers to capacitate local counterparts in biodiversity conservation in AWMS. These local guides were oriented on the activity's objectives while their experiences in locating and identifying birds were incorporated with the modified standard technique employed in the surveys.

Birds were identified using the photographic field guide by Kennedy et al. (2000), Strange (2015), and Allen (2020). The taxonomy and nomenclature were supported by the Handbook of Birds in the World (del Hoyo et al. 2014) and the BirdLife International Illustrated Checklist of the Birds of the World (del Hoyo & Collar 2016). Desmond Allen verified and identified the unidentified species. The conservation status and endemicity were known through DAO 2019-09 and IUCN Red List of Threatened Species version 2024-1. A Focus Group Discussion (FGD) was

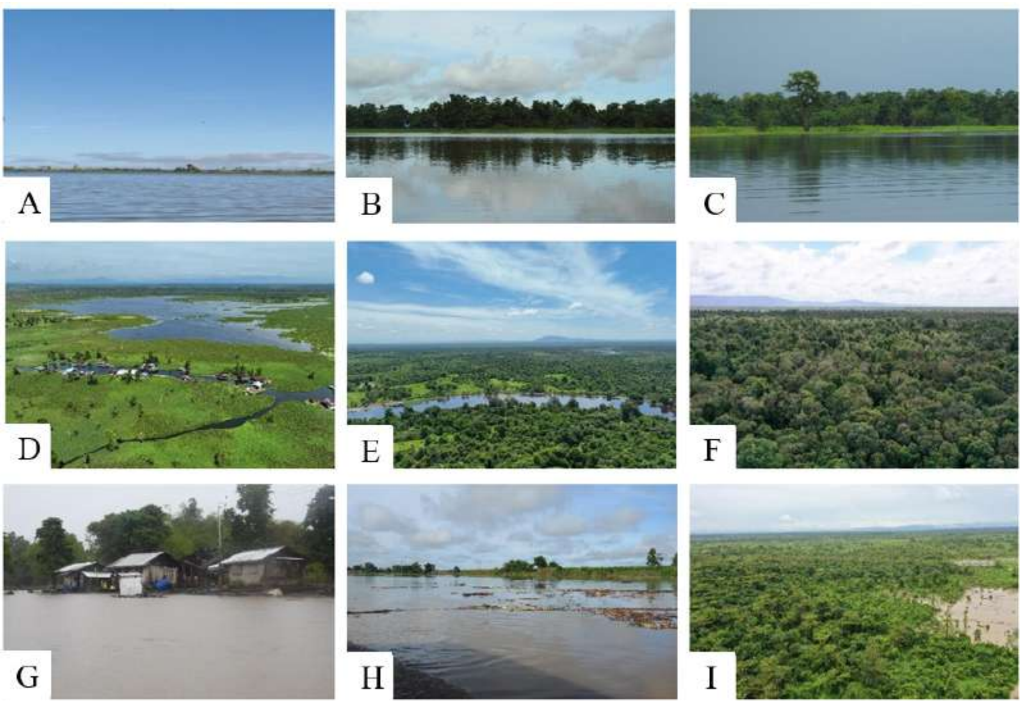

Figure 2. Landscape view of sampling sites within the Agusan Marsh Wildlife Sanctuary (AMWS), illustrating the diverse ecological features of key areas: A) Lake Mihaba, B) Lake Kelobidan, C) Lake Mambagongon, D) Lake Panlabuhan, E) Lake Tugno, F) Caimpugan Peat Swamp Forest, G) Dinagat-Mambagongon Creek, H) Sabang Gibong-Sabang Adgawan River, and I) Sago Forest.

conducted with the designated Community Monitoring Group (CMG) of AMWS, comprising 122 individuals, including Indigenous Peoples and tenured migrants. Results of FGD provided supplementary data and insights on the possible threats to biodiversity around the AMWS.

3 Results and Discussion

Composition, Richness, Conservation Status, and Endemicity

Eighteen orders, 54 families, 115 genera, and 150 avifauna species were documented in the Agusan Marsh Wildlife Sanctuary (AMWS) from January 2023 to August 2024. The family Ardeidae had the highest species richness with 16 species, followed by families Columbidae (n=13), Rallidae and Scolopacidae (n=9), and Accipitridae and Cuculidae (n=7). Conversely, the most represented genera were *Ardea* (n=4), *Diceaum* (n=4), and *Ixobrychus* (n=4), followed by *Amaurornis, Ducula, Lonchura, Phapitreron*, and *Tringa* (n=3, respectively). The number of species documented constitutes about 21.43% of the 700 identified avifauna in the Philippines (Jensen et al. 2018) (Table 1). It is more than three-fourths (76.53%) of the total 196 bird species in the Eastern Mindanao Biodiversity Corridor (EMBC). Compared to the list of Sucaldito & Nuñeza (2014), there is an increase of 19.05% in terms of species richness. Additionally, the proportion of endemic (17.84%) and threatened (9.34%) is relatively low compared to the Philippine avifauna, which can be attributed to the high number of migratory birds since wetland habitats offer abundant resources like food and resting areas that are particularly suited to migratory birds (Beatty et al. 2014). Most of the Philippine endemic birds are forest-dependent, which can be found in the highland or isolated forest ecosystems rather than in lowland wetland areas like the AMWS (Fjeldså & Bowie 2021). Table 2 shows the comprehensive list of the avifauna recorded in AMWS for the migratory and non-migratory season (2023-2024).

The total number of avifauna documented in AMWS is 54.56% greater than that of Olango Island Wildlife Sanctuary (OIWS) (n=97), a Ramsar site and one of the East Asian-Australasian Flyway (EAAF) Network in the Philippines (Xu & Xu 2018). By the East Asian-Australasian Flyway Partnership (EAAFP), specifically the criteria for membership in the EAAF Network, over 20,000 individual migratory birds have been regularly documented in OIWS, with key EAAFP species such as the Curlew sandpiper, Red knot, Great knot, Chinese crested tern, and Chinese egret being regularly observed (EAAFP n.d). Conversely, AMWS lacks a thorough enumeration of the migratory bird population in the region. If the PAMO of AMWS intends to pursue inclusion in the EAAF Network sites, they should concentrate on the criteria indicating that AMWS consistently supports over 1% of the individuals in a population of a specific migratory waterbird species or subspecies. Moreover, the Caimpugan Peat Swamp Forest has 17.91% (n=79) more bird species than the Leyte Sab-a Basin Peatland (n=67) (Matutes & Densing 2022).

The noted increase in species richness in this study may have been influenced by the survey duration, quantity of sites, and improved management of AMWS. Sulcadito & Nuñeza (2014) conducted sampling for 6 months at four sites, from August to January. This period also marks the migratory season. This duration is commendable; however, it may not encompass species that might prefer to migrate to AMWS from other wetland regions in the Philippines during February or document the early migration in July. This study's prolonged two-year survey period (2023-2024), encompassing both migratory and non-migratory seasons enables more comprehensive documentation of species that may be seasonally absent or less discernible in shorter studies.

Table 1. Comparison of bird species in the Philippines, EMBC, and Agusan Marsh Wildlife Sanctuary (AMWS). Fieldwork data in AMWS (Sumilhig et al. 2023-2024).

	Philippines (Jensen, 2018)	Eastern Mindanao Biodiversity Corridor (EMBC) (PEF, CI, & DENR, 2008)	Agusan Marsh Wildlife Sanctuary (AMWS)	
			Sucaldito & Nuneza, 2014	2024
No. of species	700	196	126	150
No. of endemic species	241	91	31	43
No. of threatened species	182	22	7	17

Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order ACCIPITRIFORMES													
Family **Accipitridae**													
Accipiter trivirgatus (↓)	Crested Goshawk	Banog	LC[a]	Scarce Resident						■			
Butastur indicus (↓)	Grey-faced Buzzard	Sawi	LC[a]	Migrant					■				
Haliaeetus leucogaster (↓)	White-bellied Sea-eagle	Mana-o	LC[a]	Resident	■	■							
Haliastur indus (↓)	Brahminy Kite	Banog	LC[a]	Resident	■	■	■	■	■	■	■		
Icthyophaga ichthyaetus (↓)	Grey-headed Fish-eagle	Mana-o	NT[a], VU[b]	Rare Resident		■	■	■		■			
Pernis steerei (↓)	Philippine Honey-buzzard	Banog	LC[a]	Endemic					■				
Spilornis holospilus (↓)	Philippine Serpent-eagle	Mana-o, Sikop	LC[a]	Endemic	■	■	■	■	■	■			■
Family **Pandionidae**													
Pandion haliaetus (↑)	Osprey	Agila, Banog	LC[a]	Migrant	■	■	■						
Order ANSERIFORMES													
Family **Anatidae**													
Anas acuta (↓)	Northern Pintail	Duyang	LC[a]	Migrant	■								
Anas luzonica (↓)	Philippine Duck	Kaging-king	VU[ab]	Endemic	■	■		■				■	
Aythya fuligula (—)	Tufted Duck	Pato	LC[a]	Migrant	■		■	■		■			
Dendrocygna arcuate (↓)	Wandering Whistling-duck	Gakit	LC[a]	Resident	■	■		■		■	■		
Spatula querquedula (↓)	Garganey	Paitan	LC[a]	Migrant			■						
Order BUCEROTIFORMES													
Family **Bucerotidae**													
Penelopides affinis (↓)	Mindanao Hornbill	Tariktik	LC[a], EN[b]	Endemic	■	■	■	■	■	■	■		■
Rhabdotorrhinus leucocephalus (↓)	Writhed Hornbill	Tariktik	VU[ab]	Endemic					■				
Order CAPRIMULGIFORMES													
Family **Apodidae**													
Collocalia esculenta (—)	Glossy Swiftlet	Sayaw	LC[a]	Resident		■	■						■
Family **Caprimulgidae**													
Lyncornis macrotis (—)	Great-eared Nightjar	Kanda-rapa, Tagoli-long	LC[a]	Resident		■	■						■
Family **Podargidae**													
Batrachostomus septimus (↓)	Philippine Frogmouth	Buho, Tagak	LC[a]	Endemic					■				
Order CHARADRIIFORMES													
Family **Charadriidae**													
Pluvialis squatarola (↓)	Grey Plover	Tarinting	LC[a]	Migrant				■	■				
Family **Jacanidae**													
Hydrophasianus chirurgus (?)	Pheasant-tailed Jacana	Pang-ag	LC[a]	Resident				■					

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order CHARADRIIFORMES													
Family **Laridae**													
Chlidonias hybrida (—)	Whiskered Tern	Buwang, Taga-dagat	LC[a]	Migrant	■	■	■	■		■	■	■	■
Sterna hirundo (?)	Common Tern	Buwang, Taga-dagat	LC[a]	Migrant		■	■	■				■	
Family **Recurvirostridae**													
Himantopus himantopus (↑)	Black-winged Stilt	Agatsona	LC[a]	Migrant	■				■				
Himantopus leucocephalus (↑)	Pied Stilt	Tiki, Tuklong	LC[a]	Migrant	■	■	■	■	■	■			
Family **Rostratulidae**													
Rostratula bengha-lensis (?)	Greater Painted-snipe	Pakubo	LC[a]	Resident	■								
Family **Scolopacidae**													
Actitis hypoleucos (↓)	Common Sandpiper	Til-aw, Tung-aw	LC[a]	Migrant					■				
Charadrius dubius (—)	Little Ringed Plover	Taringting	LC[a]	Migrant	■		■	■					
Gallinago gallinago (↓)	Common Snipe	Pat-ing	LC[a]	Migrant					■				
Gallinago megala (?)	Swinhoe's Snipe	Pat-ing	LC[a]	Migrant	■	■					■		■
Numenius phaeopus (↓)	Eurasian Whimbrel	Balang -kawitan	LC[a]	Migrant	■	■	■						
Pluvialis fulva (↓)	Pacific Golden Plover	Pulgon	LC[a]	Migrant		■		■					
Tringa glareola (—)	Wood Sandpiper	Til-aw, Tung-aw	LC[a]	Migrant	■	■	■	■	■			■	■
Tringa nebularia (—)	Common Green-shank	Til-aw	LC[a]	Migrant		■	■	■					
Tringa stagnatilis (↓)	Marsh Sandpiper	Til-aw, Tung-aw	LC[a]	Migrant	■						■		
Order COLUMBIFORMES													
Family **Columbidae**													
Chalcophaps indica (↓)	Grey-capped Emerald Dove	Agbaan, Manatad	LC[a]	Resident					■				
Columba vitiensis (—)	Metallic Pigeon	Tukmo	LC[a]	Resident					■				
Ducula aenea (↓)	Green Imperial-pigeon	Kalapati	NT[a]	Scarce Resident		■	■	■					■
Ducula pickeringii (↓)	Grey Imperial-pigeon	Kalapati	LC[a]	Near Endemic					■	■			
Ducula poliocephala (↓)	Pink-bellied Imperial-pigeon	Alimokon, Manatad	NT[a], CR[b]	Endemic	■								
Geopelia striata (—)	Zebra Dove	Alimokon, Bato- bato	LC[a]	Resident				■	■	■		■	
Macropygia tenuirostris (↓)	Philippine Cuckoo- dove	Kokok	LC[a]	Resident		■	■						
Phapitreron amethystinus (↓)	Amethyst Brown- dove	Tukmo, Alimokon	LC[a], CR[b]	Endemic	■			■	■				■
Phapitreron brevirostris (↓)	Short-billed Brown- dove	Alimokon	LC[a]	Endemic	■	■	■	■	■	■	■	■	■

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order COLUMBIFORMES													
Family **Columbidae**													
Phapitreron leucotis (↓)	White-eared Brown Dove	Alimokon	LC[a]	Endemic		■	■	■	■				■
Ramphiculus leclancheri (↓)	Black-chinned Fruit-dove	Paloma	LC[a]	Near Endemic								■	
Spilopelia chinensis (↑)	Eastern Spotted Dove	Kalapati	LC[a]	Resident	■		■		■	■	■	■	■
Streptopelia tranquebarica (↓)	Red Turtle Dove	Tukmo, Alimokon	LC[a]	Resident	■	■		■		■		■	
Treron axillaris (↓)	Philippine Green- pigeon	Punay	LC[a], VU[b]	Endemic	■	■	■	■	■		■	■	
Treron vernans (↓)	Pink-necked Green-pigeon	Punay	LC[a]	Resident	■	■	■	■	■	■	■	■	■
Order CORACIIFORMES													
Family **Alcedinidae**													
Alcedo atthis (↓)	Common Kingfisher	Kasay-kasay	LC[a]	Migrant	■	■				■			
Ceyx argentatus (↓)	Southern Silvery Kingfisher	Kasay-kasay, Sibit	NT[a], VU[b]	Endemic		■				■			
Ceyx mindanensis (↓)	South Philippine Dwarf-kingfisher	Tiklis, Sarig	VU[ab]	Endemic					■				
Halcyon gularis (?)	White-throated Kingfisher	Sagsag	LC[a]	Endemic		■	■	■	■	■			
Todiramphus chloris (↓)	Collared Kingfisher	Binti-binti	LC[a]	Resident	■	■	■	■	■	■	■		
Family **Meropidae**													
Merops americanus (—)	Rufous-crowned Bee eater	Tamsi-tamsi	LC[a]	Endemic					■				■
Merops philippinus (—)	Blue-tailed Bee eater	Tamsi-tamsi	LC[a]	Resident			■		■		■		
Order CUCULIFORMES													
Family **Cuculidae**													
Cacomantis merulinus (—)	Plaintive Cuckoo	Buwaw, Pook	LC[a]	Resident	■				■	■			■
Cacomantis variolosus (↓)	Brush Cuckoo	Buwaw, Pook	LC[a]	Resident				■	■	■			
Centropus melanops (↓)	Black-faced Coucal	Kokok, Ubon-ubon	LC[a]	Endemic					■	■			■
Centropus viridis (—)	Philippine Coucal	Kokok, Ubon-ubon	LC[a]	Endemic	■	■	■	■	■	■	■		■
Chalcites minutillus (—)	Little Bronze-cuckoo	Tuko-tuko, Kulikuli	LC[a]	Resident					■				
Eudynamys scolopaceus (—)	Western Koel	Kuh-uh, Kaw- kaw	LC[a]	Resident	■	■	■						
Surniculus velutinus (↓)	Philippine Drongo- cuckoo	Ku-ol	LC[a]	Endemic					■				

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status (a=IUCN; b=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order FALCONIFORMES													
Family **Laridae**													
Falco pere-grinus (↑)	Peregrine Falcon	Agilang-gamay	LC[a]	Migrant			■						
Order GALLIFORMES													
Family **Phasianidae**													
Gallus gallus (↓)	Red Jun-glefowl	Manok ihalas	LC[a]	Resident						■			■
Synoicus chinensis (—)	Asian Blue Quail	Suwa	LC[a]	Resident					■				
Order GRUIFORMES													
Family **Rallidae**													
Amaurornis cinerea (?)	White-browed Crake	Buwaw	LC[a]	Resident		■							■
Amaurornis olivacea (?)	Philippine Bush hen	Buwaw	LC[a]	Endemic						■	■		
Amaurornis phoenicurus (?)	White-breasted Waterhen	Unggas	LC[a]	Resident		■		■	■	■			
Gallicrex cinerea (↓)	Water-cock	Buwaw	LC[a]	Resident	■	■	■	■		■			
Gallinula chloropus (—)	Common Moorhen	Karab	LC[a]	Resident	■	■	■	■		■		■	■
Hypotaenidia philippensis (—)	Buff-banded Rail	Tikling	LC[a]	Resident					■			■	■
Hypotaenidia torquate (?)	Barred Rail	Tikling	LC[a]	Resident						■			
Porphyrio pulverulentus (?)	Philippine Swamphen	Tubtub	LC[a]	Endemic	■	■	■	■			■	■	■
Zapornia fusca (?)	Ruddy-breasted Crake	Buwaw	LC[a]	Resident				■					
Order PASSERIFORMES													
Family **Acanthizidae**													
Gerygone sulphurea (—)	Golden-bellied Gerygone	Ol-ul, Uwak-uwak	LC[a]	Resident		■							
Family **Acrocephalidae**													
Acrocephalus stentoreus (—)	Clamorous Reed-warbler	Kong-kong	LC[a]	Migrant			■	■	■	■	■		■
Family **Artamidae**													
Artamus leucoryn (—)	White-breasted Wood-swallow	It-it	LC[a]	Resident		■	■		■	■		■	■
Family **Campephagidae**													
Lalage nigra (↓)	Pied Triller	Salak	LC[a]	Resident	■	■				■		■	■
Family **Cisticolidae**													
Cisticola exilis (↑)	Golden-headed Cisticola	Pitpit Ko-gon, Dignos	LC[a]	Resident							■	■	
Cisticola juncidis (?)	Zitting Cisticola	Pitpit, Barat	LC[a]	Resident						■			
Orthotomus frontalis (↓)	Rufous-fronted Tailorbird	Tirtir, Sing-sing	LC[a]	Endemic					■	■	■		
Orthotomus nigriceps (↓)	Black-headed Tailorbird	Tirtir, Sing-sing	LC[a]	Endemic						■			

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order PASSERIFORMES													
Family **Corvidae**													
Corvus macrorhynchos (↓)	Large-billed Crow	Uwak	LC[a]	Endemic		■	■			■			■
Family **Dicaeidae**													
Dicaeum australe (↓)	Red-keeled Flowerpecker	Tamsi	LC[a]	Endemic	■	■	■		■	■	■		■
Dicaeum hypoleucum (↓)	Buzzing Flowerpecker	Tamsi	LC[a]	Endemic					■				
Dicaeum pygmaeum (↓)	Pygmy Flowerpecker	Tamsi	LC[a]	Endemic					■	■			
Dicaeum trigonostigma (↓)	Orange-bellied Flowerpecker	Tamsi	LC[a]	Resident		■			■	■			■
Prionochilus olivaceus (↓)	Olive-backed Flowerpecker	Tamsi	LC[a]	Endemic					■				■
Family **Dicruridae**													
Dicrurus striatus (↓)	Short-tailed Drongo	Buwal	LC[a]	Endemic					■				
Family **Estrildidae**													
Lonchura atricapilla (—)	Chestnut Munia	Maya	LC[a]	Resident		■						■	
Lonchura leucogastra (—)	White-bellied Munia	Maya	LC[a]	Resident					■				
Lonchura punctulate (—)	Scaly-breasted Munia	Maya	LC[a]	Resident					■	■			
Padda oryzivora (↓)	Java Sparrow	Mayang-kosta	LC[a]	Intro-duced					■				
Family **Hirundinidae**													
Hirundo rustica (↓)	Barn Swallow	Sibad, Layang-layang	LC[a]	Migrant				■	■	■	■		
Hirundo tahitica (?)	Pacific Swallow	Layang-layang	LC[a]	Resident						■			■
Family **Laniidae**													
Lanius cristatus (↓)	Brown Shrike	Tababaras	LC[a]	Migrant					■			■	
Family **Locustellidae**													
Cincloramphus timoriensis (—)	Tawny Grassbird	Tibsok	LC[a]	Resident							■		
Helopsaltes ochotensis (↓)	Middendorff's Grasshopper-warbler	Pang-pang	LC[a]	Migrant						■			
Megalurus palustris (?)	Straited Grassbird	Turtoriyok	LC[a]	Resident							■	■	
Family **Monarchidae**													
Hypothymis azurea (↓)	Black-naped Monarch	Pipit Asul	LC[a]	Resident					■	■			■
Terpsiphone cinnamomea (↓)	Southern Rufous Paradise-flycatcher	Suwal	LC[a]	Near Endemic					■	■			■
Family **Motacillidae**													
Motacilla cinerea (—)	Grey Wagtail	Niyotsiyot	LC[a]	Migrant	■								
Motacilla tschutschensis (↓)	Eastern Yellow Wagtai	Niyotsiyot	LC[a]	Migrant					■				

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order PASSERIFORMES													
Family **Muscicapidae**													
Copsychus mindanensis (↓)	Philippine Magpie-robin	Siloy, Dominiko	LC[a]	Endemic						■			
Cyornis rufigastra (↓)	Mangrove Blue-flycatcher	Mamal	LC[a]	Resident						■			
Muscicapa griseisticta (—)	Grey-streaked Flycatch-er	Mamal	LC[a]	Migrant	■			■	■				
Saxicola caprata (—)	Pied Bushchat	Siloy	LC[a]	Resident		■	■	■				■	
Family **Nectariniidae**													
Aethopyga bella (—)	Hand-some Sunbird	Tamsi	LC[a]	Endemic	■	■			■	■	■		■
Cinnyris jugularis (—)	Olive-backed Sunbird	Tamsi	LC[a]	Resident			■		■	■	■		■
Family **Oriolidae**													
Oriolus chinensis (↓)	Black-naped Oriole	Antolihao	LC[a]	Resident			■	■		■	■	■	■
Family **Passeridae**													
Passer montanus (↓)	Eurasian Tree Sparrow	Langgam-pari, Maya	LC[a]	Intro-duced					■				
Family **Phylloscopidae**													
Phylloscopus xanthodryas (—)	Japanese Leaf-warbler	Tingting, Liwliwa	LC[a]	Migrant	■								
Family **Pittidae**													
Pitta sordida (↓)	Western Hooded Pitta	Pita-pita	LC[a]	Resident					■				■
Family **Pycnonotidae**													
Hypsipetes philippinus (—)	Philippine Bulbul	Tagmaya	LC[a], OTS[b]	Endemic						■		■	■
Pycnonotus goiavier (↑)	Yellow-vented Bulbul	Pirok-pirok	LC[a]	Resident		■	■	■	■	■	■	■	■
Family **Rhipiduridae**													
Rhipidura nigritorquis (↓)	Philippine Pied Fantail	Tarerekoy	LC[a]	Endemic		■	■		■	■	■		■
Family **Sturnidae**													
Aplonis panayensis (—)	Asian Glossy Starling	Galan-syang	LC[a]	Resident				■				■	
Sarcops calvus (↓)	Coleto	Sal-ing		Endemic					■				■
Family **Timaliidae**													
Macronus striaticeps (↓)	Brown Tit-babbler	Mang-mang	LC[a]	Endemic	■							■	■
Order PELECANIFORMES													
Family **Ardeidae**													
Ardea alba (?)	Great White Egret	Tulabong	LC[a]	Migrant	■	■	■	■	■	■	■	■	■
Ardea cinerea (?)	Grey Heron	Tugak	LC[a]	Migrant				■	■				
Ardea intermedia (↓)	Intermediate Egret	Tulabong	LC[a]	Migrant	■	■	■	■	■	■	■	■	■
Ardea purpurea (↓)	Purple Heron	Tugak	LC[a]	Resident	■	■	■	■	■	■	■	■	■
Ardeola speciosa (?)	Javan Pond-heron	Lapay	LC[a]	Resident	■	■	■	■	■	■	■	■	■

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order PELECANIFORMES													
Family **Ardeidae**													
Bubulcus ibis (↑)	Cattle Egret	Tugak	LC[a]	Resident		■	■	■				■	
Butorides striata (—)	Green-backed Heron	Lapay, Kuhaw	LC[a]	Resident		■	■			■			
Egretta garzetta (↓)	Little Egret	Tulabong, Tugak	LC[a]	Migrant	■	■	■	■	■	■	■	■	■
Egretta sacra (—)	Pacific Reef-egret	Kuro-sagi	LC[a]	Resident	■								
Ixobrychus cinnamomeus (?)	Cinnamon Bittern	Lapay	LC[a]	Resident	■	■	■	■		■	■		
Ixobrychus eurhythmus (↓)	Schrenck's Bittern	Lapay	LC[a]	Migrant				■					
Ixobrychus flavicollis (?)	Black Bittern	Lapay	LC[a]	Resident	■	■	■			■			■
Ixobrychus sinensis (?)	Yellow Bittern	Lapay	LC[a]	Resident	■	■	■	■		■		■	
Nycticorax caledonicus (—)	Rufous Night-heron	Lapay	LC[a]	Resident	■	■	■	■		■			
Nycticorax nycticorax (↓)	Black-crowned Night-heron	Lapay	LC[a]	Resident		■			■			■	
Family **Threskiornithidae**													
Plegadis falcinellus (↓)	Glossy Ibis	Tugak	LC[a]	Rare Resident					■				
Order PICIFORMES													
Family **Megalaimidae**													
Psilopogon haemacephalus (↓)	Copper-smith Barbet	Pokpok	LC[a]	Resident	■				■				
Family **Picidae**													
Chrysocolaptes lucidus (↓)	Buff-spotted Flame-back	Piko-piko	LC[a]	Endemic					■				
Dryocopus javensis (↓)	White-bellied Wood-pecker	Tugatiti, Katiktik	LC[a]	Resident					■	■			■
Mulleripicus fuliginosus (↓)	Southern Sooty Wood-pecker	Tugatiti, Katiktik	VU[a]	Endemic			■						
Picoides maculatus (↓)	Philippine Pygmy Wood-pecker	Pokpok, Balalatok	LC[a]	Endemic					■	■			■
Order PSITTACIFORMES													
Family **Psittacidae**													
Loriculus philippensis (↓)	Philippine Hanging-parrot	Kusi	LC[a], CR[b]	Endemic	■	■	■		■	■			■
Prioniturus discurus (↓)	Blue-crowned Racquet-tail	Kilit	LC[a], OTS[b]	Endemic									■
Bolbopsittacus lunulatus (↓)	Guaiabe-ro	Butitok	LC[a]	Endemic	■	■			■	■	■		
Order STRIGIDAE													
Family **Strigidae**													
Otus everetti (↓)	Mindanao Lowland Scops-owl	Kuwago, Saw- saw	LC[a]	Endemic					■	■			■
Ninox spilocephala (↓)	Mindanao Boobook	Kuwago	NT[a], VU[b]	Endemic			■						
Family **Tytonidae**													
Tyto longimembris (↓)	Eastern Grass-owl	Saw-saw	LC[a]	Resident					■				■

Continuation. Table 2. Species composition and remarks of newly recorded avifauna in the Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

Species Name	Common Name	Local Name	Conservation Status ([a]=IUCN; [b]=DAO 2019-06)	Endemicity	Sampling Sites/ BMS Sites in Agusan Marsh Wildlife Sanctuary (AMWS)								
					Lake Mihaba	Lake Kelobidan	Lake Mambagongon	Lake Panlabuhan	Caimpugan Peat Swamp Forest	Lake Tugno	Dinagat-Mambagongon Creek	Sabang-Gibong-Sabang Adgawan	Sago Forest
Order SULIFORMES													
Family **Anhingidae**													
Anhinga melanogaster (↑)	Oriental Darter	Kasili-silihon	NT[a], VU[b]	Rare Resident			■						
Family **Palacrocoracidae**													
Phalacrocorax carbo (↑)	Great Cormorant	Tiong	LC[a]	Migrant		■							
Order TROGONIFORMES													
Family **Trogonidae**													
Harpactes ardens (↓)	Philippine Trogon	Ibong Adarna	LC[a]	Endemic					■				
				Total Number of Species per Site	54	64	55	51	79	68	33	34	52

Note: Areas with black ink indicate the presence of the species, while blank areas represent its absence in the area. The population trend according to the IUCN is indicated as decreasing (↓), increasing (↑), and stable (—). Conservation statuses: CR=Critically Endangered; VU=Vulnerable; EN=Endangered; NT=Near Threatened; OTS=Other Threatened Species.

This approach is particularly crucial for migratory species that inhabit the sanctuary during specific times of the year. Increasing the number of survey locations from four (across two municipalities) to nine (spanning six municipalities) inherently enhances the probability of encountering a wider array of species, particularly those that may be localized or specific to particular habitats. The expanded geographic coverage improves the representativeness of the biodiversity assessment. Magurran & McGill (2011) underscore the significance of temporal and spatial sampling strategies in precisely evaluating biodiversity, illustrating that prolonged sampling durations can effectively capture seasonal and annual fluctuations in species composition. Guillera-Arroita et al. (2014) also underscore the significance of survey duration in precisely estimating species occupancy and detectability, indicating that extended sampling periods can enhance the reliability of biodiversity assessments. Yoccoz et al. (2012) support the assertion that prolonged monitoring is essential for identifying temporal trends in species richness and comprehending ecological dynamics over time. Moreover, following the enactment of AMWS under the ENIPAS Act of 2018, improved management strategies, including rigorous enforcement of conservation regulations, habitat restoration efforts, and community involvement, could foster a more robust ecosystem, promoting increased species diversity and abundance.

Based on the recorded species, 43 (29%) are endemic to the Philippines. Of these, 13 species (9%) are Mindanao endemics (Figure 3). With about one-third of its species found only in the Philippines, the protected area plays a vital role in preserving the country's unique biodiversity. According to Ibañez (2010), the high concentration of endemic species entails the significance of an area inhabited by unique animals. A total of 35 species (23%) recorded in the area are migratory, a relatively high number compared to the nearest highland, Mt. Hilong-Hilong, which has 16 migratory species (Gracia et al. 2021). However, Xu and Xu (2018) documented 48 migratory bird species in OIWS, which is 37.14% more than in AMWS. Despite this, the findings highlight AMWS's importance as part of broader migratory routes, particularly for the East Asian-Australasian Flyway Partnership (EAAFP). Among the 67 resident species in AMWS, 41% are common residents, 2% are rare residents, and 1% are scarce residents, further emphasizing its ecological significance.

On the other hand, about 11% (n=16) of these birds fall in the threatened classification based on IUCN and DAO 2019-09 and consist of 6% (n=9) vulnerable, 2% (n=3) critically endangered, 1% (n=2) near threatened,1% (n=1) in the endangered, and 1% (n=1) Other Threatened Species (OTS) classification (Figure 4). This data highlights the critical role of AMWS in supporting and potentially stabilizing these populations, making it a high-priority area for conservation efforts. Avifauna are valuable indicators of global patterns in biodiversity conservation due to their high sensitivity to environmental changes, and they are also used as indicator species to monitor ecosystem health (Mallari et al. 2001, Mekonen 2017) and the presence of these threatened birds in AMWS may reflect broader environmental pressures such as habitat loss, pollution, climate change, and resource scarcity (Dutta 2017). The records of threatened species are also the starting points in prioritizing management and conservation plans and strategies in this protected area.

Variations in the species composition and richness were also observed across the nine (9) BMS Sites in AMWS. Figure 5 shows that Caimpugan Peat Swamp Forest documented the highest bird species (n=80, 53%). It is followed by Lake Tugno (n=68, 45%), a peat-forming ecosystem. Species richness is also relatively high in Lake Kelobidan (n=62, 41%) and Lake Mihaba and Mambagongon (n=53, 35%). Dinagat-Mambagongon Creek recorded the least bird species (n=33, 22%), which can be attributed to the significant impact of human settlement and anthropogenic activities within the riparian ecosystem of this creek. As human development fragments the habitat, birds struggle to access the resources they need for feeding and migration (Boesing et al. 2020). The continuing degradation of the riparian vegetation can also contribute to the birds' challenges from moving to different landscapes, significantly reducing the number of species able to thrive in such fragmented habitats (Hale et al. 2014, Yurong et al. 2020). Some documented endemics, migratory, threatened, and notable resident avifauna are shown in Figures 6, 7, 8, and 9, respectively.

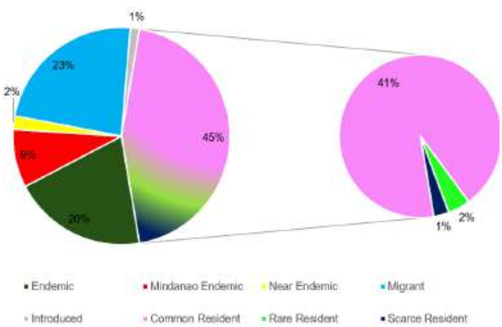

Figure 3. Geographic range description of the recorded avifauna in Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

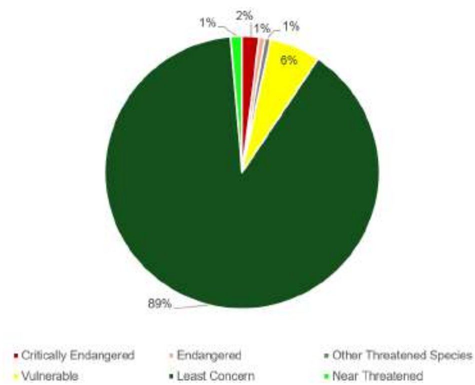

Figure 4. Conservation status of avifauna in Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines.

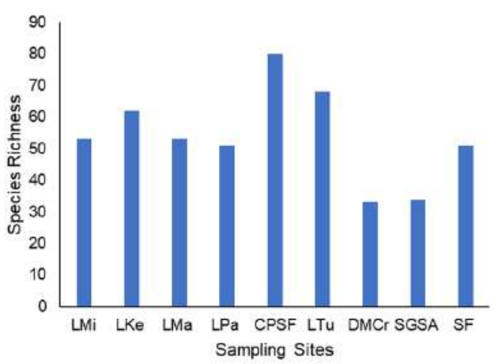

Figure 5. Species richness of avifauna in Agusan Marsh Wildlife Sanctuary (AMWS), Agusan del Sur, Caraga Region, Philippines. LMi= Lake Mihaba; LKe= Lake Kelobidan; LMa= Lake Mambagongon; LPa= Lake Panlabuhan; CPSF= Caimpugan Peat Swamp Forest; LTu= Lake Tugno; DMCr= Dinagat-Mambagongon Creek; SGSA= Sabang Gibong-Sabang Adgawan River; SF= Sago Forest.

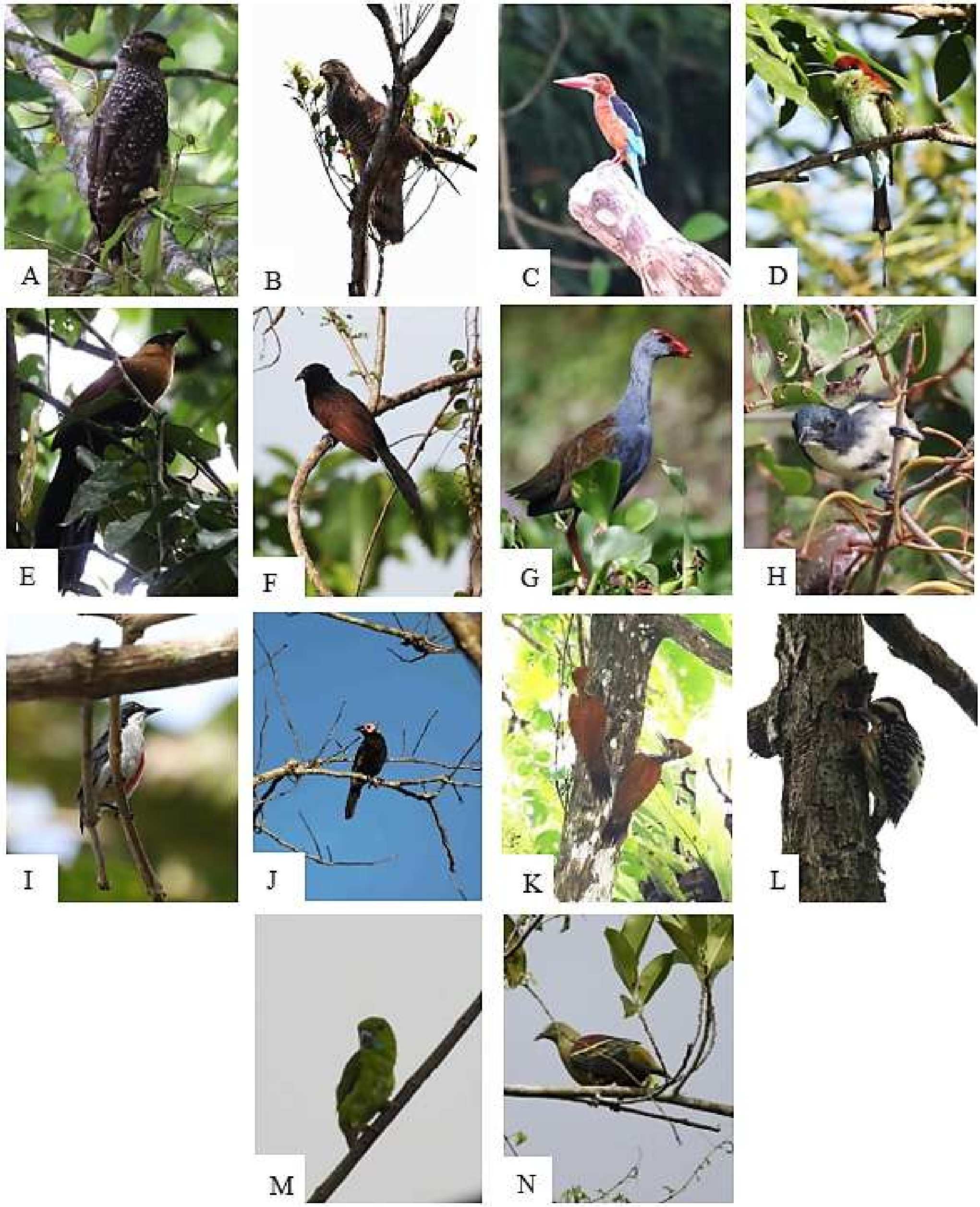

Figure 6. Some of the Philippine endemic birds recorded in Agusan Marsh Wildlife Sanctuary. A) Philippine Serpent-eagle (*Spilornis holospilus*), B) Philippine Honey-buzzard (*Pernis steerei*), C) White-throated Kingfisher (*Halcyon gularis*), D) Rufous-crowned Bee- eater (*Merops americanus*), E) Black-faced Coucal (*Centropus melanops*), F) Philippine Coucal (*Centropus viridis*), G) Philippine Swamphen (P*orphyrio pulverulentus*), H) Pygmy Flowerpecker (*Dicaeum pygmaeum*), I) Red-keeled Flowerpecker (*Dicaeum australe*), J) Coleto (*Sarcops calvus*), K) Buff-spotted Flameback (*Chrysocolaptes lucidus*), L) Philippine Pygmy Woodpecker (*Picoides maculatus*), M) Guaiabero (*Bolbopsittacus lunulatus*), and N) Philippine Green-pigeon (*Treron axillaris*).

Figure 7. Some of the migratory birds documented in Agusan Marsh Wildlife Sanctuary (AMWS). A) Grey-faced Buzzard (*Butastur indicus*), B) Osprey (*Pandion haliaetus*), C) Common Tern (*Sterna hirundo*), D) Great Cormorant (*Phalacrocorax carbo*), E) Common Sandpiper (*Actitis hypoleucos*), F) Wood Sandpiper (*Tringa glareola*), G) Pacific Golden Plover (*Pluvialis fulva*), H) Common Greenshank (*Tringa nebularia*), I) Eurasian Whimbrel (*Numenius phaeopus*), J) Common Kingfisher (*Alcedo atthis*), K) Brown Shrike (*Lanius cristatus*), L) Great White Egret (*Ardea alba*), M) Little Egret (*Egretta garzetta*), N) Grey Heron (*Ardea cinerea*), O) Intermediate Egret (*Ardea intermedia*), and P) Black-winged Stilt (*Himantopus himantopus*).

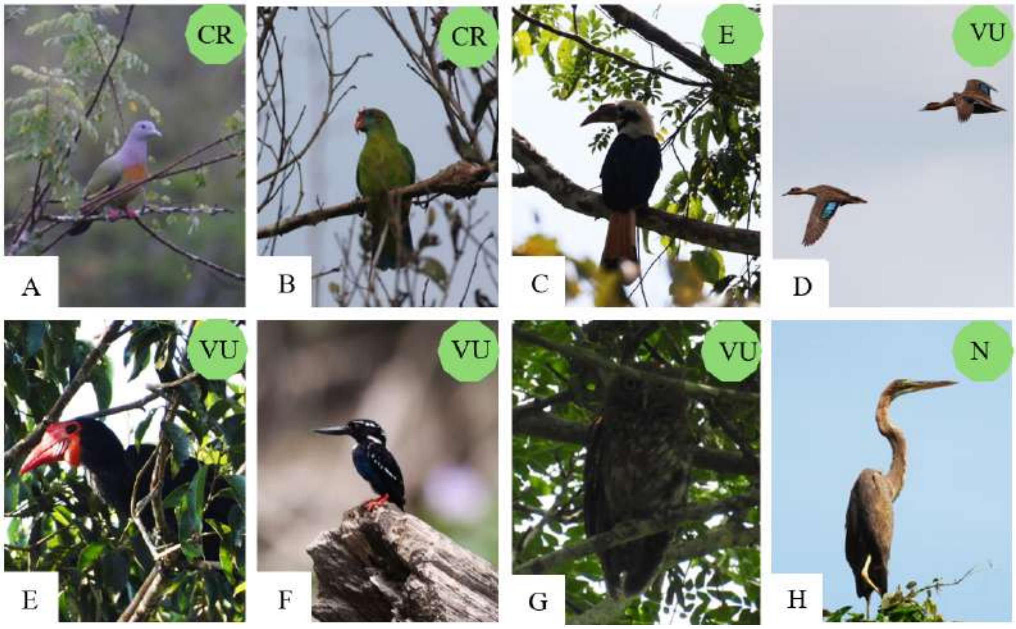

Figure 8. Some of the threatened birds documented in Agusan Marsh Wildlife Sanctuary (AMWS). A) Pink-bellied Imperial-pigeon (*Ducula poliocephala*), B) Philippine Hanging-parrot (*Loriculus philippensis*), C) Mindanao Hornbill (*Penelopides affinis*), D) Philippine Duck (*Anas luzonica*), E) Writhed Hornbill (*Rhabdotorrhinus leucocephalus*), F) Southern Silvery Kingfisher (*Ceyx argentatus*), G) Mindanao Boobook (*Ninox spilocephala*), and H) Oriental Darter (*Anhinga melanogaster*).

Threats to Biodiversity

The results of the Focus Group Discussions (FGDs) revealed that all lakes designated as BMS Sites serve as fishing grounds and primary sources of livelihood for the Agusanon Manobo. Rice and corn cultivation is typical along the riparian ecosystem in rivers and creeks within the AMWS. Wildlife hunting was prevalent across all sites, while timber cutting and harvesting other forest products, such as rattan, were common activities in the Caimpugan Peat Swamp Forest. Other concerns include the conflicting tenure around AMWS, particularly areas under the Indigenous People's claims, and the misclassification of land use, especially in peatlands. Table 3 depicts the comprehensive result of the Focus Group Discussion among the designated Community Monitoring Group (CMG) of AMWS.

Addressing the concerns and threats in AMWS is critical for protecting its biodiversity and ensuring the indigenous people's reliance on these resources for survival. Enhancing enforcement of the Wildlife Act (RA 9174) and the ENIPAS Act of 2018 (RA 11038) through the augmentation of deputized environmental law enforcement units or the deputization of park rangers known as Bantay Danao, as well as collaboration with Local Government Units (LGUs) to improve patrol systems, is a viable solution to combat illegal activities. Nonetheless, Indigenous Peoples' rights must be consistently enforced by the IPRA of 1997 (RA 8371). Sustainable fishing practices must be strictly followed by the Philippine Fisheries Code of 1998 (RA 8550) and in collaboration with the Bureau of Fisheries and Aquatic Resources (BFAR). To prevent expansion, agricultural activities in AMWS peatlands, riparian zones, and the Multiple Use Zone (MUZ) should be regulated. They can be accomplished through regular monitoring and implementing Communication, Education, and Public Awareness (CEPA) initiatives. If resource utilization is required and cannot be avoided, the Special Use Agreement for Protected Areas (SAPA) should be implemented in AMWS. Local Ordinances should also be used to enforce penalties imposed

Figure 9. Some notable resident bird species recorded in Agusan Marsh Wildlife Sanctuary (AMWS). A) Pheasant-tailed Jacana (*Hydrophasianus chirurgus*), B) Purple Heron (*Ardea purpurea*), C) Brush Cuckoo (*Cacomantis variolosus*), D) White-bellied Munia (*Lonchura leucogastra*), E) Black-naped Monarch (*Hypothymis azurea*), F) Olive-backed Sunbird (*Cinnyris jugularis*), G) Striated Grassbird (*Megalurus palustris*), H) Common Moorhen (*Gallinula chloropus*), I) Glossy Ibis (*Plegadis falcinellus*), and J) Rufous Night-heron (*Nycticorax caledonicus*).

by the LGU through the endorsement of the Protected Area Management Board (PAMB). The introduction of alternative livelihoods for the Agusanon Manobo is strongly encouraged, particularly community-based forest management (CBFM) and biodiversity-friendly enterprises (BDFEs). Engaging in dialogues to reconcile Indigenous Peoples' intellectual property rights with regulations is critical for understanding land tenure. In collaboration with the Department of Agrarian Reform (DAR) and the Department of Environment and Natural Resources (DENR), the government should prioritize revising land use maps to accurately classify wetlands and recognize peatlands, mitigating the consequences of land use misclassification. The government should also pass legislation that establishes guidelines for using and managing wetlands, particularly peatlands.

Table 3. Focus Group Discussion: Livelihood, resource use, and existing threats in Agusan Marsh Wildlife Sanctuary (AMWS).

Activity/ Concern	Description	Affected Areas	Key Stakeholders	Impact
Fishing	Source of livelihood for the Agusan Manobo	Core zones, buffer zones, designated lakes of AMWS	Agusanon Manobo, local fisher-folks, LGU	Depletion of fish stocks, overfishing concerns
Agriculture	Rice and corn cultivation along ripar-ian ecosystem; land use conversion through agricultural expansion	Waterways and Riparian Zones of AMWS	Local farmers	Soil erosion, agro-chemical pollution
Wildlife Hunting	Hunting for subsistence and economic purposes	All Biodiversity Monitoring Sites	Agusanon Manobo	Decline in wildlife population
Timber Cutting and Forest Product Harvesting	Extraction of tim-ber and non-timber products like rattan and bamboo	Caimpugan Peat Swamp Forest	Agusanon Manobo and AMWS tenured migrants	Deforestation, loss of biodiversity
Conflicting Tenure Claims	Disputes over land tenure and Indigenous People's claims	Areas under Certificate of Ancestral Domain (CADT)	Agusanon Mano-bo, DENR, DAR, NCIP	Tension between stakeholders, resource mismanagement
Land Use Misclassification	Misclassification of peatlands and oth-er critical habitats as Alieanable and Disposable land	Peatlands, Wetlands, and Riparian zones of AMWS	DAR, DENR, LGUs	Habitat degradation, improper land use
Invasive Species	Proliferation of water hyacinth	Water system and entire marsh ecosystem	DOST, DENR	Competition with native species, disruption of ecosystem

4 Conclusion and Recommendations

The Agusan Marsh Wildlife Sanctuary (AMWS) is a crucial conservation area with high species richness, serving as a key habitat for endemic, threatened, and migratory bird species. With 150 avifauna recorded, the protected area supports Philippine endemics and migratory species along the East Asian-Australasian Flyway, highlighting its national and global ecological significance. The Caimpugan Peat Swamp Forest exhibits the greatest species richness, whereas areas affected by human habitation and habitat fragmentation, like Dinagat-Mambagongon Creek, demonstrate diminished diversity. Although designated as a protected area, AMWS encounters biodiversity threats from human activities, including wildlife hunting, timber extraction, agricultural encroachment, land tenure disputes, and misclassification of land use. Efficient management strategies are essential to alleviate these pressures, maintain the biodiversity of AMWS, and promote sustainable livelihoods for local communities, particularly the Agusanon Manobo, who rely on the lakes and rivers for fishing and agriculture. Moreover, the comprehensive conservation of the nine (9) Biodiversity Monitoring System sites, particularly those with significant populations of endemic and migratory species, is essential for safeguarding avifaunal diversity. Additional ornithological research is highly recommended, mainly for concentrating on the population and diversity of migratory bird species, to create a solid basis for the designation of AMWS as part of the Philippines' East Asian-Australasian Flyway Network Site.

5 Acknowledgement

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Statement of Conflict of Interest

The authors declare no conflict of interest associated with the submission and publication of this manuscript.

Author Contribution

HJ Sumilhig *conceptualization and design, including data collection, formal analysis, manuscript writing*. AM Talitod *for the writing and revision process.* CY Yurong *handled data curation, formal analysis, and mapping.* M Tumarao *helped gather resource materials and took bird photographs*. S Vasquez and E Ibonia *for the planning, implementation, and supervision of the study, as well as data analysis.*

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Amphibian and Reptile Roadkill Incidents Along Butuan City–Las Nieves Road, Philippines, with Notes on Temporal and Spatial Mortality Distribution

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A B S T R A C T

Roads significantly impact biodiversity, and animal roadkill may be one of the most crucial human-caused mortality factors for some species. This study aimed to document amphibian and reptile roadkill incidents along a 25.5-kilometer stretch of the Butuan to Las Nieves Road from June 2021 to February 2022. A total of 214 carcasses were recorded from three amphibian species (n=204), namely, *Kaloula pulchra, Polypedates leucomystax* and *Rhinella marina,* and five reptilian species (n=10), namely, *Dendrelaphis philippinensis, Lycodon capucinus, Naja samarensis, Coelognathus erythrurus,* and *Malayopython reticulatus*. In this study, most roadkill victims were invasive alien species, and the cane toad, *R. marina*, exhibited the greatest mortality among species (roadkill rates= 7.76 ind./km). The high roadkill incidence of the invasive species could unintentionally aid in reducing and managing its population in the affected areas. However, since roadkills are incidental, it is not a reliable control measure. Although minimal, we recorded some endemic species impacted by vehicle collisions, which could also affect their population. The highest recorded herpetofauna roadkill incidents were in June and September (n=35). A significant difference in roadkills was recorded across sampling months (p<0.000). The acquired rainfall data indicated peak rainfall levels in November and December 2021 (284.2mm and 627.4mm, respectively). The study's results showed no significant relationship between roadkill mortality and rainfall (p-value= 0.412, r^2= -0.313). The spatial pattern of roadkills was analyzed using the Kernel Density Estimation (KDE) in Quantum Geographic Information System, and three roadkill hotspots were identified. Most roadkill hotspots within the heatmap were located on road portions near forested and plantation areas and waterways. Analyzing habitat suitability and connectivity might improve the capacity to anticipate the location of roadkill hotspots. This study is the first to report on herpetofauna roadkill incidents in Butuan City and the Caraga Region.

Keywords: *Herpetofauna, Hotspots, Monitoring, Roadkill, Rainfall*

1 Introduction

Amphibians and reptiles are vulnerable to roadkill incidents due to their seasonal migrations, slow movement, and specific habitat needs, threatening their populations worldwide (Jones et al. 2024). Amphibians, for instance, frequently crossroads to reach breeding sites, especially during rainy seasons or times of the year when they migrate in large numbers, leading to high mortality rates on highways that intersect their natural habitats (Beebee 2013). In temperate regions, where amphibians are influenced significantly by temperature, particularly during spring and fall, experienced a high rate of roadkill mortality. Notable roadkill events have detrimental impacts on herpetofauna populations (Jones et al. 2024, Langen et al. 2009, van der Ree et al. 2015). The roadkill incidents have led to the construction of tunnels and barriers for amphibians and other herpetofauna to mitigate population declines. Similarly, reptiles, including turtles and snakes, frequently crossroads to access areas for mating, feeding, or sunbathing, which increases the possibility of vehicle collisions (Row et al. 2007).

Road mortality can be very devastating to these species because many amphibians and reptiles have low reproduction rates and delayed maturation. Hence, population recoveries from even slight increases in adult mortality are unlikely (Gibbs & Shriver 2002). Amphibians are vulnerable to environmental changes because their permeable skin and reliance on aquatic and terrestrial habitats make them especially vulnerable to habitat fragmentation and pollution. These often tend to be factors exacerbated by roads and accompanying infrastructure (Hels & Buchwald 2001). In other countries, such as tropical regions where seasonal amphibian migrations are prominent, roads showed fragmented habitats significantly and reduced the species' genetic flow and population resilience (Beebee 2013, Hartel et al. 2010, Allentoft & O'Brien 2010).

Roadkill incidents can both aid and impede the spread of invasive alien species. High mortality among invasives may temporarily reduce their population in affected areas. However, if these species are adaptive, roadkills may inadvertently assist the spread by encouraging broader dispersal and enabling surviving individuals to establish new habitats (Santos et al. 2011). In tropical areas, the population of invasive alien species continues to increase despite the frequent records of roadkill incidences, underscoring the complexity of managing these populations (Shine 2010; Shine et al. 2018).

Extrinsic factors influencing road mortality vulnerability can be both spatial (e.g., surrounding environments (Caro et al. 2000) and temporal (e.g., seasonal changes) in nature. The time series of road deaths are often correlated with seasonality. The influence of different seasons has variable effects on the frequency of roadkills depending on the location. For instance, seasonal temperature changes in temperate zones dictate the timing of amphibian migrations and associated road mortality peaks (Coelho et al. 2012). In contrast, in tropical countries such as the Philippines, rainfall patterns are more significant drivers of herpetofauna activity and roadkill occurrences (Oddone Aquino and Nkomo 2021). Therefore, landscape factors, road infrastructure, traffic volume, speed, niches, species behavior, and seasonality influence roadkill.

Although amphibians and reptiles are far more vulnerable species than mammals or birds, Fahrig and Rytwinski (2009) claim that little study has been done on the consequences of roads on their populations. On a landscape scale, the consequences of road networks on amphibian and reptile populations are rarely examined. Some road-killed species disappear quickly, coupled with the intricate network of roads making road-killed animals difficult to distinguish (Heigl et al. 2017). In the Philippines, studies of roadkills have been limited. Documented cases include anurans in an urbanized area in Davao City (Gersava et al. 2020) and freshwater turtles in Palawan (Bernando 2019). Beyond these studies, no other published research on roadkills has been conducted in the Philippines to date.

One crucial national secondary road in Agusan del Norte is the Butuan City to Las Nieves road. Agricultural farms and secondary forest habitats surrounded it. It is a key site connecting the Municipality of Las Nieves to the City proper, making it a potentially significant site for roadkill impacts on local wildlife. Unlike temperate countries with significant seasonal migrations, the roadkill patterns in this area are influenced by tropical rainfall patterns and human-modified landscapes. Hence, this study focused on amphibian and reptile roadkill incidence from Barangay Maguinda, Butuan City, to Barangay San Roque, Las Nieves road. Roadkill data can be a valuable tool for monitoring amphibian and reptilian population dynamics and movement patterns. The information may help with the protection and conservation of endemic species and the creation of efficient mitigation plans for invasive species. This study provides a unique perspective on roadkill impacts in the Philippines, particularly within the Butuan and Caraga regions, where such data are scarce.

2 Materials and Methods

Description of the Study Area

The amphibian and reptile roadkill incidence monitoring was conducted from Barangay Maguinda, Butuan City, to Barangay San Roque, Las Nieves Agusan del Norte, Philippines (initial coordinates 8°49'32.1"N, 125°35'41.3"E; last point coordinates 8°42'4.9"N, 125°39'54.2"E). It is a two-lane national secondary road supporting the primary national roads by directly linking Las Nieves to Butuan City. The survey route covers a total distance of 25.5 km. The area was chosen because of its forested nature and proximity to the Agusan River. The region's climate is defined as hot, oppressive, and overcast. The temperature ranges typically from 25°C to 31°C throughout the year, with temperatures rarely falling below 23°C or rising above 32°C. Outlying areas were open farmland like rice, coconut, corn, and rubber farms (Phil Atlas 2021).

Data Collection and Sampling

The chosen route was surveyed from June 2021 to February 2022. We used a motorcycle to track the defined path at 20-25 km/h, conducting observations twice monthly from 0800 to 1200 hours with a two-week interval between surveys. These surveys were carried out on fair weather. The survey route started in Las Nieves, proceeded to Butuan City, and then returned to the starting point covering both sides of the road. Two people monitored the amphibian and reptile roadkill found on the roads. The carcasses were photo-documented, and distinguishing characteristics were noted to aid identification. Features that are peculiar to each species include body size, coloration, patterning, and distinctive markings. Other factors, such as the surrounding habitat and the condition of the carcass (e.g., degree of decomposition), were also noted to provide additional information for species identification. The journals of Sanguila et al. (2016) and Diesmos

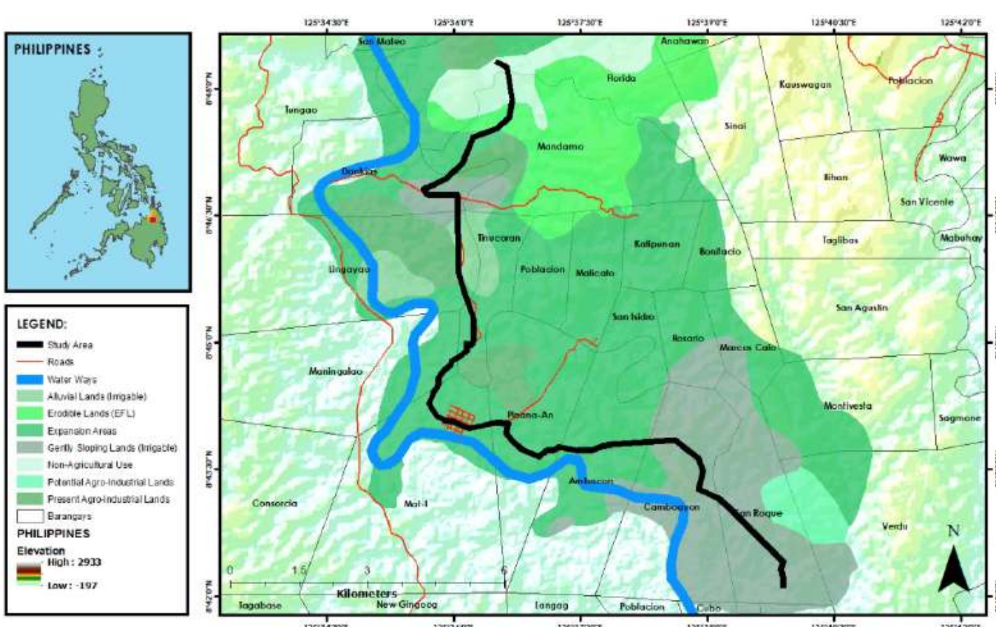

Figure 1. Location of the study route from Brgy. Maguinda, Butuan City to Brgy, San Roque, Las Nieves, Agusan del Norte, Philippines.

et al. (2015) were used to determine the lowest possible identification. Geographic coordinates were recorded at each incidence to record the exact location of each sample. We removed all carcasses off the road to avoid duplicate counting. The daily rainfall data of Butuan City to Las Nieves was obtained from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAG-ASA), Butuan City.

Heat Map Generation

Quantum Geographic Information System Software (QGIS Software) was used to analyze and create heat maps of herpetofauna roadkills. QGIS uses Kernel Density Estimation (KDE) to generate heat maps. This method applies a kernel function to each data point to calculate density. After calculating the overlapped kernels, this program creates a continuous surface with low densities in blue and high densities in red. The resulting heatmap shows the concentration of points across the geographic area under study.

Data Analysis

The roadkill rates of amphibians and reptiles were calculated using the formula:

$$Roadkill\ Rates = \frac{Number\ of\ individuals\ killed}{Distance\ traveled}$$

T-test was used to examine whether the number of roadkills varied across months of survey using Paleontological Statistics Software (PAST 4.15). The relationship between rainfall and roadkills was examined using a correlation test ($p<0.05$) with the number of roadkills recorded per month as the dependent variable using SPSS v28. The graphs were generated using Python version 3.13 and the Matplotlib and Seaborn libraries for visualization.

3 Results and Discussion

Roadkill species registered

We recorded 214 roadkill incidences, accounting for 204 amphibians and ten reptile individuals during the nine months of monitoring along the Butuan - Las Nieves Road, Agusan del Norte, Philippines. Of the 214 carcasses, 95% represented three amphibian species. Families include Microhylidae (0.46%, n = 1 spp.), Bufonidae (92.52%, n = 1 spp.), Rhacophoridae (1.40%, n = 1 spp.), and an unidentified species (0.93%, n = 2 spp.). The remaining 5% represented five reptile species from Family Colubridae (2.33%, n=3 spp.), Elapidae (1.40%, n = 1 spp.), Pythonidae (0.46%, n = 1 spp.), and unidentified (0.46%, n = 1 spp.) (Table 1 and Figure 2). Most of the casualties found were globally classified as Least Concern by the IUCN (2021). Table 1 shows that the Cane toad, *Rhinella marina* (92.52%), Oriental wolf snake, *Lycodon capucinus* (1.40%), and the Visayan cobra, *Naja samarensis* (1.40%) were the dominating roadkill victims. Due to advanced decomposition, three carcasses (two amphibians and one reptile) could not be identified, which obscured key physical features necessary for accurate identification.

Rhinella marina (Figure 2A) was the most recorded amphibian species in the survey area. This species was initially introduced in the Philippines as a biological control agent to curb the rapidly growing population of sugarcane pests. It can be found in severely degraded natural and man-made habitats in low elevations (Diesmos et al. 2006). The abundance of *R. marin*a in habitats near roads can also be attributed to its high tolerance for environmental disturbances and its natural toxins, which make it less vulnerable to predation. One *Kaloula pulchra* (Figure 2B) roadkill was recorded during the survey. Despite its tolerance for habitat disturbance, *K. pulchra* had the lowest recorded roadkill incidence over the nine months of monitoring. This invasive alien species is becoming increasingly abundant in degraded habitats of low elevation, especially in areas near bodies of water like ponds and ditches (Diesmos et al. 2006). Three road-killed individuals of *P. leucomystax* (Figure 2C) were recorded in an agricultural area and banana plantation close to the residential neighborhood. *Polypedates leucomystax* is a native species in Southeast Asia. It is an arboreal species known as “palakang saging” or "banana frog" in the Philippines (Siler et al. 2012). This native species is known to occur in sympatry with alien species in the same habitat (Diesmos et al. 2006).

Furthermore, we recorded one *Malayophython reticulatus* (Figure 2D) road-killed individual on the agricultural road. This highly adaptable snake can be found in various environments, including lowland and lower montane forests, agricultural regions, scrublands, and mangrove edges (Cruz et al. 2018). One juvenile *Coelognathus erythrurus* (Figure 2E) roadkill was recorded in an agricultural area. The Philippine red-tailed rat snake is a non-venomous indigenous species in the Philippines, particularly Mindanao (Sanguila et al. 2016). Weinell et al. (2019) described adult *C. erythrurus* with a tail that is substantially lighter than the back half of the body; the other back half may or may not be darker than the front half of the body. Three road-killed individuals of *Naja samarensis* (Figure 2F) were recorded. This highly venomous snake, the Samar cobra, is a WHO-listed Category 1 endemic to the southern Philippines. It is distinguished by its black and bright yellow body coloring and is a deadly snake species of medical significance (Palasuberniam et al. 2021). It can also spit (or spray) poison into assailants' eyes, causing

Table 1. List of amphibians and reptiles roadkills recorded along Maguinda, Butuan City to San Roque, Las Nieves Agusan del Norte, Philippines across months of the survey.

Species	IUCN (Population trend)	Distribution Status	Abundance (% of Total Kills)	Roadkill rates (ind./km)
Amphibians				
Bufonidae				
Rhinella marina (Cane toad)	LC ↑	IAS	198 (92.52%)	7.76
Microhylidae				
Kaloula pulchra (Banded bullfrog)	LC -	IAS	1 (0.46%)	0.04
Rhacophoridae				
Polypedates leucomystax (Common Tree Frog)	LC -	N	3 (1.40%)	0.12
unidentified	-	-	2 (0.93%)	0.08
Reptiles				
Colubridae				
Dendrelaphis philippinensis (Philippine bronzeback treesnake)	LC -	PE	1 (0.46%)	0.04
Coelognathus erythrurus (Philippine Trinket snake)	LC -	PE	1 (0.46%)	0.04
Lycodon capucinus (Oriental wolf snake)	LC -	IAS	3 (1.40%)	0.12
Elapidae				
Naja samarensis (Southern Philippine Cobra)	LC ↓	PE	3 (1.40%)	0.12
Pythonidae				
Malayopython reticulatus (Reticulated Python)	LC *	N	1 (0.46%)	0.04
unidentified	-	-	1 (0.46%)	0.04
Total			**214**	

Legend: IUCN = Least Concern (LC); Population trend= increasing (↑), stable (-), unknown (*); Distribution Status = Invasive Alien Species (IAS); Philippine Endemic (PE); N (Native to Southeast Asia)

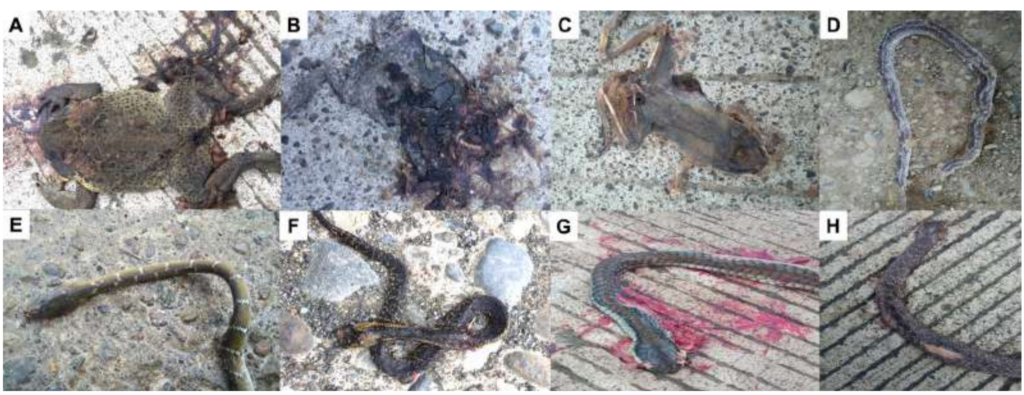

Figure 2. Amphibian and reptile roadkills from Brgy. Maguinda, Butuan City to Brgy, San Roque, Las Nieves, Agusan del Norte, Philippines during the survey period: A. *Rhinella marina*, B. *Kaloula pulchra*, C. *Polypedates leucomystax*, D. *Malayophython reticulatus*, E. *Coelognathus erythrurus*, F. *Naja samarensis*, G. *Dendrelaphis philippinensis*, and H. *Lycodon capucinus*.

venom ophthalmia (Cruz et al. 2018). This snake lives in various habitats, from lowlands to highlands (up to 800 meters), and may be locally common in agricultural areas or near human habitation. One *Dendrelaphis philippinensis* (Figure 2G) was identified. It is an entirely arboreal, diurnal colubrid unique to the Philippines and is one of the *D. caudolineatus* polytypic groups. *Dendrelaphis philippinensis* is found across the Mindanao Pleistocene Aggregate Island Complex (PAIC), with historical records from the small islands of Dinagat and Siargao in the northeast region of Mindanao PAIC (Sanguila et al. 2016). We recorded three *Lycodon capucinus* (Figure 2H) carcasses, one from the residential road and two in the agricultural area. The Oriental wolf snake is a widespread invasive alien species in the Indo-Australian Archipelago. This snake is common in agricultural and urban areas across Southeast Asia. It has brown dorsal skin striped with yellowish patterns that produce a 'reticulate' pattern (Sanguila et al. 2016).

Amphibian and Reptile Roadkill Incidences

Roadkill incidences of amphibians and reptiles significantly differ across months ($p < 0.000$). The heatmap in Figure 3 shows the survey's total roadkill occurrences per month. Amphibians were presented in the top row and reptiles in the bottom row. Darker shades indicate a higher number of roadkill counts. Most amphibian roadkill incidences were highest in June (N = 34) and September (N = 33), with February being the least (N = 13). Reptile roadkill remains relatively low throughout the months.

The presence of invasive alien species during the survey indicates that these species might be more widespread in the area and may increase pressure on native herpetofauna populations. The high roadkill incidence of the invasive alien species *Rhinella marina* (92.52%, 7.76 ind./km) along the Butuan to Las Nieves Road is noteworthy. Although roadkill is an unintentional outcome of vehicle collisions, it is potentially beneficial in controlling populations of invasive species, particularly in the case of *R. marina*, which can outcompete native animals for food and space and has few natural predators (Diesmos et al. 2006). Therefore, by eliminating individuals from the ecosystem, these roadkill incidents may indirectly aid in population control.

More amphibian individuals were recorded than reptiles because amphibians are more likely to cross roads during seasonal migrations (Galoyan et al. 2017). Additionally, amphibians tend to live close to water sources, typically at intersections with roads, making it more likely that they will come into contact with vehicles. Especially during rainy seasons, certain anuran species, particularly those that nest in vernal pools, lay

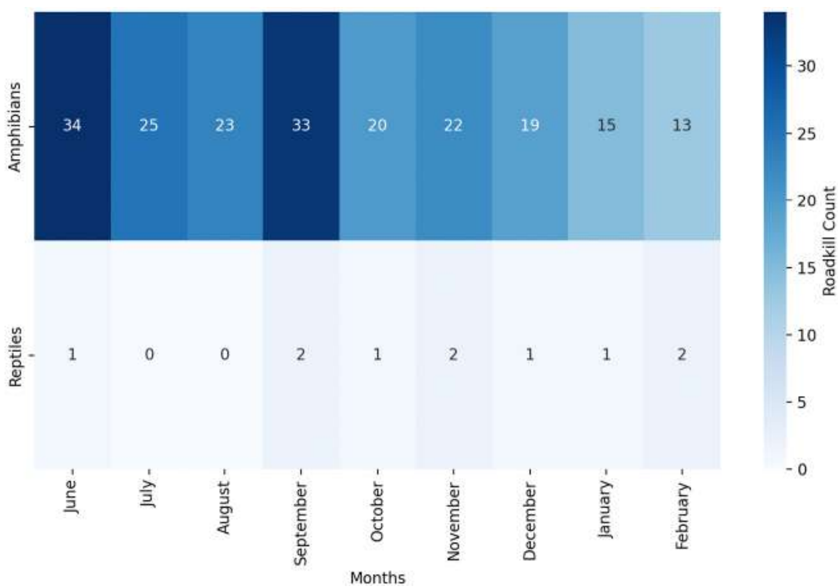

Figure 3. Monthly roadkill counts of amphibians and reptiles on the road from Brgy. Maguinda, Butuan City to Brgy, San Roque, Las Nieves, Agusan del Norte, Philippines.

their eggs in temporary pools that occur in roadside ditches and obstructed drainages (Dimauro and Hunter 2002). Amphibians' slower movement and relatively small size limit driver visibility and increase the likelihood of accidental collisions with vehicles (Elzanowski et al. 2009).

Roads are among the warm surfaces that reptiles, especially snakes and lizards, frequently deliberately seek to sunbathe on. However, many reptiles can move quickly when disturbed (Alexander 2012). Their ability to sprint, climb, and even make abrupt direction changes is partially attributed to their physical structure, which includes stronger, more developed limb and tail muscles (Alexander 2012) compared to amphibians. The study recorded carcasses of five snake species without any carcasses of lizards or skinks. Snakes are observed on sun-warmed surfaces like roads, providing an ideal thermoregulation heat source to maintain body temperature, significantly increasing their risk of road mortality, as they are more likely to encounter vehicles while basking (Kioko et al. 2015; Ashley and Robinson 1996).

Temporal Patterns of Roadkill

Roadkill trends may be impacted by rainfall, which has been proposed as a climatic indicator that affects seasonal variations in species abundance and behavior (Teixeira et al. 2013). Figure 4 shows that roadkill incidents were high from June to September 2021 despite low rainfall rates. In addition, despite the heavy rainfall, there were few roadkill records between November 2021 and January 2022. The high rainfall in December 2021 is due to the impact of Typhoon Odette. The correlation analysis revealed a weak and non-significant relationship between rainfall and mortality rates (amphibians: *p*-value = 0.399; r^2 = -0.321 and reptiles: *p*-value = 0.839; r^2 = -0.079).

While rainfall can influence animal behavior, the intersection of several factors, such as environmental conditions, road features, and species behavior, determines the likelihood of roadkill. Environmental factors that can influence roadkill rates on amphibians and reptiles can be temperature (Meek 2009), seasonality (Fahrig et al. 1995), light conditions (Garriga et al. 2012), flooding (Ashley and Robinson 1996), climate and weather conditions (Oddone Aquino and Nkomo 2021). Also, the low roadkill rates during rainy seasons may be explained by heavy rainfall frequently lowering road traffic volumes because of reduced motor and vehicle travel. During rainy seasons, drivers also prefer to slow down and increase following distances, resulting in fewer road accidents (Peng et al. 2018, Rahman and Lownes 2012). Road visibility also decreases; hence, traffic density decreases (Peng et al. 2018). Non-essential trips are also frequently avoided, which lowers the likelihood of wildlife encounters and roadkill incidents. Other factors influencing roadkills are spatial proximity, infrastructure, traffic volume and speed, and landscape features (Oddone Aquino and Nkomo 2021). Roadkill hotspots are often linked to habitat proximity and species-specific movement patterns rather than rainfall alone (Clevenger

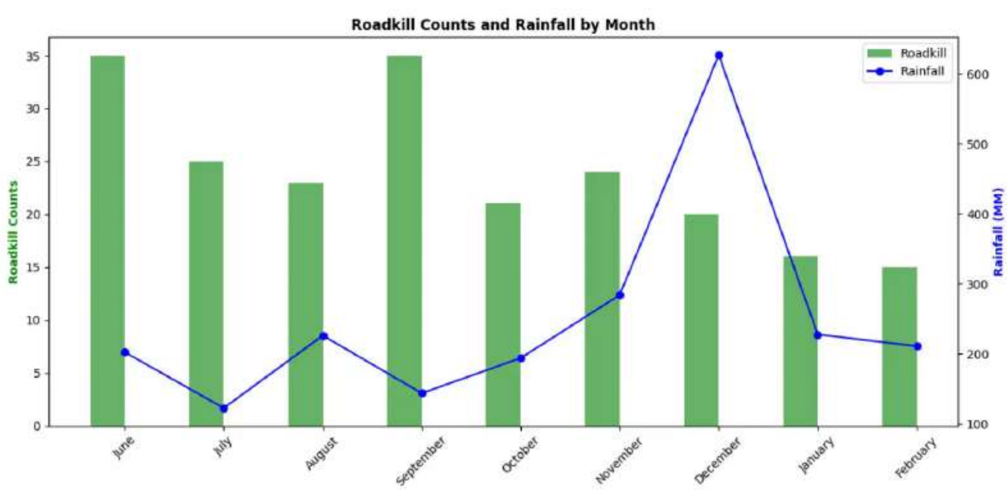

Figure 4. Temporal distribution of herpetofauna roadkills from Brgy. Maguinda, Butuan City to Brgy, San Roque, Las Nieves, Agusan del Norte, Philippines. Roadkill (bar) versus monthly mean rainfall (line).

& Waltho 2000, Oddone Aquino and Nkomo 2021). These reports mean that although rainy nights likely favor some species to cause roadkill, it does not guarantee increased incidents.

Concentration pattern and heat maps

The spatial distribution of amphibian and reptile carcasses across the Butuan to Las Nieves road is shown in Figure 5. The heatmap highlights areas with high species values (indicated by warmer colors) where both amphibians and reptile carcasses are concentrated. The roadkill incidences along the surveyed route showed concentrations of road-killed species in particular locations along the road. A single hotspot in June, August, and October was next to a rice field and rubber plantation, indicating a strong clustering pattern. In July, two hotspots were identified; all hotspots are near forested and agricultural areas with coconut plantations, rice, and corn fields. November has three identified hotspots: one was near the residential area, and the two were near forested and agricultural areas. One hotspot for December, January, and February is near an agricultural area with a banana plantation, coconut plantation, rice and corn fields, and a forested area.

Generally, across months, a total of three hotspots were identified. Dense vegetation, forest patches, and waterways may cause the hotspots recorded in the Las Nieves. Most roadkill hotspots were located on road portions near forested and plantation areas, with fewer roadkill in parts along town areas, which conformed to the reports of Karunarathna et al. (2013), Clevenger et al. (2003) and Vijayakumar et al. (2001). Since roads bisect forested or plantation areas, it can contribute to habitat fragmentation, forcing animals to cross roads to access different parts of their habitat. This increases roadkill risk and disrupts population connectivity, potentially isolating populations (Fahrig 2003, Forman & Alexander 1998). Also, animals with nesting sites next to roadways or adequate habitats across the road may be more likely to become part of mass road-crossing activities, exposing them to roadkill (Riley et al. 2014). Waterways also intersect the surveyed road. Waterways provide crucial resources for amphibians and some reptiles (Jones et al. 2024), but they are also susceptible to pollution and sedimentation from nearby agricultural activities.

Hotspot A was near forested and agricultural areas with coconut tree plantations and corn fields. Most of the carcasses in hotspot A were amphibians. Two *P. leucomystax* individuals were found in hotspot A. Hotspot B was near the agricultural area with rice fields, corn fields, rubber plantations,

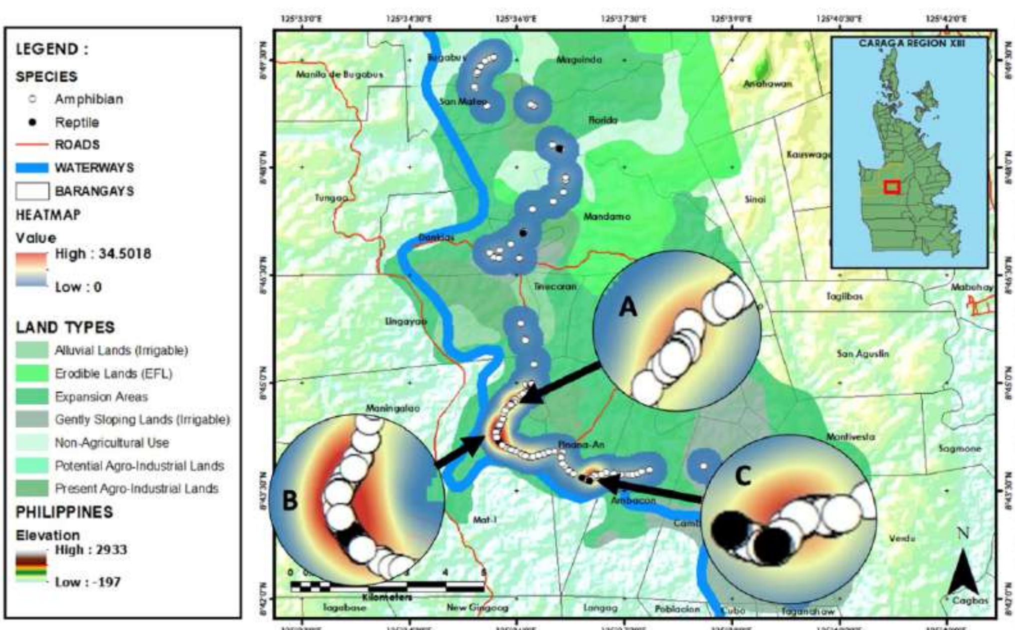

Figure 5. Spatial distribution and heatmap of roadkill from Brgy. Maguinda, Butuan City to Brgy, San Roque, Las Nieves, Agusan del Norte, Philippines during the nine months of monitoring.

and vegetable farms. This hotspot was also near a canal, a potential refuge site for herpetofauna. One reptile species was recorded in the hotspot B area, *C. erythrurus*, and amphibians were the most abundant carcasses in the hotspot. Hotspot C was near the banana plantation, coconut plantation, rice field, corn field, and forested area. Most casualties of carcasses in hotspot C are reptiles and amphibians; two of the *Naja samarensis* and one of *Lycodon capucinus* were notably recorded in hotspot C. Hotspots A and B belong to one barangay in the Las Nieves area, which is dense in agricultural areas.

Understanding amphibian and reptile distribution patterns and populations could be a tool for effective conservation measures. Since most recorded species were invasive alien species, roadkills can be considered an unintentional but helpful strategy to address the increase, spread, and potential impacts of these species on native species. Monitoring the movement patterns of these species can help formulate mitigation strategies.

4 Conclusion and Recommendations

The study monitored the number of roadkill incidents of amphibians and reptiles for nine months, analyzed the relationship between roadkill and rainfall, and created heat maps. The spatiotemporal findings can aid in determining the temporal crash pattern of herpetofauna and predicting the critical periods when such animal-vehicle collisions will occur in a specific location. Movements of herpetofauna during rainy seasons may increase the probability of animal collisions with cars, trucks, and motorcycles. Higher mortality was recorded along the road near dense vegetation and waterways because of adequate habitats and breeding sites, which makes the animals more vulnerable to road incidents. The survey area had high rates of invasive alien species, which could be a management strategy for Invasive Alien Species (IAS) migration. However, roadkill as a mitigation method is not a planned and reliable management approach. In general, invasive species are better managed through deliberate actions, including habitat management, public awareness campaigns, and controlled culling. Roadkill data on IAS can help track movement patterns and population dynamics, which can then help guide mitigation measures. Several limitations in this study, such as corpses remaining on the road and environmental variables relating to reptile and amphibian habitat suitability, are recommended for further research. It is also recommended to gather sufficient data and extend the sampling effort for in-depth analysis and improved sample design. To further enhance the ability to predict the location of roadkill hotspots, a thorough examination of herpetofauna species' habitat suitability and connectivity may be carried out.

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Statement of Conflict of Interest

To ensure impartiality, EF Gamalinda, a member of the JESEG Editorial Board, was excluded from the review process of this article. The authors confirm that there are no conflicts of interest related to the publication of this paper.

Author Contribution

SJ Mulig c*ontributed to the conceptualization, collection, analysis, and interpretation of data*; NJ Naling *focused on data analysis, particularly map generation and illustration*; E.F. Gamalinda was *involved in conceptualization, analysis, interpretation, and writing for publication*; CS Naling played a role in the *conceptualization, analysis, interpretation of data, writing, and supervision.* All authors approved the final manuscript version.

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