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Flying Fox Species Identification and Habitat Assessment on Luban Island, Philippines: Evidence of Ecological Shifts and Conservation Implications

Ramil L. Ramos[1,2]* and Phoebe Nemenzo-Calica[1]

[1]Master of Science in Environmental Science Program, Faculty of Advanced and International Studies, Davao Oriental State University, Mati City, Davao Oriental, 8200 Philippines, Ramil L. Ramos: https://orcid.org/0009-0009-1623-6273, Phoebe Nemenzo-Calica: https://orcid.org/0009-0004-7987-3951
[2]Department of Environment and Natural Resources Office (DENR) Mati City, Davao Oriental, 8200 Philippines, Ramil L. Ramos: https://orcid.org/0009-0009-1623-6273

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*Corresponding author: ramilramos500@gmail.com

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ABSTRACT

Luban Island in the Mati City, Davao Oriental, Philippines, is a popular tourist destination renowned for its natural beauty, tranquil environment, and home to unique and endangered species, particularly the rare flying foxes. This study aimed to contribute to their conservation by (1) identifying bat species, (2) conducting a population count and assessing foraging areas, and (3) evaluating habitat conditions. The bat colony was initially identified as the Golden-crowned flying fox (*Acerodon jubatus*). However, recent assessments show that the roosting colony is now either the Island flying fox (*Pteropus hypomelanus*), the Large flying fox (*Pteropus vampyrus*), or a mixed colony of both species. Population counts were conducted using a roost exit count, which recorded no fewer than 3,000 flying foxes, and a photographic count, which documented at least 2,060 individuals. The foraging areas of the flying foxes cover approximately 22.0 hectares, including 1.32 hectares of closed canopy, 1.46 hectares of grassland, 12.37 hectares of shrubland, and 0.21 hectares of perennial crops, providing a diverse and abundant resource base for feeding. Habitat assessments involved field surveys that identified key roosting trees, including *Xanthostemon verdugonianus, Lithocarpus sulithi, Shorea astylosa, Canarium ovatum,* and mangrove species *Rhizophora* spp. and *Sonneratia alba*. Other tree species, including bitaog, balite, coconut, rattan, and various wildlife, were also recorded. The findings of this study offer critical insights that can inform conservation strategies for flying foxes on Luban Island.

Keywords: Conservation, endangered species, foraging areas, fruit bats, wildlife habitat

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INTRODUCTION

Pteropus, a genus within the suborder Yinpterochiroptera, comprises some of the largest bats in the world, commonly known as fruit bats or flying foxes (Montiani-Ferreira et al., 2022). Found in regions such as South Asia, Southeast Asia, Australia, and parts of the Indian and Pacific Oceans, there are at least 60 species of flying foxes (Vanderduys et al., 2024). Flying foxes have long life spans and low reproductive rates, with most species producing only one offspring per year (Power et al., 2024). This slow life history and their vulnerability to overhunting, natural disasters, and habitat loss, make them susceptible to population decline. Despite their role as essential pollinators and seed dispersers, helping to regenerate forests, they are often persecuted for their perceived threat to crops and can be vectors of diseases like Australian bat lyssavirus, Hendra virus, and Nipah virus, contributing to human health concerns (Bonilla-Aldana et al., 2021; Chomel et al., 2022).

Given these threats, the conservation of flying foxes has become increasingly urgent, many species are facing population declines. The conservation of flying foxes is critical, as about half of the species in this genus have experienced population declines (Lunn et al., 2021). The International Union for Conservation of Nature (IUCN) (2025) classified 23 species as vulnerable, 21 as endangered, two as critically endangered, and unfortunately, six as extinct, highlighting the urgent need for focused conservation efforts. Given their declining numbers and ecological importance, flying foxes, including the giant golden-crowned flying fox (*Acerodon jubatus*), have become a focal point for conservation efforts. These bats are endangered due to habitat destruction, poaching, and human disturbances (Jumao-as et al., 2023). Despite legal protections, enforcement remains inadequate, and the threats to their populations persist.

To address these challenges, localized studies are essential, and recent research in the Mati City, specifically on Luban Island, has begun to shed light on the status and distribution of flying fox populations. The Mati City, specifically on Luban Island, is home to diverse flying fox species whose population and distribution have been poorly documented. Key insights into these large fruit bat's species composition and spatial distribution, which are important for pollination and seed dispersal, are now provided. Population sizes of flying foxes were estimated, and critical foraging areas were identified, addressing a significant gap in localized research. The environmental conditions affecting the bats, such as habitat quality, vegetation, roosting sites, and the impact of human activities like deforestation and urbanization, were determined. This contributes to developing effective conservation strategies to ensure the survival and sustainability of flying fox populations on Luban Island and in the broader Davao Oriental province.

Building on the understanding of the broader conservation needs, this study focuses on specific research within the Mati City, particularly on Luban Island, which has long lacked detailed documentation of flying fox populations and their distribution. It aimed to contribute to their conservation by (1) identifying bat species, (2) conducting a population count and assessing foraging areas, and (3) evaluating habitat conditions. The sampling process for this objective involved conducting field surveys on Luban Island, located in the Mati City, Davao Oriental, Philippines. The island has an approximate total area of 22.0 hectares, consisting of various vegetative covers, including 1.32 hectares of closed-canopy forest, 1.46 hectares of grassland, 12.37 hectares of shrubland, and 0.21 hectares of perennial crops. These vegetation types were selected to provide suitable roosting and foraging habitats for avifauna, including flying foxes. Sampling was conducted in systematically to ensure that all habitat types were represented in the assessment, with observations distributed across these key areas.

Regarding species identification, the flying fox colony observed in Luban Island, located in the Mati City, Davao Oriental, was initially identified as *Acerodon jubatus*, or the golden-crowned flying fox (see Figure 2A). However, field observations conducted in partnership with the Department of Environment and Natural Resources (DENR) Regional Office indicated that the colony may instead be composed of *Pteropus hypomelanus* (island flying fox), *Pteropus vampyrus* (large flying fox), or potentially a mix of these species (see Figures 2A and 2B).

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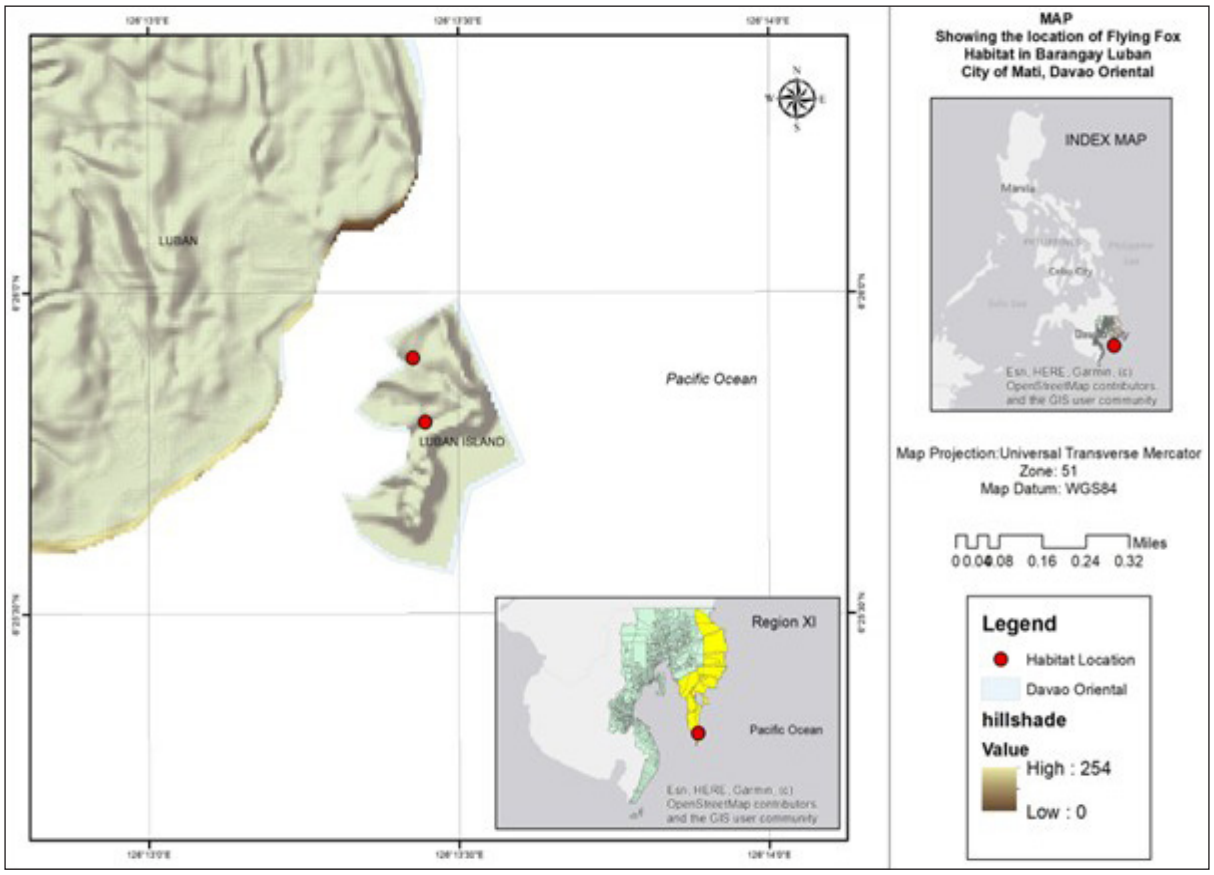

Figure 1. Map of the study area in Luban Island, Mati City, Davao Oriental, Philippines.

To ensure the accuracy and reliability of the bat species identification in this study, we followed a standardized protocol involving both morphological assessment and expert consultation. Field observations were conducted to assess key morphological traits of the flying foxes, including body size, fur coloration, wing structure, and facial features. Detailed photographs of key body parts, such as the face, wings, and body size, were taken to identify species. These photographs were reviewed with field notes and cross-referenced with taxonomic literature and species descriptions to identify distinguishing characteristics. The morphological features observed in the field were compared with known characteristics of *Pteropus hypomelanus* and *Pteropus vampyrus*, as outlined in reputable taxonomic references. Key traits examined included body size, wing span, fur coloration, and specific anatomical features such as the structure of the face, ears, and wings.

After an initial identification based on field observations and photographic evidence, the species was cross-verified by consulting with bat experts familiar with the species in the Philippines. Expert confirmation was sought through direct communication with researchers and taxonomists specializing in Philippine bat species. Additionally, the identification was supported by reviewing the latest taxonomic literature on *Pteropus* species, focusing on field guides and research papers that provide detailed descriptions of species differentiation. Recent taxonomic revisions were incorporated to ensure that the most up-to-date information was considered during the species identification. Based on the comparison of morphological traits, expert input, and taxonomic literature, it was determined that the population on Luban Island is most likely composed of *Pteropus hypomelanus* and *Pteropus vampyrus*, or a mixed colony of both species. This protocol ensures that the species identification was conducted with high accuracy, transparency, and scientific rigor, and expert consultation remains a critical component of our species identification process in future studies.

Figure 2. The different species of flying fox found in Luban Island, Mati City, Davao Oriental, Philippines: *Acerodon jubatus* (red circle) (A), the golden-crowned flying fox, a critically endangered species, and *Pteropus vampyrus* (yellow circle) or large flying fox; *Pteropus hypomelanus* or island flying fox (B).

Beyond the complexities of their species identification, flying foxes warrant heightened protection for several compelling reasons. First, they play a crucial ecological role as pollinating agents and seed dispersers, contributing significantly to the regeneration of natural forests (Kagan, 2022; Mwinyi and Nnko, 2022). Second, their foraging and roosting behaviors indirectly support the livelihoods of buffer zone communities that depend on forests for water, timber, non-timber forest products, and natural protection from extreme weather events. Third, flying foxes hold cultural and spiritual significance for many Indigenous communities in the Philippines. Finally, large flying foxes are considered "umbrella species", their conservation protects vast areas of habitat, which in turn benefits numerous other wildlife species sharing the same ecosystems. Given their ecological, economic, and cultural importance, the continued decline of flying fox populations signals an urgent need for intensified conservation strategies, community-based protection programs, and stronger enforcement of wildlife protection laws.

In light of these critical conservation needs, the study then turned to the second objective, which was to conduct a population count and assess foraging areas. A collaborative field survey involving CENRO Mati and DENR personnel was conducted to estimate the flying fox population and analyze their nightly foraging behavior. Three strategic observation points were designated: OP1 (N 6.428665, E 126.222646) was used for photographic counting, OP2 (N 6.432384, E 126.222443) was positioned for roost exit counts, and OP3 (N 6.429789, E 126.224307) served for close-range behavioral observations. These locations were selected to maximize coverage and reduce double-counting during the roost exodus. To minimize bias and ensure accurate population estimates, observers used photographic equipment to document and count individuals as they exited the roost, beginning shortly after 6:00 PM, depending on local sunset times. Replication was ensured by conducting multiple observation sessions across different nights, involving several trained observers at each location. This helped to reduce potential observer bias and account for variability in bat activity across the observation period.

This timing of the roost exit aligns with the natural foraging schedule of fruit bats (Christiano, 2024; Tanalgo et al., 2021b). Like the flying fox, fruit bats begin their foraging during twilight hours to avoid predators and maximize feeding opportunities (Christiano, 2024; Kumar et al., 2024; Singh, 2023). Based on the roost exit and photographic counts, the estimated population in the colony was at least 3,000 individuals, with photographic documentation confirming at least

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2,060 individuals (see Table 1). Group 1 observed a maximum of 2,900 bats flying northward, while Group 2 counted at least 300 individuals flying in a southwestern direction. The photographic evidence alone confirmed a reliable estimate of the colony's size. Group 1, stationed at a key observation point, recorded more bats flying in a northern direction, suggesting that these individuals were heading towards primary foraging grounds. Meanwhile, Group 2 observed a smaller group of bats flying southwestern, possibly toward secondary or seasonal feeding areas. This division in flight patterns supports the idea that these bats use multiple foraging sites, which is critical for their survival and reproductive success, as it ensures access to diverse food resources.

Table 1. Roost exit count and photographic count of flying foxes in Luban Island, Mati City, Davao Oriental, Philippines.

Group observers	Roost exit count	Photographic count
1	At least 2,900	At least 2,060
2	At least 300	-
Total	At least 3,000	At least 2,060

The selection of assessment locations for the study was carefully planned to maximize spatial coverage and minimize the likelihood of double-counting during the roost exodus. Such planning is critical in bat monitoring, as roosting behavior and flight patterns can result in complex dynamics that make accurate counting challenging (Alviola et al., 2023; Roswag et al., 2025; Tanalgo et al., 2021a). The strategic placement of observation points ensures a more reliable estimate of the population size by capturing different angles of the roost exit, reducing biases in data collection. Furthermore, integrating photographic techniques with direct observation significantly improves the accuracy of bat population counts. This dual approach has been proven effective in enhancing the precision of wildlife monitoring efforts, as photographic evidence allows for a more thorough post-observation verification of numbers (Alviola et al., 2022). Such methods are particularly useful in the case of flying fox colonies, where large group sizes and rapid movements complicate visual counts.

In addition to ensuring accurate population counts, understanding the movement patterns of the colony is vital for developing effective conservation strategies. According to Frick et al. (2024), habitat protection should not only focus on roosting sites but also on key foraging areas that extend far beyond the roosting locations. This highlights the need for a landscape-level approach to conservation, considering the broader ecological context in which these species thrive. Ensuring the protection of both roosting sites and foraging routes will help maintain the health and stability of the flying fox population on Luban Island. This flight pattern also provides valuable insight into the spatial ecology of the colony. The northern route taken by the majority of the bats likely leads to primary foraging grounds, while the southwestern route may indicate secondary or seasonal feeding areas.

Understanding these routes is crucial in landscape-level conservation planning, as foraging areas often extend well beyond roosting sites. Protecting these foraging zones ensures that flying foxes have sustained access to food resources, necessary for reproduction, colony stability, and ecosystem services like pollination and seed dispersal (Todd et al., 2022; Yabsley et al., 2021). If these routes intersect with human developments or agricultural areas, conservation strategies such as buffer zones or protected corridors could be implemented to reduce conflict and preserve habitat connectivity.

These findings highlight the importance of consistent monitoring efforts and the value of using multiple, complementary methods to estimate population sizes of elusive or highly mobile species like flying foxes (Bergmann, 2024). We observed a discrepancy between the two population count methods: ≥3,000 individuals recorded through the roost exit method and 2,060 through photographic counting. While both methods were intended to estimate population size, they differed in approach and had inherent limitations. The roost exit count involved direct visual estimation, which was subject to visibility

constraints, rapid movement of bats, and potential double-counting. In contrast, the photographic method, though more precise in capturing static images for later analysis, was limited by image quality, field conditions, and camera coverage. The two methods were conducted during separate observation sessions and not simultaneously, introducing variation in bat activity across sessions and may have contributed to differences in the final counts. Despite efforts to minimize observer bias and account for timing, the asynchronous implementation limited our ability to conduct a rigorous statistical comparison, such as a kappa coefficient analysis.

Given these methodological constraints, we opted for a qualitative comparison and acknowledged that more controlled, simultaneous sampling would be required for future statistical validation. Additionally, while we observed bats taking multiple flight paths during roost exodus, likely influenced by foraging areas and environmental conditions, could not definitively map or quantify these dispersal patterns within the scope of this study. Future work could incorporate GPS telemetry or drone-based monitoring to capture detailed flight trajectories and better understand the spatial ecology of these populations.

Turning to the third objective, evaluating habitat conditions, this aspect of the study focused on assessing the vegetation types and the quality of the roosting and foraging habitats on Luban Island. The ecological role of each habitat type was examined about flying fox behavior. The closed canopy forest (1.32 ha) served as the primary roosting habitat due to its tall emergent trees, which offered shade and structural support for colonies. Shrubland (12.37 ha) and perennial crops (0.21 ha), including coconut and fruiting trees, were observed and reported to be used as foraging areas. Grassland (1.46 ha), though not directly used for feeding or roosting, appeared to function as movement corridors linking different vegetated patches. These observations were derived from field visits, photographic evidence, and interviews with local stakeholders. While more detailed quantification (e.g., through tracking or direct feeding studies) was beyond this study's scope, this qualitative assessment provides insight into the functional roles of habitat types in supporting flying fox populations.

Building upon this habitat-level understanding, the study focused on the tree species within these areas, particularly those used for roosting. Habitat assessment involved recording the dominant roosting tree species, crucial for flying fox survival. In each habitat type, the trees were categorized, and the relative abundance and health of these trees were recorded. Sampling was replicated across different locations within each habitat type to ensure a comprehensive assessment. Expert botanists were involved in identifying species to reduce bias in tree identification and classification, and the health of the trees was assessed based on observable signs of disease or damage. The results of these assessments helped to define the suitability of the habitats for supporting flying fox populations and other associated wildlife.

Figure 3. Roosting behavior and habitat use of flying foxes (*Pteropus* spp.) on Luban Island: Dense forest canopy where roosting trees are partially obscured (A). Individual flying foxes are visibly roosting in the upper branches of mid-elevation trees (B). Large aggregation of flying foxes occupying a single Ficus tree, a key roosting and foraging resource (circled in red) (C). These images illustrate variations in roosting density and tree preference within the study area.

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As illustrated in Figure 3, flying foxes roost in varying densities, from scattered individuals in mixed forest canopies (top-left and top-right) to dense colonies clustered in dominant Ficus trees (bottom). These trees provide essential shelter and serve as a perennial food source, bearing fruit throughout the year, which is crucial for these bats' survival and reproductive success (Preece, 2024). The availability of such consistent food resources, alongside stable roosting habitats, is critical to the ecological sustainability of frugivorous bat populations in the Philippines (Alviola et al., 2022; Alviola et al., 2023). The ecological importance of these trees as keystone resources reinforces the need to protect roosting habitats from threats like logging, land conversion, and other disturbances.

Beyond Ficus species, other tree species on the island, such as *Calophyllum inophyllum* (bitaog), *Ficus* spp. (balite), *Cocos nucifera* (coconut) and native rattan species further enhance the habitat's suitability for flying foxes. Their consistent availability of food supports the dietary needs of flying foxes, which in turn sustains their ecological functions, such as pollination and seed dispersal (Bhanda et al., 2025; Lugo et al., 2023; Ramírez-Fráncel et al., 2022). The importance of these trees as a year-round food source underscores the necessity of protecting these critical resources, which, in turn, benefits the larger ecosystem.

Complementing these inland food sources, the presence of mangrove ecosystems in the lower coastal areas of Luban Island (see Figure 4) further highlights the ecological richness of the habitat. Dominated by *Rhizophora apiculata*, *Rhizophora mucronata*, and *Sonneratia alba* (pagatpat), these mangroves add another habitat complexity layer supporting flying fox populations. The role of mangrove ecosystems in the lower coastal areas of Luban Island further strengthens the importance of habitat diversity in supporting flying fox populations. Mangroves offer a suite of ecological services that extend beyond roosting space. Mangrove forests serve as crucial buffers against coastal erosion, providing natural protection from storm surges and extreme weather events. These ecosystems also play a significant role in carbon sequestration, which is vital for mitigating the impacts of climate change—a growing global threat to biodiversity (Osland et al., 2022).

Figure 4. Mangrove trees are found on Luban Island.

Recognizing this ecological interdependence, Tanalgo and Hughes (2021) emphasize that conservation strategies must adopt a holistic approach that considers the interconnectedness of species within an ecosystem. Protecting Luban Island's closed-canopy forests, shrublands, and mangroves ensures the flying fox population's survival and preserves the island's overall biodiversity. These habitats support a wide range of species, many of which rely on similar ecological functions such as pollination, seed dispersal, and habitat connectivity. Therefore, efforts to protect the habitats of Luban Island must include all species, recognizing that the survival of one species, like the flying fox, is often closely tied to the well-being of others.

The study integrated Indigenous and Traditional Ecological Knowledge (IEK/TEK) alongside opportunistic wildlife observations to further evaluate habitat conditions and ecological interactions to strengthen this holistic perspective. Informal interviews with local settlers were conducted to gather knowledge on local wildlife,

specifically identifying the presence of notable species such as sea turtles, dugongs (Dugong dugon), and Philippine tarsiers (Carlito syrichta). These interviews were supplemented by direct observations during field surveys, where wildlife sightings were recorded in collaboration with local communities, ensuring that scientific and indigenous perspectives were incorporated into the data collection process.

To ensure the reliability of these findings, the study used a systematic approach to wildlife observation, with surveys conducted at multiple locations across different times of day and night to capture a broad range of species presence. Sampling was replicated over several weeks, with observations made during various weather conditions to account for potential biases introduced by environmental factors. While the opportunistic nature of these wildlife observations has limitations regarding standardized sampling, efforts were made to reduce biases by diversifying the observation periods and involving local knowledge to validate findings.

The conservation of the golden-crowned flying fox and other flying fox species on Luban Island is vital not only for the survival of these charismatic creatures but also for cascading benefits for the broader ecological community. The findings from opportunistic wildlife observations underscore the importance of protecting this unique island as a biodiversity hotspot. The presence of other endangered species further reinforces the interconnectedness of the island's ecosystems. These species are not isolated from one another; rather, their survival is intricately tied to the health of the ecosystems they inhabit, which depend on the same environmental features that support the flying fox population.

Building on this understanding, the ecological importance of flying foxes extends well beyond their immediate roles as pollinators and seed dispersers. Their conservation is essential for their survival and the regeneration of forests, the pollination of flowering plants, and the dispersal of seeds that sustain a wide range of species (Pulscher et al., 2021). These ecological services are directly linked to the survival of other species observed on the island. For instance, the presence of dugongs and sea turtles in the coastal areas of Luban Island is closely tied to the health of seagrass beds, which are maintained by nutrient cycling facilitated by other species, including the flying foxes. Protecting flying foxes and their habitats thus indirectly benefits these marine species by preserving the ecological integrity of coastal and mangrove ecosystems (Walker et al., 2022).

Additionally, the presence of the Philippine tarsier, an endemic primate, further underscores the importance of protecting the forested areas of Luban Island. Tarsiers are highly sensitive to habitat disturbance and rely on dense, intact forest cover for shelter and foraging (Bejar et al., 2024; Torrefiel et al., 2023). Their survival is closely linked to the stability of the forests that also serve as roosting and foraging sites for flying foxes. By conserving these forests, we ensure the tarsier's continued survival and safeguard the many other species that share this habitat, including the flying foxes. These species rely on the same interconnected habitat matrix, making protecting one species integral to the survival of others.

Extending this interconnectedness, bird observations conducted opportunistically during the assessment period highlight the island's ecological richness. Species were categorized as endemic (E), resident (R), or migrant (M), and their conservation status was noted where applicable, such as Least Concern (LC). The variety of bird species recorded on Luban Island, as shown in Table 2, reflects the diversity of life supported by its intact ecosystems. Many of these birds depend on the same forest and coastal habitats sustained by flying fox ecological functions, such as seed dispersal and pollination. Their co-occurrence underscores the shared reliance on well-preserved natural habitats and further supports the case for integrated, habitat-wide conservation efforts.

Moreover, partially enabled by bat-facilitated seed dispersal, dense canopy and understory vegetation provide nesting sites and protective cover for forest-dwelling birds (Gonzalez et al., 2020). Maintaining the habitats that support fruit bats ultimately supports these apex predators by sustaining the lower levels of the food chain (Aziz et al., 2021). This reinforces

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Table 2. Opportunistic observation of birds recorded during the assessment.

Family	Common name	Scientific name	Distribution	Status
Ardeidae	Little egret	*Egretta garzetta*	R, M	LC
	Pacific reef egret	*Egretta sacra*	R	LC
Accipitridae	White-belied sea eagle	*Haleaeetus leucogaster*	R	LC
Rallidae	Barred rail	*Gallirallus torquatus*	R	LC
Scolopacidea	Common sandpiper	*Actitis hypoleucos*	M	LC
Columbidae	Common emerald dove	*Chacophaps indica*	R	LC
Apodidae	Glossy swiftlet	*Collocalia esculenta*	R	LC
Alcedinidae	Stork-billed kingfisher	*Pelargopis capensis*	R	LC
	Collared kingfisher	*Todiramphus chloris*	R	LC
Rhipiduridae	Philippine pied fantail	*Rhipidura nigritorquis*	E	LC
Corvidae	Large-billed crow	*Corvus macrorhynchos*	R	LC
Hirundinidae	Barn swallow	*Hirundo rustica*	R	LC
	Pacific swallow	*Hirundo tahitica*	R	LC
Locustellidae	Striated grassbird	*Megalurus palustris*	R	LC
Sturnidae	Asian glossy starling	*Aplonis panayensis*	R	LC
Muscicapidae	Mangrove blue flycatcher	*Cyornis rufigastra*	R	LC
Nectariniidae	Olive-backed sunbird	*Cinnyris jugularis*	R	LC
Passeridae	Eurasian tree	*Passer montanus*	R	LC

Legend: E- Endemic; R-Resident; M-Migrant; LC-Least Concern.

the concept of umbrella species conservation, where protecting a wide-ranging species like the flying fox inadvertently shelters many coexisting species (Morales et al., 2023; Zarri, 2024).

Complementing these scientific insights, incorporating Indigenous Ecological Knowledge (IEK) further validates and enriches our understanding of these interspecies relationships. Local residents have long observed seasonal overlaps in bird migrations and bat foraging, revealing synchronized ecological rhythms shaped by generations of place-based experience. Such knowledge, gathered through informal interviews, offers valuable insights into species behavior, fruiting cycles, and habitat dynamics that short-term ecological assessments might overlook. Integrating IEK into conservation strategies enhances scientific understanding and ensures that interventions are culturally grounded and locally supported. Given their role as stewards of the land, the involvement of Indigenous communities is vital to the long-term success and sustainability of conservation initiatives on Luban Island.

Ultimately, protecting flying foxes on Luban Island extends beyond the bats themselves. By preserving the habitats that these bats rely on, we are also safeguarding the ecosystems that support a diverse array of species, including dugongs, sea turtles, tarsiers, and various bird species. The conservation of flying foxes acts as an umbrella strategy, where protecting one species leads to the protection of many others, resulting in a more resilient and functional ecosystem. This interconnectedness of species and habitats on Luban Island underscores the need for an integrated, holistic approach to conservation, that values the complexity of ecological relationships and aims to preserve the biodiversity of the entire island, not just individual species.

While this study provides valuable insights into the flying fox populations and habitat conditions on Luban Island, several limitations must be considered when interpreting the findings. First, the scarcity of published studies on flying fox populations, especially in areas like Luban Island, limits the ability to directly compare the results with similar studies in the Philippines. The limited availability of comparable data makes it difficult to draw broader conclusions about the general state of flying fox populations across the country. In terms of sampling, despite efforts to minimize

bias by conducting systematic field surveys and selecting strategic observation points, there may still be inherent biases in the sampling process. The choice of observation points (OP1, OP2, and OP3) was based on accessibility, potentially excluding certain roosting or foraging areas that could have influenced the population estimates. Moreover, while replication was ensured by conducting multiple observation sessions, there could have been observer variability, as bat activity may fluctuate across different nights. The study was also constrained by a limited temporal scope, which may not have captured seasonal variations in bat activity or habitat quality, as flying fox populations and behaviors are subject to seasonal fluctuations.

Additionally, while the habitat assessment focused on the quality of roosting and foraging habitats, it was limited to visible vegetation and tree health characteristics, without deeper analysis of other factors like soil quality or hidden ecological stressors. Using Indigenous and Traditional Ecological Knowledge (IEK) further enriched the study. Still, the informal nature of the interviews and differences in local knowledge and experience might have introduced biases. Furthermore, local knowledge may not fully represent the broader ecological picture. Finally, while the study emphasizes the interdependence of species on Luban Island, alternative interpretations could suggest that the observed ecological relationships are opportunistic rather than symbiotic, and human activities could influence the population dynamics of flying foxes and other species on the island.

Building on this ecological perspective, the study also addresses a critical data gap concerning flying fox populations on the understudied Luban Island, Mati City, Davao Oriental. While the objective was not to propose new ecological theories, the findings provide empirical support for established frameworks such as the umbrella species concept, habitat connectivity, and the keystone role of frugivores like *Pteropus* spp. Importantly, by integrating Traditional Ecological Knowledge (TEK/IEK) with field-based ecological assessments, this research demonstrates a scalable, community-driven approach to biodiversity monitoring in archipelagic regions. This methodological synergy enhances local conservation efforts and lays the groundwork for future research and policy initiatives grounded in both scientific and cultural knowledge systems.

CONCLUSION

This study aimed to assess the flying fox populations and their habitats on Luban Island in the Mati City, Davao Oriental, Philippines, focusing on contributing to the conservation of these endangered species. The results confirmed the presence of a significant flying fox colony, initially identified as the Golden-crowned flying fox (*Acerodon jubatus*). Still, more recent assessments suggest that the colony consists of either the Island flying fox (*Pteropus hypomelanus*), the Large flying fox (*Pteropus vampyrus*), or a mixed population of both species. The population count revealed at least 2,060 flying foxes, with observations indicating that the colony consists of at least 3,000 individuals during roost exits. These flying foxes utilize a diverse range of habitats across 22.0 hectares of land, including closed-canopy forests, shrublands, grasslands, and perennial crop areas, providing vital resources for their foraging needs. The habitat assessment identified key roosting tree species such as *Xanthostemon verdugonianus, Lithocarpus sulith*i, and various mangrove species, which are essential for the flying fox survival.

Additionally, integrating Indigenous Ecological Knowledge (IEK) enhanced the understanding of species interactions and ecological dynamics on Luban Island. Informal interviews with local settlers provided valuable insights into the presence of other endangered species such as dugongs (Dugong dugon), sea turtles, and Philippine tarsiers (Carlito syrichta), reinforcing the interconnectedness of Luban Island's ecosystems. This holistic approach underscores the need for a comprehensive conservation strategy incorporating scientific and local knowledge, ensuring that conservation measures are culturally appropriate and ecologically effective.

The findings from this study provide crucial information for the ongoing conservation of flying foxes on Luban Island. They highlight the importance of maintaining their habitat and addressing the broader ecological needs of the

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island's species. By protecting the flying fox population, we also ensure the conservation of other species that depend on the same ecosystem, making the flying fox an umbrella species that facilitates the protection of the entire island's biodiversity.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ramil L. Ramos: led the study from conception to manuscript writing; Phoebe Nemenzo-Calica: providing academic supervision, design input, data interpretation, and critical revisions; both authors approved the final manuscript and are accountable for its content.

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