Biodiversity Assessment of Flora and Fauna in Bukit Panchor Forest Reserve: Conservation Implications Based on IUCN Status

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Citation: Chee Kong Yap, Biodiversity Assessment of Flora and Fauna in Bukit Panchor Forest Reserve: Conservation Implications Based on IUCN Status, Ann Env Sci, 2024; 1(1): 1-12.

Published Date: 19-09-2024 **Accepted Date:** 15-09-2024 **Received Date:** 05-09-2024

Keywords: Biodiversity; Conservation; Bukit Panchor Forest Reserve; IUCN status; Flora and fauna; Vulnerable species

Abstract: Lowland tropical rainforests, renowned for their rich species diversity, are predominant across Malaysia but increasingly face threats from human activities. This study, conducted on 8 April 2024 at the Bukit Panchor Forest Reserve (BPFR), aimed to assess the impact of nearby rural settlements, recreational areas, and private agricultural lands on the reserve's native flora and fauna. Using comprehensive landscape surveys, field observations, photographic documentation, and digital tools, we documented species distribution across various taxonomic groups and evaluated their conservation status according to the International Union for Conservation of Nature (IUCN). A total of 20 species were identified, including birds, amphibians, reptiles, mammals, insects, and angiosperms. Most species were classified as Least Concern, though two species—Ratufa bicolor (Near Threatened) and Dryobalanops aromatica (Vulnerable)—require conservation attention. Avian species exhibited the greatest diversity with four species, including Nisaetus cirrhatus limnaeetus and Lonchura striata subsquamicollis, both categorized as Least Concern. Amphibians and reptiles were represented by two species each, including Chalcorana labialis and Eutropis multifasciata. Insect biodiversity was substantial, with five species documented, contributing to the ecological health of the reserve. Furthermore, five angiosperm species were identified, notably Gmelina arborea and the vulnerable Dryobalanops aromatica. These findings underscore the ecological significance of BPFR and highlight the necessity of sustained conservation efforts to safeguard its biodiversity, particularly for species facing higher risk.

1. Introduction

Malaysia's tropical rainforests, renowned for their rich biodiversity, span a variety of forest types including hill dipterocarp, lowland dipterocarp, montane, peat swamp, and mangrove forests. These forests are predominantly shaped by dipterocarp trees from the Dipterocarpaceae family, such as Shorea sp., Hopea sp., and Dyrobalanops sp., which are vital not only for the landscape but also for their economic value. The Malaysian rainforests are globally recognised as biodiversity hotspots, providing essential habitats that support a vast array of flora and fauna, many of which are endemic to the region. These forests' intricate structural and compositional diversity enables them to sustain a complex web of life, where both vertebrates and invertebrates thrive within the abundance of ecological niches (Zakaria et al., 2016).

However, these forests are under severe threat from human activities such as agricultural expansion, urbanisation, and industrialisation, driven by rapid population growth. These pressures lead to habitat fragmentation, deforestation, and degradation, which in turn jeopardise the survival of native plants and wildlife. The ongoing loss of tropical rainforests, exacerbated by invasive species and climate change, is a major driver of biodiversity loss in these ecosystems (Morris, 2010). The consequences of deforestation extend far beyond the local environment, affecting global ecological balance, contributing to climate change, and threatening the livelihoods of communities that depend on these forests (Muthee et al., 2022; Cusack et al., 2016).

Given the critical importance of these ecosystems, environmental assessments are essential to monitor the health and biodiversity of rainforest habitats. Such assessments are crucial for understanding how both natural and human-induced changes impact forest composition, structure, and function (van der Sande, 2016). The Bukit Panchor Forest Reserve (BPFR), a lowland dipterocarp forest, offers a unique opportunity to study these dynamics. Despite its relatively small size, BPFR harbours a rich diversity of species and serves as a vital refuge for flora and fauna. Its proximity to agricultural land and status as a recreational destination make it an ideal site for studying the environmental impacts on species diversity. By assessing the ecological health of BPFR, this study aims to contribute to a deeper understanding of how external stressors affect forest ecosystems and their inhabitants, thereby encouraging necessary conservation efforts for local biodiversity.

2. Materials and Methods

2.1. Survey Areas

The survey was conducted on 8 April 2024, starting from 10.00 a.m. to 12.00 p.m. at the Bukit Panchor Forest Reserve (N5.1602°, E 100.5480°), Penang, Malaysia (Mohamad, n.d.). The forest reserve is in the southernmost district of Seberang Perai Selatan, within Nibong Tebal. The study site comprised 446 hectares of lowland dipterocarp forests with small patches of freshwater swamps and Bukit Panchor hill of 416 meters high. A water catchment reservoir under Penang Water Authority is also located near the forest reserve in the south. It was gazetted as a permanent forest reserve in 1963 before being elevated into state park status in 2008 as it boasted immense biodiversity in the protected forest areas with approximately 8 species of bats, 67 species of herpetofauna, and 130 species of birds (Charko, 2019). This forest reserve borders with Kedah and Perak state and is located beside rural settlements and private agricultural land that has been heavily exploited and deforested. Forest Department of Peninsular Malaysia (FDPM) states that Bukit Panchor Forest Reserve is categorised as an amenity forest that promotes recreational and aesthetical attractions.

Figure 1: Location map of Penang (Seberang Perai), Bukit Panchor Forest Reserve where the observational survey was conducted.

2.2. Field documentation and observation

Field documentation within the Bukit Panchor Forest Reserve involved systematic observation and photographing of both flora and fauna species along designated forest trails and a swamp boardwalk. These areas were selected due to their proximity to the agricultural land bordering the reserve, which provided a diverse range of habitats for species observation.Photography was employed as the primary method of documentation to capture the diversity of organisms present. A DSLR camera (Nikon D3400) equipped with a Nikkor AF-P 70-300mm telephoto lens was utilized to photograph distant or elusive wildlife, ensuring that detailed images of various species were obtained. In addition to the DSLR camera, a smartphone (Samsung Galaxy A24) was used for more immediate and flexible documentation, particularly for capturing human activities and infrastructure within the reserve. This dual-method approach allowed for a comprehensive visual record of the biodiversity and anthropogenic impacts observed during the survey.

2.3. Identification of organisms and human activities

The identification of the photographed specimens was conducted using a combination of digital tools and traditional field guidebooks. Google Lens and iNaturalist apps provided real-time assistance in the preliminary identification of species based on visual characteristics. These applications use machine learning algorithms to match photographs to existing databases, offering probable species identifications that can be further verified. For avian species, the eBird and Merlin apps were utilised, which are specifically designed for bird identification and recording. In addition to these digital resources, several authoritative field guides were consulted for accurate taxonomic identification. These included "A Field Guide to the Birds of Malaysia: Including Sabah and Sarawak" (2020), "Field Guide to the Mammals of South-East Asia" (2nd Edition, 2019), and "Natural Trails of Seberang Perai" (2019). These references provided detailed descriptions and key identification markers, ensuring accurate classification of the observed species. The conservation status of the identified organisms was assessed using the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. This global resource categorises species based on their risk of extinction, providing essential information for understanding the ecological significance of the species found within the reserve.

3. Results

From Table 1 (Figures 2-8), the present study documented a total of 20 species of flora and fauna within the Bukit Panchor Forest Reserve (BPFR), covering a range of taxonomic groups. Among the avian species, 4 distinct bird species were identified, distributed across the orders Accipitriformes, Piciformes, and Passeriformes. Notable species include Nisaetus cirrhatus limnaeetus from the family Accipitridae, which holds a status of Least Concern (LC), and Lonchura striata subsquamicollis from the family Estrildidae, also listed as Least Concern. These bird species represent the rich avian biodiversity present within the reserve, contributing to its ecological stability.

In the amphibian class, 2 species from the order Anura were recorded, both belonging to the family Ranidae. These included Chalcorana labialis and Hylarana erythraea, both of which were categorized as Least Concern. Their presence reflects the relatively undisturbed aquatic environments within BPFR, providing suitable habitats for these amphibians.

Two reptile species were represented by two species from the order Squamata, with members from the families Scincidae and Agamidae. The species identified include Eutropis multifasciata (Scincidae) and Draco sp. (Agamidae), both classified as Least Concern. Draco species, known for their gliding abilities, underscore the forest’s structural complexity that supports such specialized fauna.

In terms of mammals, 2 species from the order Rodentia were documented, both squirrels. These include Callosciurus notatus, classified as Least Concern, and Ratufa bicolor, which is categorized as Near Threatened (NT). The presence of Ratufa bicolor suggests some degree of environmental pressure, possibly due to habitat loss, that warrants further attention. The identification of these mammalian species adds to the understanding of the BPFR's mammalian diversity.

Insects were well-represented with 5 species across the orders Lepidoptera, Orthoptera, and Odonata. This included butterflies such as Tanaecia iapis and Graphium sarpendon, both categorized as Least Concern. These findings indicate a healthy insect population in BPFR, which plays a crucial role in pollination and maintaining the ecological balance.

Lastly, the study identified 5 species of angiosperms (flowering plants), including species from various orders like Lamiales, Alismatales, and Arecales. Noteworthy examples include Gmelina arborea (Least Concern) and Dryobalanops aromatica, which is classified as Vulnerable (VU). The Vulnerable status of Dryobalanops aromatica highlights the need for focused conservation efforts to protect this valuable species within the reserve.

Table 1: Checklist of flora and fauna documented within Bukit Panchor Forest Reserve (BPFR)

Class	Order	Family	Species	International Union for Conservation of Nature (IUCN) status
Aves	Accipitriformes	Accipitridae	*Nisaetus cirrhatus limnaeetus* (Horsfield, 1788)	Least Concern (LC)
	Piciformes	Picidae	*Reinwardtipicus validus xanthopygius* (Finsch, 1905)	Least Concern (LC)
		Megalaimidae	*Psilopogon chrysopogon laetus* (Robinson & Kloss, 1918)	Least Concern (LC)
	Passeriformes	Estrildidae	*Lonchura striata subsquamicollis* (Baker, 1925)	Least Concern (LC)
Amphibia	Anura	Ranidae	*Chalcorana labialis* (Boulenger, 1887)	Least Concern (LC)
			Hylarana erythraea (Schlegel, 1837)	Least Concern (LC)
Reptilia	Squamata	Scincidae	*Eutropis multifasciata* (Kuhl, 1820)	Least Concern (LC)
		Agamidae	*Draco* sp.	Least Concern (LC)
Mammalia	Rodentia	Sciuridae	*Callosciurus notatus* (Boddert, 1785)	Least Concern (LC)
			Ratufa bicolor (Sparrman, 1778)	Near Threatened (NT)
Insecta	Lepidoptera	Nymphalidae	*Tanaecia iapis* (Godart, 1824)	Least Concern (LC)
			Cupha erymanthis (Drury, 1773)	Least Concern (LC)
		Papilionidae	*Troides amphrysus rufiollis* (Butler, 1879)	Least Concern (LC)
			Graphium sarpendon (Linnaeus, 1758)	Least Concern (LC)
	Orthoptera	Chorotypidae	*Erucius* sp.	Least Concern (LC)
	Odonata	Libellulidae	*Lyriothemis biappendiculata* (Selys, 1878)	Least Concern (LC)
Angiospermae	Lamiales	Lamiaceae	*Gmelina arborea* Roxb	Least Concern (LC)
	Alismatales	Araceae	*Schismatoglottis* sp.	Least Concern (LC)
	Arecales	Arecaceae	*Licuala* sp.	Least Concern (LC)
Magnoliopsida	Malvales	Dipterocarpaceae	*Dryobalanops oblongifolia* Dyer	Least Concern (LC)
		Dipterocarpaceae	*Dryobalanops aromatica* C. F. Gaertn.	Vulnerable (VU)
	Myrtales	Melastomaceae	*Miconia* sp.	Least Concern (LC)

Figure 2: The presence of human activities (A, B, C, D) within Bukit Panchor Forest Reserve (BPFR)

Figure 3: The swampy landscape of lowland rainforests in Bukit Panchor Forest Reserve (BPFR) interspersed with tarred trails and broadwalks (A, B, C, D, E, F)

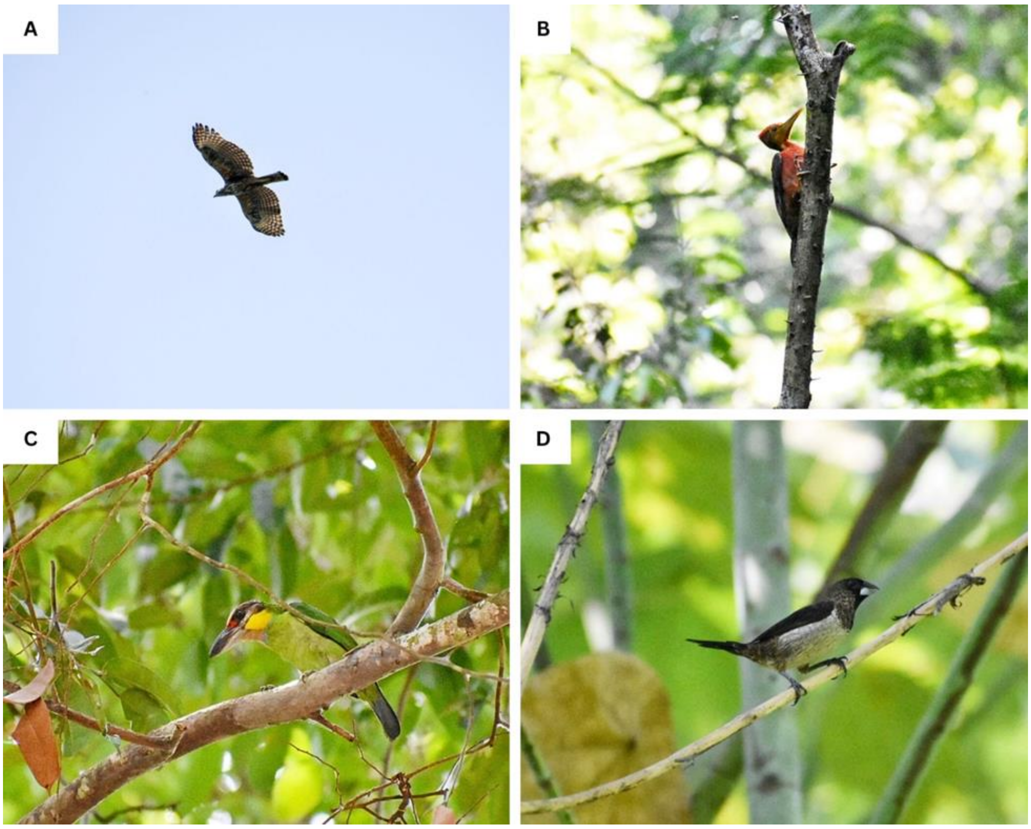

Figure 4: Nisaetus cirrhatus limnaeetus (A), Reinwardtipicus validus xanthopygius (B), Psilopogon chrysopogon laetus (C), and Lonchura striata subsquamicollis (D)

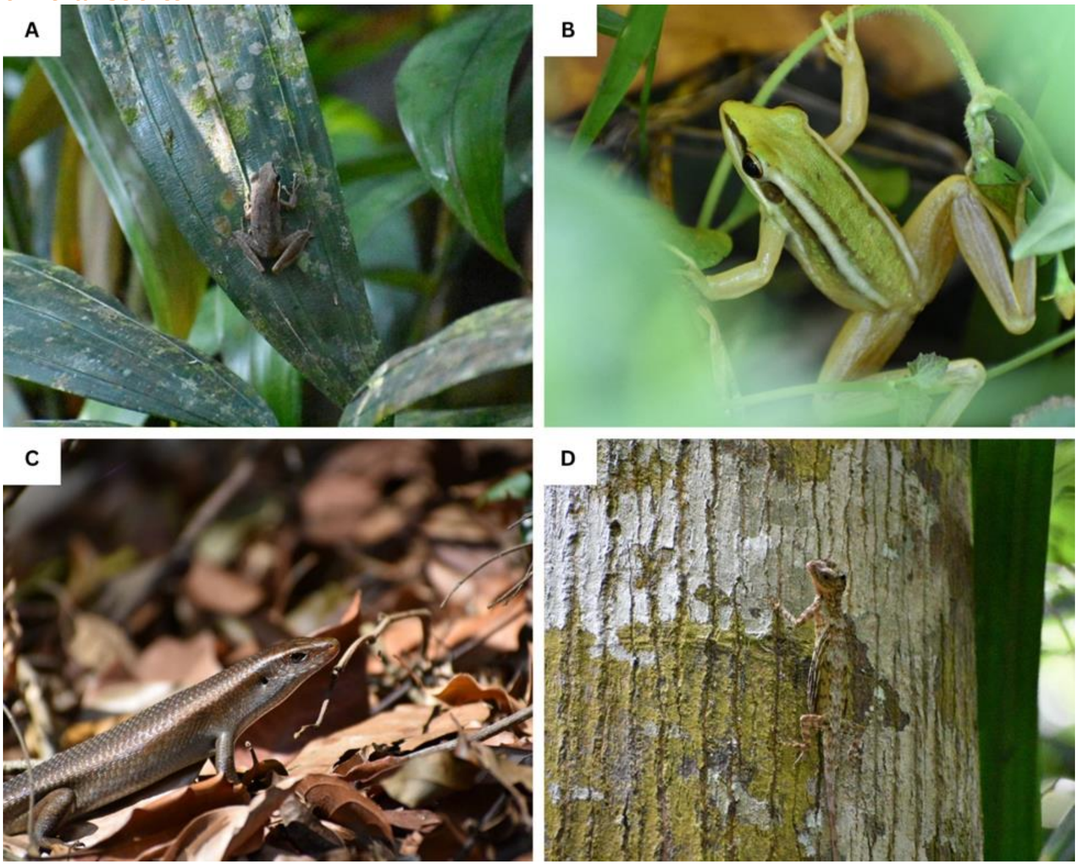

Figure 5: Chalcorana labialis (A), Hylarana erythraea (B), Eutrophis multifascata (C), and Draco sp. (D)

Figure 6: Callosciurus notatus (A) and Ratufa bicolor (B)

Figure 7: Tanaecia iapis (A), Troides amphrysus rufiollis (B), Cupha erymanthis (C), Graphium sarpedon (D), Erucius sp. (E), and Lyriothemis biappendiculata (F)

Figure 8: Gmelina arborea (A), Dryobalanops oblongifolia (B), Dryobalanops aromatica (C), Miconia sp. (D), Schismatoglottis sp. (E), and Licuala sp. (F)

4. Discussion

4.1. Presence of human activities

Bukit Panchor Forest Reserve (BPFR) is a protected area renowned for its eco-tourism attractions, and serves activities such as hiking, trekking, camping, caving, and bird-watching. While these recreational opportunities promote engagement with nature, they also introduce substantial human presence, which can have adverse effects on wildlife. Species often perceive humans as predators, leading to heightened alertness, altered behavioural patterns, and disrupted ecological niches (Bötsch et al., 2018). These disturbances can reduce population densities, cause physiological stress, and even lead to reproductive failures, ultimately altering species and community compositions. The creation of tarred trails and boardwalks, particularly near sensitive swamp areas, exemplifies the physical disruptions caused by human activities. These structures fragment the vegetation, potentially degrading the forest system significantly (Ballantyne et al., 2014). Furthermore, BPFR's proximity to private agricultural land introduces additional challenges. The interface between agricultural and forest ecosystems often results in microclimatic shifts, reduced soil fertility, and the spread of agrochemicals. This disturbed border also becomes a gateway for invasive species, which can outcompete native flora and fauna, further destabilizing the ecosystem (Ribeiro et al., 2019). Given these impacts, ecological assessments of species interactions become critical. Such assessments can help elucidate the functional roles of species within the ecosystem and their responses to environmental stressors, providing valuable insights for conservation efforts (McGill et al., 2006).

4.2. Fauna

4.2.1. Avian diversity: During the survey, bird sightings were highest in the morning, with species like the Golden Whiskered Barbet (*Psilopogon chrysopogon laetus*) and White-rumped Munia (*Lonchura striata subsquamicollis*) observed in the forest understory. These passerine birds, which are understory specialists, are particularly vulnerable to habitat disturbances, as they rely on specific nesting sites within the understory (Nor Hashim & Ramli, 2013). Their presence indicates the level of habitat fragmentation, as changes in bird diversity often reflect broader ecological shifts (Jayasilan, 2019). The sighting of the Changeable Hawk-Eagle (*Nisaetus cirrhatus limnaeetus*) in the afternoon further underscores the significance of raptors as bioindicators. Raptors, being apex predators, are sensitive to environmental changes, and their population trends can reveal underlying ecological instabilities (Kumar et al., 2022). Moreover, raptors play a crucial role in monitoring environmental contaminants, as persistent, bioaccumulative, and toxic (PBT) chemicals can enter their food web, affecting their foraging behaviour and health (Gómez-Ramírez et al., 2014).

4.2.2. Herpetofauna diversity: Only two frog species, the White-lipped Frog (*Chalcorana labialis*) and the Green Paddy Frog (*Hylarana erythraea*), were observed near the swamp area. Similarly, two reptile species, the Common Sun Skink (*Eutrophis multifasciata*) and the Flying Lizard (*Draco* sp.), were encountered along the tarred trails. Herpetofauna, consisting of reptiles and amphibians, are key bioindicators due to their sensitivity to environmental contaminants and habitat alterations (Mifsud, 2014). The proximity of BPFR to agricultural land raises concerns about heavy metal runoff, including copper and pesticides, which can accumulate in aquatic ecosystems. Amphibians and reptiles in these areas are at risk of deformities, immunosuppression, and other sub-lethal effects from such pollutants (Smalling et al., 2015). The swamp area, which shares waterways with nearby agricultural land, may serve as a conduit for these contaminants, gradually biomagnifying in exothermic organisms like frogs and lizards

4.2.3 Mammal diversity: Small mammals, such as the Plantain Squirrel (Callosciurus notatus) and the Malayan Giant Squirrel (*Ratufa bicolor*), were observed foraging in the forest canopies. While *C. notatus* is adaptable and commonly seen, *R. bicolor* prefer pristine forests and is a key indicator of forest health (Roy et al., 2022). The fragmented habitats in BPFR provide natural and modified microhabitats for these mammals, which play crucial roles in food webs and help monitor environmental contamination through their diets (Zamani, 2021).

4.2.4. Insect diversity: BPFR's insect population, particularly butterflies and dragonflies, also offers insights into the ecosystem's health. Species like the Malayan Birdwing (*Troides amphrysus rufiollis*) and Red-and-white Bombardier (*Lyriothemis biappendiculata*) were observed along swamp areas and trails. Insects, especially those from the Lepidoptera and Odonata orders, are sensitive to habitat changes and climatic effects, making them valuable bioindicators of land exploitation and pollution levels

(Chowdhury et al., 2023). Lepidoptera have been widely utilised to evaluate the degree of heavy metal and pollutant levels in industrialised and metropolitan areas (Mauricio da Rocha et al., 2010) while, dragonfly from the order Odonata is known as the best indicator of current land exploitation and degradation (Rocha-Ortega et al., 2019). The impact of adjacent agricultural activities is evident in the population dynamics of these insects, highlighting the need for ongoing monitoring.

4.3. Flora

4.3.1. Plant diversity: The entire part of Bukit Panchor Bukit Reserve is predominated by large dipterocarp trees that shape most of its landscape as a lowland rainforest. Most of the plants in this dipterocarp-dominated forest reserve belong to Angiosperms from the family Dipterocarpaceae and Dipterocarps produce flowers inter-annually that promote mass flowering and mass fruiting phenomena (Prohaska et al., 2023). The presence of dipterocarp trees such as Camphor (*Dryobalanops aromatica*) and Keladan (*Dryobalanops aromatica*) form the forest landscape in this forest reserve with covering canopies of emergent-type trees that provide various habitat niches for forest dwellers. Along the tarred trail, palms such as *Licuala* sp. and shrubs such as *Miconia* sp. are the most common species found. The *Schismatoglottis* sp. grow within the swamp near the boardwalk areas. Plants in the forest reserve can reflect the impacts of pollutants in the environment through the observation of their distribution patterns, symbiotic relationships, and vegetational covering they provide in the areas (Rai, 2016). The possible threats of heavy metal run-offs into the soil from the nearby agricultural land can be investigated through the accumulative concentration of chemical traces in plant structures such as leaves and barks (Sawidis et al., 2011). However, the proximity of agricultural land raises concerns about soil pollution from heavy metal runoff, which can accumulate in plant structures and alter distribution patterns (Salinitro et al., 2019).

4.4. The impact of Habitat Fragmentation, Deforestation, and Recreation on the Survival of Ratufa bicolour and Dryobalanops aromatica

R. bicolour and D. aromatica suffer from habitat fragmentation, deforestation, and recreation. These influences can change their ecology and behaviour in many ways. R. bicolour needs canopy cover to survive, but agricultural expansion and recreational routes can lessen it. Arboreal animals need canopy cover for habitat, locomotion, and foraging. Increased canopy openness reduces resource availability and canopy connectivity, which are essential for species like R. bicolour, in the Lacandona rainforest, Mexico (Constantino, 2016). Access to agricultural land increases the possibility of pesticide exposure, further straining sensitive species. This exposure may cause physiological stress and toxicity, affecting health and reproduction.

Deforestation is critical to habitat deterioration. Deforestation and road development have fragmented Amazonian forests, changing microclimates and making them more vulnerable to droughts and fires. Changes like this harm many animal species, particularly forest-dependent ones (Horan et al., 2008). Fragmentation limits R. bicolor's migration and habitat. Recreational activities can harm animals. Wildlife abundance is affected by human disturbances in urban habitat fragments. Roads negatively affected cougars and grey foxes, showing how human infrastructure may alter wildlife habitats and behaviour (Bro et al., 2004). Recreational pathways may enhance human-wildlife encounters in BPFR, causing R. bicolour to stress and avoid.

Deforestation and habitat fragmentation can lower D. aromatica population density and reproductive success. Long-term effects of selective logging in dipterocarp forests, like the Pasoh Forest Reserve, reveal reduced recruitment rates and slightly affected growth rates, affecting population size structure (García-Feced et al., 2011). Over time, this recruitment drop might reduce population viability. The Chinese study on habitat fragmentation by road and railway networks also shows how transportation networks affect endangered species. Habitat fragmentation is worse for species like D. aromatica that have higher intrinsic mobility or area needs (Ntukey et al., 2022). This fragmentation diminishes habitat availability and impairs species-sustaining biological processes. Habitat connectedness should be maintained and restored to reduce these consequences. Wildlife corridors and community conservation awareness initiatives may help. To guarantee sustainable human-animal cohabitation in Tanzania's Wami Mbiki–Saadani wildlife corridor, community activities, wildlife corridor mapping, and restoration approaches can improve elephant habitat protection (Ntukey et al., 2022).

Therefore, habitat fragmentation, deforestation, and leisure threaten R. bicolour and D. aromatica. These activities result in agrochemical exposure, canopy cover loss, mobility and feeding disruption, and habitat loss. Successful conservation efforts must prioritise habitat connectivity and acknowledge the many ways humans affect animals.

4.5. Mitigating Detection Bias in Species Observation

The detection bias of cryptic or elusive species, which may be underrepresented due to their behaviour or habitat preferences, may restrict species observation investigations. Species that are active at certain times or in less accessible regions of a reserve may not be caught in research. To avoid this issue, early morning and late afternoon, when particular species are most active, were used for the survey. Imperfect detection is a typical species distribution modelling issue. False absences and positives can influence model estimates and overestimate findings. Error severity is generally related to environmental factors, including habitat features that impact species detection (Guillera-Arroita, 2017). The spatial organisation and fragmentation of habitats can compound the impacts of habitat loss on species, making it harder to detect species responses to habitat fragmentation (Fithian et al., 2014).

Citizen science data is useful but sometimes biased owing to sloppy data gathering. Machine learning, spatial filtering, and resampling have improved rare species habitat association and distribution patterns by addressing class imbalance and geographical bias (Robinson et al., 2018). However, accessibility still affects species distribution information, especially in distant tropical areas. SDMs can fill these gaps but must account for spatial distribution biases to prevent confusing habitat traits and accessibility (Ewers & Didham, 2005).

Volunteer surveys, however, focused on high-profile species, can aid non-target species conservation. These studies can determine species distributions and populations in seldom-visited locations, highlight risks to vital ecosystems, and help local people improve capacity and education (Fernandes et al., 2018). Geographical sample biases might still impact species richness-environment interactions, requiring methodologies to measure and account for inventory incompleteness (Yang et al., 2013).

Multiple detection/non-detection records from different survey methodologies and multiple site visits reduce detection bias. This technique gathers important data regarding the observation process, eliminating false absences (Guillera-Arroita, 2017). Visual surveys must handle observation problems, including availability and perceptual biases. Radiotelemetry and visual surveys can reveal detection bias and enhance species abundance and habitat use estimates, especially for cryptic species (Béguinot, 2018).

Therefore, the species observation studies are limited by detection bias, but extensive survey procedures, improved modelling, and diverse data sources can reduce this bias. Surveying at different times of day and using several methodologies can improve species distribution data accuracy and dependability, enabling better conservation planning and management.

4.6. Preserving Biodiversity and Ecological Services in Lowland Dipterocarp Forests Amidst Agricultural and Recreational Pressures

The BPFR has species richness patterns comparable to Malaysia's Pasoh and Ulu Muda lowland dipterocarp forests. Similarities include bird diversity and dipterocarp species like D. aromatica. BPFR's closeness to agricultural and recreational areas presents issues, especially for sensitive species like R. bicolour and D. aromatica. Social bees and beetles play a vital part in pollination biology in lowland dipterocarp woods like Sarawak, Malaysia. These woodlands' great plant species diversity depends on these pollinators (Momose et al., 1998). Tree variety is crucial in Bornean lowland dipterocarp forests, as shown by floristic studies. Slik et al. (2003) identify significant taxa and connect floristic patterns to abiotic variables like rainfall and distance. These studies demonstrate lowland dipterocarp woods' biological complexity and heterogeneity, contributing to biodiversity.

Studies have shown that the richness of tree species increases ecological carbon storage. Carbon fluxes and stocks are greater in species-rich forests. This link promotes biodiversity preservation for ecological and carbon storage advantages (Liu et al., 2018). Each new tree species enhanced the total carbon stored by 6.4% in subtropical forests in southeast China, supporting the maintenance of species-rich forests like BPFR (Liu et al., 2018).

While dipterocarp tree growth rates are only marginally altered by selective logging in the Pasoh Forest Reserve, recruitment rates are dramatically lowered. This decline affects dipterocarp population size, showing that these woods are sensitive to human disturbances (Yamada et al., 2016). Similarly, species-specific blooming signals among Shorea species at the Pasoh Research Forest show that dryness and chilly temperatures may greatly impact reproductive cycles and forest regeneration (Chen et al., 2018).

Bee diversity along disturbance gradients in Southeast Asian tropical lowland forests shows how forest disturbance affects pollinators. Primary woods have more bees, especially Apidae, but disturbed forests have more species. This shows that forest composition and disturbance levels strongly affect pollinator dynamics, essential for forest regeneration and biodiversity (Liow et al., 2001). Tree species richness increases forest production due to species complementarity, emphasising the relevance of varied forest ecosystems. Species richness in tropical lowland dipterocarp forests likely increases production and ecological resilience, as in European temperate forests (Morin et al., 2011).

Hence, BPFR is similar to other lowland dipterocarp forests in Malaysia, but its closeness to agricultural and recreational areas requires special conservation measures. To preserve BPFR's biodiversity and ecological services, these methods should reduce habitat fragmentation and promote essential species, including R. bicolour and D. aromatica. Integrating study findings emphasises the relevance of species richness and tackling anthropogenic issues.

4.7. Agroforestry as a Multidimensional Solution for Biodiversity Conservation and Sustainable Development Along BPFR Boundaries

Agroforestry systems along the BPFR boundaries with agricultural areas offer a potential, multidimensional solution to biodiversity protection and habitat connectivity. Adding trees to agricultural crops reduces habitat fragmentation, conserving biological corridors for species like R. bicolour (Near Threatened). Agroforestry's ability to preserve biodiversity, improve soil health, and help local populations matches BPFR's conservation goals.

Monoculture farming has caused biodiversity loss and pollinator decrease. Temperate agroforestry systems boost biodiversity and pollination. According to Niether et al. (2020), agroforestry systems promote sustainable agriculture by increasing system yields, economic performance, and biodiversity conservation compared to monocultures. These advantages are especially important in BPFR, where agricultural expansion threatens ecosystems.

A meta-analysis of cocoa agroforestry systems found that despite lower cocoa yields than monocultures, the system yields were 10 times greater, promoting food security and income diversification (Warren-Thomas et al., 2019). Similar schemes like BPFR might make agriculture more sustainable and protect biodiversity. Agroforestry also improves habitat connectivity and reduces pesticide exposure for insect pollinators (Varah et al., 2013), crucial for maintaining ecological balance near forest reserves like BPFR.

Agroforestry's socioeconomic benefits also drive its adoption. According to Mukhlis et al. (2022), agroforestry boosts smallholder incomes, food security, and gender equality in rural areas. Despite these benefits, smallholder farmers in underdeveloped countries like BPFR seldom use agroforestry due to a lack of supportive state policy. Policies encouraging agroforestry adoption and local capacity-building initiatives might overcome these limitations and improve conservation and rural development.

Agroforestry improves soil microbial populations necessary for nutrient cycling and soil health. Agroforestry systems increase bacterial number and species richness, enriching soils with nutrients (Chavan et al., 2023). These findings are important for the BPFR region, where agricultural runoff might impair soil quality and endanger ecosystems. Besides biodiversity and soil health, agroforestry reduces climate change by sequestering carbon. Research shows that agroforestry systems, especially those with fast-growing trees, can sequester carbon (Pandey, 2002). Through carbon storage, these technologies alleviate strain on natural trees, preserving BPFR ecosystems.

Agroforestry systems around BPFR handle ecological and socio-economic issues. This strategy can minimise habitat fragmentation and increase biodiversity, soil health, pollination, and local economic advantages. BPFR may integrate biodiversity protection with sustainable rural development by integrating trees with agricultural crops, creating a more resilient and balanced environment.

4.8. Suggestion on Conservation Efforts

The impacts of agricultural and recreational activities on forest ecosystems and biodiversity in Bukit Panchor Forest Reserve can be alleviated. Firstly, agroforestry methods can be used through the integration of a variety of crops and intricate tree layers not only provide habitats for many native organisms such as birds, insects, and plants; but also preserve the soil biota (Apriyani et al., 2024). Agroforestry is highly applicable to protect the biodiversity that is potentially affected by agricultural encroachments as it could create habitats for disturbance-tolerant species, preserve the genetic diversity of vulnerable species, decrease the rate of conversion and clearings of natural habitats, build the connective corridors between two different sensitive habitats, and maintain the ecosystem services at the highest functional level to protect against habitat loss and degradations with the preservation of 50% to 60% diversity equal to natural forests (PUdawatta et al., 2019). Next, the Bukit Panchor Forest Reserve should implement more stringent and sustainable eco-tourism operations that underscore the concept of ecology, economy, and social equity (‘planet, profit, people) (Cerveny, 2022). It is to ensure that visitors are aware of the conservation of flora and fauna to protect the ecological well-being of the forests and also provide economic opportunities to the local populace.

5. Conclusion

The BPFR remains a vital ecological area within Malaysia’s lowland tropical rainforests, despite the growing pressures from surrounding human activities, such as rural settlements, recreational areas, and private agricultural lands. This study highlights the richness of the reserve’s biodiversity, with a total of 20 species documented across several taxonomic groups, including birds, amphibians, reptiles, mammals, insects, and angiosperms. While most species were classified as Least Concern according to the IUCN Red List, the presence of vulnerable species such as *Ratufa bicolor* (Near Threatened) and *Dryobalanops aromatica* (Vulnerable) emphasizes the need for focused conservation initiatives. These species, along with the diverse range of avifauna, amphibians, and insects, contribute significantly to the ecological integrity of the BPFR. The findings of this survey indicate that while BPFR still supports a diverse range of species, continued conservation efforts are essential to mitigate the impact of anthropogenic activities. Efforts should focus on preserving habitats, preventing further deforestation, and protecting species that are particularly vulnerable. This study serves as a baseline for ongoing monitoring and reinforces the importance of safeguarding Malaysia’s lowland tropical rainforests. Furthermore, future research should explore the long-term effects of human encroachment and the development of sustainable strategies to balance conservation with local human activity, ensuring the reserve’s biodiversity thrives for generations to come.

6. Acknowledgements

The author would like to express utmost gratitude to the Department of Biology, Universiti Putra Malaysia (UPM) and respected lecturer, Prof. Dr. Yap Chee Kong for giving the opportunities and guidance in conducting the case study.

7. Conflicts of Interest

The author declares no conflict of interest

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