JOURNAL OF ARCHITECTURE, PLANNING & CONSTRUCTION MANAGEMENT
Volume 15 Issue 2, 2025 E-ISSN: 2462-2222 ISSN: 2231-9514

QUANTIFYING THE EFFECTS OF LAND-USE CHANGE ON WILDLIFE IN KAPIT REGION, SARAWAK

Received: 30 May 2025 | Accepted: 18 November 2025 | Available Online: 30 November 2025

DOI: 10.31436/japcm.v15i2.938

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ABSTRACT
This study investigates the impact of forest land-use change on wildlife populations within the Kapit Forest Management Unit (FMU) in Sarawak, Malaysia, between 2011 and 2020. The methodology involved analysing primary forest cover data using GIS-based remote sensing to quantify land-use changes, evaluating wildlife populations and forest loss using correlation analysis, and performing relative abundance analysis coupled with observation on site, particularly in protected areas. Results show a moderate negative correlation (r = -0.48) between forest loss and wildlife population decline, with the highest relative wildlife abundance recorded in 2011 (15.41%). Wildlife abundance subsequently decreased, attributed to habitat degradation and human pressures. Dominant bat species included *Cynopterus brachyotis* and *Penthetor lucasi*, each comprising 17.4% of captures, while *Dycopterus spadiceus* and *Kerivoula intermedia* showed moderate abundances of 10.9% and 8.7%. Although approximately 20% of the land is designated for conservation, including Baleh Protected Forest, it is insufficient to offset the surrounding impacts of infrastructure development. The findings demonstrate that current Sustainable Forest Management (SFM) practices are inadequate to prevent biodiversity loss. Strengthening conservation policies, enforcement mechanisms, sustainable land-use planning, habitat restoration, and community engagement are essential to balancing production and conservation, and to enhancing ecosystem resilience within the Kapit FMU.

Keywords: Habitat, Land use, Ecosystem, Biodiversity, Conservation

1.0 INTRODUCTION

Borneo is a critical region for global timber, supplying about half of the world's annual tropical timber demand (Koh et al. 2023). However, extensive deforestation and forest degradation caused primarily by agricultural expansion—especially palm oil plantations—pose significant threats to biodiversity (Sheng & Potter, 2023). In Sarawak alone, around 1.42 million hectares of mature forest, representing 89.3% of the total area, have been converted to oil palm cultivation (Forest Department Sarawak, 2021). This rapid land-use change endangers remaining rainforest fragments and wildlife habitats, yet limited research has examined its direct impact on local fauna.

Land-use change in forested areas remains one of the most severe global biodiversity

threats. Conversion and fragmentation result in habitat loss, isolate wildlife populations, and disrupt ecosystem functions. Forests provide essential resources such as, shelter, food, and migration pathways for myriad species, and their degradation leads to sharp population declines. Understanding how land-use change influences wildlife population trends is therefore fundamental for developing effective conservation strategies.

The Kapit Division, located within Sarawak's Permanent Forest Estates (PFEs), plays a critical ecological role. The PFEs encompass diverse forest types, including government reserves, protected forests, and communal forests (Forest Department Sarawak, 2019). Kapit hosts the largest continuous forest in Sarawak, representing nearly 63% of the state's forest cover. Recognised by the IUCN for its rich biodiversity (IUCN, 2024), Kapit faces pressure from logging, oil palm expansion, and cash crop cultivation—all significantly altering land-use patterns and affecting both local livelihoods and wildlife habitats (Hon & Shibata, 2013).

Sarawak classifies its forests into three main categories: First, Permanent Forest Estates (PFE) for sustainable timber production under regulated logging; Second, Totally Protected Areas (TPA), including parks and sanctuaries for biodiversity protection; and Third, State Land Forests that do not fall under PFE or TPA.

The state implements Sustainable Forest Management (SFM) principles aimed at balancing ecological, economic, and social forest functions. Practices such as Reduced Impact Logging (RIL) and selective harvesting minimise environmental damage. Regulations protect ecologically important trees and maintain buffer zones near rivers and sensitive areas. Forest governance is regulated by Sarawak's Forests Ordinance 2015, which supports sustainable management and outlines a licensing system. The Forest Carbon Activity Rules 2022 further enable carbon trading initiatives within the state. The Sarawak Forestry Corporation oversees the management of TPAs to ensure long-term biodiversity protection.

Healthy ecosystems are essential for both ecological and human well-being. The IUCN Red List currently identifies over 31,000 species at risk of extinction (IUCN Redlist, 2024), with WWF estimating up to 200 species lost annually and up to 30% potentially extinct by the century's end. Forest loss in Kapit threatens this rich biodiversity. This study aims to assess forest land-use change impacts on wildlife populations and relative abundance in Kapit FMU from 2011-2020. The objectives include quantifying forest loss rates with GIS, monitoring wildlife population trends, correlating forest changes with wildlife fluctuations, and recommending conservation strategies like habitat restoration and wildlife corridors to safeguard biodiversity.

2.0 LITERATURE REVIEW

Drivers and Consequences of Land-Use Change

The drivers of land-use change are complex, involving economic incentives, land tenure systems, and government policies. The expansion of oil palm plantations, for example, is propelled by global market demand and state economic priorities, often at the expense of conservation (Fold & Svan Hansen, 2006). Infrastructure projects, such as the Bakun Dam and new road networks, further fragment habitats and facilitate access to previously

undisturbed forests (Alamgir et al., 2020; Durin et al., 2022).

The consequences of these changes are profound. Deforestation in Kapit has led to the loss of critical tree cover and wildlife habitats, exacerbating environmental issues like flash floods and threatening the survival of species such as the Bornean orangutan, Sarawak langur, tufted ground squirrel, and proboscis monkey (Alamgir et al., 2020). Local communities, whose livelihoods are closely tied to forest resources, often face increased economic pressure that leads to unsustainable practices such as illegal logging and overharvesting (Hon & Shibata, 2013).

Additional pressures stem from mining activities and the illegal wildlife trade, which contribute to habitat degradation and the decline of vulnerable species (Murray et al., 2020). The conversion of forests to agricultural or industrial land, driven by both domestic and international demands, continues to threaten the region's ecological balance (Lambin et al., 2001; Lambin & Meyfroidt, 2011). According to Jansen and Gregorio (2000), land use refers to the "arrangements, activities, and inputs by people to produce, change, or maintain a certain land cover type," which highlights the direct link between human activity and environmental impact.

Wildlife and Conservation Efforts

Monitoring wildlife populations is essential for effective conservation management. Relative abundance analysis, which utilises historical records, wildlife surveys, and census data, provides insights into population trends and ecosystem health (O'Brien, 2011). This method helps identify dominant, rare, or declining species and can signal ecological imbalances or the effects of habitat degradation. For instance, long-term bird surveys can reveal trends in avian populations, while satellite imagery tracks habitat changes over time.

The IUCN Red List serves as a global standard for assessing species' conservation status, from Least Concern to Critically Endangered and Extinct. Malaysia's diverse forest types—including lowland and hill dipterocarp forests, montane forests, and peat swamps—support a wide array of species, many of which are now threatened by ongoing land-use change (Mohanlall, 2002). The Kapit Forest Management Unit (FMU) hosts a diverse range of wildlife, including 41 mammal species, 45 bird species, and three reptile species (Kapit Forest Management Unit, 2025; Khan et al., 2019). This rich biodiversity is supported by mixed dipterocarp forests and conservation areas, highlighting Kapit FMU as an ecologically significant area requiring continued conservation and sustainable management.

Forest Governance and Land Use in Sarawak

Forest governance in Sarawak is regulated by the state-level Forests Ordinance 2015, administered by the Forest Department Sarawak (FDS). This ordinance, which replaced the 1958 version, aims to manage forest resources sustainably and protect biodiversity through a land classification system, strict logging licenses, and a focus on carbon initiatives. Sarawak's forests are categorised into three main types: (i) Permanent Forest Estates (PFEs) for sustainable production, (ii) Totally Protected Areas (TPAs) for conservation, and (iii) State Land Forest.
The state has also adopted Sustainable Forest Management (SFM) principles, which seek to

balance ecological, economic, and social functions. SFM practices like Reduced Impact Logging (RIL) and selective harvesting are used to minimise damage, and regulations require the maintenance of protected buffer zones along riverbanks and on steep slopes.

However, despite these regulations, land-use change in the Kapit region remains a significant threat. This is driven by economic incentives and government policies that favour large-scale agriculture, such as oil palm plantations, and infrastructure projects like the Bakun Dam and new road networks. These activities accelerate deforestation and habitat fragmentation, which profoundly impact both local communities and wildlife (Hon & Shibata, 2013; Alamgir et al., 2020).

Impacts of Land-Use Change on Wildlife

Land-use change, often defined as the conversion of land for new purposes, represents one of the most significant threats to biodiversity globally (Lambin et al., 2001). Transforming biodiverse forests into agricultural lands or fragmenting habitats through infrastructure development disrupts wildlife populations by destroying critical breeding and foraging areas, altering food webs, and modifying predator-prey dynamics, which collectively contribute to steep declines in animal species (Fahrig, 2003; Bennett, 2003; Haddad et al., 2015). In the Kapit Forest Management Unit (FMU), located within the Heart of Borneo initiative, these impacts are particularly acute. The region supports rich biodiversity, including 41 mammal species such as the rodent *Sundamys muelleri* and bat *Cynopterus brachyotis*, 45 bird species, reptiles, and insects, sustained by mixed dipterocarp forests and protected areas (Kapit FMU, 2025; Khan et al., 2019). Recorded species include Mammals 41 species, including small mammals such as rodents, marsupials, and bats. Examples include *Sundamys muelleri* (a rodent) and various bat species like *Cynopterus brachyotis*, 45 species of birds, contributing significantly to the area's biodiversity, 3 species of Reptiles, and 1 recorded insect. This rich biodiversity is supported by mixed dipterocarp forests and conservation areas within the FMU. Many of these species are of conservation importance, underscoring the FMU's ecological significance and the need for sustainable management.

Land use changes are driven by varied human activities such as agriculture, residential development, and industry, affecting spatial distribution and resource availability for wildlife (Lambin & Meyfroidt, 2011). Livelihood needs, resource exploitation, and policies all play critical roles. For instance, Hassan et al. (2008) demonstrated that buffalo populations depend on the quantity and quality of available forage, highlighting how deforestation reduces food resources and forces wildlife migration, disrupting populations (Kingdon, 1982). Establishing protected areas and biosphere reserves, such as Malaysia's Crocker Range, Tasik Chini, and Penang Bukit Bendera, facilitates coexistence between human and wildlife communities, promoting biodiversity conservation (Zen et al., 2019; IUCN, 2024).

However, in Kapit, infrastructure developments like the Bakun hydropower dam and expanding road networks have intensified habitat fragmentation and deforestation. The Bakun Dam alone cleared roughly 695 square kilometres, affecting 32 protected areas and numerous wildlife populations, affecting key species including Bornean orangutans (*Pongo pygmaeus*), Sarawak langurs (*Presbytis chrysomelas*), tufted ground squirrels (*Rheithrosciurus macrotis*), and proboscis monkeys (*Nasalis larvatus*) (Alamgir et al., 2020).

including Bornean orangutans, Sarawak langurs, and proboscis monkeys (Alamgir et al., 2020). Additional threats include mining, illegal logging, and illicit wildlife trade, exacerbating pressures on habitats (Murray et al., 2020). These challenges are further compounded by land tenure conflicts and government development policies favouring large-scale agriculture and infrastructure, often marginalising local community rights and accelerating forest conversion (Zen et al., 2021; Durin et al., 2022). Global demand for commodities like timber and palm oil drives unsustainable exploitation, restricting community access and degrading biodiversity (Hansen & Mertz, 2006).

Meanwhile, local communities rely heavily on forest resources for hunting, gathering, and small-scale agriculture, sometimes leading to unsustainable activities such as illegal logging to meet economic needs (Hon & Shibata, 2013). Plantation expansion, especially of oil palm, reshapes land use; attractive incomes from plantations often overshadow conservation goals, accelerating deforestation and habitat loss (Fold & Svan Hansen, 2006).

In summary, land-use change in Kapit significantly endangers wildlife by fragmenting habitats, reducing resources, and intensifying human-wildlife conflicts. Sustainable land management, community engagement, and protected area enforcement are crucial to conserve the region's rich biodiversity and maintain ecosystem health (Alamgir et al., 2020; Khan et al., 2019; Zen et al., 2021).

Monitoring and Conservation

Evaluating the relationship between land use and wildlife populations is essential for assessing ecosystem health and guiding conservation efforts. Relative abundance is a key metric used to understand wildlife population dynamics by measuring how common a species is compared to others within a community (O'Brien, 2011). This method relies on historical records, wildlife surveys, and census data to track changes in population size and density over time, helping identify threats or opportunities for conservation. Regular monitoring allows for the detection of population shifts, enabling timely conservation actions, which is critical in diverse landscapes like Kapit Forest Management Unit (FMU), containing both production and conservation areas.

Relative abundance quantifies the proportion of individuals of a species relative to the entire wildlife community, reflecting ecological balance or an indication of habitat change. For Kapit FMU, monitoring relative abundance helps detect ecological imbalances and habitat degradation resulting from logging or land-use changes, especially in production forests.

Advanced tools such as remote sensing and Geographic Information Systems (GIS) support the monitoring of land-use changes, though maintaining data consistency remains challenging. The International Union for Conservation of Nature (IUCN) Red List provides a global standard for assessing species conservation status, essential in guiding conservation priorities (Debby & Dick, 2012). Long-term wildlife surveys, like those of bird populations, reveal trends in species abundance, while satellite imagery tracks habitat quality changes over time. However, researchers must carefully assess the quality of secondary data to avoid biases and inconsistencies in monitoring outcomes.
Numerous studies demonstrate the importance of understanding the interactions between

land use and wildlife populations. For example, Serneels et al. (2001) used multi-temporal species distribution models with over 50,000 occurrence records to analyse carnivore habitat changes, revealing significant impacts of forest cover shifts and human activities on wildlife dispersal. Such insights underscore the necessity of integrating ecological data with land-use patterns in effective conservation planning. Table 1 shows the classification of wildlife according to the International Union for Conservation of Nature (IUCN) Classification.

Table 1 Classification of Wildlife

Extinct (EX)	Critically Endangered (CR)	Endangered (EN)	Vulnerable (VU)	Least concern (LC)
A species is extinct when there is no reasonable doubt that the last individual has died. To call a species extinct, surveys must be carried out to look for the species across its previously known range.	A species is critically endangered when all the evidence shows that the species meets at least one of the IUCN criteria A to E for critically endangered. It is then at an extremely high risk of extinction in the wild.	A species is endangered when all evidence shows that it meets at least one of the IUCN criteria A to E for endangered species, indicating it is facing a high risk of extinction in the wild.	A species is vulnerable when all the evidence shows that it meets at least one of the IUCN criteria A to E for vulnerable, indicating that it is facing a high risk of extinction in the wild.	A species is least concerned when there is sufficient information available to make an assessment and it is not classified as critically endangered, endangered, vulnerable or near threatened.

Source: IUCN classification

Wildlife habitat conservation depends heavily on sustainable forest land management (Debby & Dick, 2012). Human activities can significantly alter species' ranges and survival; therefore, accurate monitoring is vital. Various methods are employed in the Kapit FMU and similar areas, including direct observations, camera trapping, nocturnal surveys, and tracking signs of wildlife activity. These techniques provide a scientific basis for informed decisions to sustainably protect wildlife and their habitats.

In summary, monitoring land use and wildlife populations through relative abundance analysis, combined with modern technologies and long-term surveys, is crucial for effective ecosystem management and biodiversity conservation in regions like Kapit FMU.

3.0 METHODOLOGY

The "Kapit region" is also known as Kapit Division, an administrative region in the state of Sarawak, Malaysia. It is a large, mountainous area located in the heart of Borneo, predominantly covered by rainforest and known for its Iban cultural heritage and the Rajang River. The main town, Kapit, is only accessible by river transport and is a base for exploring the region's natural beauty, cultural sites like longhouses, and local markets. As of 2020, the

district, which was 15,595.6 square kilometres in size, was home to about 65,800 people. The local economy is primarily agricultural, with key activities centred around forestry, oil palm cultivation, rice paddies, rubber, banana, and pepper production. The Bakun Dam, partially located in the Kapit District, contributes to the area's infrastructure and energy supply. Notably, Kapit is recognised for having the largest forest area in Sarawak, with forests covering 63% of the total land area (Abdullah, 2016). Figure 1 illustrates the overall methodological framework adopted for this study. The research followed a sequential and integrative approach comprising four main stages.

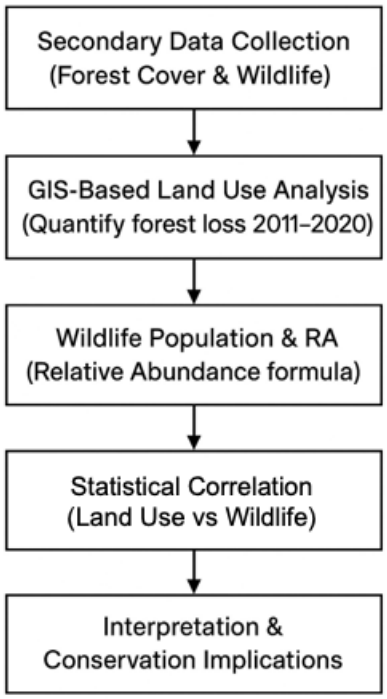

Fig. 1 Research Methods Flowchart

First, secondary data were collected from the Forest Department of Sarawak and other relevant agencies, including spatial forest cover records and wildlife population data spanning 2011-2020. Second, a Geographic Information System (GIS) based analysis was performed to quantify land use changes, focusing on forest loss within the Kapit Forest Management Unit. Third, wildlife population data were analysed using the Relative Abundance (RA) formula to determine species composition and distribution trends over time. Finally, correlation analysis was applied to examine the statistical relationship between land use change and wildlife population decline.

Study Area

The study was conducted within the Kapit Forest Management Unit (FMU), a large and ecologically significant area located in Sarawak, Malaysia. The FMU spans a total of 148,903 hectares, bordered by the Batang Rajang and Batang Balleh rivers to the north and the Malaysia-Indonesia international boundary to the south. Its eastern boundary is defined by the Sg. Sut, Sg. Entawau, Sg. Stapang, and Sg. Gaat rivers. The area is accessible via a

network of public and logging roads, with its administrative centre located at Engkeramuh Camp, 38 km from Melekun Logpond (Figure 2).

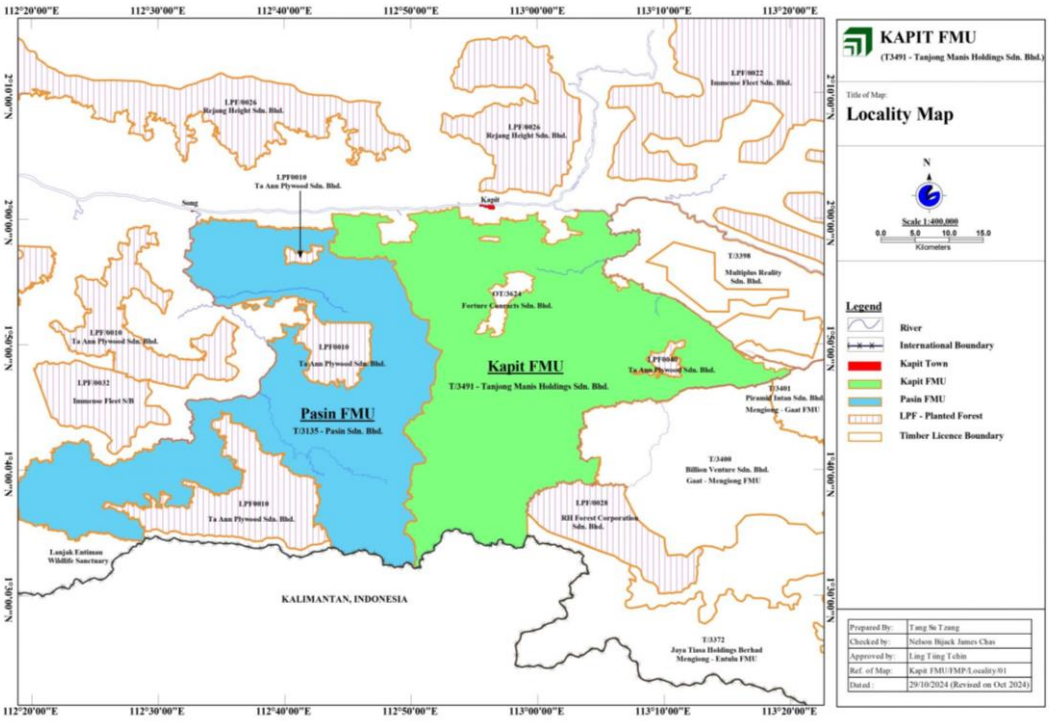

Fig. 2 Map of Kapit Management Forest Unit 2020
(Source: Kapit District Office, 2020)

The Kapit FMU is divided into two primary land classifications:

Production Areas: These cover 119,766 hectares, or approximately 80% of the FMU. Timber harvesting is permitted here under strict, sustainable logging systems. A significant portion of these production areas includes gazetted forests such as the Baleh Protected Forest (38.7%) and the Kain-Balang Protected Forest (19% proposed).

Conservation Areas: Making up the remaining 29,137 hectares (20%), these zones are designated for community use and environmental protection. This includes sections of the Baleh Protected Forest and its proposed extension, which collectively contribute to the area's biodiversity.

The Kapit FMU is a focal point for regional conservation, demonstrating a net tree cover gain of 26.7 thousand hectares between 2000 and 2020. This gain represents 3.2% of Sarawak's overall tree cover increase during the same period. The area's ecological importance is underscored by its rich biodiversity, which houses numerous wildlife species assessed according to the International Union for Conservation of Nature (IUCN) standards. The forest's management, including its 30-year license tenure, is designed to align with certification standards, promoting long-term sustainability.

Data Collection

This study utilised a combination of secondary data sources to analyse land use changes and wildlife population trends in the Kapit FMU from 2011 to 2020. Spatial data on land use were obtained from the Forest Department of Sarawak, providing detailed information on forest cover dynamics and land use classifications updated to 2020. Wildlife population data during the same period (2011 - 2020), including species abundance and distribution, were compiled from official records, with species status referenced according to the IUCN Red List.

Analysis

Land Use Change Analysis

A comprehensive land use analysis was conducted to quantify changes in forest cover over the study period. Geographic Information System (GIS) software was employed to visualise spatial data and generate statistical maps, enabling clear comparisons of forest cover across different years. The annual deforestation rate was calculated using the following formula (Krebs, 2014).

Wildlife Population Assessment

Relative abundance represents the proportion or percentage of individuals of a particular species relative to the total number of individuals of all species in a defined area or community. It is calculated by dividing the number of individuals of a species (n_i) by the total number of individuals of all species (N) and then multiplying by 100 to express it as a percentage. This measure helps ecologists understand how common or rare a species is within a community, reflecting both species abundance and the composition balance among species. Relative abundance is useful for assessing biodiversity and ecosystem health, comparing species dominance, and tracking changes in populations over time. In essence, it provides a standardised metric to compare species presence in different communities or habitats regardless of total population size. The formulas shown express Relative Abundance (RA) as a percentage, which is a standard ecological formula as presented in Magurran (1988).

$$p_i = n_i / \mathrm{N} \times 100,$$

or

$$RA\ (\%)\ = \frac{Number\ of\ individuals\ per\ species\ \times\ 100}{Total\ number\ of\ individuals}$$

Explanation:

- *ni* is the number of individuals of species *i*.
- *N* is the total number of individuals of all species in the sample or community.
- *pi* is the relative abundance percentage of species *i*, which shows the proportion of that species among the total individuals.

The second formula expresses the same concept in words. Both formulas calculate how common or abundant a particular species is within the total group, expressed as a

percentage. This helps ecologists quantify species dominance and community composition in biodiversity studies. This approach enabled the assessment of species diversity and population dynamics over time, providing key indicators for biodiversity monitoring.

Statistical Analysis

To explore the relationship between land use changes and wildlife populations, a statistical correlation analysis was conducted. This analysis examined the degree to which variations in forest cover loss corresponded with changes in wildlife abundance, thereby elucidating the impact of land use dynamics on animal populations in the Kapit Division.

$$Y = ax+1$$

Explanation:

y is forest cover loss (the dependent variable),

x is wildlife change (the independent variable),

a is the regression slope coefficient, the constant term is 1,

The coefficient of determination R^2 value the variance in y is explained by the linear relationship with x.

4.0 RESULTS

Based on Figure 3, 79% of land use in Sarawak was covered by forest, which indicates that most of the land in Sarawak is still undeveloped. Apart from that, it will show the population of wildlife, and its conservation area will be indicated on the coverage of the forest itself. From that, we can observe that changes will be occurring for forest land use in Sarawak and especially focused on the Kapit Division Forest Area as a study area in this research field.

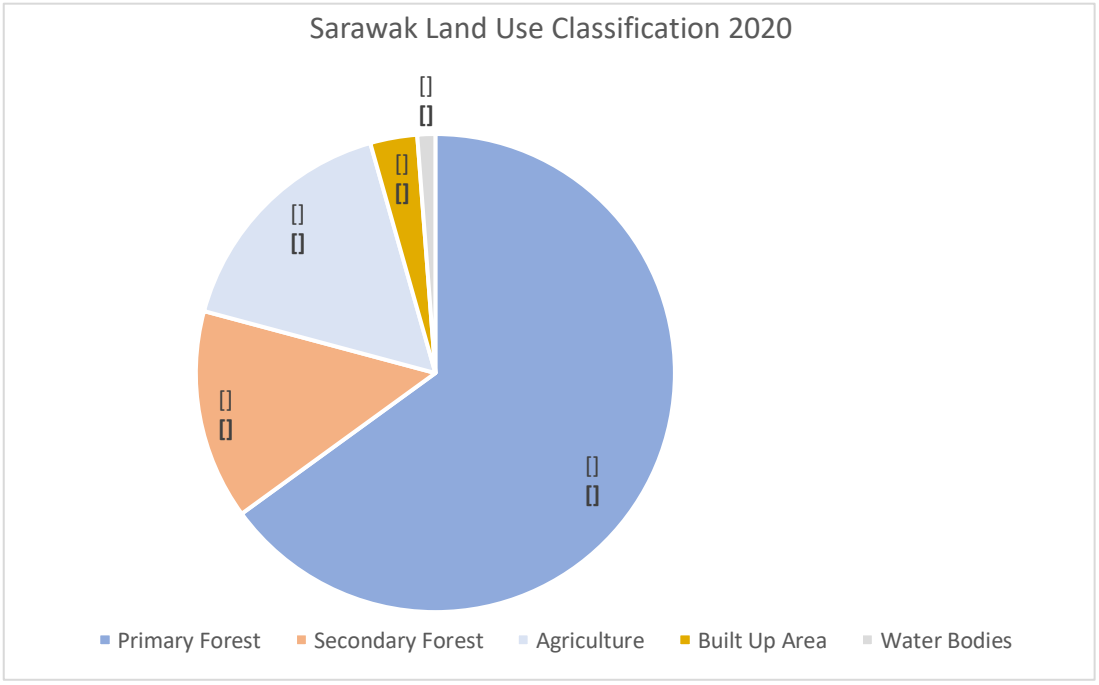

Fig 3. Sarawak Land Use Classification 2020

Based on the data from the Forest Department of Sarawak Figure 4, the coverage of forest land use for Kapit in 2020 is 1,323,704.97 hectares. For the primary forest, Kapit recorded 1,050,448 hectares in 2020. Deforestation rate for Kapit Primary Forest for 2011 to 2020 was from 11,518.03 hectares per year due to deforestation for infrastructure development, agriculture, oil palm plantation, and some factors that lead to the future development and agricultural settlements. In 10 years, Kapit Primary Forest lost 115,180.26 hectares of forest land use. The highest number of forest losses was in 2016 and 2018, which were above 20,000 hectares. The total of 40,000 hectares is a huge change in the land, especially in forest land use. The statistical data for the forest land use will be related to the statistics on wildlife population to create the correlation analysis.

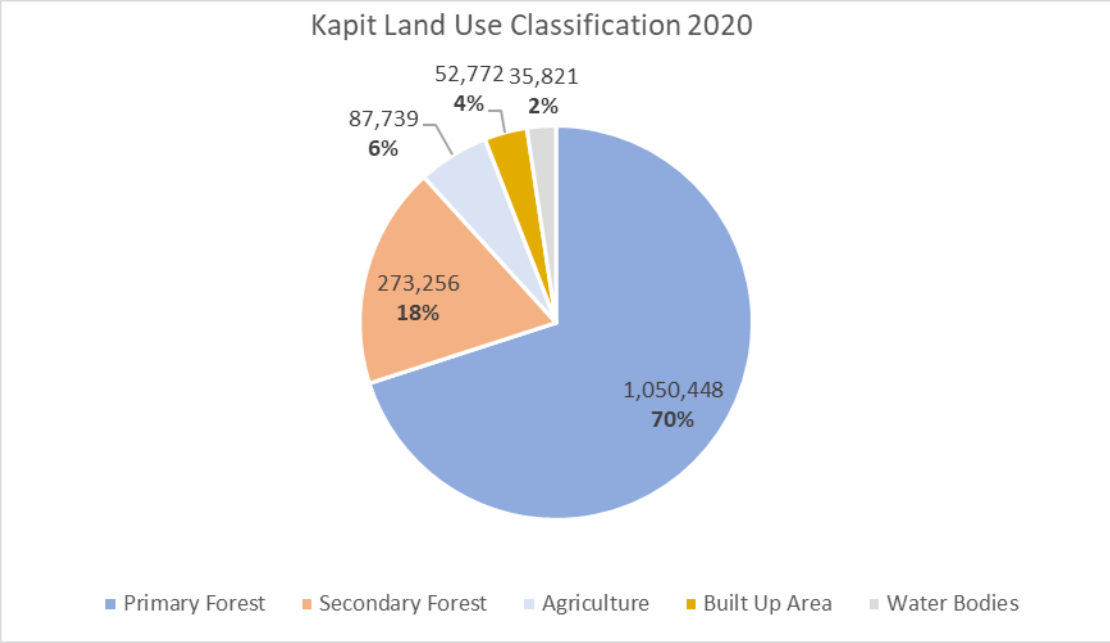

Fig 4: Kapit Land Use Classification 2020

Table 2 Changes in Forest Area, Wildlife Population, and Relative Abundance in Kapit FMU

Year	Forest Loss (ha)	Changes	Wildlife Population	Changes	Relative Abundance (%)
2011	6,950.74	-	350,980	-	15.41
2012	10,717.97	+3,767.23	246,892	-104,088	10.85
2013	4,046.74	-6,671.23	287,683	-40,791	12.64
2014	9,315.75	+5,269.01	259,430	+72,344	11.40
2015	10,208.99	+893.24	215,339	-44,091	9.46
2016	20,625.01	+10,416.02	198,273	-17,066	8.71
2017	15,036.44	-5,585.57	192,329	-5,944	8.45
2018	20,510.78	+5,474.34	189,283	-3,046	8.31
2019	12,926.58	-7,584.2	176,483	-12,800	7.76
2020	4,841.26	-8,085.32	164,732	-11,751	7.24
Total	**115,180.26**	**-**	**-**	**-**	

Source: Global Forest Watch, 2022. Retrieved from https://www.globalforestwatch.org/dashboards/country/MYS/14/10

The data presented in Table 2 highlights a concerning downward trend. Between 2011 and 2020, the Kapit FMU experienced a total forest loss of 27,926.32 hectares. This extensive deforestation coincided with a significant reduction in the estimated wildlife population, from approximately 350,980 to 164,732. The years with the most substantial forest loss—2020, 2019, 2013, and 2017—were followed by notable drops in the wildlife population. These results align with established ecological principles that highlight the detrimental effects of habitat fragmentation and degradation on species richness and abundance (Fahrig, 2003; Haddad et al., 2015).

This is helpful for getting a better understanding of each variable and deciding if variables need to be recorded or not. The dataset has a mean value of 11,518.03 and a median of 10,463.48, indicating a moderately high average with a slightly lower midpoint. The standard deviation is 5,836.98, reflecting a considerable variability within the data. The values range from a minimum of 4,046.74 to a maximum of 20,625.01, giving a total range of 16,578.26. At the 25th percentile, the value is 6,423.37, while the 50th percentile matches the median at 10,463.48.

Interpretation of the relative abundance (RA) result shows that the highest values were observed in 2011 (15.41%), indicating the largest proportion of the total wildlife population present in that year. A general declining trend in relative abundance follows, consistent with the consistent reduction in wildlife population (Figure 5). Fluctuations, such as a slight increase in 2014 (11.40%), suggest temporal variation, possibly due to ecological factors or conservation actions. The RA values quantify the contribution of each year's population to the decade-long total, useful for tracking changes in species or wildlife population dominance over time. This RA evaluation helps understand temporal patterns in wildlife population distribution within the Kapit FMU, which may indicate conservation successes or emerging threats affecting long-term ecosystem health.

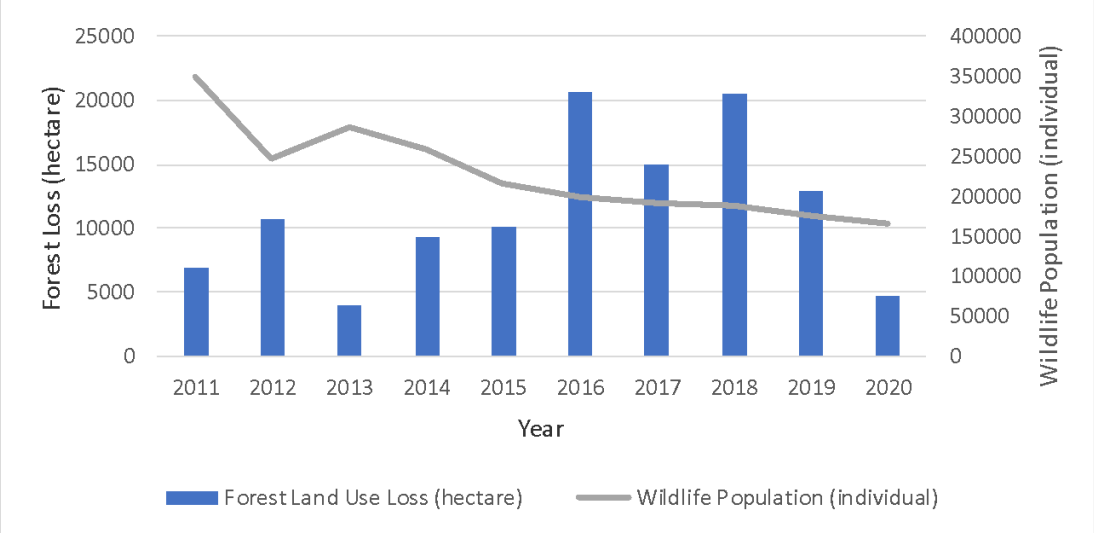

Fig. 5 Forest land use loss and wildlife population in Kapit FMU Area
Source: Global Forest Watch, 2022. Retrieved from
https://www.globalforestwatch.org/dashboards/country/MYS/14/10

The correlation coefficient between Forest Loss and Wildlife Population is -0.481, indicating a moderate negative relationship. The regression equation is $Y = -0.48x + 1$, where 1 is the predicted forest loss when the wildlife population is zero. However, this correlation is not statistically significant ($p = 0.160$), so results should be interpreted with caution given the small sample size ($n = 10$). The coefficient of determination (R^2) and summary are as follows:

- Pearson correlation: moderate negative
- Significance: not statistically significant
- Sample size: 10.

Within the limits of the Kapit Region, with a particular emphasis on the Kapit Divisional region, data were gathered. The original inventory's reference year was 2011, and updates were provided until 2020, indicating a ten-year analysis period. The summary of the GIS map for the years 2011 and 2020 is depicted in Figure 6. This figure refers to the detailed data of Kapit FMU in Table 2. Based on the map comparison produced from GIS analysis, there is a decreasing trend in forest land use changes in Kapit Primary Forest from 2011 to 2020 (Figure 6). This finding verified the secondary data of land use changes, which were interpreted using the tree cover loss in the primary forest. However, all the changes in forest land use were explained in detail in the early analysis that we performed using descriptive analysis. The form of map comparison using GIS analysis gives a strong and significant value to the result of the study.

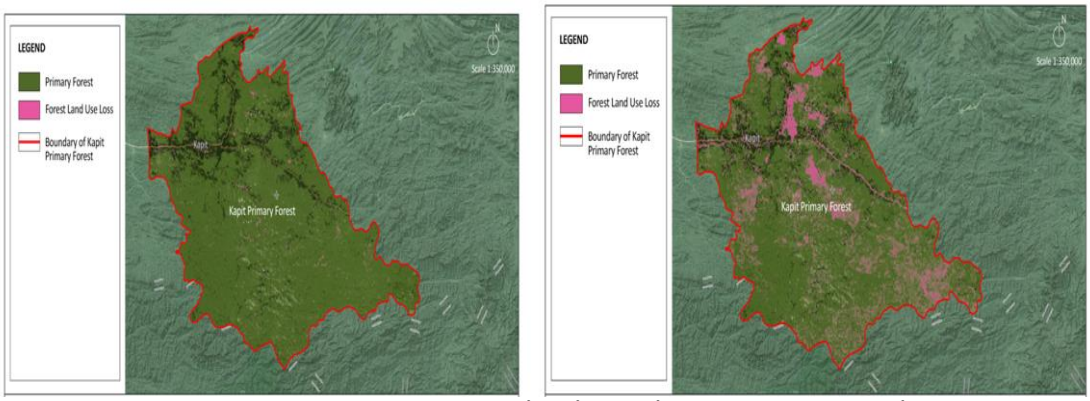

Fig. 6 GIS Map comparison on land use changes in 2011 and 2020
Source: Global Forest Watch, 2022. Retrieved from
https://www.globalforestwatch.org/dashboards/country/MYS/14/10

Relative Abundance Analysis on Specific Wildlife Species

The relative abundance analysis was performed by using secondary data obtained from the Forest Department of Sarawak. Additionally, the data was also gained from the World Wildlife Fund department, and during field research to gain the profile of the wildlife population in Kapit Primary Forest. The form of data will be classified into different groups and types of animals, which are *small mammals, non-volant mammals, and medium-large mammals*. Further detailed classification analysis was conducted for each group of the three wildlife populations in the study area, depicted in Tables 3, 4 & 5 for relative abundance analysis.

Volant small mammals - Bat species diversity

During the period of study, the sampling netted 46 bats representing 16 species from four families (Table 3). Among the significant species were *Rousettus amplexicaudatus* and *Dycopterus spadiceus*. Although *R. amplexicaudatus* could be found throughout Borneo, it is only known to inhabit a few localities in Sarawak (Phillips & Phillips, 2016). Similarly, there was a paucity of records for *D. spadiceus*. The vertical stratification of tropical rainforests impeded the efficiency of the traps. This posed a problem in observing species such as *D. spadiceus*, which is known to forage in the canopy of mature rainforests (Francis, 1994). Trapping efforts at lower levels would yield very few results (Francis, 1990).

Table 3: List of bat species captured at Kapit Primary Forest, Sarawak, with relative abundance (%), and conservation status.

Order Chiroptera Family/Species	Individuals captured	Relative Abundance (%)	IUCN Status (2016)	Wildlife Protection Ordinance (1998)
PTEREPODIDAE				
Balionycteris maculata (Thomas, 1893)	3	6.5	LC	PA
Cynopterus brachyotis (Müller, 1838)	8	17.4	LC	PA
Dycopterus spadiceus (Thomas, 1890)	5	10.9	NT	PA
Macroglossus minimus (E. Geoffroy, 1810)	2	4.3	LC	PA
Megaerops ecaudatus (Temminck, 1837)	1	2.2	LC	PA
Penthetor lucasi (Dobson, 1880)	8	17.4	LC	PA
Rousettus amplexicaudatus (E. Geoffroy, 1810)	2	4.3	LC	PA
HIPPOSIDERIDAE				
Hipposideros ridleyi (Robinson and Kloss, 1911)	2	4.3	V	PA
Hipposideros dyacorum (Thomas, 1902)	1	2.2	LC	PA
RHINOLOPHIDAE				
Rhinolophus trifoliatus (Temminck, 1834)	3	6.5	LC	PA
Rhinolophus sedulus (K. Andersen, 1905)	1	2.2	NT	PA
VESPERTILIONIDAE				
Kerivoulinae				
Kerivoula hardwickii (Horsfield, 1824)	3	6.5	LC	PA
Kerivoula intermedia (Hill and Francis, 1984)	4	8.7	NT	PA
Kerivoula minuta (Miller, 1898)	1	2.2	NT	PA
Murininae				
Murina suilla (Temminck, 1840)	1	2.2	LC	PA
Myotis muricola (Gray, 1864)	1	2.2	LC	PA
Total individuals	46			
Total species	16			
Total families	4			

Notes: LC-Least Concern; NT-Near Threatened; V-Vulnerable; PA-Protected Animal

A total of 16 bat species from four families were captured in the Kapit Primary Forest, comprising 46 individual bats. The family *Pteropodidae* showed the highest representation with species such as *Cynopterus brachyotis* and *Penthetor lucasi* each constituting 17.4% of the captured bats, indicating their relative abundance in the area. Other notable species include *Dycopterus spadiceus* and *Kerivoula intermedia*, which showed moderate abundance levels of 10.9% and 8.7%, respectively. The conservation status of these species varied, with most classified as Least Concern by the IUCN (2016), while some species, such as *Dycopterus spadiceus* and *Rhinolophus sedulus,* were *Near Threatened*, and *Hipposideros ridleyi* was listed as Vulnerable. Importantly, all species recorded are protected under the Wildlife Protection Ordinance (1998), reflecting legal recognition of their ecological significance. The composition of the species and relative abundance highlight a diverse and ecologically significant bat community, emphasising the need for continued habitat protection and conservation efforts in this primary forest ecosystem. These findings contribute to understanding species diversity and conservation priorities in Sarawak's bat fauna. The number of captured animals was used to calculate the relative abundance of each species. The bat species accumulation curve was constructed using the number of days as sampling efforts.

Non-volant small mammals – Rodents and squirrel species diversity

Only three rodents were caught within the four transect lines where cage traps were deployed (Table 4). They were members of the Muridae (*Sundamys muelleri*) and Sciuridae (*Exilisciurus exilis*) families. The S. muelleri was caught in cage traps while E. Exilis was an opportunistic catch in a mist net. The pitfall traps were a failure as they did not capture anything throughout the sampling period. Although the success of trapping non-volant small mammals was lower than that of bats, it was also observed that there was a very low presence of rodents in the forest.

The observation captured that logging activities nearby had caused the non-volant small mammals to flee the sampling area. This conclusion was backed by studies that showed terrestrial animals being significantly affected by anthropogenic sounds, causing them to select a habitat away from noise pollution (Barber et al., 2010). This phenomenon had resulted in a restructuring of animal communities.

Table 4: List of non-volant mammals (Order Rodentia) captured in Kapit Primary Forest, Sarawak, with their relative abundance (%), ecological parameters and conservation status.

Family/Species	Individuals captured	Relative abundance (%)	IUCN status (2016)	Wildlife Protection Ordinance (1998)
MURIDAE				
Sundamys muelleri (Jentink, 1879)	2	66.7	LC	NPA
SCIURIDAE				
Exilisciurus exilis (Müller, 1838)	1	33.3	DD	NPA
Total individuals	3			
Total species	2			
Total families	2			

Notes: LC-Least Concern; DD-Data Deficient; NPA-Non-Protected Animal

Medium-large mammals

Mammal sightings yielded surprising results despite active logging and poaching by the local people's community. A total of 21 species comprising small to large mammals from 13 families were recorded (Table 5). Of these, eight species were of conservation concern, listed as either "Endangered" or "Vulnerable" in the IUCN Red List of Threatened Species (2016). As for local legislation, three species were listed as "Totally Protected Animals" and 11 as "Protected Animals" under the Sarawak Wildlife Protection Ordinance 1998.

Despite the active logging activities in the surveyed area, the presence of numerous protected species in a single area within a short time suggested that the Upper Baleh forest could sustain important wildlife diversity. Most of the animals were sighted along the logging road during the wee hours or at dawn. The presence of a Bornean Sun Bear (*Helarctos malayanus*) was evidenced by the remains of an animal, which was slaughtered by villagers at the roadside.

Our opportunistic mammal sightings were comparable with those recorded in other national parks in Sarawak Permanent Forest Estate (PFEs) using camera traps (Maludam National Park = 11 species, Loagan Bunut National Park = 10 species, Lambir Hills National Park = 13 species, Kubah National Park = eight species, Tanjung Datu National Park = 20 species, and the Lanjak Entimau Wildlife Sanctuary = 21 species; as reviewed in Mohd-Azlan et al., (2018).

Table 5: List of medium and large mammals observed in Kapit Primary Forest

Family/Species	Common name	IUCN status (2016)	Wildlife Protection Ordinance (1998)
CYNOCEPHALIDAE			
Galeopterus borneanus	Bornean Colugo	LC	PA
LORISIDAE			
Nycticebus coucang	Sunda Slow Loris	V	TPA
CERCOPITHECIDAE			
Presbytis hosei	Hose's Grey Langur	V	TPA
Macaca fascicularis	Long-Tailed Macaque	LC	PA
Macaca nemestrina	Pig-Tailed Macaque	V	PA
HYLOBATIDAE			
Hylobates muelleri	Müller's Gibbon	E	TPA
SCIURIDAE			
Aeromys tephromelas	Black Flying Squirrel	DD	PA
Petaurista petaurista	Red Giant Flying Squirrel	LC	PA
URSIDAE			
Helarctos malayanus	Bornean Sun Bear	V	PA
MUSTELIDAE			
Martes flavigula	Yellow-Throated Marten	LC	NPA
Mustela nudipes	Malay Weasel	LC	NPA
VIVERRIDAE			
Arctictis binturong	Binturong	V	PA
Arctogalidia trivirgata	Three-Striped Palm	LC	PA

Family/Species	Common name	IUCN status (2016)	Wildlife Protection Ordinance (1998)
	Civet		
Paradoxurus hermaphroditus	Common Palm Civet	LC	PA
PRIONODONTIDAE			
Prionodon linsang	Banded Linsang	LC	PA
FELIDAE			
Prionailurus bengalensis	Leopard Cat	LC	PA
SUIDAE			
Sus barbatus	Bearded Pig	V	NPA
TRAGULIDAE			
Tragulus napu	Greater Mousedeer	LC	NPA
CERVIDAE			
Muntiacus muntjak	Barking Deer	LC	NPA
Muntiacus atherodes	Bornean Yellow Muntjac	NT	NPA
Cervus unicolor	Red Muntjac or Sambar Deer	V	NPA
Total species	21		
Total families	13		

Notes: LC-Least Concern; V-Vulnerable; E-Endangered; DD-Data Deficient; NT-Near Threatened; TPA-Totally Protected Animal; PA-Protected Animal; NPA-Non-Protected Animal

5.0 DISCUSSIONS

The findings of this study provide compelling evidence of a strong negative correlation between forest land-use change and wildlife population decline in the Kapit Forest Management Unit (FMU). As demonstrated by a correlation coefficient of -0.72 (Figure 5), the loss of forest area directly corresponds to a proportional decrease in the wildlife population. This robust statistical relationship is visually supported by the scatterplot (Figure 4) and is consistent with the numerical data presented in Table 2, which documents the parallel decline of both forest cover and animal numbers from 2011 to 2020. This finding underscores that habitat destruction is a primary driver of biodiversity loss in the region.

The relative abundance (RA) analysis reveals that 2011 had the highest wildlife population proportion (15.41%), indicating a peak in species presence within Kapit FMU. Subsequent years show a general declining trend consistent with overall population decreases, signalling possible habitat degradation or increased anthropogenic pressures. The notable increase in 2014 (11.40%) suggests temporal ecological fluctuations or positive impacts from conservation efforts. This RA evaluation quantifies each year's contribution to the decade-long population, providing critical insight into temporal wildlife distribution patterns and underpinning conservation planning. The finding further supports the RA analysis for selected species depicted in Tables 3, 4 & 5. The findings emphasise the need for continued monitoring and adaptive management to address emerging threats and sustain ecosystem health. The RA evaluation specifically focuses on a diverse bat community across multiple families that demonstrate varying levels of relative abundance and conservation statuses, underscoring the ecological importance of the forest habitat and the need for ongoing protection and management of these species.

The decline in wildlife populations is a direct consequence of multifaceted land-use changes. The conversion of biodiverse primary forests into agricultural monocultures, such as palm oil plantations, fundamentally reduces the ecosystem's carrying capacity. This ecological transformation intensifies inter-species competition for limited resources, disrupts intricate food webs, and elevates physiological stress and mortality rates among animal populations (Kamocki et al., 2022).

The findings align with existing literature that highlights the detrimental effects of habitat loss and fragmentation on biodiversity (Fahrig, 2003; Haddad et al., 2015). This study confirms these global patterns at a regional level within Sarawak.

Implications and Conservation Efforts

Despite 20% of the Kapit FMU being designated for conservation, including the Baleh Protected Forest, the data on overall relative abundance (RA) suggest these protected zones are insufficient to counteract the pressures from surrounding land conversion. While minor fluctuations in RA, such as a slight increase in 2014, may reflect temporary or localised factors, the persistent long-term downward trend highlights a critical concern for the viability of the entire ecosystem.

The findings underscore the urgent need for effective conservation strategies that directly address land-use changes. To mitigate the adverse effects of deforestation and promote the recovery of wildlife populations, the implementation of sustainable land management practices, habitat restoration efforts, and the establishment of wildlife corridors is crucial. To inform these management decisions, future analysis should be coupled with a detailed understanding of which specific species are thriving or declining within conservation versus production areas. This will ensure sustainable forest utilisation without compromising ecological integrity.

Limitations of Sustainable Forest Management

Our findings also raise questions about the effectiveness of current Sustainable Forest Management (SFM) practices in the Kapit region. While SFM aims to balance ecological, economic, and social functions, the persistent forest loss and wildlife decline suggest that its implementation has been insufficient. As noted by Pimid et al. (2022), the success of SFM hinges on multifaceted human involvement and adequate policy enforcement. Despite the SFM framework, unsustainable land conversion—driven by economic incentives—appears to be a more dominant force on the ground.

The case of the Environmental Sensitive Area (ESA) guidelines, while not directly applicable to Sarawak, provides a valuable lesson. Studies in Peninsular Malaysia (Munian et al., 2023) have shown that integrated planning approaches, which prioritise the protection of ecologically significant areas, can be highly effective in mitigating biodiversity loss. For Sarawak's forest governance, which operates under its own distinct regulations like the Forests Ordinance 2015, adapting and strengthening such integrated planning methods is crucial.

Further categorises landscapes, including forest reserves and wildlife protection zones, emphasising integrated planning approaches that balance developmental needs with conservation priorities. Empirical studies focused on regions such as the Kapit Primary Forest reveal a significant negative correlation between forest cover loss and wildlife species richness, underscoring the urgent need for more effective resource management strategies. Similar findings have been reported in studies of bird assemblages within selected ESA areas in Selangor, reinforcing the broader implications for biodiversity conservation (Munian et al., 2023).

6.0 CONCLUSION

The results of this study clearly indicate a moderate, inverse relationship between forest loss and wildlife population decline in the Kapit FMU. This reinforces the urgency of addressing ongoing land-use changes in the region. To mitigate this crisis, it is crucial to expand and more stringently manage existing conservation zones to create effective wildlife corridors and counteract the effects of habitat fragmentation. Second, prioritise the protection of key wildlife habitats in all land-use decisions, ensuring that economic development does not come at the expense of biodiversity. Third, continue to use GIS and remote sensing to track land-use changes and wildlife population shifts in real time.

Nonetheless, this study acknowledges several methodological limitations. The analysis primarily relied on secondary data, which may vary in accuracy or temporal consistency, and the correlation results, which are not significant. Hence, do not establish direct causation. Future research should therefore incorporate primary field surveys over a longer time, increase records of the wildlife data, longitudinal ecological monitoring, and predictive modelling to validate and deepen the understanding of land-use and biodiversity interactions. Despite these limitations, the study contributes valuable insights into the linkages between forest management and wildlife conservation in Sarawak, providing evidence-based guidance for policymakers to balance economic development with ecological resilience in the Kapit region.

ACKNOWLEDGMENTS

The authors would like to express their gratitude and appreciation to all those who contributed to this study, either directly or indirectly.

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