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DISTANCE-BASED NATURAL AND MAN-MADE HABITAT FACTORS SHAPE BIRD COMMUNITY STRUCTURE IN OIL PALM-FOREST INTERFACES

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ABSTRACT

Land sparing of high conservation value forests (HCVFs) for conservation efforts is one of the sustainable practices in oil palm plantations. The oil palm-forest interface is linked to increased biodiversity, but how the habitat factors influence biodiversity is not well understood. The study investigated the influence of distance-based natural and man-made habitat factors on bird community structure within oil palm-forest interface sites in Peninsular Malaysia. The study compared bird communities across different oil palm landscapes: monoculture (MCP), with forest patch (FPP) and adjacent to a large forest (NFP). The findings demonstrate that NFP supports the highest species richness and diversity, followed by FPP and least at MCP. Closer distance to settlement yields higher total bird and omnivore abundance, but the opposite trend was found with frugivores and insectivores. Surprisingly, a closer distance to an unpaved road also revealed higher total bird, frugivore and insectivore abundance. Although natural habitat factors posed no significant influence on the total bird abundance, guild-specific and forest-dependency groups, they still enhance bird diversity at the landscape level through spill-over effect. Overall, these findings underscore the importance of incorporating the distance-based habitat configuration, as well as the value of preserving and maintaining HCVFs for sustainable planning while highlighting the conservation plantation strategies.

Keywords: agriculture, birds, high conservation value forests (HCVFs), spill-over effect.

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INTRODUCTION

Agricultural activity is often associated with biodiversity loss (Adhikari et al., 2019). The same notion is especially relevant for oil palm plantations (OPP), which are predominantly established in tropical rainforest region that are recognised as biodiversity hotspots and harbours a wide range of flora and fauna (Fitzherbert et al., 2008; Waide, 2018). Despite biodiversity concerns, the oil palm industry remains strong, due to its economic contribution to the country (Nasution et al., 2021). OPP in Malaysia takes up a large amount of land, spanning approximately 5.65 million hectares as of 2023 (Parveez et al., 2024). These plantations encompass some unsuitable agricultural areas such as hilly or swampy areas, which are often left for high conservation value forests to safeguard ecologically and socially significant habitats (Roundtable Sustainable Palm Oil [RSPO], 2023). However, there were contradictory opinions on the effectiveness of fragmented forests to conserve local species (Azhar et al., 2011; Edwards et al., 2010; Oon et al., 2023). Still, utilising unused areas for conservation purposes is a good alternative as forest patches can positively influence bird diversity (Azhar et al., 2011). Currently, there is no absolute approach to conserving biodiversity in OPP and researchers believe the best strategy to achieve sustainability in the oil palm industry is by combining the land sparing and land sharing approaches (Khasanah et al., 2020; Tälle et al., 2023; Yahya et al., 2017).

In an effort to improve the sustainability of the oil palm industry, the RSPO provides guidelines to reduce the negative effects of OPP on wildlife species (RSPO, 2024). The RSPO initiative, particularly reducing forest loss for palm oil expansion, was proven to be effective in primate conservation as demonstrated in the RSPO certified plantations compared to the non-certified plantations (Meijaard et al., 2017). However, their effectiveness for wildlife conservation is still underrepresented as data were insufficient, instead mostly contributed by planters' initiative to adopt conservation-friendly practices (Meijaard et al., 2020). To further preserve biodiversity in OPP, a land-sharing approach was recommended, with a preference for polycultures over monocultures (Yahya et al., 2017). This approach was generally accepted by smallholders, by leveraging their plantation land for other crops (e.g., bananas, coconut, tapioca and pineapple) either for domestic consumption or to sell for money to diversify their income (Azhar et al., 2014, 2015). Indeed, this approach was found to improve biodiversity such as birds in OPP. However, polyculture systems, including agroforestry, present considerable management challenges, particularly when implemented across large-scale plantation landscapes (Liu et al., 2018). Apparently, a more feasible approach accepted by conservationists is land sparing, in which part of land is reserved for conservation efforts, particularly high conservation value forest (HCVF) within a plantation (Edwards et al., 2010). While this emphasises the natural habitats for biodiversity, the ecosystem services provided have also increased the plantation yield, as evidenced by remote-sensing data (Oon et al., 2023).

As a way to measure habitat quality, previous studies suggest the use of indicator species in monocultures and forested landscapes (Simamora et al., 2021). To achieve this, birds are often used as they are widely recognised as biological indicators due to their sensitivity to environmental changes, making them excellent targets for assessing habitat health. This taxon has been widely studied due to its ease of spotting and has been reported to be a good biological control agent in the OPP (Koh, 2008; Razak et al., 2020; Tohiran et al., 2024; Yahya et al., 2024). Considering the diversity of pests in OPP, it is in the planter's best interest to diversify pest-control methods such as utilising biological control agents (Chung, 2012; Egonyu et al., 2022). One of the popular bird species introduced in OPP is the Barn owl, *Tyto alba javanica* which was used to control rat populations (Zainal Abidin et al., 2022). Aside from biological control, the bird's role in the ecosystem includes seed dispersal and pollination, but these functions were only directly beneficial to understorey vegetation, which is typically dominated by *Melastoma malabathricum* (Siregar et al., 2016). Some planters reduce this understorey vegetation to improve crop yield, thereby negatively affecting bird abundance and becoming a threat to sustainable oil palm production.

Aside from management approaches, recent studies have also emphasised the importance of habitat factors on bird diversity (Amit et al., 2021; Azhar et al., 2011; Yahya et al., 2016). Notably, these studies have found distance-based variables such as natural and man-made habitat factors to have a significant effect on bird species composition particularly in the oil palm landscape (Amit et al., 2021; Azhar et al., 2011; Yahya et al., 2016). However, to our knowledge, there are no studies investigating how natural (forest patch and forest border) and man-made (settlement, water source, paved road and unpaved road) habitat factors influence birds in OPP in one framework.

Therefore, this study aims to investigate how different oil palm landscapes influence bird communities. Additionally, this study also examines how distance to the natural and man-made habitat factors influences total bird abundance and the community structure (based on feeding guild and forest-dependency), across four oil palm-forest interface sites in Peninsular Malaysia. We hypothesised that bird diversity is higher in plantations next to the large forest and forest patch, compared to the monoculture plantations, in which the natural and man-made habitat factors are responsible for influencing the bird abundance and community structure. This information provides an evidence-based foundation for redesigning and improving existing OPP landscapes, prioritising habitat factors that support good biodiversity structure. Additionally, information about bird assemblages inhabiting the different landscape types could reveal the ecosystem services provided by the natural habitats and birds towards the OPP landscape. Thus, this study is anticipated to evaluate the value of maintaining forest habitats in commercial agricultural plantations to achieve ecological balance.

MATERIALS AND METHODS

Ethics

This study followed the guidelines by the Universiti Kebangsaan Malaysia (UKM) Animal Ethics Committee (reference: FST/2023/FARAH SHAFAWATI/22-MARCH/1328-MARCH-2023-OCT.-2025). Permission to conduct this study was obtained from the local authorities including Felda Global Ventures Plantation Malaysia (FGVPM), Department of Wildlife and National Parks [reference: JPHLTN. 600-6/1/4 JLD2 (119)] and Forestry Department of Peninsular Malaysia [reference: JH/100 Jld. 35(14)].

Sampling Design

This study was carried out in OPPs located in four different states in Peninsular Malaysia (*Figure 1*). These site selections are based on several criteria, which include the presence of: 1) Monoculture plantation (MCP), 2) forest patch plantation (FPP) and 3) large forest adjacent to the plantation (NFP). MCP is defined as a plantation that consists mainly of palm oil trees, whereas FPP is defined as forest fragments (~100 ha) that are surrounded by OPP and NFP is a plantation adjacent to a large forest (~1,000 ha) (Pardini, 2004). The chosen plantations were located at Lepar Utara, Pahang (3° 53′ 53.15″ N, 102° 48′ 59.10″ E), Setiu, Terengganu (5° 32′ 30.69″ N, 102° 41′ 34.72″ E), Tenggaroh, Johor (1° 58′ 22.16″ N, 104° 5′ 21.43″ E) and Aring, Kelantan (4° 58′ 22.18″ N, 102° 27′ 5.90″ E).

The sampling was conducted sequentially across landscape types within each state for a duration of 50 days from May 2023 to August 2024. At each state, 30 sampling points were selected representing 10 points at different landscape types, making a total of 120 sampling points altogether. To minimise potential double counting, sampling stations were spatially separated and surveys were conducted in a consistent order, avoiding repeated counts of the same flock within the same sampling session.

Field Sampling Method

Bird sampling covered an area of 500 m radius at each landscape type that was centred at the forest border except for MCP as illustrated in *Figure 2*. Three transect lines measuring 1,000 m were established across the sampling area, and 10 mist nets (9 m × 4 m × 30 mm) were deployed at each landscape at approximately 0.5–3.0 m from the ground. Mist nets were deployed randomly along the transect line but are spaced at least 100 m from each other, especially at potential flight path locations. Mist nets were opened from 0700–1800 hr and inspected every two hours. Captured birds were temporarily stored in cloth bags prior to identification at research stations. Mist nets were particularly useful to target elusive understorey birds that cannot be easily detected by point counts (Tan et al., 2024).

Point count surveys were conducted alongside mist nets (10 points) to account for canopy level birds. Birds were detected visually and acoustically at a radius of approximately 50 m at each point. A duration of 5 min was allocated at each point for bird census, which was carried out in the morning hours (0700–1100 hr) (Lee & Marsden, 2008). A bird census was done using binoculars (MONARCH M5 10×42 Nikon Corp., Japan). Birds detected were recorded for species and abundance. All birds were identified according to Birds of South-East Asia (Robson, 2020).

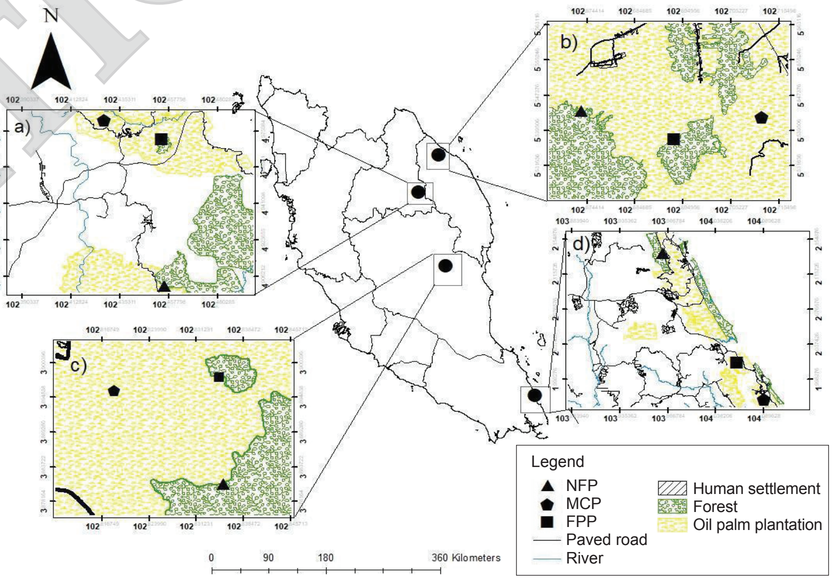
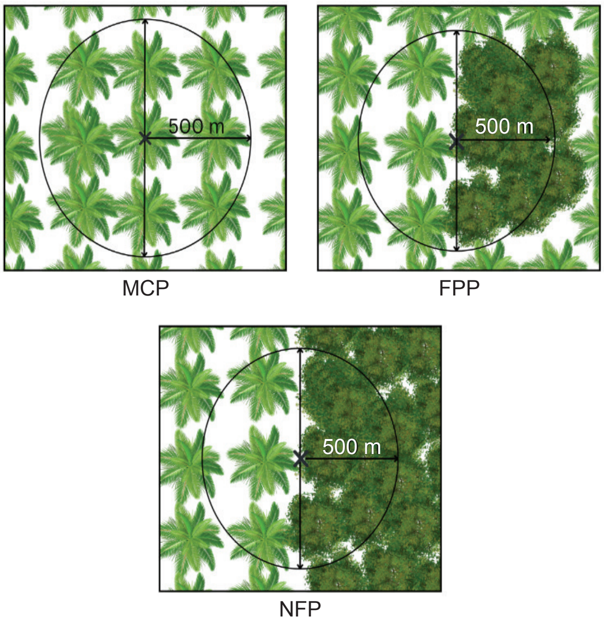


Figure 1. *Map of sampling locations in Peninsular Malaysia (a) Aring, Kelantan; (b) Setiu, Terengganu; (c) Lepar Utara, Pahang; (d) Tenggaroh, Johor.*



Note: MCP - monoculture plantation; FPP - forest patch plantation; NFP - next to forest plantation.

Figure 2. Illustration of study area at each landscape of oil palm plantation (OPP).

Each bird species was assigned to six feeding guilds based on their main diet: Carnivore (C), granivore, frugivore, insectivore, nectarivore and omnivore following a study by Petol et al. (2021). Birds with a mix of animal and plant-based diets such as frugivore-insectivore and granivore-insectivore were considered omnivores (Petol et al., 2021). Additionally, birds were categorised based on their habitat or forest-dependency status namely; forest, forest edge and plantation/open country to distinguish the distribution of birds at each landscape (Jeyarajasingam, 2012; Mohd-Taib et al., 2016; Robson, 2020). For birds that have multiple habitat niches, we categorised them based on the location of the highest occurrence in which they were detected in this study.

Habitat Variable Measurement

The habitat characteristics that we studied include natural (distance to forest patch and distance to forest border) and man-made (distance to human settlement, distance to water sources, distance to unpaved road and distance to paved road) habitat factors which were measured from each sampling point using Google Earth Pro (Google Inc. USA) (Callaghan et al., 2018). These characteristic,s were based on features in OPP that were reported to have an impact on bird diversity (Atikah et al., 2019). To measure the distance from each sampling point to different habitat variables, we designated a single reference point for each variable within each landscape of each locality. The reference point for human settlement was the building at the edge of the nearest village. For the forest patch and forest border, the boundaries of the nearest fragmented forest (~100 ha) and large forest (~1,000 ha) were selected, respectively, relative to the sampling point. The largest water canals in the study area were chosen as the reference point for water sources. For unpaved roads, the widest unpaved road in the area was designated as the reference point, whereas the nearest paved road to the sampling point was selected as the reference for paved roads. All units were measured in meters.

Statistical Analysis

Prior to all analysis, we combined the bird abundance and richness data from mist netting and point counting methods. For our analysis, raw count data rather than modelling detection probability as previous work has shown trends inferred from raw counts can be similar to those from detection-corrected models (Etterson et al., 2009). Under these conditions, any residual detectability bias in our study is limited and does not affect the main conclusions. The diversity metrics including diversity (H'), dominance (D) and species richness estimator (Chao-1), were calculated using Paleontological Statistics (PAST) software version 2.17c. Subsequently, individual-based rarefaction curves were generated to evaluate species richness across different landscapes with varying sample sizes (Magurran, 2013). This was accomplished using EcoSim software version 7.71. Rarefaction curves allow for the standardisation of sampling efforts, enabling precise comparisons of species richness between datasets (Mohd-Taib et al., 2022). Next, the Kruskal-Wallis test was used to compare species richness and abundance at different landscapes as well as feeding guild and forest dependency for each landscape.

Two generalised linear mixed model (GLMM) test was carried out in this study. The first model aims to see how the habitat variables influence total and guild-specific bird abundance across the landscape using the glmmTMB package. (Azhar et al., 2011, 2015). For this analysis, total bird abundance and the three most abundant feeding guilds (frugivore, insectivore and omnivore) were treated as the response variables, while distance-based habitat variables (e.g., distance to settlement, distance to forest patch, distance to forest border, distance to water sources, distance to unpaved road and distance to paved road) were included as fixed effects. Meanwhile, sites were included as the random effect. Although the number of sites is relatively low (four sites), we treated the site as a random effect as the main focus of this paper is on landscape categories and distance-based habitat variables rather than site-specific differences. Additionally, GLMMs run that included sites as fixed effects (not shown), produced results with similar pattern to the current models. While the first model assessed total and guild-specific responses, the second model evaluated how bird abundance in each forest-dependency group (forest, forest edge and open country) was influenced by the same set of habitat variables (distance to settlements, forest patch, forest border, water sources, unpaved roads and paved roads). The second GLMM analysis uses the same model as the first GLMM. Initially, a poisson log-link function was used for both models but was consequently changed to a negative binomial as overdispersion was detected in the data. Before running the model, we tested for multicollinearity among predictor variables using correlation tests. The model selection was guided by Akaike's Information Criterion (AIC) where we aim for the lowest AIC values to ensure the data is best fitted to our model. Statistical tests were conducted in R version 4.5.2.

Principal component analysis (PCA) was performed to visualise habitat gradients based on the environmental variables measured at each sampling point. The analysis was conducted using an environmental dataset, with landscape type as a factor. Prior to analysis, the data were log-transformed, multiplied by -1 to improve interpretability and normalised to standardise the scale. Distance-based habitat variables, including distance to settlement, distance to forest patch, distance to forest border, distance to water sources, distance to unpaved road and distance to paved road, were fitted as vectors onto the PCA ordination. Pairwise Permutational Multivariate Analysis of Variance (PERMANOVA) was conducted to assess the difference in bird assemblages at each landscape type. The analysis was based on Bray-Curtis similarity resemblance derived from presence-absence data. PCA and PERMANOVA analysis was carried out in Primer version 7.0.24.

RESULTS AND DISCUSSION

Species Diversity and Assemblages at Three Different OPP Landscapes

A total of 770 mist net hours and 3.33 point count hours at each landscape was used. Overall, 2,696 individual birds representing 92 species from 37 families were recorded throughout the study area. From these, NFP recorded the highest species richness (67 species, H' = 3.388), followed by FPP (52 species, H '= 3.181) and MCP (36 species, H' = 2.611). The diverse species of birds in NFP and FPP are mainly attributed to the forested landscapes near the plantation. The forested landscapes are characterised by their diverse floral species and multiple canopy layers, creating complex ecosystems that can support greater wildlife abundance and diversity (Amit et al., 2021). This wildlife is then 'spilled' into the plantation due to spillover effects, thus increasing bird richness in NFP and FPP (Anderson et al., 2022; Oon et al., 2023). In contrast, MCP is characterised by uniform vegetation and a single canopy level, forming simpler ecosystems that cater to a limited range of wildlife species (Yahya et al., 2017). This results in the dominance of adaptable bird species with MCP exhibiting the greatest dominance (D = 0.1202) followed by FPP (0.06158) and NFP (D = 0.05169). Most of the bird species (87%) we detected were classified as low conservation value species or IUCN Least Concern. Four vulnerable species were identified (*Aceros subruficollis, Buceros bicornis, Argusianus argus* and *Acridotheres javanicus*) and eight near-threatened species (*Calyptomena viridis, Chloropsis cyanopogon, Megalaima mystacophanos, Cyornis turcosus, Platylophus galericulatus, Stachyris maculata, Malacopteron affine* and *M. magnum*) which were mostly found in NFP and FPP but only one was detected in MCP. The presence of threatened and vulnerable birds in FPP and NFP suggests that the RSPO requirement for HCV area in OPPs proves to enhance bird species richness and abundance. Our species accumulation curve approached the asymptote for all sites and confirmed that our sampling efforts are adequate and possibly cover all species (*Figure 3*).

On another note, spillover effects were evident in our study, as forest-dependent species were occasionally detected in plantations. However, the spillover effect is limited to plantations with 'soft' edges at the oil palm-forest interface as the landscape harbours dense vines and understorey vegetation which improves habitat connectivity and facilitates the movement of wildlife across boundaries (Chapman et al., 2019). In contrast, there were limited spillover effects in plantations with 'sharp' edges, which act as strong barriers, preventing forest-dependent species from crossing into the plantations to forage (Chapman et al., 2019; Gray et al., 2016).

In terms of feeding guild, the birds were mainly insectivores (38 species) followed by frugivores (18 species), carnivores (15 species), omnivores (10 species), granivores (six species) and nectarivores (five species). There were no significant differences between landscapes for species abundance ($\chi^2(2)$ = 0.931, df = 2, p = 0.628) and species richness ($\chi^2(2)$ = 0.981, df = 2, p = 0.612). Only feeding guilds in MCP varied significantly ($\chi^2(5)$ = 13.03, df = 5, p = 0.023), but no significant difference in the distribution of feeding guilds at both FPP $\chi^2(5)$ = 7.221, df = 5, p = 0.205) and NFP $\chi^2(5)$ = 6.51, df = 5, p = 0.26).

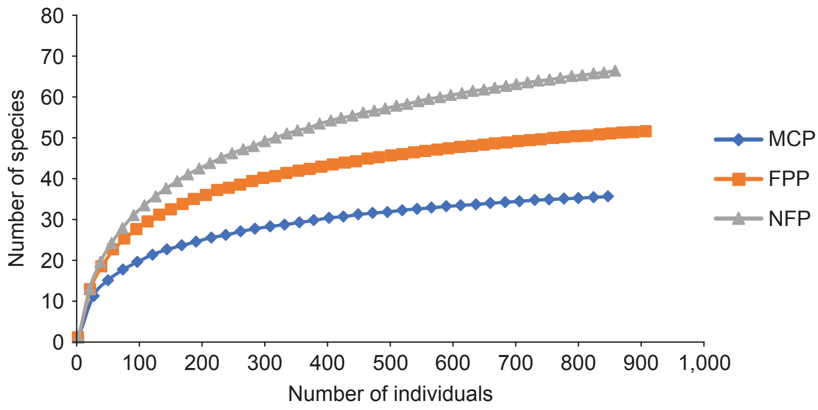


Figure 3. Species accumulation curve of species richness detected in monoculture plantation (MCP), forest patch plantation (FPP) and next to forest plantation (NFP) landscapes.

Omnivores are highly represented in monoculture landscapes, while insectivores showed the highest abundance in the oil palm-forest interfaces (*Figure 4*). This indicates that omnivores, particularly urban birds, are the most resilient and well-adapted group, likely due to their ability to exploit diverse food sources and adjust to habitat changes (Mohd-Taib et al., 2022). Omnivores in the OPPs mainly consist of *Acridotheres javanicus* and *Gallus gallus*. *A. javanicus* is highly adaptable and tends to flock near cattle herds, reaching up to approximately 50 individuals. This behaviour is likely due to cattle herds attracting prey insects such as *Oecophylla smaragdina*, *Coptotermes curvignathus*, *Valanga nigricornis*, *Sarcophaga aurifrons* and *Musca domestica* which may be the main food source for this species (Sudaryanto et al., 2020).

On the other hand, the abundance of insectivores at the oil palm-forest interfaces is likely due to the proximity to forests which exhibit similar attributes to natural landscapes. *Mixornis gularis*, a forest associated insectivorous bird, was especially abundant at the forest edges. This particular species is considered a generalist among three babblers as indicated by (Juliana & Gawin, 2020) due to its foraging behaviour and are similarly abundant in disturbed habitats. Other notable insectivorous forest-edge species were *Copsychus saularis*, *Bubulcus ibis* and *Orthotomus sutorius* as they are also abundant in the area. *B. ibis* exhibited similar behaviour as *A. javanicus* as they primarily feed on insects that are disturbed due to cattle grazing (Jumilawaty et al., 2021; Siegfried, 1971). In addition, forest and forest edge species were more abundant in the forest interior such as jungle babblers, shamas and malkohas. This suggests that greater habitat heterogeneity and diet selection in the oil palm-forest landscapes favour forest associated-insectivorous species leading to their increased abundance in the area (Mohd-Taib et al., 2022).

Nectarivores were among the least abundant across all landscapes and were absent in the monoculture plantation. Similar to a study by (Navarro et al., 2021), suggesting that monocultures were not suitable for nectarivores as the area is dominated by oil palm trees while fruiting trees were scarce. Although understorey vegetation in OPP was dominated by *Melastoma malabathricum*, a potential food source of nectarivores and frugivores (Siregar et al., 2016), nectarivores are sensitive to human activity causing them to be absent in the monoculture landscape (Navarro et al., 2021). Frugivores on the other hand have varying levels of resilience with some species being well-adapted to human activities such as *Pycnonotus goiavier* as they can survive even with proximity to human settlement, evidenced by their abundance in the monoculture and plantation with forest patches in this study (Herrera & García, 2009; Mohd-Taib et al., 2016).

As for the birds dependency on the forest, they were significantly different across landscapes with MCP ($\chi^2(2)$ = 31.003, df = 2, p < 0.01), FPP ($\chi^2(2)$ = 20.894, df = 2, p < 0.01) and NFP ($\chi^2(2)$ = 6.721, df = 2, p = 0.035). This study found that plantation or open country birds were dominant in MCP (*Figure 5*). On the other hand, forest edge birds dominated the FPP and NFP landscapes, while forest species maintained the lowest mean rank at all landscapes but were relatively higher in NFP.

Bird assemblages were distinct between landscape types such as monocultures, plantations with forest patches and plantations adjacent to intact forests. Plantation or open country birds exhibit a trend of great abundance in degraded habitat but lower abundance in natural landscapes. Similarly to (Azhar et al., 2011), he consistently found high abundance of plantation/open country and forest edge birds such as *C. saularis*, *P. goiavier*, *Halcyon smyrnensis*, *G. gallus* and *O. sutorius* in degraded habitats including plantation estate and smallholder plantation. In contrast, forest

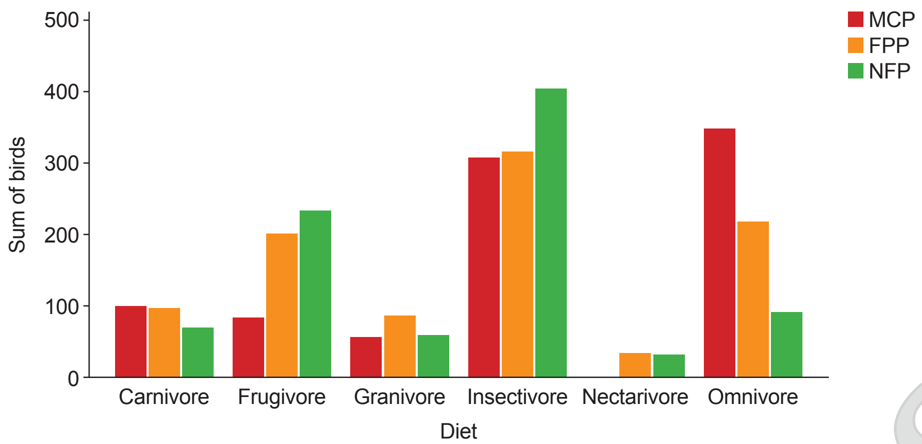


Figure 4. Bar graph illustrates the sum of birds according to their feeding guild at monoculture plantation (MCP), forest patch plantation (FPP) and next to forest plantation (NFP).

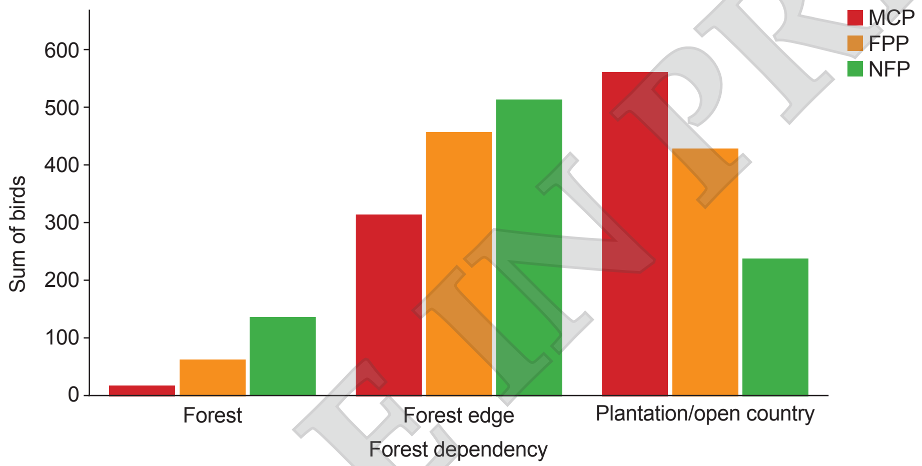


Figure 5. Bar graph illustrates the sum of birds according to their forest dependency status in monoculture plantation (MCP), forest patch plantation (FPP) and next to forest plantation (NFP).

edge birds dominated oil palm-forest interface landscapes. This is likely due to forested borders providing a perching area for insectivorous birds to hunt for flying insects in open habitats (Mulyani et al., 2020; Ortega & Capen, 2002). *M. gularis* were especially abundant at the forest boundary of forest patches and intact forest indicating their hunting preference in the area. Increased vegetation diversity at the forest boundary also increases frugivorous and nectarivorous birds in the area (Okuda et al., 2011) as spiderhunters and some bulbuls were detected in the area which are otherwise entirely absent in monocultures.

Influenced of Distance-based Habitat Factors on Bird Community Structure

GLMM was conducted to assess the influence of the predictor variables (distance to settlement, distance to forest patch, distance to forest border, distance to water source, distance to unpaved road, distance to paved road and landscape types) on the response variable (species richness and abundance). In our analysis, all variables have low multicollinearity and were used in the GLMM model. The result indicates a significant effect of all the predictor variables on the bird abundance ($p < 0.01$) except distance to nearest settlement ($p = 0.942$) and distance to paved road ($p = 0.282$) (*Table 1*).

The study indicates that distance to natural habitat factors did not significantly ($p > 0.05$) contribute to total bird abundance. Surprisingly, the total bird abundance increased with greater distance from the forest border and forest patch. The lower bird abundance with proximity to the forest-edge habitats may be attributed to high predation and parasitism rates at the oil palm-forest interface (Valentine et al., 2019). In this study, *Spilornis cheela*, which is a predator species, was particularly abundant in forested landscapes especially near the forest boundary, indicating higher predation risk in these areas. Increased predation pressure by the predatory bird likely reduced the abundance

TABLE 1. THE EFFECTS OF DISTANCE TO NATURAL AND MAN-MADE HABITAT FEATURES ON (A) TOTAL BIRD ABUNDANCE AND FEEDING GUILDS (OMNIVORES, FRUGIVORES, INSECTIVORES) AND (B) FOREST-DEPENDENCY GROUPS (FOREST, FOREST EDGE, OPEN COUNTRY)

(A) Feeding guild

Factor type	Variable	Total abundance			Omnivore			Frugivore			Insectivore		
		β	SE	p	β	SE	p	β	SE	p	β	SE	p
Natural	Distance to forest patch	0.000092	0.000081	0.255	–0.097	0.203	0.634	–0.100	0.113	0.376	0.159	0.127	0.211
	Distance to forest border	0.000094	0.000053	0.077	0.181	0.263	0.492	0.036	0.160	0.823	0.236	0.150	0.115
Man-made	Distance to settlement	–0.000045	0.000100	0.650	–0.258	0.275	0.346	0.298	0.139	0.032*	0.285	0.128	0.026*
	Distance to water sources	–0.000249	0.000306	0.417	–0.127	0.165	0.441	0.087	0.103	0.401	0.034	0.110	0.759
	Distance to unpaved road	–0.000986	0.000385	0.01*	–0.121	0.213	0.570	–0.226,	0.106	0.033*	–0.060	0.108	0.579
	Distance to paved road	0.000045	0.000118	0.705	–0.237	0.299	0.429	–0.054	0.139	0.698	–0.108	0.144	0.454

(B) Forest dependency

Factor type	Variable	Forest			Forest edge			Open country		
		β	SE	p	β	SE	p	β	SE	p
Natural	Distance to forest patch	–0.13130	0.205	0.522	0.095043	0.115	0.409	0.04764	0.192	0.804
	Distance to forest border	–0.43077	0.256	0.093	0.148791	0.144	0.302	0.38924	0.235	0.098
Man-made	Distance to settlement	0.68599	0.249	0.006*	0.048198	0.128	0.706	–0.14100	0.214	0.509
	Distance to water sources	–0.09874	0.192	0.607	–0.07114	0.099	0.474	0.01565	0.14	0.911
	Distance to unpaved road	0.38718	0.201	0.054	–0.1789	0.098	0.067	–0.28749	0.155	0.063
	Distance to paved road	–0.41137	0.171	0.016*	–0.00465	0.136	0.973	0.02505	0.217	0.908

of prey at the forest boundary. Similarly, Valentine et al. (2019) found that smaller birds nesting in shrubs near the forest edges faced a higher predation rate by predator birds such as hawks and larger songbirds. These findings suggest that close edges can create ecological traps, where seemingly favourable habitats are undermined by high predation and parasitism pressure (Khamcha et al., 2018). However, at the landscape level, proximity to natural landscapes such as forest patches and large forests still promotes higher species richness through spillover of forest dependant species (Oon et al., 2023).

Interestingly, man-made habitat factors have a greater influence on the bird community. We found that bird abundance increased, with closer distance to unpaved roads (β = –0.000986, p = 0.01). This can be explained by the presence of understorey vegetation near the roadside which enhanced habitat heterogeneity and food sources (Kroeger et al., 2022; Ortega & Capen, 2002). In our study area, oil palm trees are not planted immediately adjacent to unpaved roads, leaving narrow roadside strips. Where these strips are less intensively managed (e.g., infrequent spraying or slashing), wild grasses and shrubs can establish. This vegetation provides microhabitats that increase local habitat complexity and provides food sources and shelter that are otherwise limited within the plantation (Ortega & Capen, 2002). This allows some sections of the unpaved roads to be particularly conducive to the survival of insectivorous birds. Although unpaved roads are often associated with disturbance, they do not necessarily indicate habitat degradation. These unpaved roads can also function as movement corridors for tolerant species especially during periods of low human activity in the plantation (Morelli et al., 2014). Additionally, Ortega and Capen (2002) reported that roads provide perches in open habitats as a prey-seeking strategy for some insectivorous birds. Unpaved roads were also known to function as crossing pathways for certain mammals (Askins, 1994; Craveiro et al., 2025) and this finding might be true for birds especially for open-country species which were frequently spotted in these areas, such as *P. goiavier, H. smyrnensis* and *C. saularis*. Although rare, occasional roadkills on unpaved roads may have attracted opportunists such as *A. javanicus* and *Corvus splendens*, further increasing bird abundance in the area (D'Amico et al., 2013; Schwartz et al., 2018).

Unsurprisingly, total bird abundance was higher near settlements and is likely influenced by high numbers of omnivorous birds in the area. In this study, omnivorous birds mainly consist of *A. javanicus* which were spotted near cattle herds and are generally near settlements as previously mentioned (Sudaryanto et al., 2020). Notably, the garbage dump at the edge of settlements also harbours high numbers of *A. javanicus*, elucidating their tendency to become opportunistic feeders. This is because some omnivores are generalists and can flourish even in anthropogenic areas (Arazmi et al., 2022). Frugivores (β = 0.298, p = 0.03) and insectivores (β = 0.285, p = 0.03) on the other hand exhibit contrasting patterns from omnivores as they revealed higher abundance with greater distance from human settlements. Human settlements typically harbour little structural diversity that are not suitable for wildlife diversity. Although generalist birds flourish in anthropogenic areas, the same phenomenon is not true for frugivores and insectivores which are more sensitive due to anthropogenic pressure, limited resources and reduced habitat complexity (Campo-Celada et al., 2022; Kurucz et al., 2021). Forest-dependency analysis further supported this pattern where forest birds were significantly more abundant at sites further from settlements and tended to avoid unpaved roads, whereas open-country birds were more abundant near unpaved roads. On the other hand, total bird abundance increases with closer distance to water sources. Similarly to (Ramlah et al., 2024), she found that water sources increase bird diversity albeit mainly avians of the Rallidae family. Ponds that are used to treat palm oil mill effluent (POME) were also found to support a wide range of bird species (Hassan-Aboushiba et al., 2011). In our study, we found forest edge birds, such as *B. melanocephalos* and *P. finlaysoni* within the plantation interior, far from the forest boundary. This phenomenon is likely attributed to water canals combined with dense understory vegetation, creating a suitable microhabitat within the plantation that may provide food resources and shelter for forest edge species (Gutierrez Al-Khudhairy et al., 2023; Razak et al., 2020). We did not directly quantify vegetation characteristics at each sampling point, hence our discussion was inferred based on field observations and previous findings. Future studies should incorporate standardised methods to measure vegetation characteristics such as vegetation cover, undergrowth height and oil palm height as complementary data to analyse their influence on bird diversity especially in OPP.

Our results suggest that edge effects operate across both natural and human-made boundaries. Natural forest edges may function as ecological filters due to predation risk, microclimate and resources, which can shift bird abundance and habitat use near the forest-plantation interface (Valentine et al., 2019; Vallejos et al., 2024). In contrast, human-made edges such as unpaved roads and water canals can create structurally complex strips of vegetation within plantations and provide foraging opportunities, cover and movement pathways for tolerant and forest edge species (Morelli et al., 2014; Ortega & Capen, 2002). Together, these patterns indicate that "edges" in oil palm landscapes are not uniform but the different edge types can support different ecological niches and may favour different bird groups. We note that this study did not directly measure edge effects (e.g., microclimatic gradients, vegetation structure, or predator activity measured along transects). However, the distance-based variables used here act as a proxy for edge proximity and allow us to infer potential edge-associated patterns in bird abundance. Future work could test these mechanisms directly by pairing bird surveys with standardised measurements of vegetation structure and microclimate across forest edges and roadside edges.

Pairwise permanova analysis indicates that bird compositions were significantly different between MCP and FPP (t = 1.4378, $p(perm)$ = 0.031) as well as MCP and NFP (t = 1.7918, $p(perm)$ = 0.003). However, FPP and NFP indicate no significant difference in bird composition (t = 0.98834, $p(perm)$ = 0.481). The PCA biplot indicates distinct clustering of our sampling points in different landscapes (*Figure 6).* The first principal coordinate accounted for 26.5% of the variation whereas the second principal coordinate accounted for 23.7% (*Table 2*). As reflected in previous results, MCP exhibits the lowest diversity due to highly degraded habitat as represented by proximity to settlements and paved roads. Conversely, FPP which were more influenced by unpaved road and proximity to forest patch exhibits greater diversity than MCP. NFP on the other hand exhibited the highest bird richness as it experienced minimal human disturbance and was influenced by proximity to the forest border and water source.

TABLE 2. PCA ANALYSIS FOR FOUR PRINCIPAL COMPONENTS (PCs) THAT CONTRIBUTE TO THE HIGHEST VARIANCE OF THE DISTANCE-BASED VARIABLES MEASURED

PC	Eigenvalues	Variation (%)	Cum. variation (%)
1	1.59	26.5	26.5
2	1.42	23.7	50.3
3	1.07	17.8	68.0
4	0.832	13.9	81.9

Note: Cum. variation - cumulative variation

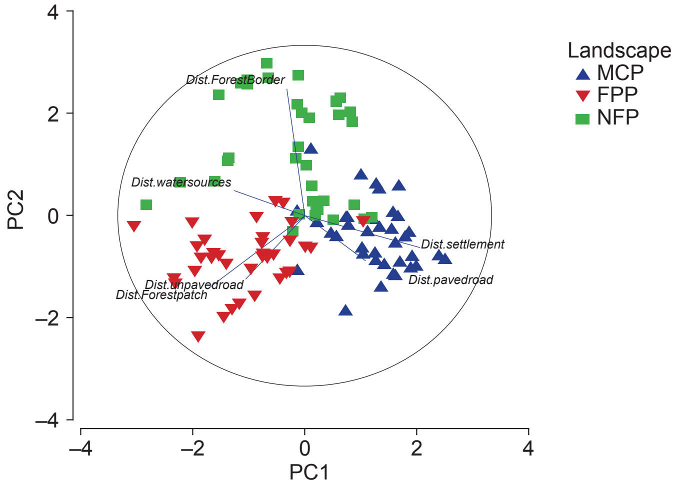


Figure 6. Principal component analysis (PCA) biplot showcasing the distribution of sampling points at three different landscapes based on environmental variables.

CONCLUSION

This study demonstrates that bird communities in oil palm plantations are shaped by both landscape type and proximity to natural and human-made habitat features. Across four sites in Peninsular Malaysia, forest-adjacent plantations supported higher bird diversity and broader guild and forest-dependency birds than monoculture plantations, highlighting the value of retaining natural elements within the plantation matrix. While natural habitat factors showed more nuanced relationships with the abundance and richness of birds. Man-made features, especially settlements and unpaved roads emerged as strong predictors with omnivores associating with disturbed areas, whereas frugivores and insectivores were more abundant farther from settlements. Forest-dependency patterns further indicated that forest species were more abundant away from settlements and were linked to forest edges while open-country birds were favoured in more open interiors and near unpaved roads. These findings support management actions that incorporate distance-based habitat configuration by maintaining forest patches, protecting water bodies and vegetated canals, managing unpaved roadsides as habitat features as well as limiting settlement expansion near forests. Future studies can focus on multi-taxa while incorporating seasonal variations to better understand the ecological interaction among bird and biodiversity responses in oil palm plantations.

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REFERENCES

Adhikari, S., Adhikari, A., Weaver, D., Bekkerman, A., & Menalled, F. (2019). Impacts of agricultural management systems on biodiversity and ecosystem services in highly simplified dryland landscapes. *Sustainability, 11*(11), 3223. https://doi.org/10.3390/su11113223

Amit, B., Tuen, A. A., & Kho, L. K. (2021). Bird species richness and their feeding guild across oil palms development through mist-netting method in Betong, Sarawak. *Journal of Oil Palm Research, 33*(4), 617–628. https://doi.org/10.21894/jopr.2021.0017

Anderson, J. A., McClean, C. J., Sim, S., Pettorelli, N., Jelling, A., Tangah, J., & Hill, J. K. (2022). Weak edge effects on trees in Bornean rainforest remnants bordering oil palm. *Biotropica, 54*(4), 921–932. https://doi.org/10.1111/btp.13115

Arazmi, F. N., Ismail, N. A., Daud, U. N. S., Abidin, K. Z., Nor, S. M., & Mansor, M. S. (2022). Spread of the invasive Javan myna along an urban–suburban gradient in Peninsular Malaysia. *Urban Ecosystems, 25*(3), 1007–1014. https://doi.org/10.1007/s11252-022-01216-9

Askins, R. A. (1994). Open corridors in a heavily forested landscape: Impact on shrubland and forest-interior birds. *Wildlife Society Bulletin, 22*(2), 339–347. https://www.jstor.org/stable/3783267

Atikah, S. N., Yahya, M. S., Puan, C. L., Zakaria, M., & Azhar, B. (2019). Can forest-associated nocturnal birds persist in oil palm agroecosystem? *Ornithological Science, 18*(2), 127–134. https://doi.org/10.2326/osj.18.134

Azhar, B., Lindenmayer, D. B., Wood, J., Fischer, J., Manning, A., McElhinny, C., & Zakaria, M. (2011). The conservation value of oil palm plantation estates, smallholdings and logged peat swamp forest for birds. *Forest Ecology and Management*, *262*(12), 2306–2315. https://doi.org/10.1016/j.foreco.2011.08.026

Azhar, B., Puan, C. L., Zakaria, M., Hassan, N., & Arif, M. (2014). Effects of monoculture and polyculture practices in oil palm smallholdings on tropical farmland birds. *Basic and Applied Ecology, 15*(4), 336–346. https://doi.org/10.1016/j.baae.2014.06.001

Azhar, B., Puan, C. L., Aziz, N., Sainuddin, M., Adila, N., Samsuddin, S., Asmah, S., Syafiq, M., Razak, S. A., Hafizuddin, A., Hawa, A., & Jamian, S. (2015). Effects of *in situ* habitat quality and landscape characteristics in the oil palm agricultural matrix on tropical understory birds, fruit bats and butterflies. *Biodiversity and Conservation*, *24*(12), 3125–3144. https://doi.org/10.1007/s10531-015-1005-6

Callaghan, C. T., Major, R. E., Lyons, M. B., Martin, J. M., & Kingsford, R. T. (2018). The effects of local and landscape habitat attributes on bird diversity in urban greenspaces. *Ecosphere*, *9*(7), e02347. https://doi.org/10.1002/ecs2.2347

Campo-Celada, M., Jordano, P., Benítez-López, A., Gutiérrez-Expósito, C., Rabadán-González, J., & Mendoza, I. (2022). Assessing short- and long-term variations in diversity, timing and body condition of frugivorous birds. *Oikos, 2022*(2), e08387. https://doi.org/10.1111/oik.08387

Chapman, P. M., Loveridge, R., Rowcliffe, J. M., Carbone, C., Bernard, H., Davison, C. W., & Ewers, R. M. (2019). Minimal spillover of native small mammals from Bornean tropical forests into adjacent oil palm plantations. *Frontiers in Forests and Global Change, 2,* 2. https://doi.org/10.3389/ffgc.2019.00002

Chung, G. F. (2012). Effect of pests and diseases on oil palm yield. In *Elsevier eBooks* (pp. 163–210). https://doi.org/10.1016/b978-0-9818936-9-3.50009-5

Craveiro, J., Bugalho, M. N., & Vaz, P. G. (2025). Roads shape seed dispersal by rodents and carnivores at forest edges. *Journal of Applied Ecology*, *62*(11), 3040–3054. https://doi.org/10.1111/1365-2664.70174

D'Amico, M., Rouco, C., Russell, J. C., Román, J., & Revilla, E. (2013). Invaders on the road: Synanthropic bird foraging along highways. *Oecologia Australis*, *17*(1), 86–95.

Edwards, D. P., Hodgson, J. A., Hamer, K. C., Mitchell, S. L., Ahmad, A. H., Cornell, S. J., & Wilcove, D. S. (2010). Wildlife-friendly oil palm plantations fail to protect biodiversity effectively. *Conservation Letters, 3*(4), 236–242. https://doi.org/10.1111/j.1755-263X.2010.00107.x

Egonyu, J. P., Baguma, J., Martínez, L. C., Priwiratama, H., Subramanian, S., Tanga, C. M., Anankware, J. P., Roos, N., & Niassy, S. (2022). Global advances on insect pest management research in oil palm. *Sustainability (Switzerland)*, *14*(23), 16288. https://doi.org/10.3390/su142316288

Etterson, M. A., Niemi, G. J., & Danz, N. P. (2009). Estimating the effects of detection heterogeneity and overdispersion on trends estimated from avian point counts. *Ecological Applications*, *19*(8), 2049–2066. https://doi.org/10.1890/08-1317.1

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., Brühl, C. A., Donald, P. F., & Phalan, B. (2008). How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution*, *23*(10), 538–545. https://doi.org/10.1016/j.tree.2008.06.012

Gray, C. L., Simmons, B. I., Fayle, T. M., Mann, D. J., & Slade, E. M. (2016). Are riparian forest reserves sources of invertebrate biodiversity spillover and associated ecosystem functions in oil palm landscapes? *Biological Conservation*, *194*, 176–183. https://doi.org/10.1016/j.biocon.2015.12.017

Gutierrez Al-Khudhairy, S., Howells, T. R., Bin Sailim, A; McClean, C. J., Senior, M. J. M., Azmi, R., Benedick, S., & Hill, J. K. (2023). Sustainable management practices do not reduce oil palm yields on smallholder farms on Borneo. *Agroecology and Sustainable Food Systems*, *47*(1), 3–24. https://doi.org/10.1080/21683565.2022.2131691

Hassan-Aboushiba, A. B., Ramli, R., & Sofian-Azirun, M. (2011). Species Composition and feeding guilds of birds utilizing palm oil mill effluent (POME) area in Carey Island, Malaysia. In *2011 2nd International Conference on Environmental Science and Technology* (IPCBEE, Vol. 6, pp. 28–31). IACSIT Press.

Herrera, J. M., & García, D. (2009). The role of remnant trees in seed dispersal through the matrix: Being alone is not always so sad. *Biological Conservation*, *142*(1), 149–158. https://doi.org/10.1016/j.biocon.2008.10.008

Jeyarajasingam, A. (2012). *A field guide to the birds of Peninsular Malaysia and Singapore* (2nd ed.). Oxford University Press.

Juliana, J., & Gawin, D. F. (2020). Foraging behaviour of three sympatric babblers (Family: Timaliidae). *Trends in Undergraduate Research*, *3*(2), a26-34. https://doi.org/10.33736/tur.2138.2020

Jumilawaty, E., Namira, N., Anggelicha, A., & Hartanto, A. (2021). Gut content analysis of cattle egrets (*Bubulcus ibis*) in Asam Kumbang Crocodile Park, North Sumatra. *IOP Conference Series: Earth and Environmental Science, 912*(1), 012105. https://doi.org/10.1088/1755-1315/912/1/012105

Khasanah, N., Van Noordwijk, M., Slingerland, M., Sofiyudin, M., Stomph, D., Migeon, A. F., & Hairiah, K. (2020). Oil palm agroforestry can achieve economic and environmental gains as indicated by multifunctional land equivalent ratios. *Frontiers in Sustainable Food Systems*, *3*, 122. https://doi.org/10.3389/fsufs.2019.00122

Khamcha, D., Powell, L. A., & Gale, G. A. (2018). Effects of roadside edge on nest predators and nest survival of Asian tropical forest birds. *Global Ecology and Conservation*, *16*, e00450. https://doi.org/10.1016/j.gecco.2018.e00450.

Koh, L. P. (2008). Birds defend oil palm from herbivorous insects. *Ecological Society of America*, *18*(4), 821–825. https://doi.org/10.1890/07-1650.1

Kroeger, S. B., Hanslin, H. M., Lennartsson, T., D'Amico, M; Kollmann, J., Fischer, C., Albertsen, E., & Speed, J. D. M. (2022). Impacts of roads on bird species richness: A meta-analysis considering road types, habitats and feeding guilds. *Science of the Total Environment*, *812*, 151478, https://doi.org/10.1016/j.scitotenv.2021.151478.

Kurucz, K., Purger, J. J., & Batáry, P. (2021). Urbanization shapes bird communities and nest survival, but not their food quantity. *Global Ecology and Conservation, 26*, e01475. https://doi.org/10.1016/j.gecco.2021.e01475

Lee, D. C., & Marsden, S. J. (2008). Adjusting count period strategies to improve the accuracy of forest bird abundance estimates from point transect distance sampling surveys. *Ibis, 150*(2), 315–325. https://doi.org/10.1111/j.1474-919X.2007.00790.x

Liu, C. L. C., Kuchma, O., & Krutovsky, K. V. (2018). Mixed-species versus monocultures in plantation forestry: Development, benefits, ecosystem services and perspectives for the future. *Global Ecology and Conservation, 15*, e00419. https://doi.org/10.1016/j.gecco.2018.e00419

Magurran, A. E. (2013). *Measuring biological diversity*. John Wiley & Sons.

Meijaard, E., Ancrenaz, M., & van Balen, B. (2020). *Biodiversity impact of RSPO certification: An assessment of good practices*. Borneo Futures.

Meijaard, E., Morgans, C., Husnayaen, Abram, N. K., & Ancrenaz, M. (2017). *An impact analysis of RSPO certification on Borneo forest cover and orangutan populations*. Borneo Futures.

Mohd-Taib, F. S., Md-Nor, S., & Arif Abdullah, S. (2016). Implications of patch size and landscape matrix towards native-forest bird species in fragmented forests. *Malaysian Applied Biology*, *45*(1), 55–63.

Mohd-Taib, F. S., Mohd-Saleh, W., & Ismail, S. N. R. (2022). Effects of landscape attribute towards bird assemblages in urban areas of Peninsular Malaysia. *Urban Ecosystems*, *25*(1), 241–251. https://doi.org/10.1007/s11252-021-01151-1

Morelli, F., Beim, M., Jerzak, L., Jones, D., & Tryjanowski, P. (2014). Can roads, railways and related structures have positive effects on birds? – A review. *Transportation Research Part D: Transport and Environment*, *30*, 21–31. https://doi.org/10.1016/j.trd.2014.05.006

Mulyani, Y. A., Haneda, N. F., Purnomo, H., & Kaban, A. (2020). Insectivorous birds in edge and interior habitats of forest plantation in Gunung Walat, Sukabumi. *IOP Conference Series: Earth and Environmental Science, 528*(1), 012026. https://doi.org/10.1088/1755-1315/528/1/012026

Nasution, A. P., Wibowo, E. A., Ramdani, R., & Rofiqah, T. (2021). Urgensity of environmental management system implementation on oil palm plantation management policies in North Sumatera. *Journal of Social Transformation and Regional Development*, *3*(1), 1–6.

Navarro, A. B., Magioli, M., Bogoni, J. A., Moreira, M. Z., Silveira, L. F., Alexandrino, E. R., Da Luz, D. T. A., Pizo, M. A., Silva, W. R., De Oliveira, V. C., Donatelli, R. J., Christianini, A. V., Piratelli, A. J., & Ferraz, K. M. P. M. B. (2021). Human-modified landscapes narrow the isotopic niche of neotropical birds. *Oecologia*, *196*(1), 171–184. https://doi.org/10.1007/s00442-021-04908-9

Okuda, T., Yamada, T., Watanabe, K., Kimura, K., Hosaka, T., Sugimoto, T., Tagashira, N., Chiba, M., Noor Azlin, Y., Azyyati, A. K., Nurfazliza, K., Ong, T., Norsham, Y., Roslina, M., Azmariah, M., Chong, M. I., Quah, E. S., & Hashim, M. (2011). Development of a forest corridor through an oil palm plantation as a long-term plan for ecosystem remediation and adaptive land use management in the tropics. In *Proceedings of the Rehabilitation of Tropical Rainforest Ecosystems Conference* (pp. 189–196). Universiti Putra Malaysia & Mitsubishi Corporation.

Oon, A., Ahmad, A., Md Sah, S., Abdul Maulud, K. N., Yahya, M. S., Lechner, A M., & Azhar, B. (2023). The conservation of biodiverse continuous forests and patches may provide services that support oil palm yield: Evidence from satellite crop monitoring. *Cleaner Production Letters*, *4*, 100036. https://doi.org/10.1016/j.clpl.2023.100036

Ortega, Y. K., & Capen, D. E. (2002). Roads as edges: Effects on birds in forested landscapes. *Forest Science*, *48*(2), 381–390. https://doi.org/10.1093/forestscience/48.2.381

Pardini, R. (2004). Effects of forest fragmentation on small mammals in an Atlantic Forest landscape. *Biodiversity and Conservation*, *13*(13), 2567–2586. https://doi.org/10.1023/B:BIOC.0000048452.18878.2d

Parveez, G. K. A., Leow, S. Sen., Kamil, N. N., Madihah, A. Z., Ithnin, M., Ng, M. H., Yusof, Y. A., & Idris, Z. (2024). Oil palm economic performance in Malaysia and R&D progress in 2023. *Journal of Oil Palm Research*, *36*(2), 171–186. https://doi.org/10.21894/jopr.2024.0037

Petol, G. H., Lolin, L., Rudolf, V., & Ardiansjah, Y. B. B. B. (2021). Avifaunal survey of Mengilan Forest Reserve and its surrounding areas in Pensiangan, Sabah, Malaysia. *Journal of Tropical Biology & Conservation (JTBC)*, *18*, 215–228. https://doi.org/10.51200/jtbc.v18i.3455

Ramlah, S., Ihsan, M., & Yusran, Y. (2024). Avian species diversity in oil palm plantations in Buol District, Central Sulawesi, Indonesia. *International Journal of Design and Nature and Ecodynamics*, *19*(1), 267–273. https://doi.org/10.18280/ijdne.190129

Razak, S. A., Saadun, N., Azhar, B., & Lindenmayer, D. B. (2020). Smallholdings with high oil palm yield also support high bird species richness and diverse feeding guilds. *Environmental Research Letters*, *15*(9), 094031. https://doi.org/10.1088/1748-9326/aba2a5

Robson, C. (2020). *Field guide to the birds of South-East Asia*. Bloomsbury Publishing.

Roundtable on Sustainable Palm Oil (2024). *Principles and criteria for the production of sustainable palm oil 2024*. https://rspo.org/wp-content/uploads/1_PC-2024-Final-Draft.pdf

Roundtable on Sustainable Palm Oil (2023). *RSPO principle & criteria 2023* (Draft 2). https://rspo.org/wp-content/uploads/ENG_Draft-2_Principles-Criteria-2023.pdf.

Schwartz, A. L. W., Williams, H. F., Chadwick, E., Thomas, R. J., & Perkins, S. E. (2018). Roadkill scavenging behaviour in an urban environment. *Journal of Urban Ecology*, *4*(1), juy006. https://doi.org/10.1093/jue/juy006

Siegfried, W. R. (1971). The food of the cattle egret. *Journal of Applied Ecology*, *8*(2), 447–468. https://doi.org/10.2307/2402882

Simamora, T. I., Purbowo, S. D., & Laumonier, Y. (2021). Looking for indicator bird species in the context of forest fragmentation and isolation in West Kalimantan, Indonesia. *Global Ecology and Conservation*, *27*(80), e01610. https://doi.org/10.1016/j.gecco.2021.e01610

Siregar, E. H., Atmowidi, T., & Kahono, S. (2016). Diversity and abundance of insect pollinators in different agricultural lands in Jambi, Sumatera. *HAYATI Journal of Biosciences*, *23*(1), 13–17. https://doi.org/10.1016/j.hjb.2015.11.002

Sudaryanto, F. X., Pudyatmoko, S., Djohan, T. S., Subagja, J., Suana, I. W., Sukmaring Kalih, L. A. T. T. W., Hardini, J., & Subagio, J. (2020). Daily activity, diet and habitat of Bali myna (*Leucopsar rothschildi*) in Nusa Penida, Bali, Indonesia. *Biodiversitas Journal of Biological Diversity, 21*(10), 4474–4482. https://doi.org/10.13057/biodiv/d211002.

Tälle, M., Öckinger, E., Löfroth, T., Pettersson, L. B., Smith, H. G., Stjernman, M., & Ranius, T. (2023). Land sharing complements land sparing in the conservation of disturbance-dependent species. *Ambio*, *52*(3), 571–584. https://doi.org/10.1007/s13280-022-01820-1

Tan, B. K., Norazlimi, N. A., Lokman, M. I. N. & Halim, A. M. A. (2024). Comparative studies of avian composition at Ayer Hitam Utara Forest Reserve, Muar, Johor. *Enhanced Knowledge in Sciences and Technology, 4*(2), 709–715.

Tohiran, K., Nasir, D. M., Burhanuddin, M., Nobilly, F., Zulkifli, R., Moslim, R., Yahya, M. S., Norhisham, A. R., Lechner, A. M., & Azhar, B. (2024). First records of diurnal and nocturnal predatory birds from artificial hunting perch trials in oil palm plantations. *BioControl*, *69*(6), 635–646. https://doi.org/10.1007/s10526-024-10279-w

Valentine, E. C., Apol, C. A., & Proppe, D. S. (2019). Predation on artificial avian nests is higher in forests bordering small anthropogenic openings. *Ibis*, *161*(3), 662–673. https://doi.org/10.1111/ibi.12662

Vallejos, L. M., Prevedello, J. A., Vecchi, M. B., & Alves, M. A. S. (2024). Species traits and latitude mediate bird responses to forest edges globally. *Landscape Ecology*, *39*(3), 53. https://doi.org/10.1007/s10980-024-01845-9

Waide, R. B. (2018). Tropical rainforest. In B. Fath (Ed.), *Encyclopedia of ecology* (2nd ed., pp. 679–683).

Yahya, M. S., Puan, C. L., Azhar, B., Atikah, S. N., & Ghazali, A. (2016). Nocturnal bird composition in relation to habitat heterogeneity in small scale oil palm agriculture in Malaysia. *Agriculture, Ecosystems & Environment*, *233*, 140–146. https://doi.org/10.1016/j.agee.2016.09.003

Yahya, M. S., Ibrahim, N. L., Kamarudin, N., Ahmad, S. N., Atikah, S. N., Sanusi, R., Norhisham, A. R., Masri, M. M. M., & Azhar, B. (2024). Higher avian biodiversity, increased shrub cover and proximity to continuous forest may reduce pest insect crop loss in small-scale oil palm farming. *Journal of Applied Ecology*, *61*(6), 1255–1268. https://doi.org/10.1111/1365-2664.14632

Yahya, M. S., Syafiq, M., Ashton-Butt, A., Ghazali, A., Asmah, S., & Azhar, B. (2017). Switching from monoculture to polyculture farming benefits birds in oil palm production landscapes: Evidence from mist netting data. *Ecology and Evolution*, *7*(16), 6314–6325. https://doi.org/10.1002/ece3.3205

Zainal Abidin, C. M. R., Mohd Noor, H., Hamid, N. H., Ravindran, S., Puan, C. L., Kasim, A., & Salim, H. (2022). Comparison of effectiveness of introduced barn owls, *Tyto javanica javanica*, and rodenticide treatments on rat control in oil palm plantations. *Journal of Pest Science*, *95*(2), 1009–1022. https://doi.org/10.1007/s10340-021-01423-x