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Research article

Avifaunal communities as indicators of silvicultural impacts in mangrove forests

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A B S T R A C T

Although the Matang Mangrove Forest Reserve (MMFR) in Malaysia is suggested to be a global reference for sustainable silviculture, the impact of greenwood extraction on local biodiversity and ecological functionality remains under-researched. To fill this gap, a rapid biodiversity assessment was conducted using birds as ecological indicators to investigate the effect of mangrove silvicultural management on avian communities. Changes in the diversity of bird species and dietary guilds in response to forest age and management were assessed using the point-count method with visual and auditory observations. This was done in both "productive" forests, consisting of even-aged *Rhizophora* plantations producing poles and charcoal, and in "protective" forests where extractive activities are prohibited. Remarkably, all avifaunal functional guilds were present in both young "productive" and "protective" forests, however the "productive" forests supported fewer bird assemblages in terms of species richness and total taxonomic diversity compared to the floristically rich and structurally complex "protective" forests. The bird species' response to silvicultural disturbances also varied, with adverse effects especially occurring in functionally specialized species. Furthermore, back mangroves and transition zones to terrestrial forests were found to support a higher avifaunal diversity, possibly because of the enhanced habitat heterogeneity. Finally, this study highlights the use of bird communities as ecological indicators for assessing the quality of mangrove forests, and emphasises the crucial role of habitat and landscape heterogeneity in supporting diverse avifauna and ecosystem functionality highlighting the need for more research integrating mangroves and adjacent ecosystems.

1. Introduction

Mangroves are assemblages of trees, shrubs, palms and ferns that are adapted to grow in (sub)tropical and warm temperate latitudes along the intertidal areas of bays, estuaries, lagoons, and backwaters (Mukherjee et al., 2014; Dahdouh-Guebas et al., 2021). They provide ecosystem goods and services critical to human well-being (*loc. cit.*), and play a pivotal role for sustaining a wide variety of local fauna (Schmitt and Duke, 2015; Kathiresan et al., 2015; Zamprogno et al., 2023). In turn, mangrove fauna plays an important role in the proper functioning

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of this ecosystem (Nagelkerken et al., 2008; Buelow and Sheaves, 2015; Yahya et al., 2020; Cannicci et al., 2021). The loss of about half of the global mangrove cover so far, together with its continuous decline due to natural and anthropogenic pressures, is a major scientific concern (Hamilton and Casey, 2016) and prompted the scientific community to emphasize the need for more functional ecological research in mangroves (Dahdouh-Guebas et al., 2022). Not only do mangroves continue to decline (Goldberg et al., 2020), though less than *ca.* 20 years ago (Duke et al., 2007; Friess et al., 2020), more worrying is that they even do so in protected areas (Heck et al., 2024). Vast mangrove areas are being exploited for timber and charcoal production in countries such as Indonesia, Thailand, Vietnam and Malaysia (Sillanpää et al., 2017; Yudha et al., 2021; Satyanarayana et al., 2021). Overall, the mangrove management practices are primarily aimed at efficient resource production or service provisioning while biodiversity conservation is often compromised, thus negatively impacting many ecosystem services (Walters, 2004; van Oudenhoven et al., 2015). Yet, there is potential to protect mangroves while maximising their ecosystem goods and services (Dabalà et al., 2023) and for restoration areas there are new tools to track progress toward restoration targets in the recovery of degraded, damaged, or destroyed mangroves (Gatt et al., 2024).

Mangrove plantations are often monospecific, altering the natural species composition and forest structure (Goessens et al., 2014; Malik et al., 2015; Zimmer et al., 2022; Chen et al., 2024). These landscape modifications could change vegetation dynamics and local environmental conditions (Paillet et al., 2010; Chaudhary et al., 2016), resulting in the reduction or complete loss of (micro)habitats (Paillet et al., 2010; Carugati et al., 2018). Local degradation of biodiversity caused by silvicultural activities can impair essential functions in the ecosystem, such as important interspecies interactions, thus affecting long-term ecosystem resilience (Taylor et al., 2013; Chaudhary et al., 2016; Mohd-Taib et al., 2020). This in turn can initiate negative cascading effects that could have critical consequences for ecosystem functioning and services (Gaston and Fuller, 2008; Dornelas, 2010; Chaudhary et al., 2016). Therefore, balancing economic activities, such as commercial timber extraction, with conservation programs is essential for the preservation of mangrove biodiversity.

The Matang Mangrove Forest Reserve (MMFR) on the west coast of Peninsular Malaysia (Fig. 1A–B) accounts for about 38 % of the total mangrove cover of the mainland (Goessens et al., 2014; Afizzul et al., 2020). Nearly 80 % of mangroves here belong to the "productive" forest that is dominated by *Rhizophora* spp. and managed for a steady-state resource exploitation of timber products (poles and charcoal) (Chen et al., 2024). The management of the MMFR also focuses on other objectives, such as shoreline protection, protecting fish nursery grounds, providing wildlife habitat and a sustainable seedbank, as well as fostering research and education, through the allocation of the so-called "protective" forest areas (Ariffin & Mustafa, 2013; Goessens et al., 2014, Yusop & Muhamad Nor, 2021). In addition, "restrictive productive" forest (for selective tree logging in exceptional cases) and "unproductive" (dryland) forest areas exist within the MMFR (Fig. 1B). Some authors considered MMFR to be one of the most "sustainably" managed mangrove forests in the world (Ammar et al., 2014; Ramli et al., 2018; Afizzul et al., 2020), but others reported decreased yields over time (Goessens et al., 2014). The question of "sustainable for whom" has never been clearly answered. Various stakeholders hold different opinions regarding the MMFR management and most of them are positive toward the charcoal production system (Hugé et al., 2016; Martinez-Espinosa, 2020). However, silvicultural management affects the long-term vegetation structure and ecosystem resilience, leading to reduced ecosystem services, such as carbon sequestration (Wolswijk et al., 2022; Chen et al., 2024). While numerous studies have been conducted on the vegetation structure and floral biodiversity of the MMFR (e.g. Goessens et al., 2014; Otero et al., 2019; Lucas et al., 2020), only a few exist on the fauna (Khaleghizadeh et al., 2014; Azimah and Tarmiji, 2018; Mohd-Taib et al., 2020). Importantly, the effect of mangrove management on the faunal diversity and the ecological functionality has largely escaped investigation, with no previous records

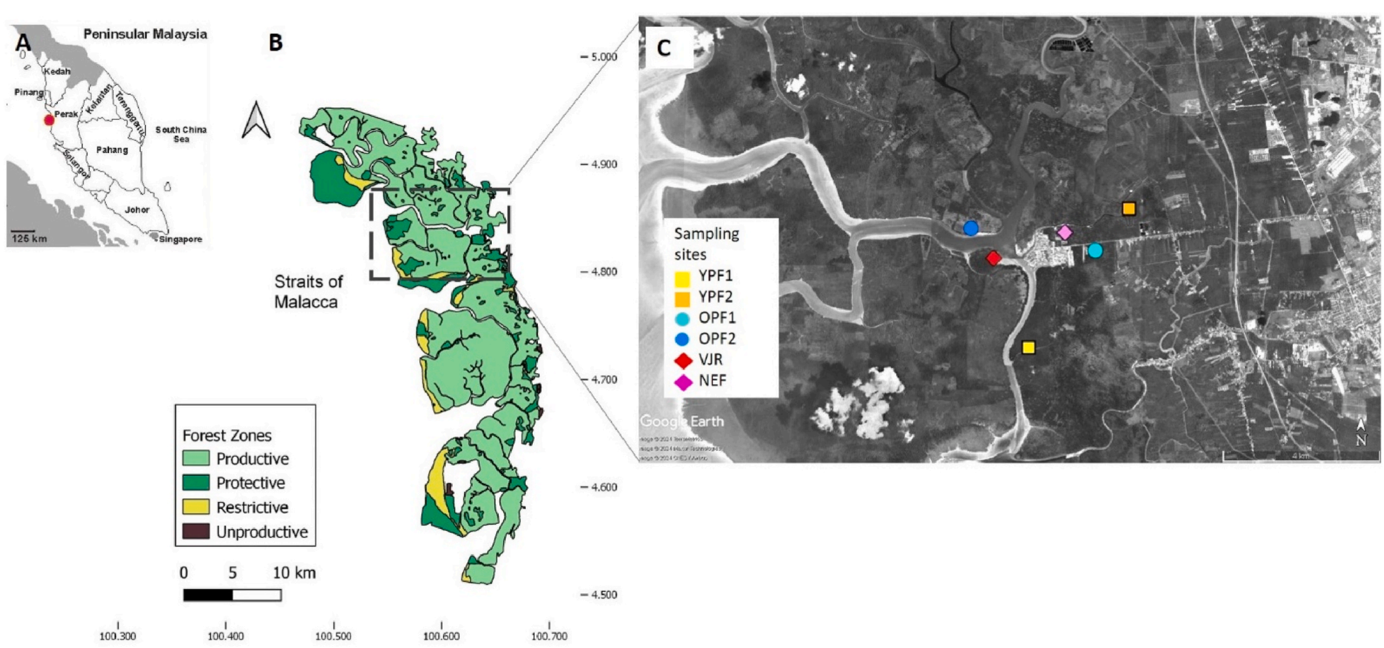

Fig. 1. Composite map of survey area - **(A)** Map of Peninsular Malaysia (adapted from Goessens et al., 2014). **(B)** Map of Matang Mangrove Forest Reserve showing the four forest zones. The "productive" forest, and to a lesser extent the restrictive "productive" forest, are subject to commercial timber exploitation, with consecutive 30-year rotation cycles with intermediate thinnings at 15 and at 20 years, while the "protective" forest is free from commercial timber exploitation. The dotted square represents the sampling area. **(C)** Detailed map of the sampling area (Source: Google Earth) indicating the six sampling sites. Young Productive Forest (YPF): "productive" forest areas after first thinning (i.e. after 15 years); Old Productive Forest (OPF): "productive" forest areas after second thinning (i.e. after 20 years); Nature Education Forest (NEF) and Virgin Jungle Reserve (VJR): "protective" forest areas set aside by the management for research, education and conservation of biological diversity.

on the distribution of functional/dietary guilds in different aged forest stands.

Understanding the ecological state of a forest and its potential change is of fundamental importance to forest management, as it allows taking appropriate conservation and management decisions (Hagerman and Pelai, 2018). Limited by logistical, financial and time constraints, detailed biodiversity assessments are however difficult to conduct, especially in a tropical tidal environment (Williams et al., 1994; Garson et al., 2002). Therefore, ecological indicators which can be rapidly and accurately assessed, are widely used to measure the ecological response of the forest under a silvicultural management scheme (Rodrigues and Brooks, 2007; Chiarucci et al., 2011).

Avifaunal communities are known to be reliable indicators for rapid biodiversity assessments (Sarkar & Margule, 2002; BirdLife-International, 2004) and are rather easy to monitor in the field (Gardner et al., 2008). They can represent habitat quality in response to subtle environmental changes (Morrison, 1986; Acharya et al., 2011; Sekercioglu, 2012), through their relationships with unique habitat conditions, and their ecological versatility and mobility (MacArthur and MacArthur, 1961; Steele et al., 1984; Chettri et al., 2005). Bird species richness is also associated with plant species richness and understory density which are known to influence their food resources (Mohd-Azlan et al., 2015) and show species-specific interactions (Noske, 1995; Noske, 1996; Kutt, 2007; Acevedo and Aide, 2008; Mohd-Azlan et al., 2012).

Due to the extensive "productive" forest cover, the MMFR consists of a mosaic of even-aged *Rhizophora* stands characterized by a very low floral diversity and reduced mangrove zonation (Lucas et al., 2020). Hence, the impact of the ongoing silvicultural practices on its faunal diversity and ecological functionality needs to be ascertained for future conservation and management. The present study conducted a rapid biodiversity assessment using birds as ecological indicators to assess for the first time the effect of silvicultural management on the avian species presence and their dietary guilds distribution in different areas of the MMFR. The specific objectives were (i) to identify bird communities from "productive" and "protective" forest stands of varying ages, (ii) to detect bird species richness and taxonomic diversity in response to silvicultural disturbances, and (iii) to examine changes in the bird dietary guilds vis-à-vis vegetation structure. We hypothesised that the "productive" forest zones have a lower habitat heterogeneity due to monocultural even-aged forest stands, *i.e.* lower floristic diversity and structural complexity, compared to the "protective" forest stands. The effect of the management on the bird community assemblages is expected to be negative with lower species richness, diversity and abundance in the "productive" stands. We also expect specialized dietary guilds to be absent from the young "productive" stands. Hence, this paper is an attempt to check whether the management of MMFR is sustainable for avifaunal communities.

2. Materials and methods

2.1. Study sites

The MMFR, covering 40,288 ha, is administered under the Kuala Sepetang, Kuala Trong and Sungai Kerang ranges by the State Forestry Department of Perak, Peninsular Malaysia (Ariffin & Mustafa, 2013) (Fig. 1B). Since 1902, the MMFR is managed as a Permanent Forest Reserve in which the "productive" forest has been systematically exploited for poles and charcoal production (see Satyanarayana et al., 2021; Chen et al., 2024 for a detailed review). The silvicultural management in the "productive" forest consists of a 30-year rotation cycle with two intermediate thinnings at the age of 15 and 20 years for pole production, and clear-felling at the age of 30 years for charcoal production (Yusop & Muhamad Nor, 2021). An average of 750 ha is clear-felled annually through this systematic rotation, through yearly allocation of forest coupes to a total of 121 contractors (Yusop & Muhamad Nor, 2021).

Altogether, six sampling sites were chosen from the Kuala Sepetang range for this study (Fig. 1C, Table 1). Sites were selected based on forest age, location accessibility (local tides are semi-diurnal), and travel time. The Matang Working Plan released for 2010–2019 (Ariffin & Mustafa, 2013) was followed to identify the age of mangroves in "productive" forest compartments. Out of six sites, two sites after the first thinning were selected to represent the Young Productive Forest (YPF1 & YPF2), and another two sites after the second thinning and before the clear-felling to represent the Old Productive Forest (OPF1 & OPF2). The remaining two sites within the "protective" forest, chosen as control sites, are known by their non-commercial designation as the 'Nature Education Forest' (NEF) and the 'Virgin Jungle Reserve' (VJR). Both YPF and OPF are dominated by *Rhizophora apiculata* Blume and *R. mucronata* Lam., with the occasional presence of other species such as *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff., *B. gymnorhiza* (L.) Lam. On the other hand, the NEF and VJR, while having a higher abundance of *Rhizophora* spp, present more diverse flora with *Avicennia marina* (Forssk.) Vierh., *Ceriops tagal* (Pers.) C.B.Rob., *Sonneratia caseolaris* (L.) Engl., *Xylocarpus granatum* König, etc. (Ariffin and Mustafa, 2013; Goessens et al., 2014).

2.2. Data collection

The study was conducted in June–July 2015 with at least 12 stations, 100 m apart, from waterfront to back mangrove along a transect, in each sampling site (Fig. 2). The bird census at each station was conducted using the point-count method, a commonly used monitoring technique for rapid biodiversity assessments, including in mangrove forests (Acevedo and Aide, 2008; Mojiol et al., 2008; Prajapati and Dharaiya, 2014; Ruiz et al., 2014; Buelow et al., 2017; Mohd-Taib et al., 2020).

At each site, three surveys were carried out on three non-consecutive days. To maximize the accuracy and reliability of the data, survey timings were standardised for each site: twice in the morning (within 4 h after sunrise) and once in the afternoon (within 4 h before sunset). No site was surveyed twice on the same day, nor on consecutive days to maximize the timing for bird detection at each site. Point counts were not carried out during rain showers. The birds were observed over a fixed time-period of 10 min at each station (Huff et al., 2000; Sutherland, 2006), and identified through a combination of *in situ* visual observation (using Bushnell waterproof 10 × 42 mm binoculars), bird vocalization (Noske, 1996), and ex-post auditive identification based on field recordings (using a Samsung Galaxy V SM-G313HZ smartphone and analysed through Audacity 2.1.0) (Audacity Team, 2021). In

Table 1
Characteristics of the six sampling sites in the Matang Mangrove Forest Reserve, Peninsular Malaysia. Ages mentioned are at the time of sampling (2015). The Young Productive Forest stands I and II (YPF1 & YPF2) underwent the first thinning (*i.e.* after 15 years), the Old Productive Forest stands I and II (OPF1 & OPF2) underwent the second thinning and were close to clear-felling age (*i.e.* after 20 years and before 30 years). The other two sites within the "protective" forest, namely Nature Education Forest (NEF) and Virgin Jungle Reserve (VJR), are free from commercial timber exploitation and set aside by the management for research, education, and conservation of biological diversity (Ariffin & Mustafa, 2013).

Study site	Treatment	Age (years)	Latitude (N)	Longitude (E)
Productive forest				
YPF1	After 1st thinning	~16	04°48′57.7″	100°37′40.40″
YPF2	After 1st thinning	~18	04°50′53.77″	100°39′2.75″
OPF1	Before clear-felling	~27	04°50′17.70″	100°38′34.18″
OPF2	Before clear-felling	~30	04°50′34.43″	100°36′50.32″
Protective forest				
NEF	Education, conservation	~30-35	04′50′32.30″	100′38′8.80″
VJR	Research, conservation	~90	04°50′10.04″	100°37′9.65″

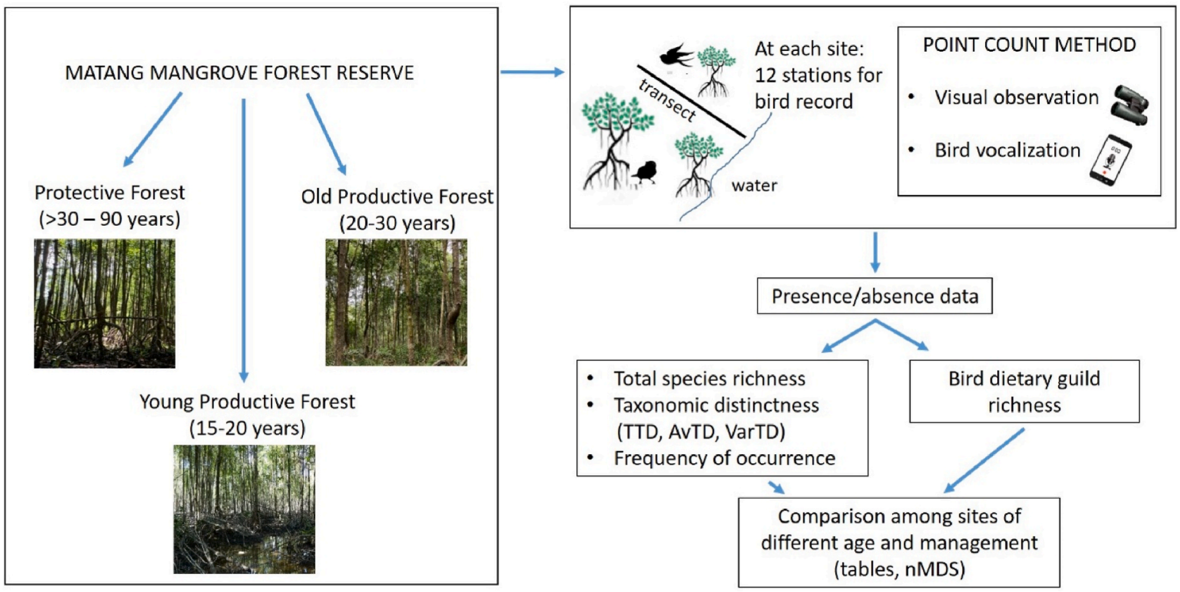

Fig. 2. Flowchart of the methodology to assess the avifauna diversity in the MMFR. TTD: Total Taxonomic distinctness, AvTD: Average Taxonomic distinctness, VarTD: variation in taxonomic distinctness.

addition, "A Field Guide to the Birds of Peninsular Malaysia and Singapore" (Jeyarajasingam and Pearson, 2012) and reliable reference calls for all bird species from https://xeno-canto.org/were followed (Xeno-canto Foundation, 2021) as well as del Hoyo et al. (2014). The bird nomenclature follows IOC World Bird List v.13.1 (Gill et al., 2023).

In order to assess the impact of long-term silvicultural management, we focused on the resident forest birds that are present year-round and depend heavily on the mangrove habitat (Norhayati et al., 2009). Therefore, bird species associated with water, migratory species, and flythroughs were not recorded. In addition, species from the families *Apodidae* and *Hirundinidae* (swallows and swifts – as aerial feeders) as well as nocturnal species (e.g. nocturnal owls) were excluded from the data collection. The remaining pool of bird species was assumed to be characterized by less variable habitat requirements and therefore form a more functionally integrated community that depends heavily on the mangrove habitat (von Euler and Svensson, 2001; Norhayati et al., 2009; Bregman et al., 2014).

2.3. Data analysis

2.3.1. Diversity and composition

To describe the diversity of bird assemblages at each sampling site, data of all 12 point-count stations were pooled. For each site, total species richness (S), total taxonomic distinctness (TTD or $S\Delta^+$, the total taxonomic breadth of a sample), average taxonomic distinctness (AvTD or Δ^+, the average taxonomic breadth of a sample), and variation in taxonomic distinctness (VarTD or Λ^+, the unevenness in taxonomic structure of a sample) were calculated and compared between sites. All these indices are based on presence/absence data and provide information on the taxonomic diversity and relatedness of species within a dataset (Clarke et al., 1999; Clarke and Gorley, 2015; Tolimieri and Anderson, 2010). When sampling effort is equal between samples, it is recommended to compare the TTD between samples or studies (Clarke et al., 2014), which is particularly useful to compare the "productive" and "protective" forest sites in the present study. On the contrary, AvTD and VarTD are unbiased by sampling effort, size or design, and consequently enable a comparison over historic time or biogeographical space where data is collected under different conditions (Clarke and Gorley, 2015). Formulas and methods followed Clarke et al. (2014) and Clarke and Gorley (2015). The assessment of distinctness was performed using decreasing path weights at the higher taxonomic levels (ω: 40, 70, 90, 100 for species, genus, family, and order respectively), giving more weight to the fine-level taxonomy (Clarke and Gorley, 2015). All these biodiversity indices were computed using PRIMER v7 software.

To explore the responses of individual bird species to silvicultural management, its frequency of occurrence was calculated for each site. It is the number of point-count stations in which a particular species was recorded divided by the total number of point-count stations at a given site, rounding the occurrence measures to the nearest hundredth (Nalwanga et al., 2012). This was also calculated for all sites together, to compute a total frequency of the bird species occurrence. This measure gives an indication of a sampling site as a species' habitat (dos Anjos et al., 2015), introducing more information into the dataset than incidence details. A high value of this metric implies a strong use of the site habitats by the bird species, and vice-versa.

To assess similarity in bird species composition across sampling sites, the non-metric multidimensional scaling (nMDS) was performed using the Bray-Curtis dissimilarity, on R-Software 4.2.2 (R Core Team, 2022). This ordination relied on bird frequencies of occurrence to describe their community composition and the scope of sampled sites as their habitat.

2.3.2. Bird dietary guilds

To grasp the functional diversity of the bird community assemblages, their dietary guilds based on the primary food source were considered. Information on diet was compiled from various authoritative sources (*e.g.* Noske, 1995; Kutt, 2007; Jeyarajasingam and Pearson, 2012; del Hoyo et al., 2014; Mohd-Azlan et al., 2015; Mohd-Taib et al., 2020), and classified into seven categories: *carnivore* (vertebrate-eaters, including mammals, amphibians, reptiles, and fish; crustacean-eaters; macro--benthic invertebrate eaters), *frugivore*, *granivore*, *insectivore*, *nectarivore*, *bark-foraging insectivore* (for species that specifically found prey off or in the bark of trees, as they are specialized insectivores that require old or dead wood and bark for foraging, e.g., woodpeckers) and, *omnivore* (miscellaneous; scavenger; any species spanning three or more guilds). However, in cases where two food sources were of equal importance, the bird species was assigned to a category based on a combination of two food sources (*insectivore-nectarivore*, *insectivore-granivore*, *insectivore-carnivore*). To evaluate possible differences in functional diversity between sites, the total species richness (*i.e.* with data of all point-count stations belonging to a specific site pooled together) of each dietary guild was calculated in every site and displayed together for comparison on a bar plot (R-Software 4.2.2). These species richness values, combined with their respective proportion within each site, were provided in Appendix 1.

3. Results

3.1. Avifaunal community

In the present study, a total of 60 bird species (Fig. 3) belonging to 27 families were recorded (a classified list with the IUCN conservation status can be found in Appendix 2). The family Cuculidae (cuckoos) with six species was most frequently represented, followed by the Columbidae (pigeons and doves), Picidae (woodpeckers), Pycnonotidae (bulbuls) and Nectariniidae (sunbirds) with five species each. While the Mangrove Pitta (*Pitta megarhyncha* Schlegel, 1863) is considered as 'Near Threatened' by the IUCN Red List (IUCN, 2023), all other species are of 'Least Concern' (Appendix 2).

The total bird species richness varied substantially across the six sampling sites, ranging from 20 to 52, with the lowest being found at the YPF1 and the highest at the NEF (Table 2). There was no constant increase of species richness with forest age, notably as the YPF2 and the OPF2 displayed the same richness. The total taxonomic distinctness indicated the NEF as most taxonomically diverse ($s\Delta^{+} = 4955$), followed by the VJR ($S\Delta^{+} = 3065$), whereas the YPF1 was least taxonomically distinct ($S\Delta^{+} = 1936$). In contrast, values of average taxonomic distinctness were similar among sites. The variation in taxonomic distinctness was highest in the YPF2 ($\Lambda^{+} = 67.56$) and lowest in the OPF2 ($\Lambda^{+} = 37.40$) (Table 2).

3.2. Community composition

The most frequently encountered bird species across all sites were the Ashy Tailorbird (*Orthotomus ruficeps* Lesson, 1830), the Collared Kingfisher (*Todiramphus chloris* Boddaert, 1783) and the Common Iora (*Aegithina tiphia* Linnaeus, 1758) (Table 3). Of all 60 species recorded, 15 species were common in the study area (*i.e.* species with common names in bold, Table 3) and 17 species were found exclusively in the "protective" forest, especially at the NEF (*i.e.* species with common names highlighted in grey, Table 3). Species restricted to the other sampling sites were the Indochinese Roller (*Coracias affinis* Horsfield, 1840), the Asian Koel (*Eudynamis scolopaceus* Linnaeus, 1758) and the Cream-vented Bulbul (*Pycnonotus simplex* Lesson, 1839) at the YPF2; the Common Emerald Dove (*Chalcophaps indica* Linnaeus, 1758) and the White-rumped Shama (*Copsychus malabricus* Scopoli, 1786) at the OPF1; the Thick-billed Green-pigeon (*Treron curvirostra* Gmelin, 1789) and the Squared-tailed Drongo-cuckoo (*Surniculus lugubris* Horsfield, 1821) at the VJR.

In the non-metric multidimensional scaling (Fig. 4), bird communities formed three distinct clusters, implying a similarity in community composition for the young and old forest types: (i) a first cluster of YPF1 and YPF2, (ii) a second cluster of OPF1, OPF2 and the VJR together, (iii) a third cluster of NEF (stress = $6.327151\ e^{-5}$). Within the second cluster, a higher similarity between OPF2 and VJR was observed.

3.3. Dietary guild structure

The insectivorous feeders were represented by 27 species in total, far more than all other dietary guilds (45 % of all species) (Fig. 5) (Appendix 1). The proportions of birds in other guilds are: seven carnivorous species (12 %), six bark-foraging insectivorous species (10 %), five frugivorous species (8 %), four insectivorous-nectarivorous species (7 %), three species for insectivorous-granivorous (5 %) and two species each for insectivorous-carnivorous, granivorous, nectivorous, and omnivorous categories (each representing 3 %). While the NEF supported all dietary guilds, granivores were only present in OPF1 and NEF, insectivore-granivores in YPF2 and NEF, and nectarivores in YPF1, OPF2, and NEF. At every site, the insectivorous guild was the richest one, accounting for 40–50 % of the species recorded. However, the number of insectivores, along with carnivores and insectivore-nectarivores, decreased between "protective" and "productive" forest stands (Fig. 5). Additionally, more bark-foraging insectivorous species were found in the protective and old "productive" stands than in the young "productive" stands. A higher number of frugivorous species were observed in one "protective" and one old "productive" stand (OPF1) than in all other sites.

4. Discussion

4.1. Avifauna at matang

Despite the importance of mangrove-associated fauna for the functioning of the ecosystem (Cannicci et al., 2008, 2021; Kristensen et al., 2008; Lee, 2008; Nagelkerken et al., 2008; Lee et al., 2014), silvicultural management often neglects the assessment of faunal communities (Ellison, 2008). Here, we provide the first assessment of the impact of forest age and silvicultural mangal management practices on avian communities. The total species found in this study, *i.e.* 60 resident forest bird species, was higher than previous records from this region in surveys intended to simply report species richness. For instance, in the northern part of MMFR, Noramly (2005) observed 36 resident forest birds and Mohd-Taib et al. (2020) report 51 species, including migratory birds. In nearby regions, the Kampung Sungai Timun back mangrove (Negeri Sembilan) was reported to harbour 53 bird species, and the Kampung Yakyah (Terengganu) back mangrove had 44 species (Mohd-Taib et al., 2020). Similarly, Noske (1995) reported 47 resident forest bird species in Selangor, and Norhayati et al. (2009) noted 57 bird species (including 38 residents) in the Klang Island. Part of the differences in species counts are attributable to variations in sampling effort. However, by looking at the number of species shared with previous records (e.g. only 28 species with Noramly, 2005), it is possible to anticipate a higher total species richness across the whole MMFR. This was indeed supported by the most recent MMFR management plan (Yusop and Muhamad Nor, 2021), in which 114 resident bird species were listed - although data collection methods were not disclosed, and no assessment of forest age and management were provided.

Species such as the Cinereous Tit, the Mangrove Whistler, the Copper-throated Sunbird, the Laced Woodpecker, the Greater Flameback, etc. (species with * in Table 3) are considered restricted to mangrove forests in Peninsular Malaysia (Noske, 1995; Luther and Greenberg, 2009; Jeyarajasingam and Pearson, 2012). A specific feeding habitat preference for *Rhizophora* zones, the seaward edge, or tidal rivers in mangrove forests (Noske, 1995; Kutt, 2007) may explain why these species are relatively common across the MMFR. In addition, the Mangrove Pitta, listed as 'Near Threatened' globally, occurred in both "productive" and "protective" sites (YPF2 and NEF). Its presence at these sites is likely related to its habitat preference for muddy upper shore margins (Moh et al., 2015; Jeyarajasingam and Pearson, 2012; Erritzoe, 2020), a micro habitat found at both sites. These findings indicated that, despite the long-term continuous silvicultural management, the Matang mangrove forest is able to support bird species of conservation importance.

4.2. Community diversity

The impact of silvicultural disturbances from wood extraction on bird communities was clear from the lower number of species (20–28) observed at "productive" forest stands compared to "protective" stands (32–52 species). Within the "protective" forest areas sampled, the NEF had a higher avifaunal diversity compared to the VJR, despite the latter being a much older site (~90 years old at the time of sampling *versus* 35 years). This could be linked to the location of the NEF, that is adjacent to

Fig. 3. Photographic representation of most of the bird species present in the MMFR. NT: Nearly Threatened according to IUCN conservation status, if not indicated all other species are Least Concern (LN). Species names: 1. Crested Goshawk, 2. Brahmini Kite, 3. Crested Serpent Eagle, 4. Little Cuckoo-Dove, 5. Indochinese Roller, 6. Plaintive Cuckoo, 7. Banded Bay Cuckoo, 8. Greater Coucal, 9. Asian Koel, 10. Green-billed Malkoha, 11. Square-tailed Drongo-Cuckoo, 12. Golden-bellied Gerygone, 13. Common Iora, 14. Pied Triller, 15. Dark-necked Tailorbird, 16. Ashy Tailorbird, 17. Scarlet-backed Flowerpecker, 18. White-rumped Shama, 19. Mangrove Blue Flycatcher, 20. Asian Brown Flycatcher, 21. Little Spiderhunter, 22. Ruby-cheeked Sunbird, 23. Olive-backed Sunbird, 24. Copper-throated Sunbird, 25. Black-naped Oriole, 26. Abbott's Babbler, 27. Mangrove Pitta, 28. Spectacled Bulbul, 29. Asian Red-eyed Bulbul, 30. Olive-winged Bulbul, 31. Cream-Vented Bulbul, 32. Malaysian Pied Fantail, 33. Velvet-fronted Nuthatch, 34. Chestnut-Winged Babbler, 35. Black-winged Flycatcher-shrike, 36. Greater Flameback, 37. Common Flameback, 38. Laced Woodpecker, 39. Sunda Pygmy Woodpecker. Refer to Appendix 2 for Latin names and detailed taxonomy.

Table 2
Bird assemblage diversity indices computed for the six functional forest stands at the Matang Mangrove Forest Reserve, Malaysia. Highest site values, total excluded, are shown in bold. Site abbreviations are as in Fig. 1. Diversity index abbreviations: S: Total species richness; $S\Delta^{+}$: total taxonomic distinctness; Δ^{+}: average taxonomic distinctness; Λ^{+}: variation in taxonomic distinctness.

Diversity Index	Total	Productive Forest				Protective Forest	
		YPF1	YPF2	OPF1	OPF2	NEF	VJR
S	60	20	25	28	25	**52**	32
$S\Delta^{+}$	5724	1936	2405	2687	2407	**4955**	3065
Δ^{+}	95.41	**96.32**	96.2	95.95	96.27	95.29	95.79
Λ^{+}	71.28	48.53	**67.56**	52.66	37.4	64.73	55.83

a dryland forest patch (Ariffin and Mustafa, 2013), with several mangrove-associates (e.g. *Acanthus ilicifolius* L., *Acrostichum aureum* L.) and non-mangrove vegetation (*Calamus*, *Pandanus*, *Oncosperma* and *Ficus* spp), as well as to small agricultural patches, possibly showing edge effects. In the literature, a general consensus exists on the determinant role of floral diversity and structural complexity (*i.e.* habitat heterogeneity) in sustaining higher levels of bird diversity (MacArthur and MacArthur, 1961; Tews et al., 2004; Mohd-Azlan and Lawes, 2011), and the mangrove bird community is no exception (Noske, 1996, 2001; Kutt et al., 2007; Mohd-Azlan et al., 2012, 2015; Yudha et al., 2021). Moreover, the dominance of *Rhizophora* spp. at the VJR could be linked to its previous status as a "productive" forest (Putz and Chan, 1986; Goessens et al., 2014). Further, landward mangroves (YPF2, OPF1, and NEF) showed richer avifaunal communities than seaward mangroves (YPF1, OPF2, and VJR). Earlier, Mohd-Taib et al. (2020) also found several protected bird species in back-mangrove zones and highlighted the high conservation value of these areas. In fact, bird species diversity in a given mangrove patch is highly influenced by the surrounding matrix (Mohd-Azlan and Lawes, 2011; Mohd-Azlan et al., 2012; Yudha et al., 2021). Higher species richness and higher total taxonomic distinctness in the landward locations can further explain this situation (Clarke and Warwick, 2001). However, the similar range of average taxonomic distinctness values among the sites could be due to species that are restricted to the "protective" forest but also belonging to taxonomic groups already present in the species-poor old and young "productive" forest stands, causing a stabilization despite the difference in species richness. From a conservation point of view, it becomes essential to strengthen the value of these back mangroves, as these areas are often threatened by the expansion of agriculture/aquaculture activities or human settlements (Asante et al., 2023; Ofori et al., 2023; Dupont et al., 2025). This has been shown to be the case also for the MMFR with recent reports (Rahman et al., 2025), emphasizing the negative impact of these anthropogenic disturbances to the mangrove habitat.

4.3. Community composition

In the MMFR, bird populations clearly differed between the near-monocultural plantation forests aimed at extractive uses, and the protected mangrove stands. When exploring the frequency of occurrence data in the YPF compared to the "protective" forest, the absence or strong reduction in some large-bodied species (Brahminy Kite), old-forest specialists (Ashy Drongo, Velvet-fronted Nuthatch, Greater Flameback, Laced woodpecker), and sunbirds was observed. These functionally specialized species seem to have been strongly impacted by habitat disturbance and vegetation cover changes locally (Johnson et al., 2001; Díaz et al., 2013; Khaleghizadeh et al., 2014). In contrast to the YPF, the OPF stands were still able to support a larger proportion of foraging specialists (such as Velvet-fronted Nuthatch, Ashy Drongo, Laced Woodpecker, Greater Flameback, Copper-throated Sunbird) and large-bodied species or predators (Green-billed Malkoha, Brahminy Kite, Crested Serpent Eagle). Additionally, the pattern of mangrove growth and composition at old "productive" forests and VJR supported a high degree of similarity between these sites and thus resemblance in bird habitat use. In this context, the short distance between the OPF2 and the VJR (<1 km) may have played an important role in enabling the bird communities to partially recolonize "productive" forests of the older age. The NEF, on the other hand, attracted landward bird species (e.g. Oriental Pied Hornbill, Yellow-vented Bulbul, Asian Red-eyed Bulbul) as well as mangrove associated bird species (e.g. Plaintive Cuckoo, Greater Coucal, Oriental Dollarbird), which shows the higher ecological functionality of this site for the resident forest bird community.

The common bird species present in both disturbed and undisturbed sites of the MMFR indicate their resilience to forest cover changes, along with their ability to exploit resources that are commonly available in mangrove forests, have a larger foraging breadth, low requirements, and/or a good dispersal capacity (Noske, 1995; Jeyarajasingam and Pearson, 2012). However, alterations in the habitat structure have negative impacts on foraging specialists (Jeyarajasingam and Pearson, 2012; Sekercioglu, 2012). The decline of species with specialized niches, coupled with an increase in generalist foragers, leads to large-scale biotic homogenization and accelerates biodiversity loss (McKinney and Lockwood, 1999). Such a pattern of habitat and foraging specialist species decline was observed in this study for young "productive" forest stands. Given the fact that 74 % of the "productive" forest coupes are characterized by nearly monospecific stands of *Rhizophora* spp., the MMFR is susceptible to large-scale biotic homogenization.

4.4. Dietary guilds

Importantly, all dietary guilds, with the exception of granivores, were present in young "productive" stands. This signifies that the silvicultural management with the 30 year rotation is effective in preserving avifaunal habitat, at least to some extent. When 30 year-old "productive" forests are clear-felled, there will be a loss of habitat but thanks to the patchwork structure of the forest coupes at the MMFR nearby protective sites may create a "Remember" feedback loop in what is clearly a panarchy system (Dahdouh-Guebas et al., 2021). By drawing on their legacy, mature, protective forests indeed facilitate, first, birds seeking refuge from adjacent clear-felled areas, and second, recolonization of the same clear-cut and younger coupes. These birds (or their offspring) can return once the forest regenerating after clear-felling reaches the right habitat requirements (Fig. 6).

Nevertheless, the negative effect of species richness reduction linked to the MMFR silvicultural extractive practices was observed on several dietary guilds, namely insectivores, carnivores, and insectivore-nectarivores, at both young and old "productive" forests. The decline of bird dietary guilds and thus functional diversity provides additional evidence, alongside the previously mentioned decrease of habitat and foraging specialist species, of an existing impact of timber harvesting management. This result aligns with a recent global meta-analysis, which revealed significant changes in bird's feeding traits and functional diversity due to anthropogenic disturbances (Matuoka et al., 2020). In the case of the MMFR, young "productive" forest stands experienced a greater decline in dietary guilds compared to old "productive" or "protective" forests. Indeed, the OPF continued to support a highly specialized dietary guild, the bark-foraging insectivores. This may be linked to recolonization from the nearby VJR. On the other hand,

Table 3
Frequencies of occurrence (pooled over the three censuses) for all species recorded across the six sampling sites in the Matang Mangrove Forest Reserve, Peninsular Malaysia, in a decreasing order of total frequency of occurrence. For site abbreviations, *cf*. Fig. 1. Species marked with asterisk (*) are considered restricted to mangrove forests (Noske, 1995; Luther and Greenberg, 2009; Jeyarajasingam, 2012). Common names in bold refers to species present in all study sites. Common names highlighted in grey refer to species present in only one site.

Common Name	All Sites	Productive Forest				Protective Forest	
		YPF1	YPF2	OPF1	OPF2	NEF	VJR
Ashy Tailorbird	0.99	0.92	1	1	1	1	1
Collared Kingfisher	0.97	0.92	1	0.92	1	1	1
Common Iora	0.96	0.83	1	1	0.92	1	1
Golden-bellied Gerygone	0.83	0.83	1	0.58	1	0.75	0.83
Swinhoe's White-eye	0.75	0.67	0.92	0.75	0.5	0.92	0.75
Malaysian Pied Fantail	0.71	0.67	0.5	0.75	0.83	0.92	0.58
Cinereous Tit*	0.67	0.58	0.5	0.58	1	0.5	0.83
Mangrove Whistler*	0.63	0.58	0.58	0.58	0.58	0.67	0.75
Common Flameback	0.42	0.42	0.42	0.17	0.42	0.33	0.75
Copper-throated Sunbird*	0.39	0	0.08	0.5	0.5	0.5	0.75
Laced Woodpecker*	0.32	0	0	0.17	0.92	0.08	0.75
Velvet-fronted Nuthatch	0.31	0	0	0.42	0.58	0.25	0.58
Mangrove Blue Flycatcher*	0.29	0	0.33	0.42	0.25	0.25	0.5
Crested Serpent Eagle	0.29	0.08	0.25	0.25	0.33	0.33	0.5
Greater Flameback*	0.25	0.08	0	0.17	0.17	0.5	0.58
Ashy Drongo	0.25	0	0	0.5	0.25	0.33	0.42
Large-billed Crow	0.24	0.08	0.17	0.08	0.33	0.08	0.67
Oriental Magpie-Robin	0.22	0	0	0.25	0.33	0.58	0.17
Brahminy kite	0.21	0	0	0.17	0.25	0.33	0.5
Green-billed Malkoha	0.21	0.17	0.08	0.25	0.33	0.17	0.25
Scarlet-backed Flowerpecker	0.19	0.17	0.08	0.17	0.08	0.42	0.25

Common Tailorbird	0.18	0.17	0.33	0.08	0	0.33	0.17
Sunda Pygmy Woodpecker	0.17	0.17	0.17	0.17	0.08	0.17	0.25
Stork-billed Kingfisher	0.15	0	0	0	0.42	0.17	0.33
Ruby-cheeked Sunbird	0.13	0,.2	0	0	0.17	0.17	0
Pink-necked Green-pigeon	0.13	0.08	0.08	0,08	0.08	0.25	0.17
Brown-throated Sunbird	0.1	0	0	0	0	0.5	0.08
Oriental Pied Hornbill	0.1	0	0	0.25	0	0.33	0
Rufous-tailed Tailorbird	0.08	0	0	0	0	0.5	0
Plaintive Cuckoo	0.07	0	0.33	0	0	0.08	0
White-throated Kingfisher	0.07	0	0	0	0	0.33	0.08
Olive-winged Bulbul	0.07	0	0	0.25	0	0.17	0
Common Emerald dove	0.06	0	0	0.33	0	0	0
Banded Woodpecker	0.06	0	0.08	0	0	0.25	0
Cream-vented Bulbul	0.06	0	0.33	0	0	0	0
Asian Red-eyed Bulbul	0.06	0	0	0	0	0.33	0
Olive-backed Sunbird	0.06	0	0	0	0	0.08	0.25
Mangrove Pitta*	0.04	0	0.17	0	0	0.08	0
Abbott's Babbler	0.04	0	0	0	0	0.08	0.17
Asian Brown Flycatcher	0.04	0.17	0	0	0	0	0.08
Banded Bay Cuckoo	0.03	0	0.08	0	0	0.08	0
Pied Triller	0.03	0	0	0	0	0.17	0
Black-naped Oriole	0.03	0	0	0	0	0.17	0
Dark-necked Tailorbird	0.03	0.08	0	0	0	0.08	0
Little Spiderhunter	0.03	0	0	0	0	0.17	0
Crested Goshawk	0.01	0	0	0	0	0.08	0
Zebra Dove	0.01	0	0	0	0	0.08	0
Little Cuckoo-dove	0.01	0	0	0	0	0.08	0
Thick-billed Green-pigeon	0.01	0	0	0	0	0	0.08
Greater Coucal	0.01	0	0	0	0	0.08	0
Oriental Dollarbird	0.01	0	0	0	0	0.08	0
Indochinese Roller	0.01	0	0.08	0	0	0	0
Oriental Dwarf Kingfisher	0.01	0	0	0	0	0.08	0
Black-winged Flycatcher-shrike	0.01	0	0	0	0	0.08	0
Square-tailed Drongo-cuckoo	0.01	0	0	0	0	0	0.08
Asian Koel	0.01	0	0.08	0	0	0	0
White-rumped Shama	0.01	0	0	0.08	0	0	0
Yellow-vented Bulbul	0.01	0	0	0	0	0.08	0
Spectacled Bulbul	0.01	0	0	0	0	0.08	0
Chestnut-winged Babbler	0.01	0	0	0	0	0.08	0

the unique location of the NEF, with a wide array of food resources and heterogeneous canopy, allowed it to host all dietary guilds and exhibit the highest functional diversity. The presence of a few granivorous species only at the NEF and OPF1, both located in the back mangroves, might be due to the use of nearby terrestrial habitat. Finally, the fact that the insectivorous guild is found in all sites is consistent with the literature (*e.g.*, Mohd-Taib et al., 2020), highlighting the importance of abundant and diverse mangal insect communities (Noske, 1996; Cannicci et al., 2008; Luther and Greenberg, 2009; Mohd-Azlan et al., 2015).

4.5. *Limitations and future perspectives*

Two limitations should be highlighted: first, this study did not account for possible seasonal differences, as it is known that birds use different forest features or even habitat types during different life stages. Nonetheless, our focus on resident birds partially alleviates this limitation. Second, the sampling area was limited to the Kuala Sepetang landward mangrove range of the MMFR, not considering possible variations induced by distance to human settlements or the seafront. Both these aspects could be assessed in future research.

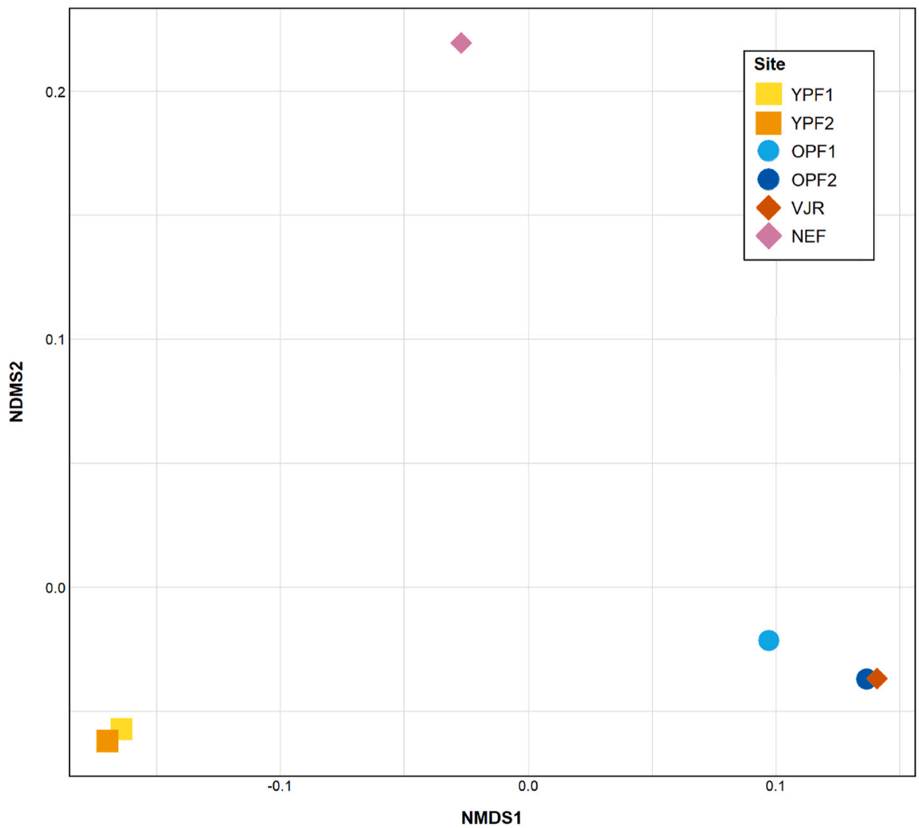

Fig. 4. Non-metric multidimensional scaling (nMDS) ordination plot of site bird compositions, based on Bray-Curtis dissimilarity, calculated from bird frequency of occurrence data. Sites correspond to Young Productive Forest stands (YPF1&2), Old Productive Forest stands (OPF1&2), and "protective" forest stands (NEF for Nature Education Forest and VJR for Virgin Jungle Reserve). Stress of the nMDS was 2.305617 e^{-5}.

Additionally, future studies should use the baseline data provided by this study to investigate the impact of silvicultural management on avian communities over time, including on nearly-threatened species such as the Mangrove Pitta. They should also investigate nesting and foraging sites of resident bird species, as well as the genetic diversity of local bird populations to ensure their long-term health.

Recent concerns on the reduction of habitat quality for migratory birds, due to pollution caused by agricultural and aquacultural activities at the Kuala Gula Bird Sanctuary located North of the MMFR (Rahman et al., 2025), call for ongoing monitoring of the migratory and residential bird species using these habitats. Such studies would be beneficial to highlight the conservation importance of the mangrove forest and raise awareness about its international importance.

Lastly, the effects of habitat fragmentation and the influence of landward transitional zones with terrestrial forested areas on the ecosystem functionality have been nearly disregarded for way too long by mangrove research, which often focused on the mangrove forest alone. Links to salt marshes are more common (Stevens et al., 2006; Kelleway et al., 2017; Cavanaugh et al., 2019). At the seaward side, however, mangroves are more often linked to adjacent seagrass and coral reef ecosystems (Nagelkerken et al., 2008, 2010; Guannel et al., 2016). We call upon mangrove researchers (incl. ourselves) to increase functional ecology research integrating species from mangrove and adjacent terrestrial ecosystems into the same study.

5. Conclusions and recommendations

This research showed that the MMFR hosts a taxonomically and functionally diverse bird community of conservation importance, despite much of the area being subjected to extractive silvicultural practices, with almost all dietary guilds found in young "productive" forests. The study also revealed the impact of ongoing silvicultural management on bird assemblage diversity, functionality, and thus habitat quality. Floristically rich and structurally complex undisturbed "protective" forests hosted more diverse avifaunal assemblages than "productive" forests. Further, disturbance effect varied among individual bird species, negatively affecting specialized species while promoting widespread generalist species. Such changes in community composition and functionality are likely to impact biotic processes (e.g., large-scale homogenization) and can affect resilience in the long-term. Additionally, this study suggests that forest age or functional type are not the sole factors influencing bird assemblages in the MMFR, even though both impacted the presence of functionally specialized species. Indeed, landward sites had higher bird species richness within forest functional types, showing the importance of back-mangrove ecosystems. This research stresses the value of "protective" forests embedded in the mosaic of near-monocultural even-aged "productive" forest stands, which could contribute to a partial recolonization of the bird communities and thus to a partial maintenance of ecosystem functionality. In addition, it points out the value of growing "productive" forest stands as these may serve as partial refugia for bird communities when other patches are cleared in the vicinity. Overall, bird communities are shown to be useful indicators of mangal habitat quality, especially with regards to anthropogenic disturbances. The impact of forest age and silvicultural practices together with the landscape organization of the forest should be further assessed, including the impact on the diversity and functionality of other faunal taxa. Furthermore, the bird assemblages in Matang should be regularly monitored to ensure the MMFR remains an area of high conservation value.

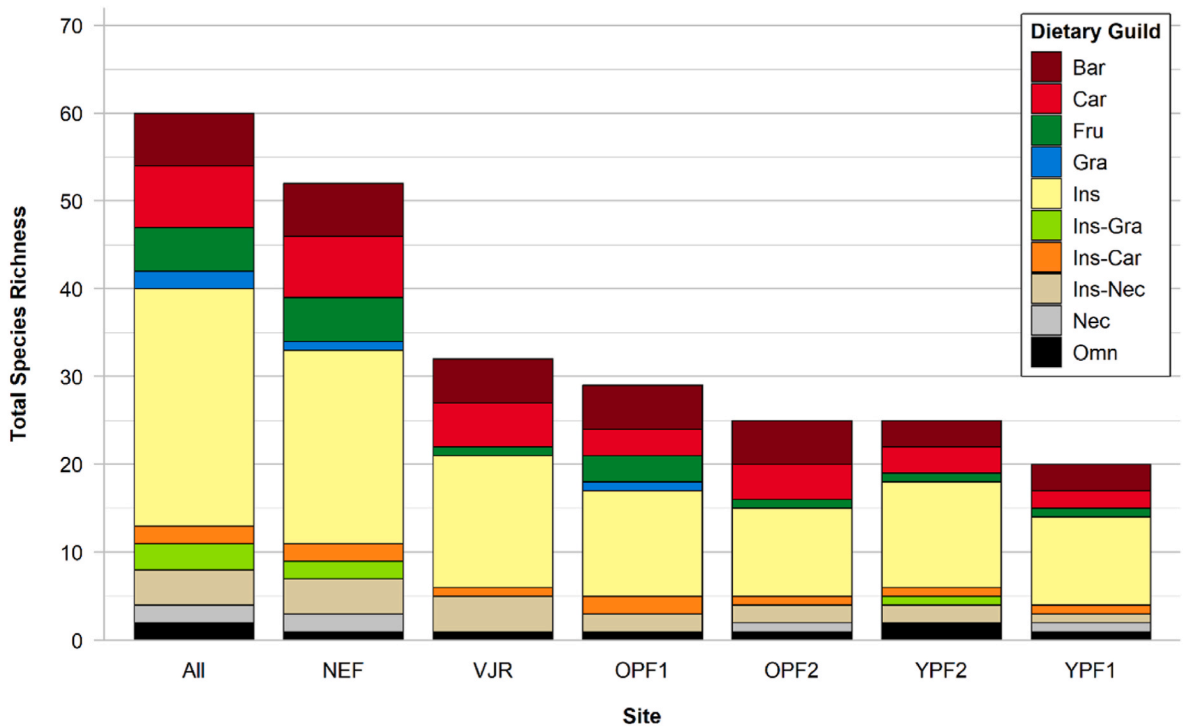

Fig. 5. Barplot of the dietary guild species richness among sites. Classification follows ten dietary guild categories based on their main food source(s): Car for carnivore, Fru for frugivore, Gra for granivore, Ins for insectivore, Nec for nectarivore, Bar for bark-foraging insectivore and Omn for omnivore, Ins-Gra for insectivore-granivore, Ins-Car for insectivore-carnivore, Ins-Nec for insectivore-nectarivore. In cases where two food sources were of equal importance, the bird species was assigned to a category based on a combination of two food sources. Sites correspond to Young Productive Forest stands (YPF1 and YP2), Old Productive Forest stands (OPF1 and OPF2), and "protective" forest stands (NEF for Nature Education Forest and VJR for Virgin Jungle Reserve).

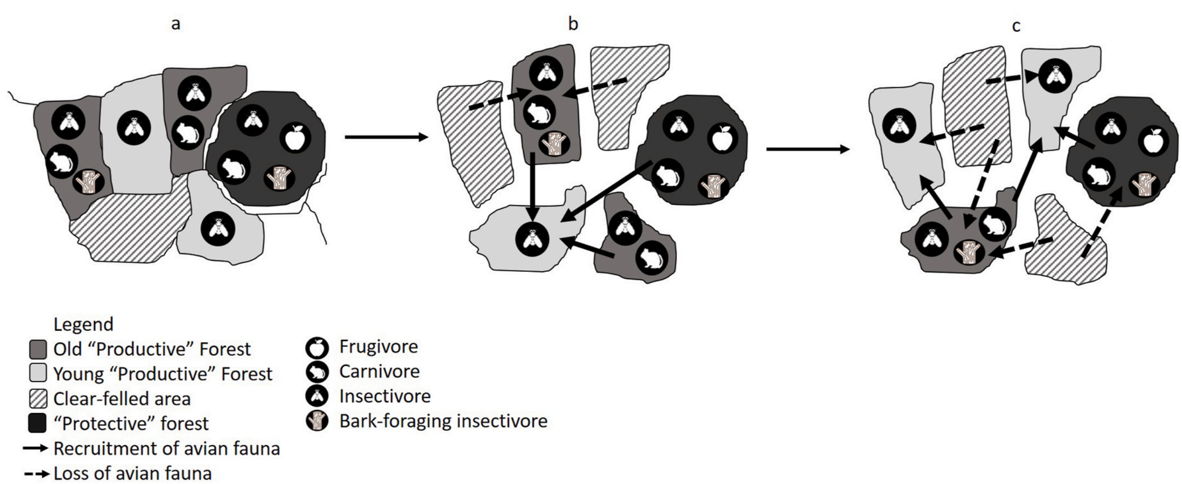

Fig. 6. Effects of the clear-felling events at 30 years in the managed areas of the MMFR as a result of the presence of adjacent forest coupes of different age (a) Younger forest will show lower bird diversity than older forest coupes, with highest number of bird species in the "protective" forest. (b) After reaching 30 years of age, "productive" forest coupes are clear-felled, causing the birds to lose their habitat with consequent shift to older forest coupes nearby, at the same time younger forest coupes are being recolonized by birds from older coupes. (c) The clear-felled coupes from panel (b) start recruiting birds from adjacent forest coupes, while the older forest coupes go through the clear-felling stage. Only the most common dietary guilds were reported in this conceptual representation.

CRediT authorship contribution statement

Giovanna Wolswijk: Writing – review & editing, Writing – original draft, Visualization, Validation. **Tom Bernard:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Jani Sleutel:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lea Fourchault:** Writing – review & editing. **Jean Hugé:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization, Writing – original draft. **Behara Satyanarayana:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Conceptualization, Writing – original draft. **Farid Dahdouh-Guebas:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices.

Appendix 1

Table of species richness and its respective proportion within each site for every dietary guild. The "productive" forest is subject to commercial timber exploitation, with consecutive 30-year rotation cycles with intermediate thinnings at 15 and at 25 years, while the "protective" forest is free from commercial timber exploitation. The Young Productive Forest stands I and II (YPF1 & YPF2) underwent the first thinning (*i.e.* after 15 years), the Old Productive Forest stands I and II (OPF1 & OPF2) underwent the second thinning (*i.e.* after 25 years), and sites within the "protective" forest (NEF & VJR) are free from commercial timber exploitation and set aside by the management for research, education, and conservation of biological diversity (Roslan Ariffin & Nik Mohd Shah, 2013).

Dietary Guilds			Productive Forest								Protective Forest			
	All Sites		YPF1		YPF2		OPF1		OPF2		NEF		VJR	
	S	%	S	%	S	%	S	%	S	%	S	%	S	%
Insectivore	27	45 %	10	50 %	12	48 %	12	41 %	10	40 %	22	42 %	15	47 %
Carnivore	7	12 %	2	10 %	3	12 %	3	10 %	4	16 %	7	13 %	5	16 %
Bark-foraging insectivore	6	10 %	3	15 %	3	12 %	5	17 %	5	20 %	6	12 %	5	16 %
Frugivore	5	8 %	1	5 %	1	4 %	3	10 %	1	4 %	5	10 %	1	3 %
Insectivore-Nectarivore	4	7 %	1	5 %	2	8 %	2	7 %	2	8 %	4	8 %	4	13 %
Insectivore-Granivore	3	5 %	0	0 %	1	4 %	0	0 %	0	0 %	2	4 %	0	0 %
Insectivore-Carnivore	2	3 %	1	5 %	1	4 %	2	7 %	1	4 %	2	4 %	1	3 %
Nectarivore	2	3 %	1	5 %	0	0 %	0	0 %	1	4 %	2	4 %	0	0 %
Omnivore	2	3 %	1	5 %	2	8 %	1	3 %	1	4 %	1	2 %	1	3 %
Granivore	2	3 %	0	0 %	0	0 %	1	3 %	0	0 %	1	2 %	0	0 %

Appendix 2

List of the resident forest bird species recorded during the study in the Kuala Sepetang Forest Range of the Matang Mangrove Forest Reserve, Peninsular Malaysia. Conservation status was obtained from IUCN (2023). LC: 'Least Concern'; NT: 'Near Threatened'.

Order / Family / *Genus species*	Nomenclatural type authority	Common name	Conservation status
ACCIPITRIFORMES			
Accipitridae			
Lophospiza trivirgata	Temminck, 1824	Crested Goshawk	LC
Haliastur indus	Boddaert, 1783	Brahminy Kite	LC
Spilornis cheela	Latham, 1790	Crested Serpent Eagle	LC
BUCEROTIFORMES			
Bucerotidae			
Anthracoceros albirostris	Shaw, 1808	Oriental Pied Hornbill	LC
COLUMBIFORMES			
Columbidae			
Chalcophaps indica	Linnaeus, 1758	Common Emerald Dove	LC
Geopelia striata	Linnaeus, 1766	Zebra Dove	LC
Macropygia ruficeps	Temminck, 1835	Little Cuckoo-dove	LC
Treron vernans	Linnaeus, 1771	Pink-necked Green-pigeon	LC
Treron curvirostra	Gmelin, 1789	Thick-billed Green Pigeon	LC
CORACIIFORMES			
Alcedinidae			
Ceyx erithaca	Linnaeus, 1758	Oriental Dwarf Kingfisher	LC
Halcyon smyrnensis	Linnaeus, 1758	White-throated Kingfisher	LC
Pelargopsis capensis	Linnaeus, 1766	Stork-billed Kingfisher	LC
Todiramphus chloris	Boddaert, 1783	Collared Kingfisher	LC
Coraciidae			
Coracias affinis	Horsfield, 1840	Indochinese Roller	LC
Eurystomus orientalis	Linnaeus, 1766	Oriental Dollarbird	LC
CUCULIFORMES			
Cuculidae			

(*continued on next page*)

Appendix 2 (*continued*)

Order / Family / *Genus species*	Nomenclatural type authority	Common name	Conservation status
Cacomantis merulinus	Scopoli, 1786	Plaintive Cuckoo	LC
Cacomantis sonneratii	Latham, 1790	Banded Bay Cuckoo	LC
Centropus sinensis	Stephens, 1815	Greater Coucal	LC
Eudynamys scolopaceus	Linnaeus, 1758	Asian Koel	LC
Phaenicophaeus tristis	Lesson, 1830	Green-billed Malkoha	LC
Surniculus lugubris	Horsfield, 1821	Square-tailed Drongo-cuckoo	LC
PASSERIFORMES			
Acanthizidae			
Gerygone sulphurea	Wallace, 1864	Golden-bellied Gerygone	LC
Aegithinidae			
Aegithina tiphia	Linnaeus, 1758	Common Iora	LC
Campephagidae			
Lalage nigra	Pennant, 1781	Pied Triller	LC
Cisticolidae			
Orthotomus atrogularis	Temminck, 1836	Dark-necked Tailorbird	LC
Orthotomus ruficeps	Lesson, 1830	Ashy Tailorbird	LC
Orthotomus sericeus	Temminck, 1836	Rufous-tailed Tailorbird	LC
Orthotomus sutorius	Pennant, 1769	Common Tailorbird	LC
Corvidae			
Corvus macrorhynchos	Wagler, 1827	Large-billed Crow	LC
Dicaeidae			
Dicaeum cruentatum	Linnaeus, 1758	Scarlet-backed Flowerpecker	LC
Dicruridae			
Dicrurus leucophaeus	Vieillot, 1817	Ashy Drongo	LC
Muscicapidae			
Copsychus saularis	Linnaeus, 1758	Oriental Magpie-Robin	LC
Copsychus malabaricus	Scopoli, 1786	White-rumped Shama	LC
Cyornis rufigastra	Raffles, 1822	Mangrove Blue Flycatcher	LC
Muscicapa dauurica	Pallas, 1811	Asian Brown Flycatcher	LC
Nectariniidae			
Anthreptes malacensis	Scopoli, 1786	Brown-throated Sunbird	LC
Arachnothera longirostra	Latham, 1790	Little Spiderhunter	LC
Chalcoparia singalensis	Gmelin, 1789	Ruby-cheeked Sunbird	LC
Cinnyris jugularis	Linnaeus, 1766	Olive-backed Sunbird	LC
Leptocoma calcostetha	Jardine, 1842	Copper-throated Sunbird	LC
Oriolidae			
Oriolus chinensis	Linnaeus, 1766	Black-naped Oriole	LC
Pachycephalidae			
Pachycephala cinerea	Blyth, 1847	Mangrove Whistler	LC
Paridae			
Parus cinereus	Vieillot, 1818	Cinereous Tit	LC
Pellorneidae			
Malacocincla abbotti	Blyth, 1845	Abbott's Babbler	LC
Pittidae			
Pitta megarhyncha	Schlegel, 1863	Mangrove Pitta	NT
Pycnonotidae			
Ixodia erythropthalmos	Hume, 1878	Spectacled Bulbul	LC
Pycnonotus brunneus	Blyth, 1845	Asian Red-eyed Bulbul	LC
Pycnonotus goiavier	Scopoli, 1786	Yellow-vented Bulbul	LC
Pycnonotus plumosus	Blyth, 1845	Olive-winged Bulbul	LC
Pycnonotus simplex	Lesson, 1839	Cream-vented Bulbul	LC
Rhipiduridae			
Rhipidura javanica	Sparrman, 1788	Malaysian Pied Fantail	LC
Sittidae			
Sitta frontalis	Swainson, 1820	Velvet-fronted Nuthatch	LC
Timaliidae			
Cyanoderma erythropterum	Blyth, 1842	Chestnut-winged Babbler	LC
Vangidae			
Hemipus hirundinaceus	Temminck, 1822	Black-winged Flycatcher-shrike	LC
Zosteropidae			
Zosterops simplex	Swinhoe, 1861	Swinhoe's White-eye	LC
PICIFORMES			
Picidae			
Chrysocolaptes guttacristatus	Tickell, 1833	Greater Flameback	LC
Chrysophlegma miniaceum	Pennant, 1769	Banded Woodpecker	LC
Dinopium javanense	Ljungh, 1797	Common Flameback	LC
Picus vittatus	Vieillot, 1818	Laced Woodpecker	LC
Yungipicus moluccensis	Gmelin, 1788	Sunda Pygmy Woodpecker	LC

Data availability

Data will be made available on request.

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