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Bird communities in the tropical peri-urban landscape of Bogor, Indonesia

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Abstract. *Nugroho SPA, Mardiastuti A, Mulyani YA, Rahman DA. 2023. Bird communities in the tropical peri-urban landscape of Bogor, Indonesia. Biodiversitas 24: 6988-7000.* Amidst the urbanization threat, peri-urban landscapes can play an important role in biodiversity conservation, particularly among birds. Therefore, to study species and functional diversity of bird communities in the tropical peri-urban landscape, we observed four habitat types (forest, plantation, built-up area, and farmland) in the Ciampea-Dramaga Landscape, Bogor, Indonesia, from September to December 2020 and September to December 2021. A standard point method was used to observe birds, and several diversity indices were used for data analysis. Altogether, we recorded 11,290 individual birds of 61 species and 33 families. The species diversity tended to be higher in the increasing habitat succession stages. Forest had the highest species diversity (H′=3.17), followed by plantation (H′=2.87), built-up area (H′=2.54), and farmland (H′=2.23). Meanwhile, functional diversity revealed that all feeding guilds can be observed in the forest. The species richness of frugivore-insectivores dominated all habitats, and their abundance are also dominated in forest and plantation habitats. In contrast, granivores dominated farmland, and fly-catching insectivores dominated built-up areas. Due to its relatively high bird diversity in the study area, it needed to be conserved, including habitat management at the landscape scale, strengthening policies and conservation actions, and raising public awareness.

Keywords: Bird, conservation, diversity, ecology, urbanization

INTRODUCTION

More than fifty percent of the global population resides in urban regions nowadays, which has led to a rapid proliferation of urban and peri-urban infrastructure across the globe (Cities Alliance 2015). Numerous instances exist in which the exponential expansion of urban environments significantly impairs biodiversity because numerous cities are constructed in regions renowned for their high biodiversity (Oertli and Parris 2019). The expanding human population and urbanization-induced landscape transformation threaten biodiversity (Gatesire et al. 2014; Cafaro et al. 2022). Urbanization and biodiversity exhibited an inverse relationship (Aouissi et al. 2021).

Peri-urban areas, located between urban and rural areas, are particularly under pressure from rapid urbanization. Urban land expansion, infrastructure development, and population growth have destroyed habitats and natural habitat loss (Laurance et al. 2015; Simkin et al. 2022). However, despite the threat of urbanization, peri-urban areas remain crucial in preserving biodiversity, particularly bird species (Karjee et al. 2022). It has been widely asserted that peri-urban areas support diverse bird species, including remnant natural habitats, green belts, and reservoirs (Evans and Evans 2007).

Peri-urban areas frequently provide various habitat types, including farmlands, urban parks, and forests, which can support various bird species (Canedoli et al. 2017; Canedoli et al. 2018; Karjee et al. 2022). However, rapid urbanization and environmental changes seriously challenge bird populations (Sol et al. 2014). Human disturbance, natural habitat loss, and fragmentation are several factors that can reduce the diversity of bird species and force them to abandon urbanized areas (Wang et al. 2022; Zhang et al. 2023). Birds respond differently to environmental change depending on their adaptation to resource-limited environments; to survive in urbanized environments, birds must adapt to or avoid these new conditions (Isaksson 2018).

Bird species diversity in a habitat can illustrate how birds respond to habitat disturbance or change (Xu et al. 2018). However, apart from species diversity, parameters to observe bird response can also be discerned through functional diversity (Fontúrbel et al. 2022), a facet of biodiversity that assesses the diversity and distribution of functional traits among community members (Meynard et al. 2011). Habitat change or disturbance may result in the replacement or erosion of functional traits already present in the community, thereby inducing alterations in the community's functions (Almeida-Gomes et al. 2019; Mariano-Neto and Santos 2023).

Therefore, to understand more about bird communities in the peri-urban area, we studied the bird communities in a tropical peri-urban landscape in the Ciampea-Dramaga Landscape, Bogor, Indonesia. Several parameters were necessary to comprehend bird population dynamics across habitats, including species richness, diversity, abundance, dominance, rarefaction-extrapolation, and community similarity. Furthermore, it was also necessary to understand the complexity of various habitat types and bird species composition regarding their functional traits, primarily by examining the feeding guild. Thus, we had three aims specifically to analyze: (i) species diversity of bird communities across different habitat types in the Ciampea-Dramaga landscape; (ii) functional diversity (feeding guild) of bird communities in each habitat type; (iii) conservation implications for bird communities in the study area. We selected the Ciampea-Dramaga Landscape because it is a peri-urban landscape in the tropics and contains various habitat types representing different vegetation succession stages. We hypothesized that the habitat types assumed to represent the vegetation succession stages influence bird communities' species and functional diversity. The variety of bird communities would be higher in habitats with higher vegetation succession stages.

MATERIALS AND METHODS

Study area

We conducted this study in a tropical peri-urban landscape, specifically at Ciampea-Dramaga Landscape located in Indonesia (6° 32′17″-6° 33′13″ S and 106° 41′57″-106° 45′33″ E), encompassing an area of approximately 10.1 km^2 (Figure 1). Ciampea-Dramaga Landscape has a varied topography, with elevations ranging from 120 to 190 m above sea level (https://earth.google.com/ accessed on 27 May 2023). The average annual temperature in the study area is approximately 26.1° C, and the annual precipitation is 3,786.6 mm (Dramaga Climatology Station), indicating a tropical climate. Administratively, Ciampea and Dramaga are sub-district areas of Bogor District, West Java Province, Indonesia. The study area is a peri-urban area of Bogor City, a transition area from urban to rural. Due to the transition area, the study landscape is characterized by a mosaic of various land use types, from forest to settlement.

We surveyed Ciampea-Dramaga Landscape in September 2020 and identified their land use types. We selected four land uses or habitat types as locations for collecting data, i.e., forest, plantation, built-up area, and farmland, assuming variations in vegetation-related conditions existed. Furthermore, we assumed that these habitat types represented different stages of vegetation succession, from high to low.

The forest habitats in the study area are classified as secondary forests and are known to be found in the Dramaga Campus, Institut Pertanian Bogor (IPB), and Dramaga Experimental Forest. The forest habitat in the Dramaga Campus area is under IPB University's management, while the Dramaga Experimental Forest area has been under the Center for Standardization of Sustainable Forest Management Instruments, Ministry of Environment and Forestry currently. Furthermore, plantation habitats can be found around the Dramaga Campus area in several locations. Built-up area habitats are found in residential neighborhoods or buildings. Then, farmland habitats in the study area included wet and dry farmland, such as paddy and dry fields.

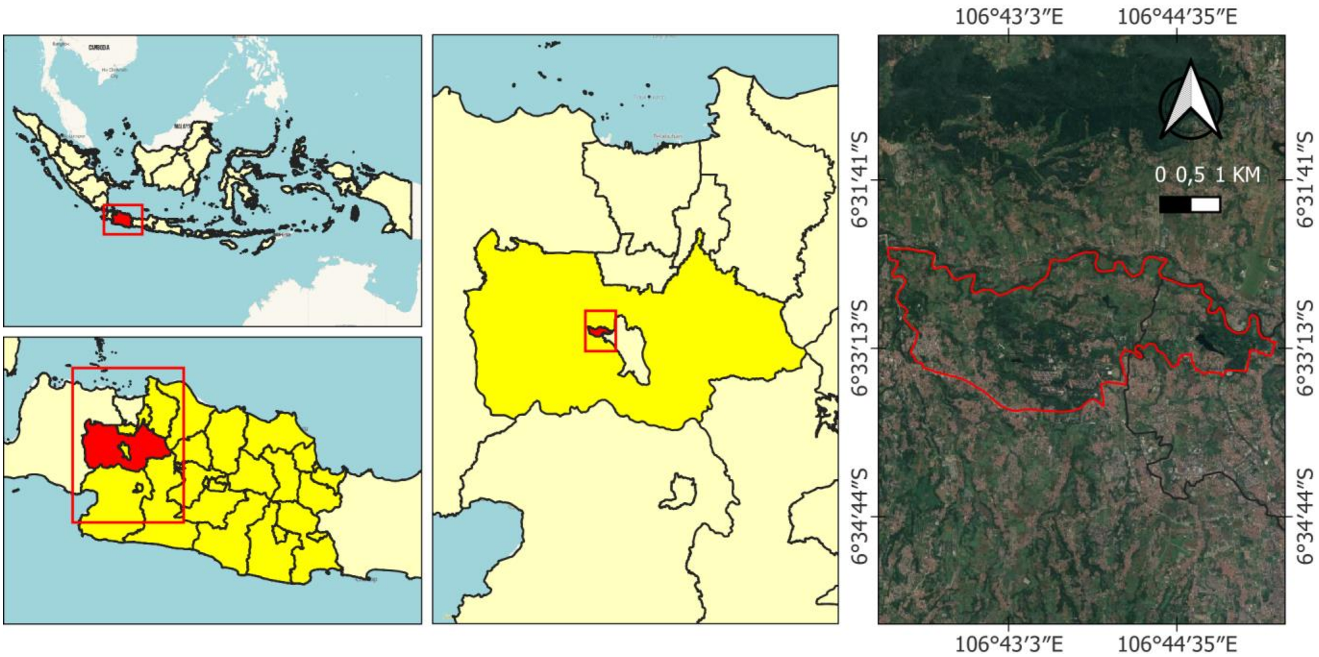

Figure 1. Map of study area showing Ciampea-Dramaga Landscape, Bogor District, West Java Province, Indonesia. The study area is a peri-urban area of Bogor City and represents a peri-urban landscape in the tropics

We measured the Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), and land cover percentage to determine the stage of vegetation succession for each habitat type. We collected NDVI data using satellite imagery and analyzed it using ArcMap software version 10.8. For LAI data, we captured images of the canopy and analyzed them with HemiView software version 2.1. In addition, we captured images of a 50x50 m plot using a drone (DJI Phantom series 4) at a height of approximately 75 m to determine the land cover percentage; after that, we analyzed the land cover object using ArcMap software version 10.8. NDVI, LAI, and land cover percentage data were collected on three plots as sampling in each land use type.

Based on NDVI and LAI measurements, forest habitat had the highest average values for both parameters, followed by plantation, built-up area, and farmland (Tables 1 and 2). Furthermore, the land cover percentage revealed that trees dominated the forest habitat despite other vegetation, such as shrubs (Table 3). The plantation habitat included trees, plantation crops, shrubs, open land, and roads. The built-up area habitat was dominated by building objects, although other objects such as trees, roads, and open land were identified. The farmland had vegetation of trees, crops, shrubs, roads, and open land. However, crops were dominated in this habitat. According to the measurement results, we concluded that forest represented the highest vegetation succession stage in this study, followed by plantations, built-up areas, and farmland.

Data collection

We observed birds from September to December 2020 and September to December 2021 using a standard point count method (Irham et al. 2018; Hasan et al. 2020; Imboma et al. 2020; Neupane et al. 2022) in the landscape studied. Therefore, to avoid bias from double counting the same individual bird, each observation point was separated by at least 300 m (Nugroho et al. 2021). When we arrived at each observation point, we allotted 10 minutes for settling time, followed by 15 minutes of observation time, in which we recorded all birds observed and heard within a 50 m radius. Bird observation was performed in the morning (6-9 a.m.) and afternoon (3-6 p.m.). Each site was observed twice as a replication (Nugroho et al. 2021). We avoided conducting observations when it was raining and windy because it would have been inefficient and potentially hazardous. We used binoculars, a camera, and an audio recorder to help identify and photograph bird species during observation. As field guides for species identification, we used the book "Birds of the Indonesian Archipelago: Greater Sundas and Wallacea" (Eaton et al. 2016; Eaton et al. 2021). In writing the nomenclature of bird species, we referred to Junaid et al. (2021) and Taufiqurrahman et al. (2022).

Table 1. Normalized Difference Vegetation Index (NDVI) values for four habitat types in the study area

Type of habitat	Normalized Difference Vegetation Index (NDVI) value			
	Plot I	**Plot II**	**Plot III**	**Mean ± SD**
Forest	0.43	0.34	0.37	0.38 ± 0.04
Plantation	0.32	0.37	0.26	0.32 ± 0.04
Built-up area	0.23	0.29	0.28	0.27 ± 0.03
Farmland	0.24	0.23	0.23	0.23 ± 0.01

Table 2. Leaf Area Index (LAI) values for four habitat types in the study area

Type of habitat	Leaf Area Index (LAI) value			
	Plot I	**Plot II**	**Plot III**	**Mean ± SD**
Forest	1.79	2.92	2.18	2.30 ± 0.47
Plantation	1.45	0.34	1.24	1.01 ± 0.48
Built-up area	0.66	0.24	0.29	0.40 ± 0.19
Farmland	0.34	0.08	0.25	0.22 ± 0.11

Table 3. Land Cover Percentage for four habitat types in the study area

Type of habitat	Description of land cover percentage in each habitat type
Forest	Trees comprised 94.16% of the vegetation in forest habitat. In addition, 5.84% of the land cover was covered by other vegetation types, such as shrubs.
Plantation	In plantation habitat, plantation crops such as *Elaeis guineensis* Jaq. comprised 41.95% of the land cover, followed by open land (26.21%), shrubs (12.03%), other plantation crops such as *Coffea sp*. (10.31%), roads (5.03%), and trees (4.48%).
Built-up area	The building object accounted for 49.09% of the land cover in this habitat, followed by open land, usually for the yard 21.53%, tree vegetation 18.28%, and roads 11.09%.
Farmland	Agricultural crops dominated the land cover in this habitat. Crops included *Zea mays* 33.55%, *Manihot esculenta* 9.73%, *Arachis hypogaea* L. 7.01%, *Colocasia esculenta* 6.79%, *Ipomoea Batatas* L. 4.73%, *Glycine max* L. 3.92%, *Oryza sativa* 3.60%, and *Musa paradisiaca* 3.91%. This habitat contained only 1.57% tree vegetation cover. In addition, there was 16,87% of open land, 4.59% of shrubs, and 3.73% of roads.

Data analysis

We combined all observational data across all habitat types for analysis. To analyze species diversity, we calculated the Shannon diversity index, Berger-Parker index, rank abundance curve, Renyi index, rarefaction-extrapolation curve, and Bray-Curtis index. The Shannon diversity index was used to measure community diversity (Magurran 2004). Next, to determine the significant difference in the Shannon diversity index between bird communities, we performed the t-test of diversity with PAleontological Statistics (PAST) software version 4.03. In addition, we used the Berger-Parker index to measure the dominance of species abundance (Magurran 2004). A rank abundance curve or Whittaker plot was constructed using the 'BiodiversityR' package to describe each bird community's species richness and abundance. We also calculated the Renyi index using the 'BiodiversityR' package for each bird community and visualized it with a curve to compare their species diversity. Next, using the 'iNEXT' package (Chao et al. 2014; Hsieh et al. 2022), we calculated a sample size based on the rarefaction-extrapolation curve to measure and predict the growth of species richness in a bird community along the increased sample size. Furthermore, we combined the Bray-Curtis index with the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) algorithm to analyze the similarity between bird communities across habitat types. We calculated the Bray-Curtis index using PAST software. All analyses above were performed using R Studio software version 4.2.3, excluding t-test diversity and the Bray-Curtis index, conducted with PAST software version 4.03.

We also analyzed the functional diversity between bird communities across habitat types. In this study, the functional diversity was represented by feeding guild composition based on species richness and abundance. We classified bird species into one of fourteen feeding guilds under their predominant diet (i.e., fly-catching insectivore, aerial sallying insectivore, tree foliage-gleaning insectivore, bark-gleaning insectivore, shrub foliage-gleaning insectivore, litter-gleaning insectivore, carnivore-insectivore, nectarivore-insectivore, frugivore-insectivore, granivore-frugivore, carnivore, frugivore, granivore, and omnivore) (Katuwal et al. 2018; Sastranegara et al. 2020; Panda et al. 2021; Shafie et al. 2023).

Finally, we classified the conservation status of bird species based on their status prevailing in Indonesia and Internationally. We referred to the Minister of Environment and Forestry Number P.106 regulation of 2018 for Indonesian fauna protected status. For conservation status internationally, we referred to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (https://www.iucnredlist.org/ accessed on 19 May 2023) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (https://checklist.cites.org/#/en accessed on 19 May 2023).

RESULTS AND DISCUSSION

Species diversity across different habitat types

Altogether, we recorded 11,290 individual birds of 61 species and 33 families during the observation in the study area (Table 4). Our survey revealed the highest bird abundance in the farmland, followed by built-up areas, plantations, and forests (Table 5). In contrast to habitats with the highest vegetation succession stages is revealed that the number of individual species was frequently low observed. Meanwhile, species richness exhibited the opposite trend; species richness tended to increase in habitats with the highest vegetation succession stages and conversely decrease in the lowest vegetation succession stages (Figure 2). Forest habitat had the highest bird species, followed by plantations, built-up areas, and farmland.

The Shannon index value indicated the same tendency as species richness that species diversity also increases with increasing habitat succession stage. Forest has the greatest species diversity, followed by plantations, built-up areas, and farmland (Table 5). As presented in the diversity profile based on the Renyi index (Figure 3), the forest appeared to be the highest at one and two alpha values, followed by plantation, built-up area, and farmland. The zero alpha value (α=0) indicates the species richness or number of species observed, the one alpha value of 1 (α=1) indicates the Shannon diversity index, and the two alpha values (α=2) indicate Simpson's diversity index. Moreover, the t-test of Shannon diversity was performed to determine the Shannon diversity difference between bird communities at a specified level of significance. Therefore, using a significance level of 95%, the t-test revealed that the species diversity between habitat types was significantly different (Table 6). Moreover, the Berger-Parker index values revealed that the higher the stage of habitat succession, the lower the Berger-Parker dominance index (Table 5). The Berger-Parker index value is close to 0, indicating that the abundance of individuals from each species in a habitat is evenly distributed. In contrast, the higher value and proximity to 1 in a habitat indicate that dominant bird species are present and that the abundance of individuals from each species is not evenly distributed.

The rarefaction-extrapolation curve of bird communities gradually flattened as the number of individuals increased (Figure 4). Species richness in the forest habitat would likely increase with greater sampling, and this can be seen from the line on the curve that has yet to reach the asymptote. In addition, increasing the number of samples would have little effect on the species richness of the plantation habitat. On the other hand, species richness in the built-up area and farmland habitats was predicted to be constant even though sampling was increased because it has reached asymptotes.

The similarity of bird communities in species composition across habitat types was analyzed using the Bray-Curtis index and visualized with a dendrogram. The Bray-Curtis cluster analysis grouped the bird communities into two major clusters with a similarity level of 0.60 (Figure 5). The composition of bird species in forest and plantation habitats was relatively similar (0.66 similarity), forming a single cluster, Cluster 1 (Table 7). On the other hand, bird communities in farmland are similar to the built-up area (0.67 similarity), forming a separate cluster (Cluster 2) distinct from other clusters.

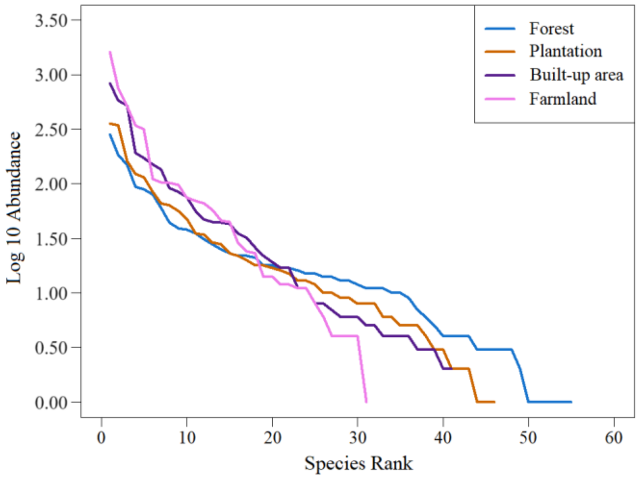

Figure 2. Rank abundance curve of bird communities across different habitat types in the study area

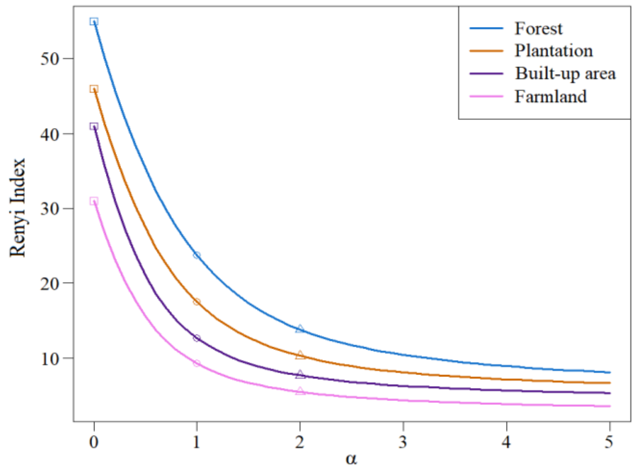

Figure 3. Diversity profile based on the Renyi index of bird communities across different habitat types in the study area

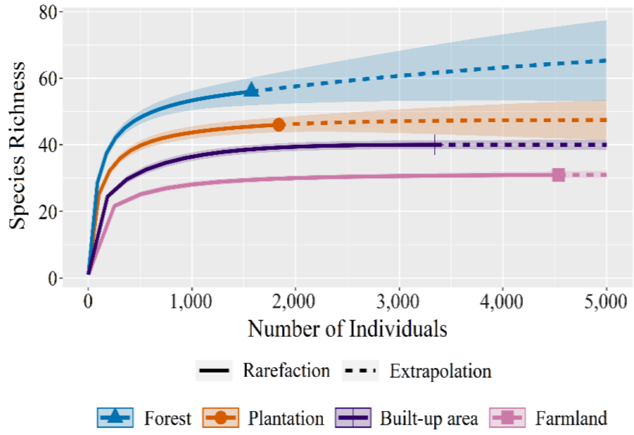

Figure 4. Rarefaction-extrapolation curve of bird communities across different habitat types in the study area

Functional diversity across different habitat types

The functional diversity was represented by the different feeding guild compositions of bird communities across habitat types in this study. The feeding guild composition was analyzed based on each feeding guild's species richness and abundance. There were 14 feeding guilds based on predominant diet: fly-catching insectivore, aerial sallying insectivore, tree foliage-gleaning insectivore, bark-gleaning insectivore, shrub foliage-gleaning insectivore, litter-gleaning insectivore, carnivore-insectivore, nectarivore-insectivore, frugivore-insectivore, granivore-frugivore, carnivore, frugivore, granivore, and omnivore. Altogether, all feeding guild types were found in the forest habitat, with the species richness varying between feeding guilds. Based on the species richness, the frugivore-insectivores (FRU-INS) have the greatest richness and dominate all habitat types (Figure 6). The fly-catching insectivores (FCI), bark-gleaning insectivores (BGI), shrub foliage-gleaning insectivores (SFGI), litter-gleaning insectivores (LGI), and omnivores (OMN) revealed a higher tendency in habitats with higher vegetation succession stages.

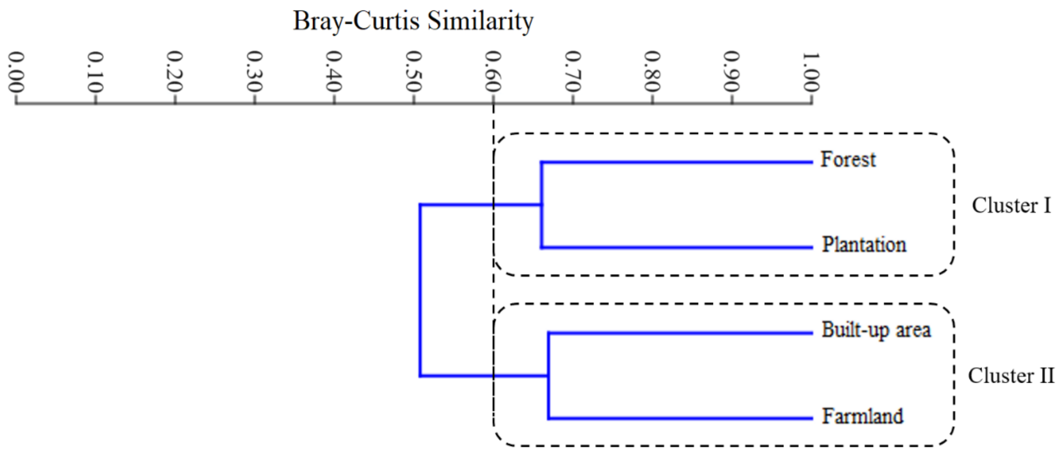

Figure 5. Bray-Curtis similarity dendrogram of the bird communities across different habitat types in the study area

Table 4. Bird species recorded during the survey in the study area

Common name	Scientific name	Feeding guild	For	Pln	Blt	Frm	Conservation Status		
							P.106 /2018	IUCN	CITES
Columbidae									
Eastern spotted dove	*Spilopelia chinensis*	GRA-FRU	●	●	●	●	NP	LC	NL
Grey-capped emerald dove	*Chalcophaps indica*	GRA-FRU	●	●	□	□	NP	LC	NL
Pink-necked green-pigeon	*Treron vernans*	FRU	●	□	●	□	NP	LC	NL
Grey-cheeked green-pigeon	*Treron griseicauda*	FRU	●	□	●	□	NP	LC	NL
Apodidae									
Cave swiftlet	*Collocalia linchi*	FCI	●	●	●	●	NP	LC	NL
House swift	*Apus nipalensis*	FCI	●	●	●	●	NP	LC	NL
Cuculidae									
Greater coucal	*Centropus sinensis*	CAR-INS	□	●	□	□	NP	LC	NL
Lesser coucal	*Centropus bengalensis*	CAR-INS	●	●	□	□	NP	LC	NL
Chestnut-breasted malkoha	*Phaenicophaeus curvirostris*	ASI	□	●	□	□	NP	LC	NL
Banded bay cuckoo	*Cacomantis sonneratii*	FRU-INS	●	●	●	●	NP	LC	NL
Plaintive cuckoo	*Cacomantis merulinus*	FRU-INS	●	●	●	●	NP	LC	NL
Brush cuckoo	*Cacomantis variolosus*	FRU-INS	●	●	●	●	NP	LC	NL
Square-tailed drongo-cuckoo	*Surniculus lugubris*	TFGI	●	●	●	●	NP	LC	NL
Rallidae									
Red-legged crake	*Rallina fasciata*	OMN	●	□	□	□	NP	LC	NL
White-breasted waterhen	*Amaurornis phoenicurus*	OMN	●	●	□	□	NP	LC	NL
Ardeidae									
Yellow bittern	*Ixobrychus sinensis*	CAR-INS	□	□	□	●	NP	LC	NL
Turnicidae									
Barred buttonquail	*Turnix suscitator*	OMN	●	●	●	●	NP	LC	NL
Accipitridae									
Crested serpent-eagle	*Spilornis cheela*	CAR	●	●	□	□	P	LC	AP II
Chinese sparrowhawk	*Accipiter soloensis*	CAR	●	●	□	□	P	LC	AP II
Alcedinidae									
Blue-eared kingfisher	*Alcedo meninting*	CAR-INS	●	●	●	●	NP	LC	NL
Javan kingfisher	*Halcyon cyanoventris*	CAR-INS	●	●	●	●	NP	LC	NL
Collared kingfisher	*Todiramphus chloris*	CAR-INS	●	●	●	●	NP	LC	NL
Megalaimidae									
Coppersmith barbet	*Psilopogon haemacephalus*	FRU-INS	●	●	●	□	NP	LC	NL
Picidae									
Sunda pygmy woodpecker	*Picoides moluccensis*	BGI	●	●	●	□	NP	LC	NL
Freckle-breasted woodpecker	*Dendrocopos analis*	BGI	●	●	●	□	NP	LC	NL
Falconidae									
Spotted kestrel	*Falco moluccensis*	CAR	□	□	●	□	P	LC	AP II
Psittacidae									
Red-breasted parakeet	*Psittacula alexandri*	GRA-FRU	●	●	●	□	P	NT	AP II
Long-tailed parakeet	*Belocercus longicaudus*	GRA-FRU	□	●	□	□	P	VU	AP II
Oriolidae									
Black-naped oriole	*Oriolus chinensis*	OMN	●	●	●	●	NP	LC	NL
Campephagidae									
Small minivet	*Pericrocotus cinnamomeus*	BGI	●	●	●	●	NP	LC	NL
Pied triller	*Lalage nigra*	FRU-INS	●	●	●	□	NP	LC	NL
Artamidae									
White-breasted wood swallow	*Artamus leucoryn*	FCI	●	□	●	□	NP	LC	NL
Vangidae									
Black-winged flycatcher-shrike	*Hemipus hirundinaceus*	ASI	●	●	□	□	NP	LC	NL
Aegithinidae									
Common iora	*Aegithina tiphia*	BGI	●	●	●	●	NP	LC	NL
Rhipiduridae									
Sunda pied fantail	*Rhipidura javanica*	ASI	●	□	□	□	P	LC	NL
Corvidae									
Slender-billed crow	*Corvus enca*	OMN	●	□	●	□	NP	LC	NL
Cisticolidae									
Bar-winged prinia	*Prinia familiaris*	SFGI	●	●	●	●	NP	NT	NL
Common tailorbird	*Orthotomus sutorius*	SFGI	●	●	●	●	NP	LC	NL
Olive-backed tailorbird	*Orthotomus sepium*	SFGI	●	●	●	●	NP	LC	NL
Locustellidae									
Striated grassbird	*Megalurus palustris*	SFGI	●	□	□	□	NP	LC	NL

Hirundinidae									
Red-rumped swallow	*Cecropis daurica*	FCI	●	●	●	●	NP	LC	NL
House swallow	*Hirundo javanica*	FCI	●	●	●	●	NP	LC	NL
Barn swallow	*Hirundo rustica*	FCI	●	□	□	□	NP	LC	NL
Pycnonotidae									
Sooty-headed bulbul	*Pycnonotus aurigaster*	FRU-INS	●	●	●	●	NP	LC	NL
Yellow-vented bulbul	*Pycnonotus goiavier*	FRU-INS	●	●	●	●	NP	LC	NL
Timaliidae									
Grey-cheeked tit-babbler	*Mixornis flavicollis*	SFGI	□	●	□	□	NP	LC	NL
Pellorneidae									
Rufous-browed babbler	*Pellorneum capistratum*	LGI	●	●	□	□	NP	LC	NL
Horsfield's babbler	*Malacocincla sepiaria*	LGI	●	●	●	●	NP	LC	NL
Sittidae									
Velvet-fronted nuthatch	*Sitta frontalis*	BGI	●	□	□	□	NP	LC	NL
Sturnidae									
Javan myna	*Acridotheres javanicus*	OMN	●	□	□	□	NP	VU	NL
Asian glossy starling	*Aplonis panayensis*	OMN	●	□	●	□	NP	LC	NL
Turdidae									
Orange-headed thrush	*Geokichla citrina*	LGI	●	□	□	□	NP	LC	NL
Muscicapidae									
Pied bush chat	*Saxicola caprata*	ASI	●	□	□	□	NP	LC	NL
Dicaeidae									
Plain flowerpecker	*Dicaeum minullum*	FRU-INS	●	●	●	●	NP	LC	NL
Scarlet-headed flowerpecker	*Dicaeum trochileum*	FRU-INS	●	●	●	●	NP	LC	NL
Nectariniidae									
Brown-throated sunbird	*Anthreptes malacensis*	NEC-INS	●	●	●	●	NP	LC	NL
Olive-backed sunbird	*Cinnyris jugularis*	NEC-INS	●	●	●	●	NP	LC	NL
Estrildidae									
Javan munia	*Lonchura leucogastroides*	GRA	●	●	●	●	NP	LC	NL
Scaly-breasted munia	*Lonchura punctulata*	GRA	●	●	●	●	NP	LC	NL
White-headed munia	*Lonchura maja*	GRA	●	●	●	●	NP	LC	NL
Passeridae									
Eurasian tree sparrow	*Passer montanus*	GRA	●	●	●	●	NP	LC	NL

Note: For: forest, Pln: plantation, Blt: built-up area, Frm: farmland, FCI: fly-catching insectivore, ASI: aerial sallying insectivore, TFGI: tree foliage-gleaning insectivore, BGI: bark-gleaning insectivore, SFGI: shrub foliage-gleaning insectivore, LGI: litter-gleaning insectivore, CAR-INS: carnivore-insectivore, NEC-INS: nectarivore-insectivore, FRU-INS: frugivore-insectivore, GRA-FUR: granivore-frugivore, OMN: omnivore, CAR: carnivore, GRA: granivore, FRU: frugivore, ●: present, □: absent, P: protected, NP: not protected, LC: least concern, NT: near threatened, VU: vulnerable, AP II: appendix II, NL: not listed

Table 5. Diversity of bird communities across different habitat types in the study area

Parameters	Type of habitat			
	Forest	**Plantation**	**Built-up area**	**Farmland**
Abundance (N)	1,571	1,838	3,345	4,536
Species richness (S)	55	46	41	31
Chao1 index (S_{chao1})	73	48	41	31
Shannon index (H')	3.17	2.87	2.54	2.23
Berger-Parker index (d)	0.18	0.20	0.25	0.36

Table 6. T-test value of Shannon diversity between different habitat types in the study area

Type of habitat	Forest	Plantation	Built-up area	Farmland
Forest	-	-	-	-
Plantation	7.21*	-	-	-
Built-up area	16.75*	8.93*	-	-
Farmland	26.17*	18.32*	10.73*	-

Note: α: 0.05, *: significant

Table 7. Bray-Curtis similarity index value between different habitat types in the study area

Type of habitat	Forest	Plantation	Built-up area	Farmland
Forest	1.00	-	-	-
Plantation	0.66	1.00	-	-
Built-up area	0.51	0.64	1.00	-
Farmland	0.37	0.52	0.67	1.00

Meanwhile, the highest richness of carnivore-insectivores (CAR-INS) and granivore-frugivores (GRA-FRU) was observed in plantation habitats. The tree foliage-gleaning insectivores (TFGI), nectarivore-insectivores (NEC-INS), and granivores (GRA) were found in all habitats, although the species richness was similar in each habitat. The aerial sallying insectivores (ASI) were only found in forest and plantation habitats, while the frugivores (FRU) only inhabited forest and built-up areas. Additionally, carnivores (CAR) were not spotted in farmland but in other habitats with a relatively small species richness.

Feeding guild abundance revealed that frugivore-insectivores (FRU-INS) dominated forest and plantation habitats (Table 8). Meanwhile, built-up area habitats were dominated by fly-catching insectivores (FCI), and farmland habitat by granivores (GRA). Several feeding guilds were most abundant in the habitat with the highest successional stage, namely the forest habitat. These feeding guilds were aerial sallying insectivores (ASI), tree foliage-gleaning insectivores (TFGI), bark-gleaning insectivores (BGI), shrub foliage-gleaning insectivores (SFGI), litter-gleaning insectivores (LGI), omnivores (OMN), and carnivores (CAR). Meanwhile, the abundance of fly-catching insectivores (FCI), frugivore-insectivores (FRU-INS), granivore-frugivores (GRA-FRU), and frugivores (FRU) varied across habitat types. However, the most incredible abundance was observed in built-up area habitats. In contrast to carnivore-insectivores (CAR-INS), the lowest abundance was found in built-up areas, while the highest abundance was found in farmland and consisted of birds from the Alcedinidae family, such as Blue-eared kingfisher *Alcedo meninting*, Javan kingfisher *Halcyon cyanoventris*, and Collared kingfisher *Todiramphus chloris*. Moreover, the highest abundance of nectarivore-insectivores (NEC-INS) was observed in forests and built-up areas, while it was lowest in plantations and farmlands. During the survey, only two species of this feeding guild were observed: Brown-throated sunbird *Anthreptes malacensis* and Olive-backed sunbird *Cinnyris jugularis*. On the other hand, granivores (GRA) dominated farmland habitats by reaching 2,610 individuals. Granivores (GRA) were observed in flocks frequently, both in small and large flocks, such as Javan munia *Lonchura leucogastroides*, Scaly-breasted munia *Lonchura punctulata*, and Eurasian tree sparrow *Passer montanus*.

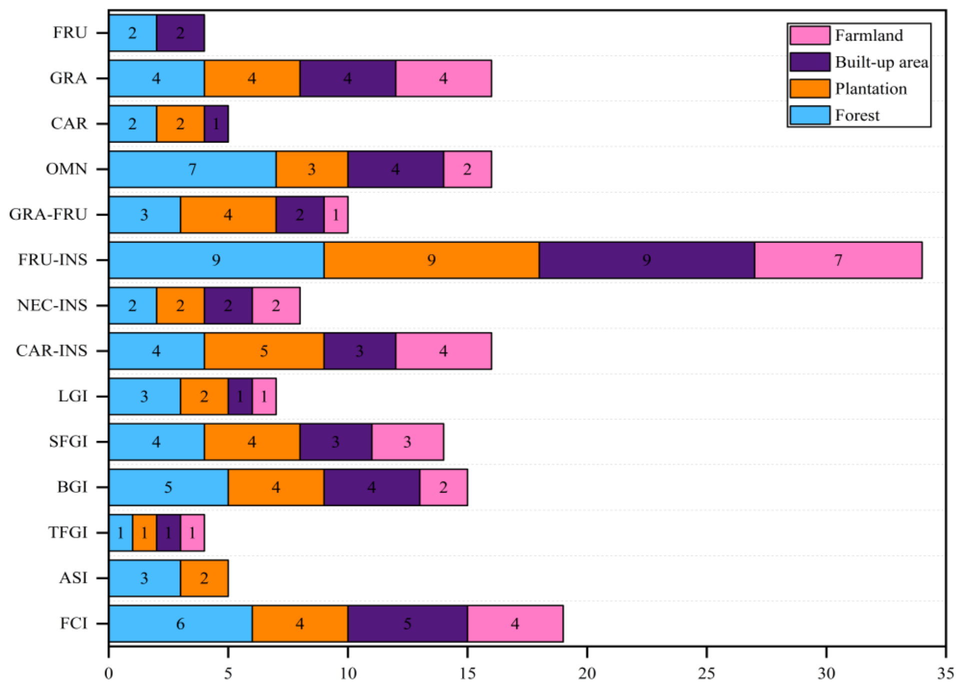

Figure 6. Feeding guild richness across different habitat types in the study area. Note: FCI: fly-catching insectivore, ASI: aerial sallying insectivore, TFGI: tree foliage-gleaning insectivore, BGI: bark-gleaning insectivore, SFGI: shrub foliage-gleaning insectivore, LGI: litter-gleaning insectivore, CAR-INS: carnivore-insectivore, NEC-INS: nectarivore-insectivore, FRU-INS: frugivore-insectivore, GRA-FUR: granivore-frugivore, OMN: omnivore, CAR: carnivore, GRA: granivore, FRU: frugivore

Table 8. Feeding guild abundance across different habitat types in the study area

Feeding guild	Forest	Plantation	Built-up area	Farmland
Fly-catching insectivore (FCI)	215	420	982	928
Aerial sallying insectivore (ASI)	18	8	0	0
Tree foliage-gleaning insectivore (TFGI)	25	15	11	12
Bark-gleaning insectivore (BGI)	54	29	35	20
Shrub foliage-gleaning insectivore (SFGI)	180	96	115	121
Litter-gleaning insectivore (LGI)	23	15	5	14
Carnivore-insectivore (CAR-INS)	75	96	34	116
Nectarivore-insectivore (NEC-INS)	61	34	53	27
Frugivore-insectivore (FRU-INS)	539	553	870	607
Granivore-frugivore (GRA-FRU)	177	130	211	66
Omnivore (OMN)	91	21	46	15
Carnivore (CAR)	6	2	3	0
Granivore (GRA)	82	419	940	2,610
Frugivore (FRU)	25	0	40	0

Bird conservation status

Altogether, approximately 55 bird species observed in the study area are not protected in Indonesia, according to the Minister of Environment and Forestry Number P.106 of 2018. Meanwhile, six bird species are protected species (Chinese sparrowhawk *Accipiter soloensis*, Crested serpent-eagle *Spilornis cheela*, Spotted kestrel *Falco moluccensis*, Red-breasted parakeet *Psittacula alexandri*, Long-tailed parakeet *Belocercus longicaudus*, and Sunda pied fantail *Rhipidura javanica*) (Table 4). We also recorded two globally vulnerable species (Long-tailed parakeet *Belocercus longicaudus* and Javan myna *Acridotheres javanicus*) and two near-threatened species (Red-breasted parakeet *Psittacula alexandri* and Bar-winged prinia *Prinia familiaris*), while most species have least concern status. Furthermore, we also recorded five species classified as Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), such as Chinese sparrowhawk *Accipiter soloensis*, Crested serpent-eagle *Spilornis cheela*, Spotted kestrel *Falco moluccensis*, Red-breasted parakeet *Psittacula alexandri*, and Long-tailed parakeet *Belocercus longicaudus*. Meanwhile, most bird species were not listed in the CITES.

Discussion

Bird species richness and diversity tended to be higher in habitats with higher stages of vegetation succession. Forest habitat had the highest species richness and diversity, followed by plantation, built-up area, and farmland. These results follow our initial hypothesis, and the same results were found in several previous studies (Casas et al. 2016; Dario 2017; Owen et al. 2020; Gunarto et al. 2021; Noe et al. 2022). Species diversity in a habitat is determined by vegetation structure and composition, habitat size, and level of human and predator disturbance (Betts et al. 2013; Liang et al. 2018; Paker et al. 2014). In habitats with advanced stages of vegetation succession, vegetation is abundant, both from the composition and strata of diverse vegetation, which can provide nesting materials, predator protection, and food sources for a particular bird species (Noe et al. 2022). The vegetation structure is also more heterogeneous in forested habitats with multiple layers of vegetation. The heterogeneity of vegetation structure can be a major factor in determining the richness and diversity of bird species (Xu et al. 2022). A more diverse vegetation structure will provide greater opportunities for bird species specializing in particular vegetation layers or compositions (Remeš et al. 2022). In contrast, bird dominance index values tended to be lower in habitats with advanced successional stages. This indicates that the dominance of bird species is lower in habitats with more advanced vegetation succession stages. Nevertheless, the distribution of bird species is more uniform. There may be less competition between bird species due to limited resources in habitats with more complex vegetation conditions.

Then, an integrated curve (the rarefaction-extrapolation curve) was used in this study. The curve is an integrated curve based on sampling theory that links rarefaction (interpolation) and extrapolation (prediction) seamlessly, standardizes samples based on sample size or sample completeness, and can be utilized to compare biodiversity data (Chao et al. 2014). Our curve in this study revealed that with increased sampling, the species richness in the forest habitat would likely increase. Moreover, increasing the number of samples would only have a minimal impact on the species richness of the plantation habitat. Despite increased sampling, species richness in built-up area and farmland habitats was predicted to remain unchanged because the extrapolation line on the curve has reached the asymptote. According to the curve, the species richness in a habitat may increase when the number of samples (times or observation sites) is increased. This is because many bird species, such as a single individual, were observed in small numbers during observations. During observations, especially in forest habitats with dense vegetation cover, it will be challenging for observers to detect the presence of birds, and a significant number of birds are detected not visually but by their sounds. Therefore, compared to the built-up area and farmland habitats, it was relatively easy for observers to detect the presence of birds because the vegetation was relatively sparse, and the birds were frequently observed in flocks.

A dendrogram of bird community similarity based on the Bray-Curtis index revealed two clusters at a similarity level of 0.60. Cluster I consisted of forest and plantation habitats with similar bird composition, whereas Cluster II consisted of built-up area and farmland habitats. In general, environmental and resource similarities contribute to the similarity of bird communities between habitats by influencing the composition of species inhabiting them to be relatively similar (Kaban 2018; Riefani and Soendjoto 2021).

We classified bird species into 14 feeding guilds in this study. Therefore, to describe the flow of energy and matter, as well as the complexity of the ecosystem as a bird habitat, it is necessary to classify bird species according to their feeding guild (Olabamiyo and Akinpelu 2017). The study showed that all feeding guilds were only recorded in forest habitats. This finding provided further evidence in favor of our initial hypothesis that functional diversity (feeding guilds) increases with the stage of vegetation succession. It appears that vegetation succession at higher stages and in more complex habitats can contribute more to biological and functional diversity (Subasinghe and Sumanapala 2014). If a habitat or place contains a variety of bird species with different feeding guilds, the habitat reveals the abundance of available resources for birds and good environmental conditions (Ding et al. 2019; Ferger et al. 2014).

Feeding guild richness revealed that the frugivore-insectivores have the greatest richness and dominate all habitat types. Our findings indicated that every habitat type could provide for the requirements of this feeding guild. Frugivorous birds may consume insects as an alternative food source (Nazaro and Blendinger 2017), allowing them to thrive in various habitats. Generally, most birds are insectivores or utilize insects as a secondary food source (Sogari et al. 2019). The insect availabilities in nature are more stable than other food sources, such as fruit which vary with the fruiting season (Wong 1986).

The feeding guild of insectivores was classified into various types according to their foraging behavior in this study. Altogether, the fly-catching insectivore, bark-gleaning insectivore, shrub foliage-gleaning insectivore, litter-gleaning insectivore, and omnivore also can be found in all habitat types and showed an increasing trend in habitats with higher stages of vegetation succession. The availability of abundant insect food and the vegetation structure can influence the dominance of insectivorous birds in an area. Vegetation structure had the most excellent effect on the species richness of insectivorous birds compared to other feeding guilds (Ferger et al. 2014). The presence of insectivorous birds in nature benefits the agriculture system as a biological control agent against insect pests (Grass et al. 2017; Garcia et al. 2020; Tela et al. 2021; Olmos-Moya et al. 2022). Numerous omnivorous species inhabiting forest habitats indicate abundant animal and plant food sources supporting omnivore food availability (Mengesha et al. 2011). These species, such as Asian glossy starling *Aplonis panayensis* and Black-naped oriole *Oriolus chinensis*, exhibited the highest abundance and dominance among omnivorous birds, frequently observed in small and large flocks.

Nectarivore-insectivore birds were observed in all habitat types, with species richness evenly distributed between habitat types and relatively small. Only two species of this feeding guild were recorded during observation: Brown-throated sunbird *Anthreptes malacensis* and Olive-backed sunbird *Cinnyris jugularis*. These two bird species are common in the Greater Sundas lowlands, including this study area, where they are known to feed on nectar and insects (Eaton et al. 2021; Taufiqurrahman et al. 2022). Nectarivore-insectivore birds in all habitat types indicate that these two species survive in their respective habitats. These birds, especially those that feed on nectar, play a crucial role in the ecosystem as pollinators (Previatto et al. 2013).

Carnivore-insectivore species, feeding on a mixture of vertebrate prey, small arthropods, and large arthropods, were observed in all habitat types in this study. Then, the carnivore-insectivore species recorded and dominated in all habitat types were fish eaters, such as Blue-eared kingfisher *Alcedo meninting*, Javan kingfisher *Halcyon cyanoventris*, and Collared kingfisher *Todiramphus chloris*. During the observation, these birds were often observed in sites relatively close to wetlands, such as a lake or river. Fish-eating birds generally depend on wetlands as a source of fish food (Panda et al. 2021). Meanwhile, carnivorous bird species feeding on vertebrate prey and large arthropods, such as Crested serpent-eagle *Spilornis cheela* and Chinese sparrowhawk *Accipiter soloensis*, were only observed in forest and plantation habitats. Meanwhile, the Spotted kestrel *Falco moluccensis* was observed in built-up area habitats. The presence of carnivorous birds as predators in an ecosystem can function to maintain the balance of the food chain system (Atmoko et al. 2022).

Granivore-frugivore birds, consuming a mixture of seeds, grains, nuts, and fleshy fruits, can be found in all habitat types, albeit with varying species richness and abundance between each habitat. This is due to the availability of food sources in all habitat types for these birds. Plantation habitats contained the greatest species richness of granivore-frugivore, with only one species deviating from forest habitats. The highest abundance of this feeding guild was found in built-up habitat areas and was dominated by the Eastern spotted dove *Spilopelia chinensis*. This species is common in the Greater Sundas, especially Java Island, and in open and built-up area habitats (Eaton et al. 2016; Eaton et al. 2021; Taufiqurrahman et al. 2022).

Granivorous birds were spotted in all habitat types, with species richness between habitat types being similar. In contrast, there were 2,610 granivorous birds in farmland habitats, the most incredible abundance. Granivorous birds, such as the Javan munia *Lonchura leucogastroides*, Scaly-breasted munia *Lonchura punctulata*, and Eurasian tree sparrow *Passer montanus*, were frequently observed in flocks, both small and large. Granivores are most prevalent in paddy and dry field habitats, indicating that the habitat seeds abundance as food for granivores. According to Titulaer et al. (2018), an essential determinant of habitat quality for seed-eating birds is the availability of seeds that are ingested profitably. Therefore, the determining factor for the presence of granivorous birds is the availability of seed food.

Frugivorous birds can only be found in forests and built-up areas with similar and relatively small species richness. Only two bird species observed are fleshy fruit eaters, namely Pink-necked green-pigeon *Treron vernans* and Gray-cheeked green-pigeon *Treron griseicauda*. This means both habitat types provide fruit-based food sources for frugivorous birds. Moreover, built-up area habitats contained the most incredible abundance of frugivorous birds; particularly in the built-up areas of the IPB Campus, many fruit trees surround the location of the buildings. The presence of frugivorous birds is essential as seed dispersers (Camargo et al. 2021; Hu et al. 2022), contributing to vegetation regrowth.

We attempted to classify the conservation status of bird species from the observation results based on their conservation status in Indonesia and Internationally, namely the regulation of the Minister of Environment and Forestry No. P.106 of 2018, International Union for Conservation of Nature (IUCN) Red List of Threatened Species, and Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The study identified six protected species in this study according to the regulation of the Minister of Environment and Forestry No.P.106 of 2018. The regulation protects flora and fauna species in Indonesia whose existences have become rare in the wild due to threats such as illegal hunting, illegal trade, and bird keeping for hobbies. This regulation is anticipated to be very beneficial for bird conservation, as it specifies which species are protected and makes all actions that threaten the survival of these species break the law. In the study area representing peri-urban landscapes where human dominance is increased intensively by urbanization, there are still protected bird species. Hence, peri-urban areas can serve as bird refuges (Katuwal et al. 2018; Echeverry-Galvis et al. 2023). Obviously, a collective concern is needed to conserve bird species and their habitat in the peri-urban areas. Conservation of protected bird species and other species not currently protected in the regulation should also be a collective concern to protect their survival so populations do not become extinct.

We recorded two vulnerable species based on the IUCN Red List of Threatened Species. Vulnerable status indicates that the species is likely to become extinct in the wild in the future. In addition, we also recorded two near-threatened species in the study area. Meanwhile, the majority of species have the least concern status. With the information on the extinction risk status in the study area, conservation efforts can be initiated to protect species and their habitats. The IUCN Red List can influence aspects of conservation such as policy strengthening, raising awareness, setting priorities, and resource allocation (Betts et al. 2020; Hoffmann et al. 2008).

Our study also identified the bird species observed during the study based on international trade regulations, namely the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Altogether, we recorded five species listed in Appendix II of CITES. CITES consists of three categories (Appendix I, II, and III), and Appendix II is a list that is not endangered. However, it could become endangered when the trade continues unregulated (Hau and Sadovy de Mitcheson 2023). Thus, collective action by stakeholders to strengthen conservation policies and actions is required to address this issue.

Based on the study results, the Ciampea-Dramaga landscape has a relatively high diversity of bird species. It can be a refugium area for birds in the tropical peri-urban landscape and still also found some protected bird species. Hence, conservation efforts are necessary to protect bird species and their habitat amidst the human disturbance threat, such as habitat fragmentation and loss. Our recommendations for conservation implications are as follows: (1) landscape-scale habitat management. Therefore, to increase the species diversity of birds, habitat enhancement efforts must be conducted, such as increasing green space areas, establishing new gardens, restoring native vegetation cover, planting fruiting trees, and planting flowering trees. Additionally, the maintenance of large decaying trees is required because large decaying trees provide nesting sites for cavity-nesting birds (Bunnell 2013; Gutzat and Dormann 2018; Bonaparte et al. 2020; Nugroho et al. 2023); (2) strengthening conservation policies and actions. In implementing conservation policies, infringements occasionally occur in the field, making its implementation not optimal. Therefore, strict regulations must be enforced to solve all types of infringements and decrease future infringements. Furthermore, to bolster conservation policies, it is also necessary to reinforce conservation actions; (3) raising public awareness. The public plays an essential role in the success of conservation, and high public awareness is required for conservation programs to be effectively implemented. Some efforts can be conducted to increase public awareness, such as public socialization activities (e.g., socialization about the importance of biodiversity preservation, regulations of capturing protected animals, and the benefit of planting trees) or posting educational videos and images about biodiversity conservation with the public on social media by government, conservation organizations, academicians, or anyone conservation-concerned.

In conclusion, bird communities' species and functional diversity in the Ciampea-Dramaga Landscape was relatively high. We recorded 11,290 individual birds from 61 species and 33 families during observations. Based on our study, species, and functional diversity appear to be affected by differences in habitat types, which correspond to the vegetation succession stage. This supports our initial hypothesis that bird species diversity would be more significant in habitats with higher stages of vegetation succession. Forest had the highest species diversity, followed by plantation, built-up area, and farmland. Moreover, the functional diversity based on feeding guild composition revealed that all feeding guild groups can be found in the habitat type with the higher stage of vegetation succession, namely forest habitat. The species richness of the frugivore-insectivores dominated all habitat types.

Based on the abundance, the frugivore-insectivore dominated in forest and plantation habitats. In comparison, granivores dominated farmland habitats, and fly-catching insectivores dominated built-up area habitats. Due to the high species diversity in the study area, some conservation efforts must be initiated, including habitat management at the landscape scale, strengthening conservation policies and actions, and raising public awareness.

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