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Habitat Heterogeneity Shapes Bird Diversity and Community Structure in Misool Island Nature Reserve, Southwest Papua

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Abstract

Misool Island, part of the Raja Ampat archipelago, lies within the ecologically important Wallacea-Sahul transition zone. Despite its high potential for endemism, the long hiatus in terrestrial surveys since the mid-20th century especially on bird communites and habitats association has created a sginificant gap for current conservation planning. This study assessed bird diversity and community structure across three habitat types: lowland forest, riparian forest, and sandstone lowland forest. Bird surveys were conducted using the strip transect method. Community structure was evaluated using standard biodiversity indices, and differences in species composition among habitats were examined using multivariate analyses based on Bray–Curtis similarity and non-metric multidimensional scaling (NMDS). A total of 555 individual birds representing 90 species from 36 families were recorded. Riparian habitats supported the highest abundance (n = 256, 58 species) , whereas the sandstone lowland forest exhibited the highest diversity values (H' = 3.30, C = 0.05, Dmg = 10.09). Evenness values were relatively high across habitats (0.81–0.85), indicating a relatively even distribution of species abundances. Multivariate analyses revealed differences in species composition among habitats, with the sandstone lowland forest supporting a more distinct bird assemblage. Feeding guild composition varied among habitats, with insectivores (34%) and insectivore-frugivores (12%) dominated overall. The area also supports 24 species protected under Indonesian regulation, 41 Papuan endemics, and one vulnerable species (*Goura cristata*). These findings provide a necessary framework for future biodiversity monitoring and the integration of sustainable, community-based ecotourism into Misool's conservation strategies.

Keywords: bird diversity, conservation, ecology, Misool Island

1. Introduction

The Raja Ampat Islands, located in Southwest Papua Province, Indonesia, cover an area of approximately 67,379 km² [1]. This archipelago comprises four major islands: Waigeo, Batanta, Salawati, and Misool. Beyond being the center of the world's coral triangle and tropical marine biodiversity, Raja Ampat is also home to endemic and unique terrestrial biodiversity, including birds, mammals, herpetofauna, and plants[2,3]. Fundamental knowledge of species lists, distribution, habitat associations, breeding behavior, and ecology is crucial for measuring an area's biodiversity and supporting conservation efforts in regions with high species richness [4].

Misool Island is one of the biodiversity centers in Raja Ampat, but terrestrial flora and fauna research, particulary birds, has been limited and outdated. Previous studies date back to the mid-20th century [5,6] and recent studies have focused mainly on marine biodiversity [7]. This leaving information on bird communites and habitat associations limited. Given the rapid environmental changes and updated conservation regulations in Indonesia, current field-based data are essential to reassess the status of bird communities and planing effective conservation action on the island.

Misool Island, covering an area of 202,358 ha, is situated between the Bird's Head of Papua and Seram Island. It comprises four districts with sixteen villages, most located in coastal areas. According to the Minister of Forestry's Decree No. 5496/Menhut-II/KUH/2014, around 115,056.64 ha is designated as the Misool Island Nature Reserve. As an island, it supports unique species communities with many endemic species, yet faces risks such as climate change, sea-level rise, and invasive species introductions that may affect its diversity, pressure native species, and shift its biogeographic equilibrium point [8].

Misool Island Nature Reserve encompasses diverse ecosystem types, including limestone lowland forest, sandstone lowland forests, mangrove forests, volcanic soil hilltop forests, shrublands, karst island clusters, freshwater areas, and coastlines [6]. This ecosystem diversity serves as one of the key determinants of bird diversity and abundance. The hypothesis of habitat heterogeneity theory states that species diversity in a landscape increase with habitat diversity, due to higher variety of habitats provide more distinguishable ecological niche dimensions [9]. Bird species have specific habitat niches and unique ecological demands, mean that their presence within an ecosystem is linked to the availability and structural quality of these habitats [10]. Birds fulfil multiple roles in the ecosystem, acting as predators, pollinators, decomposers, seed dispersers, and integral parts of the food chain [11]. The condition of bird communities serves as an excellent indicator of environmental changes at a landscape scale [12].

The classification of bird species into guilds, defined as groups of birds similarly exploiting the same resources, is fundamental in bird ecology. This approach reflects to species functional roles within the communities and enables evaluation of community structure [13]. These guilds exhibit distinct environmental tolerances, reflecting seasonal shifts in resource availability and vegetation structure. While generalist guilds, such as omnivores and insectivores, display the ecological plasticity to exploit ephemeral food sources in more open areas, specialized groups like frugivores and nectarivores remain strictly dependent on the architectural complexity of mature, undisturbed forests [14].

According to Avibase, the World Bird Database 2024 reports at least 83 bird species in the Misool Island Nature Reserve [15]. Some of these are significant flagship species, such as birds from the Paradisaeidae family, commonly known as birds-of-paradise. However, historical records, such as those by Mees [6], documented up to 166 species across the entire island of Misool. This discrepancy highlights the need for updated field surveys to clarify historical records with current biodiversity status within the protected areas of the island.

The abundance of bird species in this region fosters a sustainable nature-based tourism or ecotourism sector. However, there are significant gaps in the study of bird species, their habitats, and distribution. This basic data is crucial for supporting the nature conservation of Misool Island through the sustainable use of natural resources. Thus, it is necessary to conduct comprehensive studies on the diversity of bird species. This survey holds importance to acquire the latest data and information on the potential diversity of bird species in the Misool Island Nature Reserve. This survey aims to obtain up-to-date information on species diversity, species richness, species dominance, and species composition. Furthermore, the study seeks to characterize the community structure by analyzing feeding guilds to assess the functional diversity and ecological roles of the bird species.

2. Materials and Methods

2.1. Time and Location

The survey was conducted from August 3 to 13, 2023, in Kapatcol, Misool Island Nature Reserve, Raja Ampat Regency, Southwest Papua Province (Figure 1). Three transects were established, each representing distinct habitats. Habitat types were classified based on field observations of physiographic and vegetation characteristics, including topography, substrate type, canopy structure, proximity to water bodies, and define unique ecosystem units [16,17]. The first transect was in lowland forest (code: DR), the second in sandstone lowland forest (code: DB), and the third in riparian forest (code: RN). Habitat description of each transects showed in Table 1. The total survey effort for lowland forest and riparian forest amounted to 42.5 hours each, covering a total distance of 25 km (Table 2). Meanwhile, the sandstone lowland forest was surveyed for 30 hours over a total distance of 20 km.

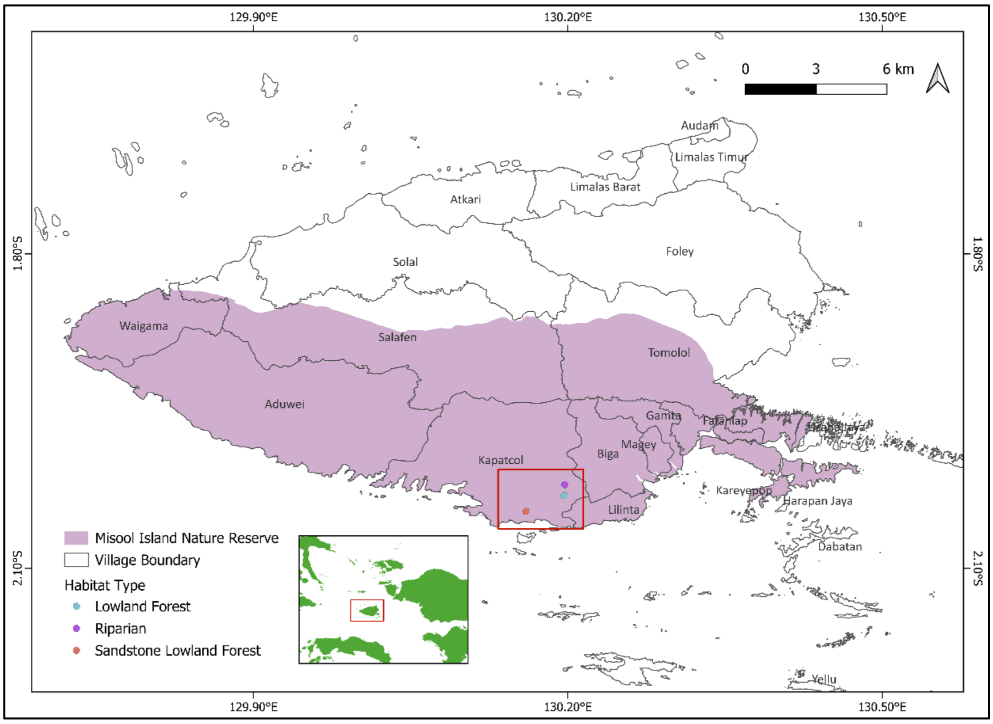

Figure 1. Map of the Research Location in Kapatcol, Misool Island Nature Reserve, Raja Ampat Regency, Southwest Papua Province, Indonesia.

Table 1. Habitat descriptions include topography, canopy structure, and dominant vegetation across the study area.

Types of habitat	Description
Lowland forest (DR)	Secondary forest with flat topography consists of several rocky river channels. The canopy cover is dense, with gaps allowing sunlight to reach the forest floor. Vegetation is dominated by *Cleistanthus* sp. (family Phyllanthaceae). Other plant species found are *Syzygium* sp., *Intsia bijuga*, *Averrhoa* sp., *Vatica rassak*, *Pometia pinnata*, and *Ficus pungens*.
Sandstone lowland forest (DB)	Secondary forest with sloping topography, several depressions and mounds of sandstone resembling coral. The canopy cover is quite open, resulting in high light intensity penetrating the forest floor. The vegetation is dominated by Euphorbiaceae family (*Homalanthus* sp. and *Alchornea rugosa*). The most commonly found plant species are *Celtis philippensis* from the Cannabaceae family and *Homalanthus* sp. from the Euphorbiaceae family.
Riparian (RN)	Consist of primary or old secondary forest with flat topography, typically along riverbanks, with dense canopy cover resulting in a moist forest floor. Vegetation is dominated by the Apocynaceae family (*Alstonia* sp. and *Koopsia* sp.), Fabaceae (*Intsia bijuga* and *Inocarpus fagifer*), and Myristicaceae (*Virola koschnyi* and *Myristica* sp.). The most found species is *Cleistanthus* sp. (Phyllanthaceae).

Table 2. Date of data collection each transect, activities, and notes.

Location	Date of data collection	Activities
Lowland forest (DR)	August 2 and 3–7, 2023	Preliminary survey (August 2); birds survey (August 3–7). Several dry, rocky streams with stagnant flow were observed, rarely visited by people, reflecting low anthropogenic disturbance.
Sandstone	August 8 and 9–12, 2023	Preliminary survey (August 8); birds survey (August 9–12). Near Kapatcol

Location	Date of data collection	Activities
lowland forest (DB)		settlement and coastal forest transition, frequently visited by people, indicating higher anthropogenic pressure and potential hunting.
Riparian (RN)	August 2 and 3–7, 2023	Preliminary survey (August 2); birds survey (August 3–7). Area rarely visited, representing a relatively undisturbed transition ecosystem.

2.2. Data Collection and Analysis

Birds were observed using the strip transect method, by walking along transect lines with a predetermined length (2,000 m) and width (50 m each on the left and right of the transect). Observers calibrated visual distance calibrations during a preliminary survey to ensure accuracy of strip width. During the main survey, observers walked at a steady, slow pace (0.5–1.0 km h^{-1}), pausing briefly for 1–2 minutes at every 100 m interval or upon encountering mixed-species bird flocks to ensure accurate identification and counting of all individuals.

To supplement the strip transect data, the MacKinnon Species List method was applied by recording every 10 consecutive species observed (visual or audio). This method allowed for the construction of a species accumulation curve to estimate the total richness and assess whether the survey effort was sufficient to capture the most of the bird community in each habitat [18,19]. Birds found outside the sampling unit were recorded but excluded from analysis. Observations were conducted during peak birds' active times: morning (06:00–09:00), noon (16:00–18:30), and night (20:00–23:00). Bird species, number of individuals, activities, and encounter locations were recorded. Bird sounds heard within the sampling unit were also recorded for later identification. Surveys were repeated for at least three days during peak activity periods under clear weather conditions to ensure optimal visibility and consistent bird activity [20].

Bird communities were analyzed using Shannon-Wiener Diversity Index (H'), Margalef Richness Index (Dmg), Simpson Dominance Index (C), and Evenness Index (E). A diversity t-test was conducted using PAST (Paleontological Statistics) software version 5.2.1 to assess significant differences in the Shannon diversity index between bird communities [21]. Additionally, a rarefaction-extrapolation curve (R/E) analysis was performed to standardize species richness across the three habitats, accounting for differences in the number of individuals observed [21]. The results are presented as rarefaction-extrapolation curves generated using the iNEXT (Interpolation and Extrapolation) package [20].

Community similarity among transects was assessed using Bray–Curtis similarity and visualized with hierarchical dendrogram. Differences in bird community composition were further analyzed using non-metric multidimensional scaling (NMDS) ordination implemented in the vegan package in R [22,23]. NMDS was used to visualize patterns of similarity and separation among habitats in multivariate space, thereby providing insights into variations in species composition across different habitat types.

Conservation status and global population trends were determined using the IUCN Red List category, while the protected status of birds followed Indonesian regulations (Regulation of the Minister of Environment and Forestry Number 106 of 2018). The species list follows the nomenclature from Burung Indonesia's 2024 List of Bird Species in Indonesia [24]. Observed birds were also classified into feeding guilds based on the primary diet [25,26], including: (1) Insectivores, (2) Nectarivores, (3) Frugivores, (4) Omnivores, (5) Carnivores, (6) Granivores, (7) Insectivores-Nectarivores, (8) Insectivores-Frugivores, (9) Insectivores-Granivores, (10) Frugivores-Granivores, (11) Insectivores-Piscivores, and (12) Carnivores-Piscivores (Table 3). The feeding guild classification was used to assess functional diversity and the ecological roles of species within communities, which may provide insights into ecosystem condition and habitat resource availability.

Table 3. Definition of feeding guild classifications [18,19].

No.	Feeding guild	Definition
1	Insectivores	Birds that feed on insects and small arthropods
2	Nectarivores	Birds that mainly feed on flower nectar
3	Frugivores	Birds that feed predominantly on fruits

No.	Feeding guild	Definition
4	Omnivores	Birds that feed on a combination of food sources, mainly human leftovers and fruits
5	Carnivores	Birds that feed mostly on non-insect animals (fish, lizards)
6	Granivores	Birds that eat seeds from the ground or plants
7	Insectivores-Nectarivores	Birds that have two food sources, such as insects and nectar
8	Insectivores-Frugivores	Birds that have two food sources, such as insects and fruits
9	Insectivores-Granivores	Birds that have two food sources, seeds and insects from plants or the forest floor
10	Frugivores-Granivores	Birds that have two food sources, fruits and seeds from plants or the forest floor
11	Insectivores-Piscivores	Birds that have two food sources, insects and fish
12	Carnivores-Piscivores	Birds that feed mostly on non-insect animals (fish, lizards) and fish that prey on vertebrates

Habitat characterization was conducted at observation transect, included documenting the topography, canopy openness, and dominant vegetation. Physical parameter, topography and canopy openness, were assessed through visual estimation at each observation transect. Topography was classified as flat (0° to <5°, found in lowland and riparian) and sloping (>5°, such as the ridges and mounds found in the sandstone lowland forest). Canopy cover was qualitatively evaluated based on the relative proportion of visible sky through the foliage, classified as dense (overlapping crowns) or open (crown or visible gaps). Plant species were identified visually in the field, focusing on the dominant trees that characterize habitats. However, specific micro-habitat variables, such as canopy cover (%), tree density, basal area, and understory density, were not quantitatively measured during the survey. The absence of quantitative structural variables is acknowledged as a study limitation.

3. Results and Discussion

3.1. Results

3.1.1. Bird Community Overview

A total of 554 individual birds representing 90 species from 36 families were recorded across the three habitat types during the study (Table 4). The composition of bird species varied among three habitats. Riparian habitats showed the highest diversity, with 256 individuals from 58 bird species. In the lowland forest habitats, 130 individuals from 35 species were observed, while the sandstone lowland forests supported 169 individuals from 49 species. The most abundant species was metallic starling *Aplonis metallica* (n= 44). Other abundant species recorded were coconut lorikeet *Trichoglossus haematodus* (n= 41), and Papuan hornbill *Rhyticeros plicatus* (n=39).

Table 4. Bird species in three habitats at Kapatcol, Misool Island Nature Reserve.

Indonesian name	Common name	Scientific name	Habitat types			Endemic
			DR	DB	RN	
Megapodiidae						
Gosong kelam	Dusky scrubfowl	*Megapodius freycinet*	+	+	+	
Maleo paruh-hitam	Black-billed brushturkey	*Talegalla fuscirostri*	+		+	
Columbidae						
Delimukan pomo	Cinnamon ground-dove	*Gallicolumba rufigula*		+		▪
Mambruk ubiaat	Western crowned-pigeon	*Goura cristata*	+		+	▪
Merpati-hutan metalik	Metallic pigeon	*Columba vitiensis*			+	
Pergam merah	Rufescent imperial-pigeon	*Ducula chalconota*	+			▪
Pergam pinon	Pinon's imperial-pigeon	*Ducula pinon*			+	▪
Pergam rempah	Spice imperial-pigeon	*Ducula myristicivora*		+		▪
Uncal ambon	Slender-billed cuckoo-dove	*Macropygia amboinensis*			+	▪
Uncal besar	Great cuckoo-dove	*Reinwardtoena reinwardti*		+		▪
Uncal sultan	Sultan's cuckoo-dove	*Macropygia doreya*			+	
Walik dahi-jingga	Orange-fronted fruit-dove	*Ptilinopus aurantiifrons*		+		▪
Walik elok	Beautiful fruit-dove	*Ptilinopus pulchellus*	+		+	▪
Walik perut-jingga	Orange-bellied fruit-dove	*Ptilinopus iozonus*		+	+	▪

Indonesian name	Common name	Scientific name	Habitat types			Endemic
			DR	DB	RN	
Podargidae						
Paruh-kodok yasa	Papuan frogmouth	*Podargus papuensis*		+		
Paruh-kodok pualam	Marbled frogmouth	*Podargus ocellatus*	+			
Apodidae						
Walet sapi	Glossy swiftlet	*Collocalia esculenta*	+	+	+	
Cuculidae						
Bubut pini	Ivory-billed coucal	*Centropus menbeki*			+	▪
Kedasi laut	Little bronze-cuckoo	*Chalcites minutillus*			+	
Tumur topi-putih	White-crowned koel	*Caliechthrus leucolophus*			+	▪
Wiwik belukar	Brush cuckoo	*Cacomantis variolosus*	+	+	+	
Fregatidae						
Cikalang kecil	Lesser frigatebird	*Fregata ariel*		+		
Phalacrocoracidae						
Pecuk-padi belang	Little pied cormorant	*Microcarbo melanoleucos*			+	
Laridae						
Dara-laut biasa	Common tern	*Sterna hirundo*		+		
Strigidae						
Punggok merah	Rufous owl	*Ninox rufa*		+		
Punggok rimba	Jungle boobook	*Ninox theomacha*	+			▪
Pandionidae						
Elang tiram	Osprey	*Pandion haliaetus*		+		
Accipitridae						
Elang-alap kelabu	Variable goshawk	*Accipiter hiogaster*		+		
Elang bondol	Brahminy kite	*Haliastur indus*	+	+		
Elang ekor-panjang	Long-tailed honey-buzzard	*Henicopernis longicauda*	+			▪
Elang-laut perut-putih	White-bellied sea-eagle	*Haliaeetus leucogaster*		+	+	
Bucerotidae						
Julang papua	Papuan hornbill	*Rhyticeros plicatus*	+	+	+	
Meropidae						
Kirik-kirik australia	Rainbow bee-eater	*Merops ornatus*		+		
Coraciidae						
Tiong lampu biasa	Oriental dollarbird	*Eurystomus orientalis*	+			
Alcedinidae						
Cekakak suci	Sacred kingfisher	*Todiramphus sanctus*		+		
Cekakak torotoro	Yellow-billed kingfisher	*Syma torotoro*	+	+	+	
Kukabura perut-merah	Rufous-bellied kookaburra	*Dacelo gaudichaud*	+	+	+	▪
Udang biru-langit	Azure kingfisher	*Ceyx azureus*	+	+	+	
Raja-udang paruh-kait	Hook-billed kingfisher	*Melidora macrorrhina*		+		
Udang-merah papua	New guinea dwarf-kingfisher	*Ceyx solitarius*		+		▪
Cacatuidae						
Kakatua koki	Sulphur-crested cockatoo	*Cacatua galerita*	+	+	+	
Kakatua raja	Palm cockatoo	*Probosciger aterrimus*	+			
Psittaculidae						
Betet-kelapa paruh-besar	Great-billed parrot	*Tanygnathus megalorynchos*	+	+		
Kasturi kepala-hitam	Black-capped lory	*Lorius lory*	+	+	+	
Nuri-ara mata-ganda	Double-eyed fig-parrot	*Cyclopsitta diophthalma*			+	
Nuri bayan maluku	Moluccan eclectus	*Eclectus roratus*	+	+	+	
Nuri hitam	Black lory	*Chalcopsitta atra*			+	
Nuri kelam	Dusky lory	*Pseudeos fuscata*		+	+	
Perkici pelangi	Coconut lorikeet	*Trichoglossus haematodus*	+	+	+	
Pittidae						
Paok-hijau papua	Eastern hooded pitta	*Pitta novaeguineae*		+		▪
Paok papua	Papuan pitta	*Erythropitta macklotii*	+	+	+	
Meliphagidae						
Cikukua tanduk	Helmeted friarbird	*Philemon buceroides*		+		▪

Indonesian name	Common name	Scientific name	Habitat types			Endemic
			DR	DB	RN	
Isap-madu dada-cokelat	Tawny-breasted honeyeater	*Xanthotis flaviventer*			+	
Isap-madu tutul	Spotted honeyeater	*Xanthotis polygrammus*			+	▪
Meliphaga aruensis	Puff-backed honeyeater	*Meliphaga aruensis*			+	▪
Meliphaga reichenbach	Mimic honeyeater	*Microptilotis analogus*	+	+		▪
Myzomela leher-merah	Ruby-throated myzomela	*Myzomela eques*		+		▪
Acanthizidae						
Remetuk rawa	Large-billed gerygone	*Gerygone magnirostris*		+		
Tepus-tikus merah	Rusty mouse-warbler	*Origma murina*			+	▪
Oriolidae						
Pitohui pucat	Southern variable pitohui	*Pitohui uropygialis*		+		▪
Pachycephalidae						
Anis-bentet kecil	Arafura shrike-thrush	*Colluricincla megarhyncha*			+	
Pitohui karat	Rusty pitohui	*Pseudorectes ferrugineus*		+		▪
Campephagidae						
Kapasan alis-hitam	Black-browed triller	*Lalage atrovirens*			+	▪
Kepodang-sungu kartula	White-bellied cuckooshrike	*Coracina papuensis*		+		
Kepudang-sungu kelek-coklat	Boyer's cuckooshrike	*Coracina boyeri*			+	▪
Artamidae						
Jagal papua	Hooded butcherbird	*Cracticus cassicus*		+	+	▪
Kekep babi	White-breasted woodswallow	*Artamus leucoryn*		+		▪
Peltops hutan	Lowland peltops	*Peltops blainvillii*	+			▪
Rhipiduridae						▪
Kipasan utara	Northern fantail	*Rhipidura isura*	+	+	+	▪
Kipasan kebun	Willie wagtail	*Rhipidura leucophrys*		+		▪
Kipasan-semak bayan	Sooty thicket-fantail	*Rhipidura threnothorax*			+	▪
Kipasan-semak hitam	Black thicket-fantail	*Rhipidura maculipectus*	+	+		▪
Dicruridae						
Srigunting lencana	Spangled drongo	*Dicrurus bracteatus*		+		
Monarchidae						
Kehicap biku-biku	Frilled monarch	*Arses telescopthalmus*	+	+	+	▪
Kehicap emas	Golden monarch	*Carterornis chrysomela*	+			▪
Kehicap tutul	Spot-winged monarch	*Symposiachrus guttula*		+		▪
Sikatan kilap	Shining flycatcher	*Myiagra alecto*	+		+	
Corvidae						
Gagak orru	Torresian crow	*Corvus orru*	+	+	+	
Paradisaeaidae						
Cendrawasih kecil	Lesser bird-of-paradise	*Paradisaea minor*	+	+	+	▪
Cendrawasih raja	King bird-of-paradise	*Cicinnurus regius*			+	▪
Melanocharitidae						
Cucuk-panjang kate	Spectacled longbill	*Oedistoma iliolophus*			+	▪
Cucuk-panjang perut-kuning	Yellow-bellied longbill	*Toxorhamphus novaeguineae*		+	+	▪
Petroicidae						
Robin belang	Black-sided robin	*Poecilodryas hypoleuca*		+	+	▪
Hirundinidae						
Layang-layang batu	House swallow	*Hirundo javanica*		+		
Phylloscopidae						
Cikrak kelam	Island leaf-warbler	*Phylloscopus poliocephalus*		+		
Kancilan kelabu	Gray whistler	*Pachycephala simplex*		+	+	
Sturnidae						
Perling ungu	Metallic starling	*Aplonis metallica*	+	+		
Dicaeidae						
Cabai papua	Olive-crowned flowerpecker	*Dicaeum pectorale*	+	+		▪

Indonesian name	Common name	Scientific name	Habitat types			Endemic
			DR	DB	RN	
Nectariniidae						
Burung-madu hitam	Black sunbird	*Leptocoma aspasia*	+	+	+	
Burung-madu sriganti	Olive-backed sunbird	*Cinnyris jugularis*		+	+	

Note: DR = Lowland forest, DB = Sandstone lowland forest, and RN = Riparian forest.

The number of species from each family ranging from 1 to 12 species. The family with the most species is Columbidae (12 species), followed by Psittaculidae (7 species), Alcedinidae (6 species), and Meliphagidae (6 species). Most other families were represented by fewer than five species, often by single-species. Rarefaction curves indicate that species richness increases with sampling effort across all habitat types (Figure 2). The curves are continued rising steeply and have not yet shown any signs of leveling off. The highest species richness was observed in sandstone lowland forest, followed by the riparian and lowland forest habitat.

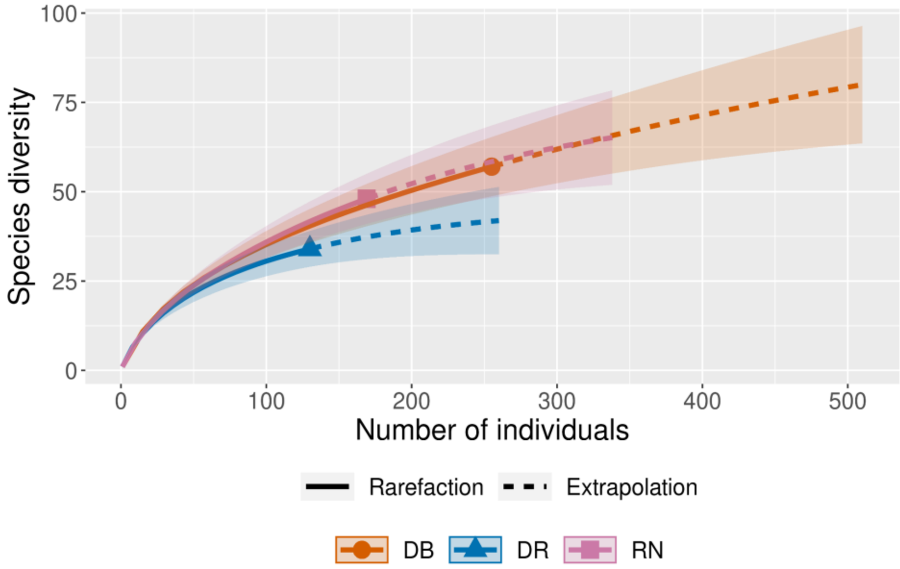

Figure 2. Rarefaction curve of bird communities across three habitat types.

3.1.2. Bird Community Diversity

An approach using the community diversity index was employed to assess bird species diversity at each location. The sandstone lowland forest showed the highest diversity (H' = 3.30) and richness (Dmg = 10.09), followed by the riparian habitat (H' = 3.16; Dmg = 9.16) and lowland forest (H' = 3.02; Dmg = 6.77). Evenness values were relatively similar across habitats (0.81–0.85), while dominance remained low in all sites (0.05–0.08) (Table 5). The results of the Hutcheson's t-test indicate that there is a significant difference in species diversity between lowland forests and sandstone lowland forests ($p < 0.05$). This suggests that sandstone lowland forests can support greater species diversity. Meanwhile between sandstone lowland forest and riparian habitat, there is no significant difference ($p > 0.05$).

Table 5. Various biodiversity indices of bird communities.

Habitat types	Parameter			
	Diversity (H')	Dominance (C)	Richness (Dmg)	Evenness (E)
Lowland forest (DR)	3.02	0.07	6.77	0.85
Sandstone lowland forest (DB)	3.30	0.05	10.09	0.81
Riparian forest (RN)	3.16	0.08	9.16	0.81

The number of species shared among transects varied across sites, with the highest number between lowland forest-riparian (24 species), followed by lowland forest-sandstone lowland forest (22 species) and sandstone lowland forest-riparian (20 species). In addition, lowland forest exhibited the highest number of unique species (27), followed by riparian (20) and sandstone lowland forest (8). Bray-Curtis similarity analysis indicated that bird communities in lowland forest and riparian showed the highest similarity (43.48%), while sandstone lowland forest showed lower similarity with lowland forest (34.29%) and riparian (28.77%). These results were supported by hierarchical cluster analysis (Figure 3), which grouped lowland (DR) and riparian together (RN). In contrast, sandstone lowland forest (DB) formed a separate cluster, suggesting a distinct bird community.

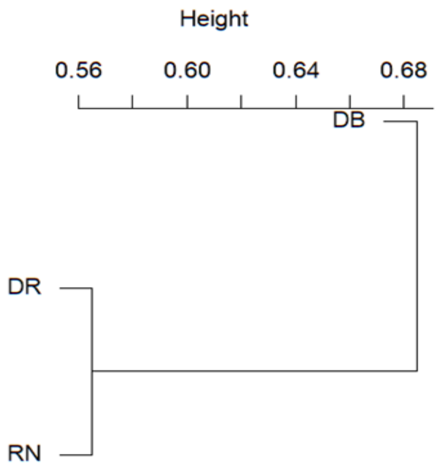

Figure 3. Hierarchical cluster dendrogram showing similarity in bird community composition among transects based on Bray-Curtis dissimilarity.

Non-metric multidimensional scaling (NMDS) ordination based on Bray-Curtis dissimilarity further illustrated differences in bird community composition among transects (Figure 4). In the ordination plot, transect sandstone lowland (DB) was positioned separately from lowland forest (DR) and riparian (RN) along the NMDS1 axis, while DR and RN appeared closer together, indicating relatively similar bird assemblages between these two habitats. This spatial arrangement demonstrates that each transect hosts a statistically unique assemblage, despite the moderate overlap in species counts previously noted.

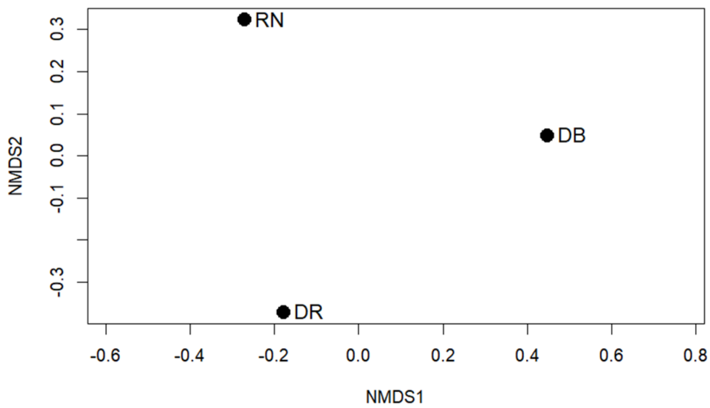

Figure 4. Non-metric multidimensional scaling (NMDS) ordination based on Bray-Curtis dissimilarity showing differences in bird community composition among transects (DR, DB, and RN).

3.1.3. Bird Community Structure based on Feeding Guild

The bird community structure across the three observation sites can be analyzed based on the grouping of primary food types (feeding guilds) (**Figure 5**). Insectivorous birds (34%) and insectivorous-frugivorous birds (12%) dominated the species composition across all three sites. The sandstone lowland forest habitat hosted the highest abundance of non-insectivorous carnivores, carnivore-piscivores, frugivores, insectivores, and insectivorepiscivores. In contrast, the riparian habitat showed the highest presence of frugivore-granivores, insectivore-frugivores, and nectarivores.

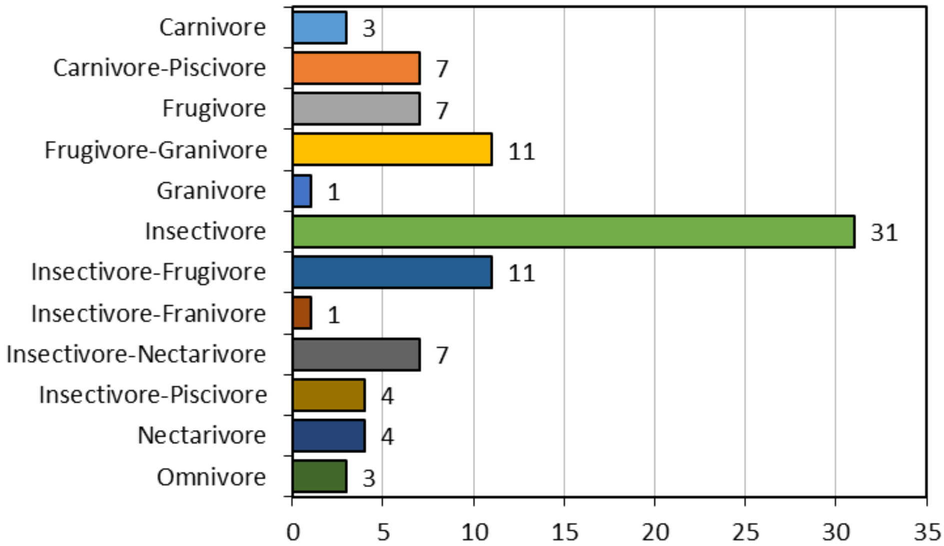

Figure 5. Classification of feeding groups in three habitats in Kapatcol, Misool Island Nature Reserve.

3.2. Discussion

3.2.1. Bird Community Structure

A total of 90 bird species from 36 families were recorded across three habitats at the study location. This survey identified more bird species than previous report on 2018, which found 75 species [27]. Comparisons with other islands in the Australasian region show considerable variation in species richness, likely influenced by differences in survey area, habitat type, methodology, and sampling effort [28–31]. Factors such as survey area, habitat type, ecosystem, altitude, timing, methodology, and data collection effort likely influenced these differences. These findings provide a basis for discussing how bird diversity, community composition, and habitat characteristics shape avian assemblages in the Misool Island Nature Reserve.

The variation in bird species across the studied habitats highlights the impact of canopy structure, shaped by edaphic characteristics and natural disturbance. River-related disturbances such as flooding and erosion create 'breaks in canopy continuity', resulting in a more open vegetation structure characterized by secondary growth [32]. Dense canopy cover typically makes bird species harder to spot. Canopy openness correlates with bird species abundance, indicated that more open canopies tend to host more visible birds than dense ones [33]. This suggests that the sandstone lowland forest habitat provides an ideal canopy cover for bird movement and observation.

Among the 36 families found, the Columbidae family has the highest species count (12 species). The finding is consistent with pattern across the Australasian region, where Columbidae occupy a wide range of forest habitats, from closed to open [3,4]. This ecological adaptability explains their higher prevalence compared to other families. Their dominance reflects high resource availability within Misool's forests, suggesting a stable phenology of fruiting trees that supports these large-bodied frugivorous populations [34,35].

Similarly, Psittaculidae species were well represented, they frequently recorded in riparian habitats (flat topography, old secondary forest), consistent with observations of New Guinea parrots favouring mature secondary forest with flatter ground [35]. The families Alcedinidae and Meliphagidae also showed high species counts, with 6 species each. Alcedinidae members are frequently found near water bodies, where they feed [4]. The abundance of rivers in the observation area likely explains the frequent sightings of Alcedinidae family members.

Diversity index values across the three sites (Table 5) were high (H' = 3.02–3.30), indicating generally stable bird communities [36]. The evenness index values ranged from 0.81 to 0.85, with value closer to 1 indicating that all species are equally abundant which reflects ecological stability in these forest types [37]. Low dominance values (0.05–0.08), further confirm that no single species dominated the community. Although the sandstone lowland forest showed slightly higher diversity values, the differences among habitats were small. Therefore, differences in bird assemblages are better explained by variations in community composition based on Bray-Curtis similarity and NMDS ordination [38].

Bray-Curtis and NMDS results (Figure 4 and Figure 5) showed that bird communities in the lowland forest and riparian habitats were more similar, while sandstone lowland forest formed a separate cluster. These results indicate that sandstone lowland forest supports a distinct bird assemblage, likely associated with differences in vegetation structure and environmental conditions [39]. Such separation in the NMDS plot underscores the role of habitat heterogeneity in maintaining regional biodiversity [40].

The distinct environmental filters, from soil substrate to canopy openness, create a mosaic of ecological 'islands' that allow specialized species to thrive and increase the overall species pool [41]. Evidence of this distinctiveness of sandstone lowland forest was further supported by the higher number of unique species recorded. Furthermore, presence of habitat-specific species suggests that environmental heterogeneity creates diverse ecological niches through variation in vegetation structure and resource availability [42,43]. This highlights the importance of habitat diversity in sustaining bird diversity and supporting habitat-specific assemblages [43].

As Misool Island is part of Raja Ampat archipelago, variation in bird communities can be explained within the framework of island biogeography. Larger areas provide more diverse habitats, allowing both habitat specialist and generalist species to occur [44]. In island ecosystems, species assemblages are shaped by habitat heterogeneity, isolation, and dispersal limitations [45,46]. Habitat diversity plays a key role to influences species richness indirectly, rather than through a direct effect on species ability to colonize or survive in larger areas [44].

The structure of the bird community based on feeding guilds (Figure 5) shows that insectivorous birds are the most dominant in all three locations, followed by insectivorous-frugivorous birds. The dominance of insectivorous bird groups in the study site correlates with the forest structure where layered forests provide optimal habitats for insect populations that sustain these birds [45]. Insectivorous birds also act as intermediate consumers that control the population of their insect prey, thereby contributing to the maintenance of ecosystem balance [46]. The presence of insectivorous–frugivorous species further indicates the availability of both insect prey and fruiting trees, highlighting the ecological importance of maintaining heterogeneous forest structure [47]. Furthermore, forest frugivorous birds also contribute to enriching forest heterogeneity through seed dispersal that support the regeneration process [48].

The sandstone lowland forest shows the highest diversity value, indicating that more open canopy structure enhances bird activity and access to food sources, especially for insectivorous and frugivorous groups. Conversely, the more closed riparian habitat supports species associated with water, such as Alcedinidae family. This suggests that habitat variation influences species presence and their ecological roles within the ecosystem. Thus, these findings can be taken into consideration in developing forest management plans using an ecosystem-based approach. Maintaining stratified forest structure is crucial to sustain both insect control and seed dispersal functions provide by bird communities.

3.2.2. Conservation Status and Population Trends

Of the 90 species recorded, 24 species (27%) are protected under Indonesian regulations (Permen LHK No. 106 of 2018), mainly from Psittaculidae and Accipitridae families. Regarding IUCN status, only one species (Western Crowned Pigeon - *Goura cristata*) is classified as Vulnerable and one is Near Threatened (Palm Cockatoo - *Probosciger aterrimus*), while the rest are of Least Concern. Global population trends show the most species are stable (53 species), although several are declining. These patterns reflect global assessments rather than site-specific trends, but provide a baseline for identifying conservation priorities in the Misool Island Nature Reserve [49]. Species with a "stable" global status may still face localized extinction risks in Misool due to site-specific anthropogenic pressures.

A total of 41 endemic bird species from 18 families were recorded, highlighting the conservation importance of Misool Island, as species with restricted geographic ranges are generally more vulnerable to habitat disturbance and therefore represent key priorities for conservation planning [50]. Anthropogenic pressures, particularly illegal wildlife trade, further increase this vulnerability [51]. Hunting and trade, driven by livelihood needs and socio-cultural practices contribute significantly, while human population growth and expanding wildlife trade intensify pressure on these species [51].

To mitigate these threats, priority habitats within the Misool Reserve must be identified and protected, including lowland forest, sandstone lowland forest, and riparian zones. These habitats provide critical resources such as nesting sites, food availability, and refuge from human disturbance for endemic and high-value species, including cockatoos and birds of paradise targeted by illegal wildlife trade [51,52]. Although specific data for Misool Island remain limited, the pressures have been widely documented across Indonesia and Papua [53,54]. Habitats supporting high concentrations of Columbidae and Meliphagidae should be prioritized. Conservation efforts should also focus on maintaining habitat connectivity to mitigate the impacts of disturbances such as cyclones and forest conversion [11,53]. Strengthening monitoring and integrating community-based ecotourism are essential to improve protection and reduce pressure from wildlife trade and hunting [51].

The high bird diversity recorded indicates strong potential for bird-based ecotourism. Management strategies such as visitor carrying capacity, habitat-based birdwatching zoning, and flagship species promotion can help balance tourism and conservation. Birdwatching zones based on habitat characteristics can minimize disturbance to sensitive species while improving visitor experience [54]. Flagship species such as parrots and crowned pigeons could enhance conservation awareness and attract birdwatching tourism [55].

4. Conclusions

This study recorded 90 bird species from 36 families across three habitat types in the Misool Island Nature Reserve, indicating high bird diversity. Diversity and Evenness indices were consistently high, suggesting a relatively balanced community structure. Although overall diversity values were similar among habitats, multivariate analyses revealed differences in species composition, with sandstone lowland forest supporting a distinct assemblage and the highest number of unique species. These findings highlight the role of habitat characteristics, particularly vegetation structure and canopy openness, in shaping bird community. Feeding guild analysis showed that insectivorous and insectivorous-frugivorous birds dominated across sites, reflecting the importance of stratified forest structure and resource availability. The presence of 24 protected and 41 endemic species, including globally threatened species *Probosciger aterrimus* and *Goura cristata* further emphasizes the conservation value of the area. However, the single sampling period and reliance on strip transect may limit the representation of seasonal variation and species detectability among habitats. Maintaining habitat heterogeneity is therefore essential for sustaining bird diversity and habitat-specific assemblages. In addition, the high diversity and visibility also indicate strong potential for birdwatching-based ecotourism that can support local livelihoods while promoting biodiversity conservation.

Author Contributions

HAH: Conceptualization, Methodology, Investigation, Writing - original draft; **KTR**: Conceptualization, Methodology, Investigation, Writing - original draft; **NR**: Investigation, Writing - Review & Editing, **FH**: Investigation, Writing - Review & Editing; **HML**, **NAP**, **ASP**, and **YHJ**: Investigation; **RA**: Validation, Writing - Review & Editing; **SA**: Writing - Review & Editing; **MIM** and **FNM**: Supervision.

Conflicts of Interest

There are no conflicts to declare.

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AI Writing Statement

During the preparation of this manuscript, the authors used GEMINI AI 3 for structure language editing and grammar checking. After using this tool, the authors carefully reviewed, verified, and edited all generated or modified content and accept full responsibility for the integrity and accuracy of the manuscript.

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