

RESEARCH ARTICLE



Avian Feeding Guild Composition in Papua Lowland Forest: A Comparative Across Habitat Types in Manokwari

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ABSTRACT

Changes in forest cover from forest to non-forest systems alter habitat structure and resource availability, thereby affecting the functional composition of bird communities. This study aimed to identify and compare the structure of avian feeding guilds along a forest successional gradient in the lowland forest of Manokwari. Bird surveys were conducted using repeated point counts across six habitat types representing early (mixed shrub and agricultural habitats), intermediate (mixed plantation and young secondary forest), and late successional (old secondary and primary forest). Species were classified into feeding guilds based on their primary food. Guild species richness and relative abundance were calculated, and the effects of habitat succession on guild abundance were analysed using a negative binomial generalized linear mixed model. A total of 55 species belonging to 15 feeding guilds were recorded. Aerial frugivores contributed the highest proportion of species richness (21.82%), whereas insectivore–nectarivore showed the highest relative abundance (21.67%), followed by arboreal frugivores (20.77%) and nectarivores (20.31%). Bird abundance was markedly higher in intermediate and late successional habitats than in early successional habitats, indicating greater trophic resource availability in more structurally complex vegetation. The GLMM revealed significant effects of habitat succession (Wald $\chi^2 = 48.32$, $p < 0.001$) and feeding guild (Wald $\chi^2 = 331.93$, $p < 0.001$) on bird abundance, demonstrating a functional shift in trophic guild dominance along the successional gradient. These findings highlight the importance of intermediate and late successional forests in maintaining functional diversity and supporting key ecosystem processes in tropical lowland forests.

Introduction

Ecologically, birds play a crucial role in various ecosystem processes, including seed dispersal, flower pollination, and as indicators of forest ecosystem balance and function [1-3]. Functional diversity represents the range of species traits that influence ecosystem processes and services. Communities with high functional diversity use resources more efficiently, enhance productivity, and increase ecosystem stability because different functional groups perform complementary ecological roles [4,5]. In avian communities, variation in feeding guilds contributes directly to ecosystem services such as seed dispersal, pollination, pest control, and nutrient cycling [6,7].

Birds are also highly sensitive to climate change and other environmental changes [8,9]. In addition, birds exhibit a variety of functional traits that are responsive to variations in environmental conditions [10], making them valuable model organisms for evaluating changes in habitat structure, ecosystem function, and functional diversity [11,12] as an important component of trophic networks and an indicator of

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environmental change [13]. The grouping of birds into guilds is significant because it directly relates to their functional ecological roles in ecosystems [14]. Guilds are a group of animals that share the same type of food, their presence in a particular area can be attributed to their food guild, habitat type, and intensity of anthropogenic disturbance [15,16].

Bird diversity in Papua is increasingly threatened, with the average rate of conversion of forest land to non-forest land in Manokwari Regency of 1,298 hectares per year [17]. In Annual notes Pusaka Bentala Rakyat in 2025 shows that deforestation in Papua reached 45 thousands hectares, equivalent to 112,500 soccer fields [18]. Changes in landscape structure, accompanied by habitat fragmentation. Changes in landscape structure, habitat fragmentation, will have an impact on changes in species composition and community functions, so that they lead to a decline in the abundance of birds and can lead to local extinction [19–23]. To date, studies on feeding guilds in forest and non-forest habitats in Papua, resulting from the conversion of forest land to non-forest, have not been conducted.

This study examines habitats across the early, intermediate, and late successional stages in lowland forests at elevations of 10–227 m above sea level in Manokwari Regency. The habitat of the early succession stage included mixed shrubs and agriculture, the intermediate succession included mixed plantation forests and young secondary forests, late succession stages included old secondary forests and primary forests. Habitat selection was based on succession stages to observe the impact of forest cover changes and the habitat succession process from the early, mid and final succession to the guild group's response. The relative abundance of each feeding guild differed across succession stages, as bird species diversity decreased with habitat changes [21]. A more diverse vegetation structure will provide greater opportunities for bird species within each vegetation layer or specific vegetation composition [22] and for the distribution and abundance of tree species [23]. Thus, there were different feeding eating guilds during the succession stages.

Research on the feeding guilds of birds on the island of New Guinea was primarily conducted in Papua New Guinea (PNG), and there is limited information available in Papua. This study aims to identify and compare the composition of bird guilds in three stages of habitat succession. We hypothesize that species richness guild groups and guild group abundance will change between forest habitats in the early succession forest habitats (mixed shrubs and agriculture), intermediate succession (mixed plantation forests and young secondary forests), and late succession (old secondary forests and primary forests), and that there is an interaction between feeding guild groups and habitat succession stages in determining bird abundance. Understanding how trophic guilds respond to forest succession is essential for revealing the mechanisms underlying community assembly and ecosystem functioning in tropical forests. Therefore, this study investigates the trophic guild structure of bird communities across successional stages in the lowland forest of Manokwari, West Papua. The results are expected to provide a functional basis for biodiversity conservation and forest management in tropical landscapes.

Materials and Methods

Study Area

The research area is located in the vicinity Manokwari City, West Papua. The eastern, western, and northern parts of the study area are characterized by continuous lowland rainforest. The eastern and western parts are located closer to Manokwari City, at a distance of 4.4 km, while the northern part is located further from the city, at a distance of 34.4 km. This location consists of two stations with the following habitat types: Early succession habitat consists of mixed shrubs and garden areas located in Mandopi Rimom Village in the northern part of Manokwari City. Intermediate succession habitat includes mixed tree forests in the eastern part and young secondary forests in the northern part of Manokwari City. Conversely, late succession habitat consists of old secondary forests in the western part of Manokwari City and primary forests in the northern part of Manokwari City (Figure 1).

The mix shrubs habitat (00°44'06.4"–00°44'10.2"S; 133°55'01.5"–133°55'04.5"E) was a former secondary forest that had been opened for traditional plantations by residents and left for years, 3–5 years, so that it is overgrown with shrubs and some pioneer vegetation particularly in Mandopi Rimom Village. The agriculture land (00°43'39.3"–00°43'51.1"S and 133°54'32.8"–133°54'55.5"E) is located approximately at least 200 m from the Mandopi Rimom Village and was planted with food crops such as taro, cassava, vegetables, bananas, and other fruit-bearing trees (rambutan, durian, langsats, areca nut), and vegetables. This habitat also contained regrowth of natural pioneer species.

Young secondary forests (00°44'16.2"–00°44'20,5"S and 133°55'06.8"–133°55'12,2"E) are forests that have been naturally cut down and restored. In this case, the felling of stands and plantations has been carried out and allowed to regrowth. The primary forest (00°44'22.5"–00°44'29.0"S and 133°55'02.9"–133°55'07.9"E) have never been cut down and have developed after natural disturbances and natural processes, regardless of age. The mixed plantation forests (00°50'35.8"–00°50'51.0" S and 134°05'27.4"–134° 05'26.0"E) Mixed plantation forest contains tree collections for educational objectives forest or an arboretum belonging to the University of Papua Manokwari. Old secondary forest (00°50'58.5"–00°51'36,1"S and 134°04'30.4"–134°05'06.6"E) are protected forest area known as Gunung Meja Forest Park, these areas are experiencing disturbances located in primary forest and secondary forests with vegetation structures and species associated with old primary forests and can function as distinct forest ecosystems of younger age groups.

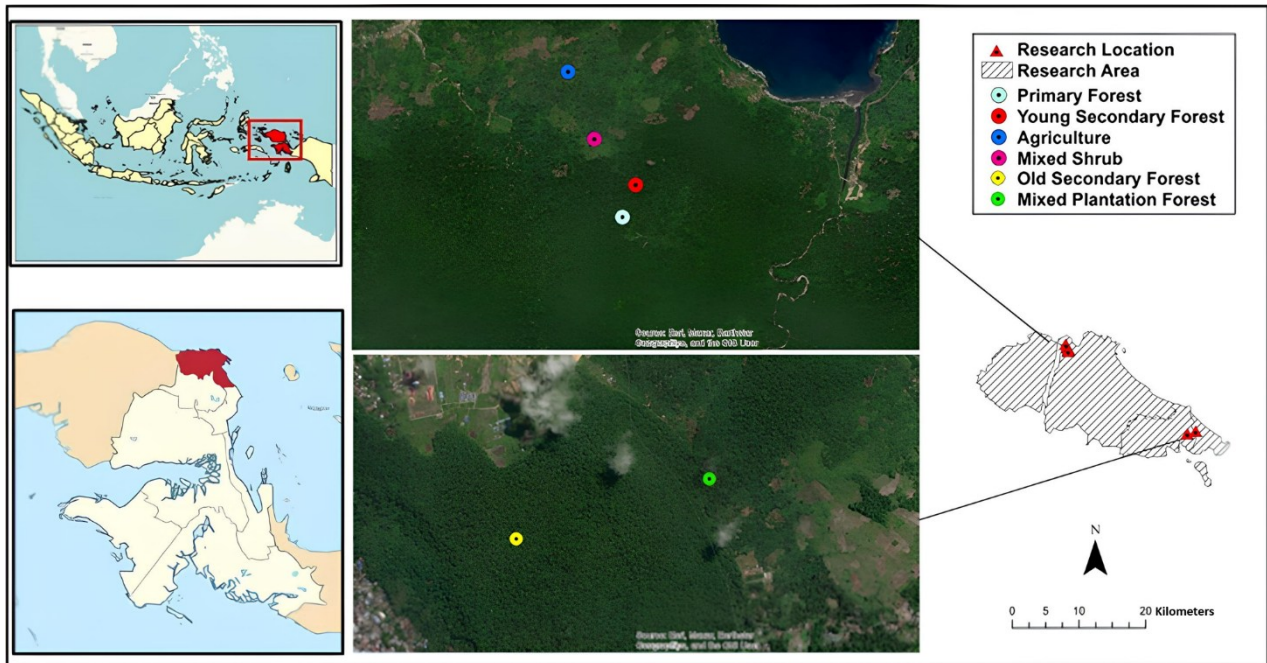


Figure 1. Research location map of the study area in Manokwari Regency. The figure shows six habitat type gradien succesion. Distribution Four habitat types in North Manokwari District and two habitat types in West and East Manokwari District.

Methods

Field observations were conducted from January to October 2023, with a total sampling effort of 150 hours. Bird surveys were conducted over 10 days (50 hours) at each stage of succession: early succession (mixed shrubs and agricultural areas), middle succession (mixed plantation forests and young secondary forests), and late succession (old secondary forests and primary forests). Bird data, including species identity, number of individuals, and substrate use, were collected using the point count method [24]. Sampling points were established in each habitat type and separated by a minimum distance of 100 m. A total of 30 points were placed in each habitat type, resulting in 180 points across all habitats. To ensure sampling independence, the distance between points exceeded the fixed detection radius (25 m), minimizing the possibility of recording the same individual at multiple points. Each point was surveyed five times on different days, and repeated observations at the same point were considered non-independent samples and included in the statistical analysis. Bird counts were conducted in the morning (06:00–09:00) and afternoon (15:00–18:00), during peak activity periods. All birds seen and/or heard within a 25 m radius were recorded for 10 minutes at each point using binoculars. A camera equipped with a telephoto lens and an audio recorder was used to document species for later identification. Species identification and nomenclature followed [22].

Data Analysis

Bird species recorded were classified into 15 guilds, based on major food, substrate, and behavior [25–30]. The categories of feeding guild are: nectarivores (NEC), insectivores-nectarivore (INS-NEC), air screening insectivore (ASI), fly-catching insectivore (FCI), tree leaf bark insectivore (TFBGI), shrub foliage-gleaning

insectivore (SFGL), litter-gleaning insectivore (LGI), insectivore-frugivore (INS-FRU), arboreal frugivore (AF), terrestrial frugivore (TF), nectarivore-frugivore (NEC-FRU), frugivore-granivore (FRU-GRA), Carnivores (CAR) Carnivore (fish or other vertebrates in water and insects), lichenivore (LIC) and Omnivore (OMN).

To examine the relationship between guilds and habitat types, the average number of individuals and species per guild was calculated in SPSS version 26, and the visualization was performed in Python 3.12. Guild proportion-based species richness is calculated as follows $100 \times (\text{number of species of the guild in habitat } j / \text{total number of species in habitat } j)$. While relative abundance describes the even distribution of individual guild species in a habitat using [28] calculated as follows in Equation 1:

$$\text{Relative Abundance (RA)} = \frac{\text{Number of species in guild}}{\text{Total number of species}} \times 100\% \quad (1)$$

The negative binomial generalized linear mixed model (GLMM) model was used because the count data were overdispersed (variance greater than the mean), making the use of a negative binomial distribution more appropriate than a Poisson model. Bird abundance was analyzed using a general linear mixed model (GLMM) with a negative binomial distribution to account for overdispersion in count data and hierarchical sampling design. Habitat succession stage and guild group were included as fixed effects, while point count stations were treated as random effects to account for repeated observations at the same location (30 stations, each surveyed five times). All surveys were conducted with the same observation duration and sampling protocol; therefore, no offset term was included in the model. The significance of model parameters was evaluated using the Wald chi-square test. Analysed GLMM Using SPSS version 26. The parameters tested the number of species and individual birds in the guild as a function of habitat. In addition, we use Python version 3.12 to visualize comparisons of the average number of guild group individuals across habitat types, as well as the percentage of guild group individuals relative to the percentage of guild species. The abundance of birds was modeled using a negative binomial generalized linear mixed model is as follows [31], in Equation 2:

$$Y_{ij} \sim \text{NB}(\mu_{ij}, \theta) \quad \log(\mu_{ij}) = X_{ij}\beta + b_j \quad (2)$$

Where Y_{ij} represents the observed number of individuals per site. The mean abundance μ_{ij} was linked to the predictors using a log link function. Habitat type, feeding guild, and their interaction were treated as fixed effects ($X_{ij}\beta$). At the same time, point count was included as a random effect (b_j) to account for repeated observations and spatial heterogeneity. The parameter θ represents the dispersion of the negative binomial distribution. The following is the GLMM model formula with guild and habitat interactions, in equation 3:

$$\log(\mu_{ijk}) = \beta_0 + \beta_1 \text{Habitat } i + \beta_2 \text{Guild } j + \beta_3 (\text{Habitat } i \times \text{Guild } j) + b_k \quad (3)$$

In addition, this study also analyzes functional diversity. Functional diversity was calculated using FRic, functional evenness using FEve, and functional divergence using FDiv, based on multiple functional traits following [32,33]. The formula to measure the volume of space occupied by the community, the uniformity of abundance distribution, and species abundance is at the edge or center of trait space, are expressed in Equations 4–6.

$$\text{FRic} = V(S) \quad (4)$$

Where, $V(S)$ was volume convex hull from all species in multidimensional trait space.

$$\text{FEve} = \frac{\sum_{i=1}^{S-1} \min\left(\frac{EW_i}{EW}, 1\right)}{S-1} \quad (5)$$

Where, EW_i was edge weight (minimum spanning tree weighty abundance), EW = average EW , and S was number of species.

$$\text{FDiv} = \frac{\sum a_i(d_i - d^-)}{a_i |d_i - d^-|} \quad (6)$$

Where, a_i was species abundance, d_i was species distance from the center of trait space.

Habitat classification followed a successional gradient based on vegetation structure. Shrub areas were characterized by pioneer vegetation with open canopies and low height, representing early successional stages [34]. Young secondary forests were dominated by small–medium trees with developing canopy layers, whereas old secondary forests showed nearly closed canopies and the presence of large trees, approaching the structure of natural forests [35,36]. Primary forests exhibited complex vertical stratification, emergent trees, and minimal disturbance [37]. Mixed plantation forests were dominated by planted species with relatively uniform stand structure and age classes [38].

Results and Discussion

Results

In total 55 species representing 25 families were identified in Manokwari Low landforests. Based on the succession stages, the composition of the species is recorded in the intermediate succession and followed by the late succession and the early succession. Based on habitat type shows that habitat young secondary forest habitats represented the highest species richness, with 44 species (80%), followed by old secondary forest, 34 species (61.82%), primary forests, 31 species (56.36%), mixed plantation forests, 25 species (45.45%), and agriculture, 19 species (34.55%). Mixed shrubs habitat was identified as the species-poor habitat, 14 species (24.45%) (Table 1 and 2).

The results of the feeding guild found were 15 groups (Table 1), by grouping into four groups based on the main food, namely nectarivore, insectivore, frugivore, and other groups (lichenivore, carnivore, and omnivore). The most abundant guild was insectivore-nectarivore (21.67%), followed by nectarivores (20.31%) and arboreal frugivores (19.86%) (Table 2). This study found that a higher number of species in a given feeding guild does not indicate a higher number of individuals. The arboreal frugivore has the highest number of species (12). However, the number of individuals is the highest for insectivore-nectarivores (2,443 individuals), followed by arboreal frugivores (2,341 individuals), and the lowest is the litter-gleaning insectivore (19 individuals) (Table 2).

Table 1. The number of bird species recorded at each successional stage. This table illustrates the distribution of bird species among feeding guilds across three stages of succession and six habitat types.

Feeding guild	Early succession		Intermediate succession		Late succession		No. of species in guild	Percentage (%)
	Mixed shrub	Agriculture	Mixed plantation forest	Young secondary forest	Old secondary forest	Primary forest		
Nectarivores								
Nectarivore	2	2	2	2	2	2	2	3.64
Insectivore-nectarivore	3	3	1	3	2	2	4	7.27
Insectivores								
Aerial screening insectivore	0	1	0	1	0	0	1	1.82
Flycatching insectivore	2	0	1	2	2	1	2	3.64
Tree foliage bark-gleaning insectivore	1	1	1	2	3	1	3	5.45
Shrub foliage gleaning insectivore	1	0	0	1	0	0	1	1.82
Litter gleaning insectivore	0	0	0	1	0	0	1	1.82
Insectivore-frugivore	3	4	1	6	2	3	6	10.91
Frugivores								
Arboreal frugivore	0	2	9	10	10	9	12	21.82
Terrestrial frugivore	1	1	1	1	0	2	2	3.64
Nectarivore-frugivore	0	0	2	2	2	2	2	3.64
Frugivore-granivore	0	1	1	2	1	2	2	3.64
Others								
Lichenivore	0	0	1	1	2	1	2	3.64
Carnivore	1	4	3	7	6	3	11	20.00
Omnivore	0	0	2	3	2	3	4	7.27
No. of species in guild	14	19	25	44	34	31	55	100.00

Frugivorous guild groups, particularly arboreal frugivores, showed the highest occurrence at each stage of habitat succession compared to other guild groups, with the greatest species richness recorded in the intermediate and late successional stages. The high abundance of arboreal frugivores indicated that successional stages significantly influenced guild composition through the availability of food resources. The lichenivore guild was recorded only in the intermediate and late successional stages, which was associated with the availability of substrates on tree trunks and branches that developed during mid and late succession. The carnivore guild also exhibited higher species richness in young and old secondary forests compared to other habitats. This guild, consisting mainly of raptors and kingfishers, showed its highest occurrence in young secondary and old secondary forest habitats, indicating that these habitats provided abundant food resources. Omnivorous guilds were observed in the intermediate and late successional stages with relatively even species richness. This suggested that omnivorous guilds were less diverse compared to other guild groups, such as arboreal frugivores and carnivores.

The study also found a group of lichenivore guilds: the Yellow-capped Pygmy Parrot and the Buffy-faced Pygmy-Parrot. This guild group is not found in the early succession stage (mixed shrubs and agriculture); this

can be attributed to the absence of vegetation at this stage of tree growth, as lichenivore guilds usually feed on moss on tree trunks and branches. The presence of this type in the intermediate and late stages of succession shows that vegetation is growing trees that provide a source of moss food for this species. During the study these species foraging on the trunk of the *Pometia coriacea* tree (Figure 2).



Figure 2. The Yellow-capped Pygmy Parrot (*Micropsitta keiensis*), a lichenivorous species, was observed foraging on the trunk of *Pometia coriacea* by gleaning moss in a lowland tropical forest.

The relative abundance (Table 2) shown the nectarivore feeding guild was dominated by Olive-backed Sunbird (12.09%), which was also the most dominant species in this study. Tree foliage bark gleaning insectivore is Spangled Drongo (6.47%), and arboreal frugivore is Helmeted Friarbird (6.43%). While the relative abundance of feeding guild groups was highest for insectivore-nectivore (21.67%), followed by arboreal frugivore (20.77%) and nectivore (20.31%), and the least were insectivore groups, such as aerial screening insectivore, fly catching insectivore, shrub foliage gleaning insectivore and litter gleaning insectivore.

Table 2. Relative abundance of feeding guilds. The table summarizes species within each feeding guild, classified by abundance from abundant to rare at the study site.

No	Feeding guilds	Comman name	Scientific name	No. of Individuals	Relative abundance of species (%)	Relative abundance group of guilds (%)
1	NEC	Black Sunbird	<i>Leptocoma aspasia</i>	926	8.22	20.31
2		Olive-backed Sunbird	<i>Cinnyris jugularis</i>	1,363	12.09	
3	INS-NEC	Black Myzomela	<i>Myzomela nigrita</i>	296	2.63	21.67
4		White-eared Meliphaga	<i>Meliphaga montana</i>	865	7.67	
5		Mountain Meliphaga	<i>Meliphaga orientalis</i>	642	5.70	
6		Scrub Meliphaga	<i>Meliphaga albonotata</i>	640	5.68	
7	ASI	Barn Swallow	<i>Hirundo rustica</i>	21	0.19	0.19
8	FCI	Northern Fantail	<i>Cacomantis variolosus</i>	144	1.28	2.00
9		Sooty Fantail	<i>Arses telescopthalmus</i>	82	0.73	
10	TFBGI	Brush Cuckoo	<i>Dicrurus bracteatus</i>	13	0.12	7.03
11		Frilled Monarch	<i>Rhipidura rufiventris</i>	50	0.44	
12		Spangled Drongo	<i>Rhipidura threnothorax</i>	729	6.47	
13	SFGI	Emperor Fairywren	<i>Malurus cyanocephalus</i>	88	0.78	0.78
14	LGI	Hooded Pitta	<i>Pitta sordida</i>	19	0.17	0.17

No	Feeding guilds	Comman name	Scientific name	No. of Individuals	Relative abundance of species (%)	Relative abundance group of guilds (%)
15	INS-FRU	White-bellied Cuckooshrike	<i>Coracina papuensis</i>	72	0.64	9.81
16		Grey-headed Cicadabird	<i>Edolisoma schisticeps</i>	146	1.30	
17		Black Cicada Bird	<i>Edolisoma melas</i>	35	0.31	
18		Brown Oriole	<i>Oriolus szalayi</i>	371	3.29	
19		Northern Variable Pitohui	<i>Pitohui kirhocephalus</i>	165	1.46	
20		Hooded Pitohui	<i>Pitohui dichrous</i>	317	2.81	
21	AF	Yellow-bibbed Fruit Dove	<i>Ptilinopus solomonensis</i>	150	1.33	20.77
22		Claret-breasted Fruit-Dove	<i>Ptilinopus viridis</i>	435	3.86	
23		Purple-tailed Imperial Pigeon	<i>Ducula rufigaster</i>	26	0.23	
24		Pinon Imperial Pigeon	<i>Ducula pinon</i>	180	1.60	
25		Zoe's Imperial Pigeon	<i>Ducula zoeae</i>	49	0.43	
26		Amboyna Cuckoo-Dove	<i>Macropygia amboinensis</i>	48	0.43	
27		Black-billed Cuckoo-Dove	<i>Macropygia nigrirostris</i>	27	0.24	
28		Large Fig-parrot	<i>Psittaculirostris desmarestii</i>	98	0.87	
29		Double-eyed Fig-parrot	<i>Cyclopsitta diophthalma</i>	147	1.30	
30		Papua Hornbill	<i>Rhyticeros placatus</i>	303	2.69	
31		Helmeted Friarbird	<i>Philemon buceroides</i>	725	6.43	
32		Yellow-Faced Myna	<i>Mino dumontii</i>	153	1.36	
33	TF	Dwarf Cassowary	<i>Casuarus bennetti</i>	12	0.11	1.36
34		Stephan's Dove	<i>Chalcophaps stephani</i>	141	1.25	
35	NEC-FRU	Rainbow Lorikeet	<i>Trichogloss haematodus</i>	335	2.97	4.33
36		Western Black-Capped Lory	<i>Lorius lory</i>	153	1.36	
37	FRU-GRA	Eclectus Parrot	<i>Eclectus roratus</i>	117	1.04	1.44
38		Sulphur-crested Cockatoo	<i>Cacatua galerita</i>	45	0.40	
39	LIC	Yellow-capped Pygmy Parrot	<i>Micropsitta keiensis</i>	20	0.18	0.77
40		Buffy-faced Pygmy-Parrot	<i>Micropsitta pusio</i>	66	0.59	
41	CAR	Pacific Baza	<i>Aviceda subcristata</i>	17	0.15	2.87
42		Brahminy Kite	<i>Haliastur indus</i>	56	0.50	
43		Grey-headed Goshawk	<i>Accipiter poliocephalus</i>	32	0.28	
44		New Guinea Harpy-Eagle	<i>Harpyopsis novaeguineae</i>	34	0.30	
45		Greater Black Coucal	<i>Centropus menbeki</i>	52	0.46	
46		Rufous Owl	<i>Ninox rufa</i>	3	0.03	
47		Papuan Frogmouth	<i>Podargus papuensis</i>	8	0.07	
48		Shovel-billed Kingfisher	<i>Clytoceyx rex</i>	10	0.09	
49		Collared Kingfisher	<i>Todiramphus chloris</i>	69	0.61	
50		Sacred Kingfisher	<i>Todiramphus sanctus</i>	28	0.25	
51		Common Paradise Kingfisher	<i>Tanysiptera galatea</i>	15	0.13	
52	OMN	Red-legged Brushturkey	<i>Talegalla jobiensis</i>	34	0.30	6.51
53		Hooded Butcherbird	<i>Cracticus cassicus</i>	143	1.27	
54		Black Butcherbird	<i>Cracticus quoyi</i>	534	4.74	
55		Magnificent Riflebird	<i>Ptiloris magnificus</i>	23	0.20	

NEC: Nectarivore, INS-NEC: Insectivore-nectarivore, ASI: Aerial screening insectivore, FCI: Flycatching insectivore, TFBGI: Tree foliage bark gleaning insectivore, SFGI: Shrub foliage gleaning insectivore, LGI: Litter gleaning insectivore, INS-FRU: Insectivore-frugivore, AF: Arboreal frugivore, TF: Terrestrial frugivore, NEC-FRU: Nectarivore-frugivore, FRU-GRA: Frugivore-granivore, LIC: Lichenivore, CAR: Carnivore, OMN: Omnivore.

Comparison of Avian Feeding Guilds Across Different Habitat Types

Results of comparative analysis feeding guild and habitat type had a significant effect on bird abundance (variable respon), with all habitat categories differing significantly from the reference habitat ($p < 0.001$). The highest abundance was recorded in habitat young secondary forest ($B = 3.938$), followed by habitat Old secondary forest and habitat Mixed plantation forest, indicating increasing bird abundance along the successional gradient. Feeding guild also showed varying abundance patterns. Guilds nectarivores, insectivore–nectarivores, insectivore–frugivores, and arboreal frugivores had significantly higher abundance than the reference guild, whereas several guilds such as guild aerial screening insectivore and guild Litter gleaning insectivore showed significantly lower abundance, indicating uneven distribution of individuals among functional groups (Table 3).

Table 3. This table shows the response variable: bird abundance. Positive estimates indicate higher abundance relative to the reference category, while negative estimates indicate lower abundance.

Variable	Estimate (B)	SE	z value	p-value
Mixed shrub	2.400	0.312	7.69	<0.001
Agricultural land	2.077	0.298	6.97	<0.001
Mixed plantation forest	2.785	0.305	9.13	<0.001
Young secondary forest	3.938	0.331	11.89	<0.001
Old secondary forest	3.249	0.320	10.15	<0.001
Nectarivore	1.547	0.221	7.00	<0.001
Insectivore–nectarivore	1.657	0.230	7.21	<0.001
Insectivore–frugivore	0.569	0.180	3.16	<0.001
Arboreal frugivore	1.136	0.205	5.54	<0.001
Aerial insectivore	-3.404	0.412	-8.26	<0.001
Flycatching insectivore	-1.060	0.265	-4.00	<0.001
Shrub foliage gleaning insectivore	-2.009	0.301	-6.67	<0.001
Litter gleaning insectivore	-3.822	0.430	-8.89	<0.001
Frugivore–granivore	-1.367	0.272	-5.02	<0.001
Lichenivore	-1.469	0.289	-5.08	<0.001
Carnivore	-1.204	0.276	-4.36	<0.001
Terrestrial frugivore	-1.204	0.276	-4.36	<0.001

Note: Response variable: Bird abundance, Positive estimates indicate higher abundance relative to the reference category, while negative estimates indicate lower abundance.

This model shows the fit, without indication of overdispersion AIC: 3059.41. Next, the results of the main effect and interaction tests Wald Chisquare III, analyzed the impact of habitat and guild group on bird numbers using negative binomial regression show habitat significantly affected bird numbers (Wald $\chi^2 = 48.32$, $df = 5$, $p < 0.001$), indicating that bird diversity varies along the habitat succession gradient. Guild group comparisons also revealed a significant difference in the number of individuals (Wald $\chi^2 = 331.93$, $df = 14$, $p < 0.001$), showing that each guild group has a different number of individuals. However, the interaction between habitat and guild was not significant (Wald $\chi^2 = 56.29$, $p = 0.166$), indicating that guilds responded similarly across habitat types. This indicates that habitat affected overall bird abundance, but did not differentially influence specific feeding guilds. It is observed that each habitat has a different guild and number of individuals (Figure 3). Young secondary forests have the highest number of individuals for almost all major guilds, such as aerial frugivore, insectivore-nectarivore, nectarivore, and insectivore-frugivore; this indicates the highest diversity and abundance occur in young secondary forests, followed by old secondary forests and primary forests with orange-reddish color for some guilds such as arboreal frugivore, insectivore-nectarivore, nectarivore. Mixed shrub, orchard, and mixed plantation habitats have a low or zero number of individuals. Some insectivore-nectarivore exceptions in mixed shrubs and aerial frugivores in mixed plantation forests, and some guilds such as aerial screening, litter gleaning insectivore, shrub foliage gleaning insectivore, and omnivore not found individuals could be due to food resource habitat.

Based on the GLMM negative binomial test and visualization display (Figure 3), there is a tendency of guild groups whose distribution in succession habitat types follows the theory of intermediate disturbance hypothesis, habitat heterogeneity hypothesis, generalist species, and species decline. The guild groups of nectarivores and insectivore-nectarivores show generalist species, with almost all habitat types at each stage of succession showing stability in the number of individuals. The arboreal frugivore group shows species that follow the theory of intermediate disturbs hypothesis (IDH); this can be seen from the increase in the number of individuals at the initial succession stage, increasing and reaching a maximum in the intermediate succession and slightly decreasing to stability in the late succession. The tree foliage bark gleaning insectivore guild group of species follows the habitat heterogeneity hypothesis, which is the increase in the number of individuals little by little at each stage of succession until it reaches the maximum point, while other guild groups such as aerial screening insectivore, flycatching insectivore, shrub foliage gleaning insectivore, terrestrial frugivore, nectarivore-frugivore, frugivore-granivore, lichenivore, carnivore, tend to fluctuate.

Functional diversity analysis was conducted to complement the taxonomic community analysis and to evaluate changes in ecological functions along the successional gradient. Based on the results of functional analysis, the index shows. Functional richness differed significantly among habitat types, with the highest values recorded in old secondary forest, followed by young secondary forest and shrub habitat. Functional evenness showed no significant difference, indicating that resource use was moderately balanced across

communities despite differences in species composition. Functional divergence was higher in primary and old secondary forests, indicating the dominance of species with distinct ecological strategies and greater niche differentiation in late-successional habitats. Functional diversity analysis was conducted to complement the taxonomic community analysis and to evaluate changes in ecological functions along the successional gradient.

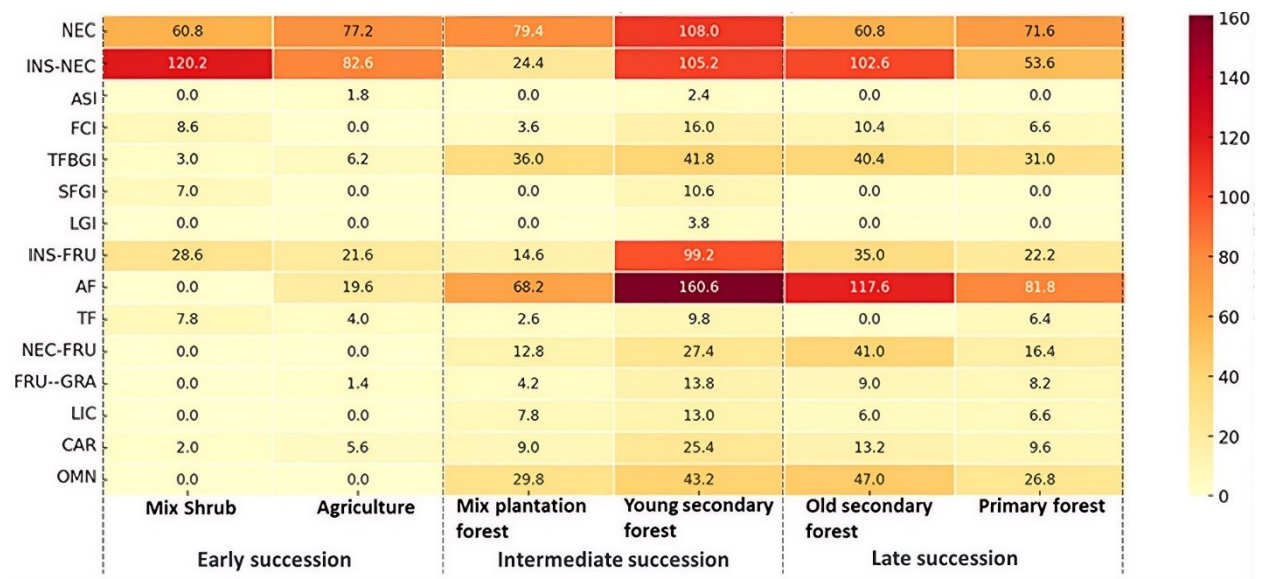


Figure 3. Heatmap averages the number of individuals based on the interaction between habitat type and feeding guilds. NEC: Nectarivore, INS-NEC: Insectivore-nectarivore, ASI: Aerial screening insectivore, FCI: Flycatching insectivore, TFBGI: Tree foliage bark gleaning insectivore, SFGI: Shrub foliage gleaning insectivore, LGI: Litter gleaning insectivore, INS-FRU: Insectivore-frugivore, AF: Arboreal frugivore, TF: Terrestrial frugivore, NEC-FRU: Nectarivore-frugivore, FRU-GRA: Frugivore-granivore, LIC: Lichenivore, CAR: Carnivore, OMN: Omnivore

Discussion

The results show significant differences in guild groups at each stage of habitat succession in Manokwari Regency, which is mainly determined by the availability of food resources in habitat types. The presence of birds in an ecosystem is closely related to food availability [39]. Based on the number of bird groups in each habitat, the intermediate and late succession stages had the most bird groups compared to the early succession stages. Our hypothesis, based on the results of the study, shows that the most feeding guild is found in young secondary forest habitats in the succession stage and declines towards stability in the final succession (old secondary forest and primary forest), compared to the habitat of the early succession stage (mixed shrubs and agriculture). This result supports the findings of Godoi et al. [40] Higher bird richness and diversity in advanced secondary forests compared to early forests.

Habitat diversity is important in influencing the feeding guilds of birds. In this study area, the bird species richness in each group is unbalanced (Table 1). Several guild groups were found across all stages of habitat succession, including nectarivores, insectivore–nectarivores, bark-gleaning insectivores, frugivore–insectivores, and carnivores. In addition, only in two stages of habitat succession were found aerial insectivores, shrub-leaf-gleaning insectivores, and litter-gleaning insectivores. These presences and absences indicate that the availability of resources in each habitat type significantly affects the presence of birds. A more diverse vegetation structure will provide greater opportunities for bird species specialising in a particular layer or composition of vegetation and provide more places to nest and forage [24,41], as well as determine the richness and diversity of bird species [42].

The GLMM results Effect of habitat on bird abundance along the successional gradient showed that habitat type had a significant, with the highest abundance recorded in young secondary forest, followed by old secondary forest and primary forest, while mixed shrub and agricultural areas supported the lowest abundance. This pattern indicates that bird abundance increases with vegetation structural complexity and resource availability along the successional gradient.

Young secondary forests provide a combination of high productivity, dense understory, and heterogeneous vegetation structure that supports various food resources such as insects, fruits, and nectar. These conditions allow both forest-associated and generalist species to coexist, resulting in higher bird abundance. Similar patterns have been widely reported in tropical forests, where secondary forests often support higher bird abundance than primary forests due to greater food availability and structural heterogeneity. Old secondary and primary forests, although slightly lower in total abundance than young secondary forests, play an essential role in maintaining habitat specialists. The presence of large trees, closed canopy, and well-developed vertical stratification creates stable microclimatic conditions and specialized foraging substrates that are required by forest-dependent species.

In contrast, mixed shrub and agricultural habitats showed significantly lower bird abundance. These habitats are characterized by open canopy, simplified vegetation structure, and high anthropogenic disturbance, which reduce niche availability and limit the occurrence of forest specialist species. Consequently, these habitats are mainly occupied by a small number of adaptable generalist species.

The dominance of these guilds reflects the high availability of trophic resources across habitats, particularly in secondary forests where flowering plants, fruiting trees, and insect populations are abundant. These guilds are functionally flexible and capable of exploiting multiple food resources and vegetation strata, making them more resilient to habitat changes.

In contrast, litter gleaning insectivores, bark gleaning insectivores, aerial insectivores, terrestrial frugivores, carnivores, and lichenivores had significantly lower abundance. These guilds are typically more specialized and strongly dependent on specific microhabitats. For example, litter gleaning insectivores require thick leaf litter, closed canopy, and stable humidity, which are mainly found in late successional and primary forests. Their low abundance indicates their sensitivity to habitat disturbance and highlights their importance as indicators of forest quality.

Functional guild dominance in the Papuan bird community. The dominance of nectarivores, insectivore–nectarivores, insectivore–frugivores, and arboreal frugivores reflects the high plant diversity and continuous resource availability in Papuan forests. The island of New Guinea is globally recognized for its extraordinary floristic richness and year-round fruiting and flowering phenology, which supports a high diversity of frugivorous and nectarivorous birds. Many of these guilds play key ecological roles as pollinators and seed dispersers. Their high abundance suggests that secondary forests in Papua still retain important ecosystem functions, particularly in maintaining plant regeneration and forest recovery processes.

On the other hand, the low abundance of litter gleaning insectivores and bark gleaning insectivores indicates their strong dependence on undisturbed forest conditions. These guilds require thick leaf litter, decomposing wood, complex bark surfaces, and stable humidity, all of which are primarily found in old secondary and primary forests. Their sensitivity to habitat simplification makes them reliable indicators of forest quality in the Papuan landscape.

Bird communities in New Guinea are strongly structured by forest type, with insectivores dominating in intact forest, while nectarivores increase in modified and secondary habitats [26]. Primary forest supports the highest diversity of frugivorous birds, while some species persist in degraded habitats as long as fruiting trees remain [43]. Nectarivores benefit from disturbed forests due to higher flower availability in open vegetation.

Ecological implications for tropical forest succession. The observed pattern demonstrates that different successional stages contribute differently to bird community structure. Young secondary forests are important for supporting high bird abundance, whereas old secondary and primary forests are crucial for maintaining functionally specialized guilds. This complementarity among successional stages suggests that landscape heterogeneity is essential for maintaining both taxonomic and functional diversity. A mosaic of habitats allows the coexistence of generalist and specialist species and enhances ecosystem stability. Secondary forest in tropical landscapes, connectivity to primary forest is a key driver of bird diversity in secondary forests [44]. Functional guild & forest structure. Forest structural complexity determines the distribution of feeding guilds by providing distinct foraging substrates and vertical strata.

The significant effect of habitat type on bird abundance reflects the strong influence of forest structural gradients in the lowland tropical landscapes of Papua. The highest abundance recorded in young secondary forests indicates that these habitats provide highly productive environments with abundant food resources, particularly insects, fruits, and nectar. In Papua, natural forest regeneration is typically rapid due to high rainfall, warm temperatures, and fertile soils, resulting in dense vegetation and complex understory even at

relatively early successional stages. These conditions create diverse foraging substrates that can be utilized by multiple feeding guilds simultaneously.

In contrast, primary forests in Papua are characterized by tall emergent trees, multilayered canopies, and stable microclimatic conditions. Although the total abundance of birds was slightly lower than in young secondary forests, these habitats are essential for maintaining forest-dependent species. Many Papuan birds, including specialized insectivores and large frugivores, are closely associated with closed-canopy forests and require large trees for foraging, nesting, and roosting. The persistence of these species indicates that primary forests still function as core habitats for maintaining ecological integrity.

Agricultural areas and mixed shrub habitats supported the lowest bird abundance. These habitats are typically associated with small-scale land-use systems, shifting cultivation, and garden-based agroforestry that are common in rural Papua. Their simplified vegetation structure, open canopy, and high disturbance levels limit the availability of ecological niches, particularly for forest specialists. As a result, these habitats are mainly occupied by a few adaptable generalist species.

The coexistence of different successional stages in the study area reflects the typical forest–agriculture mosaic found in many parts of lowland Papua. This landscape configuration is largely shaped by traditional land-use systems, smallholder gardens, fallows, and patches of natural forest. Such habitat heterogeneity allows the simultaneous occurrence of: disturbance-tolerant generalist species in open habitats, forest-associated species in secondary forests and habitat specialists in primary forests.

Lowland bird communities in New Guinea are strongly shaped by forest structure and disturbance gradients. Insectivores dominate intact forests, whereas nectarivores increase in secondary and human-modified habitats due to higher availability of flowering resources. Frugivorous birds show the highest diversity in primary forest but some species persist in degraded areas when fruiting trees are retained. Importantly, connectivity with primary forest plays a major role in maintaining avian diversity in secondary landscapes. These patterns highlight the functional linkage between feeding guild composition and vegetation complexity in tropical forests.

These findings have important implications for biodiversity conservation in Papua, which represents one of the largest remaining tracts of tropical forest in the Asia-Pacific region. First, young secondary forests should not be considered as low-value habitats. In the Papuan context, these forests function as important buffer zones, stepping stones, and supplementary feeding areas for many bird species. Second, the conservation of primary and old secondary forests remains irreplaceable because they support specialized feeding guilds that cannot survive in disturbed habitats. The loss of these forests would disproportionately affect functionally unique species and reduce ecosystem stability. Finally, maintaining a continuum of successional stages is crucial for sustaining both taxonomic diversity and functional diversity of birds in Papua.

The significant interaction between habitat type and feeding guild indicates that bird functional groups respond differently along the forest successional gradient. This pattern reflects the progressive changes in vegetation structure, resource availability, and microhabitat complexity from highly disturbed habitats to mature forests. Early successional habitats such as gardens and shrublands were dominated by generalist guilds, which are typically associated with open vegetation and fluctuating food resources. In contrast, advanced successional stages, particularly old secondary and primary forests, support a higher abundance of specialist guilds, such as arboreal frugivores and foliage-gleaning insectivores, which depend on complex canopy structure and stable microclimatic conditions. This finding confirms that forest structural development plays a crucial role in shaping the organization of bird communities in tropical landscapes.

The increase in bird abundance from early to late successional habitats reflects the increasing structural complexity and resource availability. The dominance of several feeding guilds suggests that generalist and adaptable guilds play a major role in shaping the bird community, while specialist guilds occur in lower numbers and are likely more sensitive to habitat disturbance. The differences in feeding guild abundance among habitat types indicate that habitat filtering plays an important role in structuring bird communities in tropical lowland landscapes. Forest habitats support specialized guilds. The high abundance of arboreal frugivores in primary and old secondary forests is closely related to the presence of large fruiting trees, complex canopy stratification, and stable microclimatic conditions. These habitats provide essential resources for forest-dependent guilds.

The results of this study across habitats reveal differences in guild groups at each stage of habitat succession. Habitats in the early succession stages, such as mixed shrubs and agriculture, had few guild groups when compared to habitats in the intermediate and late succession stages. According to research

Warmetan et al. [45] Agricultural and mixed shrub areas at the early succession stage have very few bird species, compared to intermediate and late succession with more complex diversity and vegetation structure. This study found 15 feeding guilds in the habitat of young secondary forests. This shows that young secondary habitats have abundant food resources. Specialist and forest-dependent species tend to become more abundant in older or more mature successional stages and generalist and open-habitat species are often more numerous in early and some intermediate stages [46,47].

The comparison between habitats and guild groups in this study was based on binomial negative regression, which shows that guild species differ in each habitat type. The presence and absence of guild species suggests that factors such as food affect it. Most bird species naturally utilize more than one habitat type [48], and the presence of the same species in different habitats suggests the availability of resources being effectively fulfilled in both natural and human-modified environments. This difference is due to the availability of food resources in each habitat. Our research findings are consistent with [34,37]; Showed, that vegetation's structural complexity, especially the canopy's height, significantly affects birds. Higher vegetation increases ecological niches, increasing species richness and functional diversity, especially in foraging substrates.

There is no significant relationship based on the number of individuals and species in a guild group; even if a group has many species, it does not matter how many individuals of each species are in the guild. Guilds can have many species, but the relationship is not necessarily significant between the richness of species and the number of individuals. Our findings show that increasing community complexity, as measured by guild diversity and species richness, does not negatively affect community viability [49]. This suggests that guilds can have many species without a significant number of individuals. This is in line with the results of our study which shows that the frugivore arboreal guild group with several species in this guild of 12 species, had a low number of individuals, compared to the group of nectarivores and insectivore-nectarivores where the number of species in the guild is only two and four species have a higher number of individuals.

This research also shows that the number of individuals of a particular guild group, at each stage of habitat succession, can follow several theories, namely, generalist species, whose number of individuals is relatively large at each stage of succession, as shown by the guild groups of nectarivores and insectivores-nectarivores. According to the study results of Remes et al. [50] and Tate et al. [51], the adaptability of generalist species allows them to thrive in changing habitats, which leads to an increase in populations during ecological succession, especially after the absence of competition from native species and habitat degradation caused by anthropogenic activities. Further, Rao et al. [52] suggest that generalist as they can colonise new areas more effectively than specialists. Their presence can lead to increased phylogenetic diversity and functional shifts within communities. The frugivore arboreal guild group shows the number of individuals following the intermediate disturbance hypothesis, which is shown by the increasing number of individuals at each stage of succession and reaching a peak in succession in young secondary forest habitats. According to Moi et al. [53] that low and high frequency disturbances limit diversity, while disturbances are creating opportunities for various species to coexist and thrive, by preventing competitive exclusion and reorganizing communities and allowing for the coexistence of strong and weak competitors, thus maintaining intermediate developmental states with high biodiversity. The theory of habitat heterogeneity hypothesis [54]. The number of habitats, morphological complexity, and availability of ecological resources contribute to increased biodiversity through supportive interactions between species. The results of our study show that the insect-eating group of guild tree bark collecting insects tends to follow this theory; This can be seen as the number of individuals increases little by little at each stage of succession until it reaches the highest number in the intermediate and late stages. According to the statement [51,52], the heterogeneity of habitat and vegetation structure is very decisive for the richness and diversity of birds.

Stages of early succession, i.e. mixed shrub habitats and agriculture, still provide insect feed, nectar, and fruit for bird species, although the number of individuals and guild groups is small (Figure 3). Birds exhibit cross-habitat feeding behavior, feeding on pests from forests and agricultural, which improves pest control in agricultural environments [55]. Although research does not show a richness of insect-eating species, it is possible that the types of plants cultivated by the community are not diverse, thus not providing an adequate food source for insects, and other environmental factors, such as microclimate.

Stages of intermediate and late succession have a high richness of species and diversity. In the young secondary forest, it was recorded in fifteen guild groups. This habitat is rich in the resources that birds need. Secondary forest are structurally complex, offer more niches, and have a higher diversity of vegetation and insects. Therefore, it can support more bird species. Secondary forests have significantly greater functional

and phylogenetic diversity than primary forests, suggesting that young, disturbed secondary forests may support high bird diversity. However, species richness does not show significant differences [56].

The presence of nectarivore groups birds is found in all habitat types and only two species, the Black Sunbird and the Olive-backed Sunbird. The largest number of insectivores and nectarivores are found in mixed shrub habitats, young secondary forests and old secondary forests. This indicates that all habitat in stage succession provide the needed resources. The results of study Sam et al. [26] showed that nectar-eating birds experienced an increase at higher altitudes in Papua New Guinea, in contrast to fruit-eating birds, which decreased in abundance. However, nectarivore birds' overall species richness is lower than that of insect-eating birds along the gradient. The insect-eating bird group insectivore-nectarivore is distributed in all habitat types. Previous studies [42,57] have indicated that insect-eating unions are most common in garden habitats rather than forest habitats. However, our results show that groups of insect eaters are evenly distributed across all habitat types with an unbalanced number of individuals that tend to differ per habitat.

The feeding guild birds insectivorous based on behavior includes aerial screening by one species of Barn Swallow was recorded in the habitat of agriculture and young secondary forests; this species is a migratory species, while fly catching insectivore, tree foliage bark gleaning insect, shrub foliage gleaning insectivore and litter gleaning insectivore. The low number of species can be attributed to limited food resource availability. This aligns with the observation Zhang et al. [56], that insect-eating birds can obtain food in agricultural and forested areas.

The insectivore-frugivore group proportion was higher in young secondary forest habitats (Figure 3). This result suggest that young secondary habitats still provide an abundant source of food. Based on habitat type, aerial frugivore has a higher proportion found in young secondary forest habitats, followed by primary forests, old secondary forests, and mixed plantation forest. Most birds eat or make insects as food alternatives [58]. This suggests that some disturbed areas have higher abundance than undisturbed ones. Furthermore, Mardiastuti [57], areas that are moderately disturbed or urban landscapes tend to have abundant sources of feed compared to undisturbed areas. frugivorous birds are commonly found in forests and agricultural areas [29].

Two species of terrestrial frugivores were recorded i.e., the Dwarf Cassowary and the Stephan's Dove. Dwarf Cassowary species are found only in primary forest habitats. Primary forest habitats are suitable for birds of prey on forest floors that need protection. Nectarivores and frugivores recorded two species: Rainbow Lorikeet and Western Black-Capped Lory. Although only two species were recorded in the study area according [22], New Guinea (Papua and Papua New Guinea) is unusual in supporting large numbers of fruit and nectar feeders. The frugivore-granivore group includes two species, namely the Eclectus Parrot and the Sulfur Crest Cockatoo. These birds are recorded in agricultural habitats, mixed plantation forests, young secondary forests, and primary forests. This condition suggests that Eclectus Parrots are a species that spreads when obtaining food.

Carnivorous birds recorded in this study belonged to the families Accipitridae, Centropidae, Strigidae, Podargidae, and Halcyonidae, with two nocturnal raptor species (Rufous Owl and Papuan Frogmouth) found in old secondary forest. The habitats of young secondary forests and old secondary forests are the most common habitats for six and five species of predators. The observation results show that these two habitats provide abundant sources of feed. The presence of carnivorous birds as predators in an ecosystem can function to maintain the balance of the food chain system [59]. Beside that, insectivorous birds are habitat specialists and least spread or settle [60], so they are more specialised in these habitats and constitute the most extensive food base for terrestrial carnivorous animals [61].

Lichenivore has only two species: Yellow-capped Pygmy Parrot and Buffy-faced Pygmy-Parrot, which are recorded in four habitat types. Lichenivore species have not been widely reported in Indonesia, specifically in Papua. The results of this research are important for advancing the guild category. They used beaks to scrape moss from tree bark, indicating a specialized adaptation for this guild, even when vegetation types were observed only on matoa trees (*Pometia coriacea*, *P. pinnata*, and *P. acuminata*). Guild Omnivores consist of four species: Red-legged Brushed Turkey, Hooded Flesh Bird, Black-Flesh Bird, and Magnificent Rifle Bird. Red-legged brush turkey species are recorded in young secondary and primary forest habitats. In contrast, the Magnificent Riflebird is recorded as a primary forest bird and is the only one in the Paradisaidae family.

From a conservation perspective, these results emphasize that secondary forests should not be overlooked in biodiversity management. Young secondary forests contribute substantially to bird abundance and may function as buffer habitats and movement corridors in fragmented landscapes. However, the conservation

of old secondary and primary forests remains irreplaceable because they support specialized guilds that cannot persist in disturbed habitats. Therefore, maintaining a continuum of successional stages is necessary to preserve the full spectrum of avian functional diversity in tropical forest ecosystems. The significant effect of habitat and feeding guild on bird abundance highlights the importance of vegetation structural complexity and trophic resource availability in shaping tropical bird communities. The presence of both generalist-dominated secondary forests and specialist-supporting primary forests indicates that conserving multiple successional stages is essential for maintaining functional diversity and ecosystem resilience.

Conclusions

In conclusion, the avian feeding guilds in the lowland forests of Manokwari Regency, Papua, exhibited relatively high diversity, comprising 15 guilds observed throughout the study period. Guilds with the highest species richness were aerial frugivores, followed by carnivores. Young secondary forest habitats support the highest number of feeding guilds. The aerial frugivore dominates the entire stage of habitat succession. Habitat comparisons reveal differences among stages of habitat succession. This research supports our hypothesis that avian feeding-guild richness and diversity differ across early, intermediate, and late succession. The richness along the successional gradient indicates that structurally complex forests provide a wider range of ecological niches for birds. The high functional divergence in old secondary and primary forests suggests the persistence of functionally distinct species, highlighting the importance of these habitats for maintaining ecosystem processes. Therefore, secondary forests should be integrated into regional spatial planning as functional refugia and biodiversity corridors in human-modified landscapes. Conservation strategies should therefore integrate primary forests, regenerating forests, and traditional agroforestry systems into a single landscape management framework.

Author Contributions

HW: Conceptualization, methodology, data curation, writing-original draft, writing-review and editing; **YAM:** conceptualization, methodology, writing-review and editing, supervision; **AM:** conceptualization, methodology, writing-review and editing, visualization; **SBR:** writing-review and editing, methodology.

AI Writing Statement

When AI assisted technologies were used in the writing process, use the following statement: During the preparation of this work the authors used ChatGPT and Grammarly in order to reference search and language refinement. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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