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Diversity of bird species in the coffee agroforestry landscape: Case study in the Pangalengan Sub-district, Bandung District, West Java, Indonesia

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Abstract. *Withaningsih S, Parikesit, Alham RF. 2020. Diversity of bird species in the coffee agroforestry landscape: Case study in the Pangalengan Sub-district, Bandung District, West Java, Indonesia. Biodiversitas 21: 2467-2480.* Traditionally, shade-grown coffee agroforestry is home to diverse taxa, including insects and mammals. However, research has shown that shade-grown coffee agroforestry is also an important habitat for various types of birds. A study on the diversity of bird species was performed in the coffee agroforestry landscape area of Perum Perhutani, Pangalengan Sub-district, Bandung District, West Java. Bird diversity data was collected using the point count method, and landscape structure analysis was performed, to quantify the characteristics of the landscape. The results were analyzed using Pearson's correlation analysis to determine the relationships between landscape structures and bird species diversity. The results of the study recorded 60 species of birds, from 29 families, among 1,581 individuals. The most dominant bird species were *Pycnonotus aurigaster*, *Orthotomus sutorius*, *Orthotomus ruficeps*, *Streptopelia chinensis*, and *Brachypteryx leucophrys*. The highest species abundance value at the research site was recorded for *Pycnonotus aurigaster,* with a relative abundance value of 22.02%. The diversity of bird species found at the study location was classified as high (H ' = 3.10). Thus, coffee agroforestry landscapes are associated with bird diversity, and diversity appears to increase when the total area (TA) increases; however the patch edge length (TE), number of spots (NP), the complexity of patch forms (MSI, MPFD) and landscape heterogeneity (SHDI) decrease. The coffee agroforestry landscape may represent an important habitat for many bird species.

Keywords: Birds, coffee agroforestry, landscape patterns, species diversity

INTRODUCTION

Human activity is inseparable from land use; thus as the human population increases, the intensity of human activities also increases. Increased human activities are generally accompanied by an increased need for space, which is not usually accompanied by an increase in space availability, encouraging changes in land use, and causing land to become a scarce resource (Nuraeni 2017).

Changes to a landscape can have impacts on the diversity of fauna species with habitats in the landscape. Therefore, changes in the landscape will have consequences on species composition. According to Rivero et al. (2016), the level of fragmentation for a landscape can be described as any change in the size, shape, similarity, contrast, or other metrics associated with the geometry and structure of a landscape.

Birds are one of the fauna groups that are vulnerable to habitat change because birds use their habitats to find food, breed, and shelter. According to McGarigal (1994), landscape structures can affect bird communities because changes in vegetation, food sources, predation, parasitism patterns, and competition can affect the richness and abundance of bird species occupying a landscape. Harms (2017) stated that habitat degradation and fragmentation due to changes in the landscape affect almost all wildlife, especially birds, and up to 85% of all bird species may be threatened with extinction due to the loss of habitat.

Factors that can affect the diversity of bird species in an area include the habitat characteristics and the disturbance caused by human activities, such as land-use changes (Kaban 2018). Birds respond differently to landscape modifications, depending on their adaptability to the environmental changes, including the size of the area and the shapes, edges, and the heterogeneity of the landscape. In natural forests, bird species diversity is assumed to be determined by the size of the habitat, in accordance with the Island Biogeography theory (MacArthur 1967), and by the sizes of the edges, based on the theory of edge effect (Primack et al. 1998). Additionally, the heterogeneity of the landscape has been shown to increase the diversity of edge species and to reduce the diversity of interior species (Forman and Godron 1986).

More specifically, coffee-based agroforestry is able to provide ecosystem services similar to those provided by forests and can fulfill economic, social, ecological, or conservation interests (O'Connor et al. 2005). Hairiah (2010) stated that coffee-based plantations play a role in supporting the economy, by meeting coffee export quotas, and each year, coffee exports require large contributions in production from individual plantations, which account for 80-95% of the total coffee land areas in Indonesia.

Ornithologists in particular note the diversity and abundance of birds - especially temperate-tropical-migratory species- in shade coffee plantation (Griscom 1932). Shade plants in coffee agroforestry are important sanctuaries for biodiversity because they represent a complex vegetation system that can benefit birds and other organisms, and these characteristics are generally not provided by other agroecosystems (Blake 1998). The coffee-based agroforestry landscape in the Pangalengan Sub-district has a multi-layered canopy structure, with shade trees, such as Rasamala (*Altingia excelsa*), Paperbark (*Melaleuca leucadendra*), and Pine (*Pinus merkusii*). This agroforestry landscape can be inhabited by birds or act as a migratory destination. The areas used for coffee-based agroforestry landscapes are assumed to influence the presence of birds in the area.

To identify the landscape structure at the research site, quantifications of landscape metrics were conducted, based on the remote-sensing imaging results. Landscape structure analysis was performed using a statistical approach and various types of implementations, based on the visualization results of landscape elements (Wu and Hobbs 2007). Haines- Young et al. (2003) suggested that the assessment of ecosystem structure and function patterns, based on ecological data, on both spatial and temporal scales is more efficient when using geographic information systems.

Up to the time that this study was conducted, no available information or scientific studies existed regarding the diversity of bird species associated with the agroforestry landscape in the Pangalengan Sub-district. Therefore, a study examining bird species diversity associated with the agroforestry landscape of this sub-district, which represents an important focal point for the coffee commodity in West Java, was necessary to obtain information regarding the diversity of bird species and the landscape use patterns of birds. The results of this study are expected to provide a source of information for conservation efforts and the management of biodiversity, especially for birds and their habitats.

MATERIALS AND METHODS

The study was conducted from February until July 2019 by collecting primary data, in the form of landscape spatial data from *Google* high-resolution satellite imagery under cloudless conditions during which all objects can be observed. Satellite images were obtained from the G*eoEye-1*, via the Google *platform*, on the QGIS application. Primary data collection for bird diversity included the names of the bird species, the number of birds, and the time of encounter (Bibby et al. 2000), as well as coordinate point counts of bird observations. The observations were done in the morning (around 06.00-09.30 a.m) and in the afternoon (from 15.00-17.30). However, observations were not conducted when the weather was foggy or while heavy downpour to lessen the data bias.

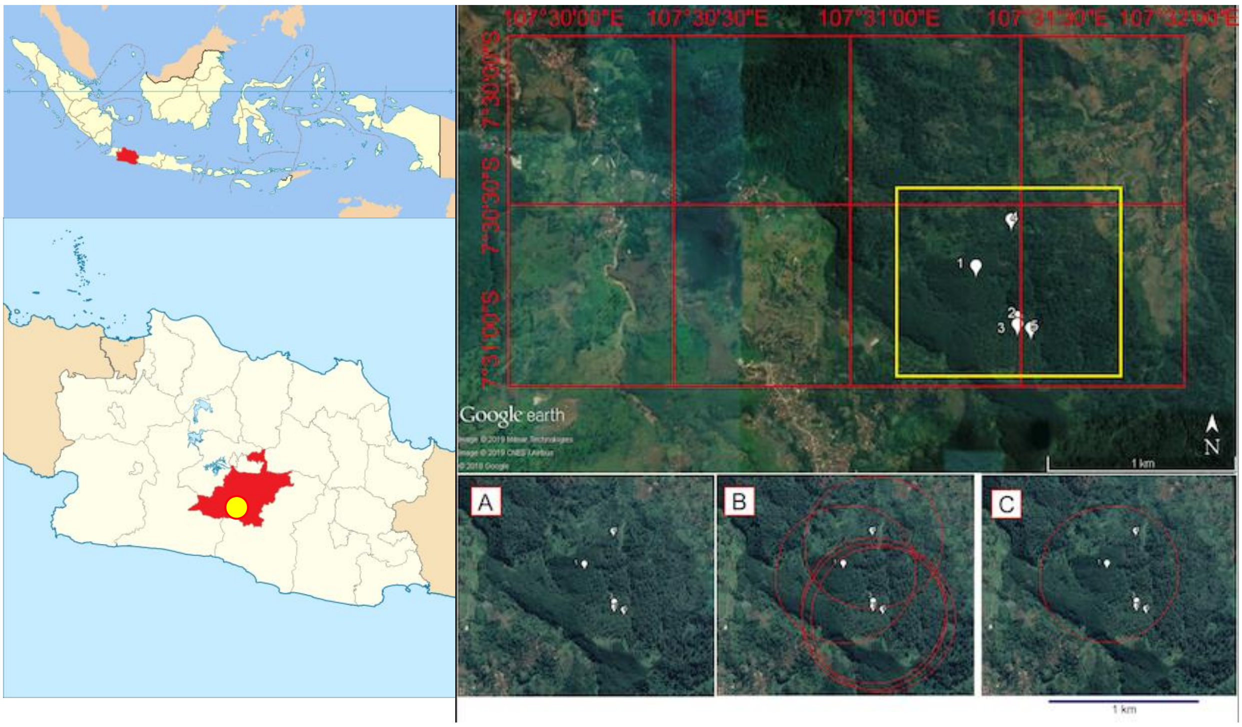

Figure 1. Study sample determination in Pangalengan Sub-district, Bandung District, West Java, Indonesia. Note: Study sample determination: A. Five birds community sampling sites in Tegalega, Lamajang Village, B. Five sampling sites intersect each other in a 500 m radius area, C. One sample site randomly was chosen as landscape analysis sample

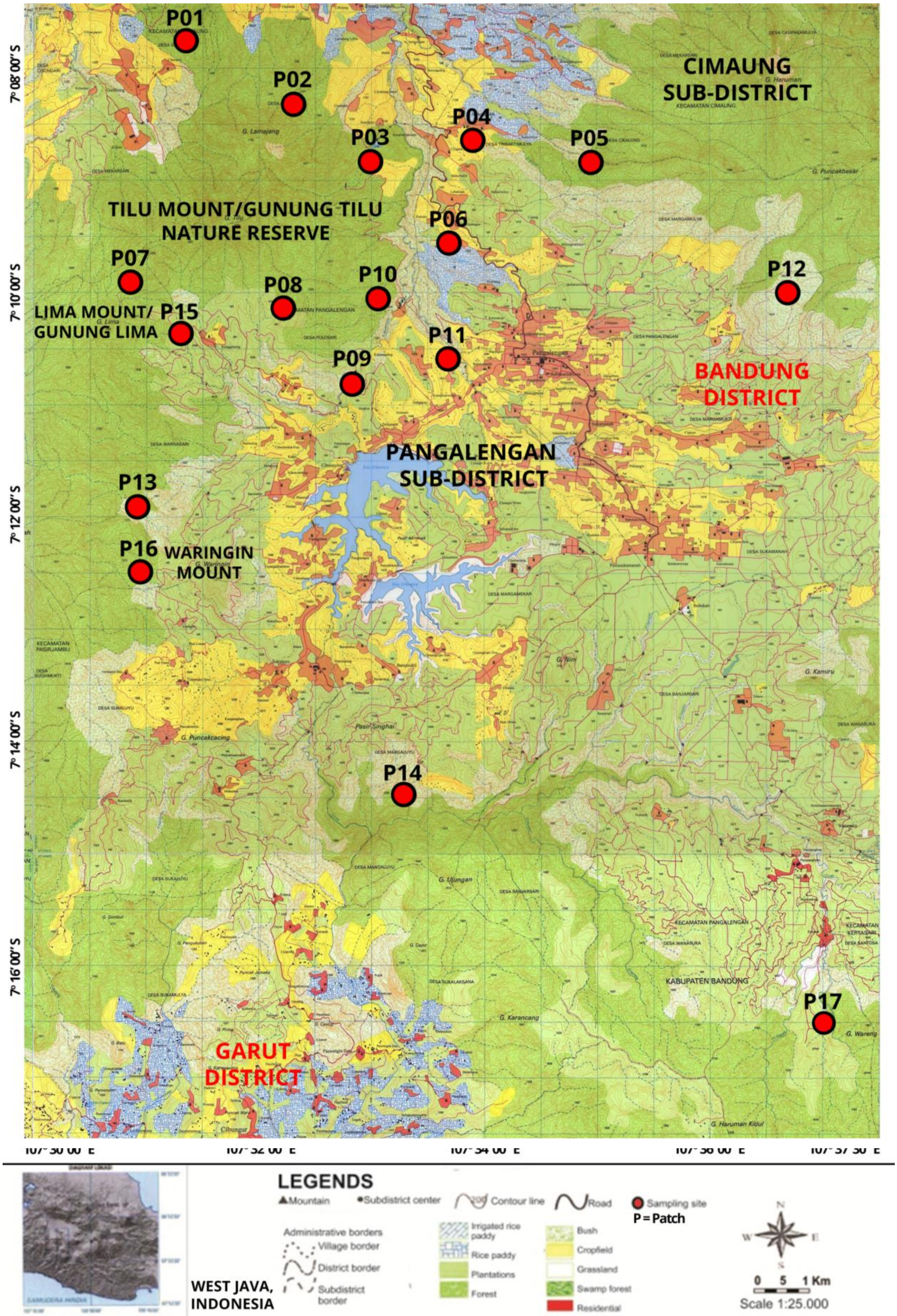

Figure 2. Location of research study in Pangalengan Sub-district, Bandung District, Indonesia

The range of the research site used for this study was determined based on a socio-ecological approach, through survey and interview methods, to obtain population data regarding coffee farmers and coffee plantation owners, which was subsequently entered into the *Frank Lynch Sampling Formula* to determine the number of samples to be studied. Out of a population of 1,333 coffee plantation owners who were members of 11 LMDHs (*Lembaga Masyarakat Desa Hutan* or Forest Village Community Institutions) in the Pangalengan Sub-district, 90 sample points were determined to be necessary. From these 90 points, circles with radii of 500 m were created for structural analyses at the micro landscape level (McGarigal 1994). The sample points for the macro landscape analysis were determined by using each of the 90 sampling points as the center point of a block circle and selecting intersected points within a radius of 500 m; this created 17 points that did not intersect which were used as a sample for the landscape analysis. The illustration of sample points determination of the landscape analysis is described in Figure 1. In each of the points, a 20-minute observation was conducted in a radius of 25 m and adjusted to the observer's ability to detect the presence of the birds (Figure 2).

Image cutting, the delineation of the range of the research site, and map digitization were performed to determine the pattern of land cover within the landscape, using QGIS 2.18.15 software. Then, an analysis of landscape parameters was performed using Fragstats 4.2 software. These parameters included Class Area (CA), Total Landscapes Area (TA), Total Edge (TE), Mean Shape Index (MSI), Mean Fractal Dimension (MPFD), Number of Patches (NP), Patch Richness (PR), dan Shannon Diversity Index (SHDI).

Data collection for bird species diversity was performed using the *point count* method, within the landscape analysis area. The results from these landscape measurements were then analyzed in terms of the relationship between the influences of the landscape and bird species diversity, using Pearson's correlation analysis in *PAST 3.0* software.

RESULTS AND DISCUSSION

Based on the research performed, a total of 60 bird species were recorded in 100 observation points from 17 sample points within the agroforestry coffee landscapes of the Pangalengan Sub-district. These 60 species belonged to 29 families, 30 of which were categorized as generalist species, and 30 of which were categorized as specialist species, including a total of 1,581 individuals (Table 1).

Of the 60 species included in the 29 families listed in Table 1, the most common species found were from the Cisticolidae family, with six species identified: Golden-headed cisticola (*Cisticola exilis*), Olive-backed tailorbird (*Orthotomus sepium*), Ashy tailorbird (*Orthotomus ruficeps*), Common tailorbird (*Orthotomus sutorius*), Brown prinia (*Prinia familiaris*), and Bar-winged prinia (*Prinia polychroa*).

The second most prevalent family was the Cuculidae family, with six species identified and recorded, including Chestnut-breasted malkoha (*Phaenicophaeus curvirostris*), Drongo-cuckoo (*Surniculus lugubris*), Sunda cuckoo (*Cuculus lepidus*), Plaintive cuckoo (*Cacomantis merulinus*), Banded bay cuckoo (*Cacomantis sonneratii*), and Rusy-breasted cuckoo (*Cacomantis sepulcralis*). These types of birds, which were found in almost all of the areas studied, had good adaptability. Widodo (2015) explained that many species of birds that belong to the Cuculidae, Pycnonotidae, and Cisticolidae families are forest settlers but are able to adapt to new landscapes outside of forests, in habitats built from various types of vegetable plants and a few shade plants found on agricultural land dikes. Thus, birds from these families can easily be found on various types of man-made land use.

The most commonly found individuals belonged to the Pycnonotidae and Cisticolidae families, including Sooty-headed bulbul (*Pycnonotus aurigaster),* Common tailorbird (*Orthotomus sutorius*), and Ashy tailorbird (*Orthotomus ruficeps*). Widodo (2015) explained that *Pycnonotus aurigaster* and *Orthotomus sutorius* are highly adaptable to the presence of humans, enabling both types of birds to withstand interference caused by human activities.

The highest numbers of families were found in patch 7, patch 16, and patch 17, with as many as 16 families identified in each patch. The highest number of species was found in patch 17 (S = 32 species), and the lowest number of species was found in patch 15 (S = 15 species). Patch 15 was dominated by tea plantation land-cover types, as well as natural forests, open land patches, mixed gardens, and roads. High levels of human activity at the time of observation, such as farming, could affect the activities and presence of various species of birds in the observation areas. Another patch, patch 17, was dominated by natural forest land cover types, as well as tea plantations and mixed forests. Kaban (2018) stated that the richness of a bird species is likely to be higher when human dominance in the habitat is lower, and vice versa.

According to the Regulation of the Ministry of Environment and Forestry (Peraturan Menteri Lingkungan Hidup dan Kehutanan) of the Republic of Indonesia, Number P.20/MENLHK/SETJEN/KUM.1/6/2018, regarding Protected Plants and Animal Types, five species of birds that are currently considered protected animals were found at the research site, including Large wren-babbler (*Napothera macrodactyla*), Large wren-babbler (*Ictinaetus malayensis*), Mountain serin (*Serinus estherae*), Orange-fronted barbet (*Megalaima armilaris*) and Black-banded barbet (*Megalaima javensis*). According to the International Union for the Conservation of Nature, in 2016, 58 species of the birds identified at our research site were included in the *Least Concern* (LC) category, and two species were included in the *Near Threatened* (NT) category.

Table 1. List of birds in research study

Family	Scientific name	Common name	Specialist (S)/Generalist (G)
Accipitridae	*Ictinaetus malayensis*	Black eagle	S
Alcedinidae	*Halcyon cyanoventris*	Javan kingfisher	S
Alcedinidae	*Todirhamphus chloris*	Collared kingfisher	S
Apodidae	*Collocalia esculenta*	Glossy swiftlet	S
Campephagidae	*Pericrocotus flammeus*	Scarlet minivet	S
Campephagidae	*Lalage nigra*	Pied triller	G
Campephagidae	*Coracina fimbriata*	Lesset cuckoo-shrike	G
Campephagidae	*Coracina larvata*	Sunda cuckoo-shrike	G
Cisticolidae	*Cisticola exilis*	Golden-headed cisticola	G
Cisticolidae	*Orthotomus sepium*	Olive-backed tailorbird	G
Cisticolidae	*Orthotomus ruficeps*	Ashy tailorbird	G
Cisticolidae	*Orthotomus sutorius*	Common tailorbird	G
Cisticolidae	*Prinia polychroa*	Bar-winged prinia	G
Cisticolidae	*Prinia familiaris*	Brown prinia	G
Columbidae	*Streptopelia bitorquata*	Island collared-dove	G
Columbidae	*Streptopelia chinensis*	Spotted dove	G
Corvidae	*Corvus enca*	Slender-billed crow	G
Cuculidae	*Phaenicophaeus curvirostris*	Chestnut-breasted malkoha	G
Cuculidae	*Surniculus lugubris*	Drongo-cuckoo	G
Cuculidae	*Cuculus Lepidus*	Sunda cuckoo	G
Cuculidae	*Cacomantis merulinus*	Plaintive cuckoo	G
Cuculidae	*Cacomantis sonneratii*	Banded bay cuckoo	G
Cuculidae	*Cacomantis sepulcralis*	Rusy-breasted cuckoo	G
Dicruridae	*Dicrurus macrocercus*	Black drongo	S
Dicruridae	*Dicrurus leucophaeus*	Ashy drongo	S
Eurylaimidae	*Eurylaimus javanicus*	Banded broadbill	S
Estrildidae	*Lonchura maja*	White-headed munia	G
Estrildidae	*Lonchura leucogastroides*	Javan munia	G
Estrildidae	*Lonchura leucogastra*	White-bellied	G
Fringillidae	*Serinus estherae*	Mountain serin	G
Hirundinidae	*Hirundo rustica*	Barn swallow	S
Laniidae	*Lanius schach*	Long-tailed shrike	S
Megalaimidae	*Megalaima armilaris*	Orange-fronted barbet	S
Megalaimidae	*Megalaima javensis*	Black-banded barbet	S
Muscicapidae	*Ficedula westermanni*	Little pied flycatcher	S
Muscicapidae	*Brachypteryx Montana*	White-browed shortwing	S
Muscicapidae	*Brachypteryx leucophrys*	Lesser shortwing	S
Nectariniidae	*Nectarinia sperata*	Purple-throated sunbird	S
Nectariniidae	*Nectarinia jugularis*	Olive-backed sunbird	S
Nectariniidae	*Arachnothera longirostra*	Little spiderhunter	S
Oriolidae	*Oriolus chinensis*	Black-naped oriole	G
Passeridae	*Passer montanus*	Eurasian tree sparrow	G
Pellorneidae	*Malacocincla sepiarium*	Horsfield's babbler	S
Pellorneidae	*Napothera epilepidota*	Eye-browed wren babbler	S
Pellorneidae	*Napothera macrodactyla*	Large wren-babbler	S
Phasianidae	*Gallus gallus*	Red junglefowl	S
Phasianidae	*Coturnix chinensis*	Blue-breasted quail	S
Phasianidae	*Arborophila javanica*	Chestnut-bellied partridge	S
Picidae	*Dendrocopos moluccensis*	Sunda woodpecker	S
Picidae	*Dendrocopos macei*	Fulvous-breasted woodpecker	S
Picidae	*Picus puniceus*	Crimson-winged woodpecker	S
Pnoepygidae	*Pnoepyga pussila*	Pygmy wren-babbler	S
Pycnonotidae	*Pycnonotus aurigaster*	Sooty-headed bulbul	G
Pycnonotidae	*Pycnonotus goiavier*	Yellow-vented bulbul	G
Sylviidae	*Cettia vulcania*	Sunda bush-warbler	G
Sylviidae	*Megalurus palustris*	Striated grassbird	G
Sittidae	*Sitta frontalis*	Velvet-fronted nuthatch	G
Stenostiridae	*Culicicapa ceylonensis*	Grey-headed flycatcher	S
Vangidae	*Hemipus hirundinaceus*	Black-winged flycatcher-shrike	S
Zosteropidae	*Zosterops palpebrosus*	Oriental white-eye	G

Bird species in the NT category included Large wren-babbler (*Napothera macrodactyla*) and Black-banded barbet (*Megalaima javensis*). Both bird species were recorded in the natural forest land cover class, in patch 17. Two identified species are listed in *Appendix* II by the Convention on International Trade in Endangered Species, including Island collared-dove (*Streptopelia bitorquata*) and Black eagle (*Ictinaetus malayensis*). One individual member of the *Streptopelia bitorquata* species was recorded in the natural forest land cover class, in patch 9. Black eagle was recorded in the natural forest class, in patches 2, 10 and 15; in the planted forest class, in patch 7, and in the tea plantation class, in patch 12. According to Aprilia (2015), *Ictinaetus malayensis* is primarily a predator in nature and is often found to have a positive correlation with balanced ecosystems in an area.

Abundance and relative frequency

Based on the analysis results, the highest individual abundance was found in patch 4 (N = 144), and the lowest individual abundance was found in patch 3 (N = 58). The abundance of species can be used to determine the density of individuals in an ecosystem. The relative abundance value demonstrated the dominant bird species found at the research site. The dominance, or relative abundance (RA), of each bird species was calculated and used to classify the species into three groups: (a) not dominant (RA = 0-2%); (b) sub-dominant (RA = 2-5%); and (c) dominant (RA > 5%) (Aprilia 2015).

The data presented in Figure 3 show the RA values for bird species recorded at the research site. Most of the species of birds found had relative abundance values that were not dominant (reaching 80%), and as many as 48 species of birds were included in the non-dominant groups, with RA values ranging from 0.6%-1.91%. In addition, 12% of all birds were classified as sub-dominant (7 species of birds) at the research site, with RA values ranging from 2.10%-4.96%. The dominant species represented 8% of all birds, from 5 species, with RA values greater than 5%. The classifications of sub-dominant and non-dominant indicate a relatively small number of individuals that were only found in some of the count points locations in our study area. The RA value for a species is related to the availability of food and habitats that supporting the presence of the birds within a landscape. The species of birds that were classified as being dominant included Sooty-headed bulbul (*Pycnonotus aurigaster*), Common tailorbird (*Orthotomus sutorius*), Ashy tailorbird (*Orthotomus ruficeps*), Lesser shortwing (*Brachypteryx leucophrys*), and Spotted dove (*Streptopelia chinensis*).

Sooty-headed bulbul was found in shrubs and tall-crowned trees, such as eucalyptus, rasamala, and pines, whereas Common tailorbird and Ashy tailorbird were heard or seen inhabiting shrubs and were frequently observed in coffee plants. Spotted dove was found walking on the ground, flying, or perched on eucalyptus plants, whereas Lesser shortwing was more often identified through its distinctive voice in several types of land cover classes, bordering natural forests.

The presence of five bird species at the observation site with high RAs compared with those of other species was supported by the availability of sufficient food sources. In addition, four species of birds, including Sooty-headed bulbul, Common tailorbird, Ashy tailorbird, and Spotted dove, were included among the generalist species, which are able to search for food and utilize trees on various types of land covers as shelter, such as pine trees.

In this research analysis, many individuals were classified as belonging to generalist species, demonstrating the availability of food and the supportive conditions for this type of species provided by the habitat. Dewi (2005) explained that the presence of generalist species will increase when environmental disturbances increase.

Generalist species are species that are able to use limited habitat elements (Hibbitts et al. 2013), whereas specialist species are more sensitive to environmental disturbances (Devictor et al. 2008). When a habitat on a specific landscape experiences a change or disturbance, specialist species will be more adversely affected than generalist species. Species that are classified as generalists are commonly distributed, can be found at altitudes of up to 2,000 meters above sea level, can be found at the edges of forests, in open forests, in secondary forests, and in bamboo groves, and are active in shrubs and treetops.

The highest relative frequency (RF) values were found for Sooty-headed bulbul (*Pycnonotus aurigaster*), Common tailorbird (*Orthotomus sutorius*), Ashy tailorbird (*Orthotomus ruficeps*), Rusy-breasted cuckoo (*Cacomantis sepulcralis*), and Lesser shortwing (*Brachypteryx leucophrys*). These high RF values showed that bird species were evenly distributed across the observation sites, based on their counts at each observation point. According to Dewi (2005), a relationship exists between the distribution of a bird species and the level of dominance for that bird species. Bird species with high distribution and dominance levels can better survive environmental changes and are likely to be found in various environmental conditions.

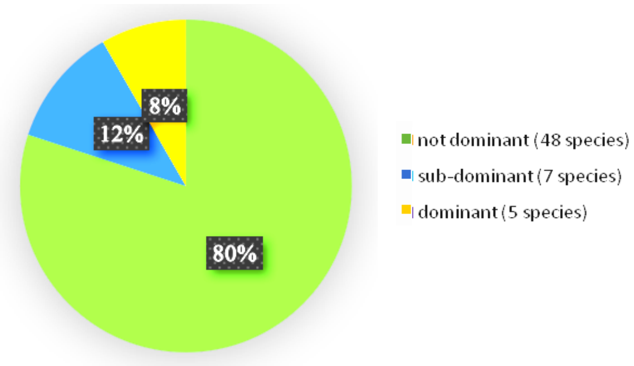

Figure 3. Relative abundance of birds at the research site

Species diversity

Bird species diversity indexes were calculated for each patch of the observation site. This study found differences in the species diversity index values for the birds observed at each observation site. Patch 17 had a high species diversity index value (H '= 3.03), whereas the other 16 locations had medium species diversity index values, indicating the moderate spread of species and moderate community stability.

Species diversity is closely related to species richness; for instance, patch 17, which had the highest species diversity index value also had the highest level of species richness compared with those for the other patches (S = 31 species). Three species of birds that were not found at other observations sites were found at patch 17, including Black-banded barbet (*Megalaima javensis*), Fulvous-breasted woodpecker (*Dendrocopos macei*), and Crimson-winged woodpecker (*Picus puniceus*). The diversity index value is closely related to the ecological conditions of an area. In addition, the diversity of bird species can act as an indicator of ecosystem integrity for a region, based on habitat fragmentation. In this study, patch 17 had the lowest fragmentation level compared with those of other patches. According to Karim (2017), large changes, such as the fragmentation of land that serves as the habitat for various species of birds, can reduce both species richness and diversity among, due to disturbances in the availability of shelter and food, which are absolutely necessary for birds. The bird diversity indexes for the 17 observation sites are presented in Figure 4.

The bird species diversity index for the entire research site was classified as high, with a value of H '= 3.10, indicating that the research location demonstrated high levels of diversity, distribution, and community stability.

Species evenness

The evenness of a bird species indicates the level of distribution for that species at an observation site. A bird species with a high level of stability has a higher chance of maintaining species sustainability. To assess the stability of a species within a community, the evenness index value of type (e) can be used. The evenness index value ranges from 0-1, where a value closer to 1 indicates that the types of birds are more evenly distributed within a location. Conversely, a value approaching 0 indicates that the birds are not evenly distributed and a dominant bird species exist at the observation site.

The evenness index value for the bird species throughout the research site was 0.76, indicating a high degree of evenness. Odum (1959) explained that evenness value can be considered to be high when it exceeds 0.6. The evenness index values for all observation patches are presented in Figure 5.

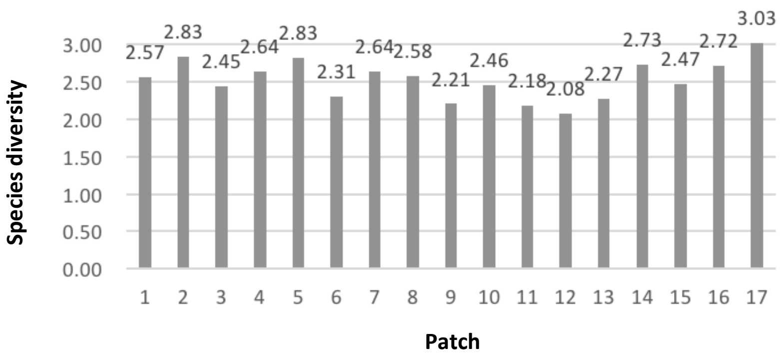

Figure 4. Bird species diversity (H') for each patch of the observation site

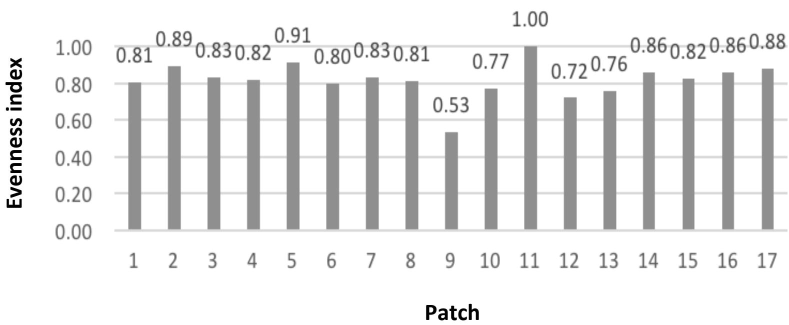

Figure 5. Evenness index values for each patch of the observation site

As shown in Figure 5, the lowest evenness index value was observed for patch 9, whereas the highest evenness index value was found for patch 11 (e = 1), indicating that in patch 11, individuals of each bird species were spread evenly and were supported by the availability of food for the species. Symonds (2008) explains that species evenness is closely related to habitat complexity or heterogeneity. Greater habitat heterogeneity is assumed to result in relatively low species specificity. In this study, patch 11, which had the highest species evenness index value, also had the highest landscape heterogeneity, based on SHDI values (See Table 1). The evenness of birds tends to increase when the landscape is increasingly heterogeneous (Kaban 2018).

In the other 15 patches, the evenness index values approached 1, indicating that the distribution of birds in this location was relatively even. These evenness index values indicated that the environment was able to provide sufficient food and shelter for the birds. Dewi (2005) explained that one of the factors that affect the presence of bird populations in occupied habitats is the availability of food resources, which can affect the bird evenness in a location. Birds have food preferences, and if a location cannot meet their needs, the birds will relocate to a location with better resources.

Landscape structure

The area for each land cover class was determined using the *Class Area* (CA) parameter. CA represents the total amount of land used by a landscape element. A large CA value denotes that the landscape element dominates that particular landscape. The matrix, therefore, is the most distinct homogeneous habitat in a landscape, as demonstrated by the largest CA value for a landscape area.

Edge measurement was performed using the *Total Edge* (TE) parameter. The highest TE value was observed for the agricultural class, and the lowest value was observed for the water class. A lower TE value indicates that the *patch* shape is more rounded, whereas a higher TE value indicates that the *patch* shape is more elongated.

Parameters used to measure variability in this study included *Patch Richness* (PR) and the *Number of Patches* (NP). The PR value indicates the richness or the number of *patches* within a landscape. A larger PR value indicates more types of land cover classes within a landscape. The largest PR values were found for patches 4 and 6, which each contained 7 land cover classes. The NP value indicates how many *patches* are on each landscape. According to Withaningsih et al. (2019), forest fragmentation may occur on the micro landscape level, as indicated by NP values greater than 1 for natural forests. NP values greater than 1 are associated with land cover class types, such as mixed gardens, agriculture patches, planted forests, roads, open lands, and settlements, with the highest values found for the settlements in patches 4 (NP = 15) and 11 (NP = 14). Higher NP values result in the formation of more small *patches*, indicating an increased fragmentation process.

The *Total Landscape Area* (TA) represents measurements of the landscape areas and indicates the total number of land cover classes. Patch 10 had the highest TA value (TA = 79.0 ha), whereas patch 12 had the lowest TA value (TA = 44.31 ha). The *Total Edge* (TE) value, in meters, indicates the sizes of the edges formed, with the highest TE value found for patch 11 (9,981 m), and the lowest value found for patch 2 (628 m). The measurements of landscape structure metrics are presented in Table 2.

The SHDI values shown in Table 2 indicate the level of sample heterogeneity at the landscape level, which varied from 0.1364 to 1.57. The SHDI values of a sample are related to the variability, as assessed by the NP and PR values, with decreasing SHDI values associated with decreases in the NP and PR values. Therefore, the level of landscape heterogeneity indicates the class variation within a landscape.

Table 2. Landscape structure metrics at the research site

Patch	TA (ha)	TE (m)	MSI	MPFD	SHDI	NP	PR
1	44.52	1614	1.59	1.09	0.66	4	2
2	78	628	1.738	1.097	0.1036	2	2
3	44.54	2649	1.88	1.13	0.49	5	4
4	44.34	9306	1.95	1.14	1.48	30	7
5	44.73	2532	1.88	1.1	0.66	3	2
6	44.52	9963	1.9	1.13	1.39	24	7
7	77.81	1936	1.98	1.11	0.29	2	2
8	78.86	4456	2.37	1.16	0.79	5	4
9	44.43	5238	1.81	1.13	1.4	15	6
10	79.0	5468	1.75	1.09	0.82	6	4
11	44.34	9981	1.74	1.12	1.57	27	6
12	44.31	3846	1.86	1.12	1.02	6	5
13	78.79	3756	1.51	1.09	1.06	7	5
14	78.32	7480	1.79	1.11	0.92	10	5
15	78.76	8604	2.5	1.19	1.41	14	5
16	77.34	2656	1.55	1.076	0.71	4	3
17	78.64	2596	1.5	1.06	1.02	3	3

Note: TA: Total Landscape Area, TE: Total Edge, MSI: Mean Shape Index, MPFD: Mean Patch Fractal Dimension, SHDI: Shannon's Diversity Index, NP: Number of Patches

Table 3. Correlation analysis results between landscape structures and bird species diversity

Variable	Abundance of individuals (N)	Species diversity index (H')	Number of species (S)
Total Landscape Area (TA)	0.32	0.45	0.54
Total Edge (TE)	0.26	-0.41	-0.34
Mean Shape Index (MSI)	0.002	-0.1	-0.21
Mean Patch Fractal Dimension (MPFD)	-0.1	-0.39	-0.47
Shannon's Diversity Index (SHDI)	0.212	-0.5	-0.38
Number of Patches (NP)	0.21	-0.42	-0.37
Patch Richness (PR)	0.16	-0.61	-0.52

The complexity of the landscape shape, according to the *patches*, was measured by the MSI and MPFD values. *Patch* shape complexity indicated whether the shape is more circular or square (McGarigal 1994). The ideal MSI value is 1, representing a perfect circle, whereas MSI values greater than 1 indicate irregular shapes. Higher MSI values indicate more complex *patch* shapes, with more edges. Overall, the sample patches had MPFD values greater than 1, indicating that the *patches* had complex shapes. Similarly, the MSI values for the sample patches were greater than 1, indicating that all of the *patches* in our research site were complex and irregular. According to Mardiastuti (2014), complex habitats are associated with the availability of resources, both in terms of food and diverse shelters for birds. More complex habitats, characterized by large numbers of vegetation types, have higher food resources and habitat availability for birds.

Relationship between agroforestry landscape structures and bird species diversity

Pearson's correlation coefficient can determine the relationships between various landscape structures and bird species diversity within a landscape. Pearson's correlation coefficient analyses were performed between landscape structure parameters, as independent variables, and bird species diversity, as the dependent variable. The results of the correlation analyses are presented in Table 3.

The TA variable was positively correlated with the N, H 'and S variables, indicating that higher TA values are associated with higher N, H' and S values. TA is a factor that influences bird species diversity. Primack et al. (1998) described the biogeographic theory, which states that islands with larger areas have a greater number of species compared with islands with smaller areas. Large islands provide less possibility of geographical isolation and can support larger populations of each species, increasing the chances of speciation and reducing the chances of extinction for newly formed or newly arrived species. Therefore, reducing the natural habitats on an island is likely to reduce the number of species it can support.

The largest TA value was found for patch 10 (TA = 79 ha), in which 129 total individuals belonging to 24 species of birds were observed, with a species diversity index value of 2.46. The lowest TA value was found for patch 12 (TA 44.31 ha). in which 89 total individuals belong to 18 species of birds were observed, with the lowest species diversity index value (H '= 2.08), as shown in Figure 6.

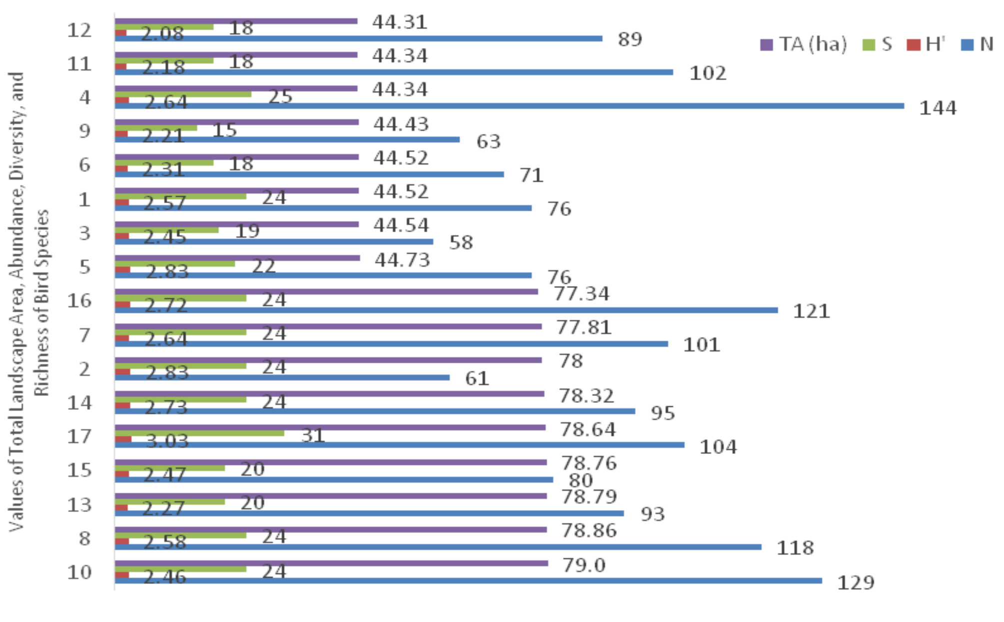

Figure 6. Values of total landscape area, abundance, diversity, and richness of bird species

Dewi (2005) explained that the TA value affects the diversity of bird species found within a landscape. The size of the area affects the availability of food resources, and a larger landscape can accommodate various types of vegetation that support the needs of birds, increasing species diversity.

In this study, patch 4, which had the second-lowest TA value (TA = 44.34 ha) also contained the largest number of individuals among all sample patches (N = 144), including 25 species of birds, among which 8 species were classified as specialist types, and the diversity index for this patch was classified as medium (H '= 2.63). These results may be due to the conditions of the surrounding landscape and human activities on agricultural land, which tended to be high at the observation sites. Furthermore, patch 4 was dominated by Sooty-headed bulbul (*Pycnonotus aurigaster*), which represented 22% of observed individuals, Javan munia (*Lonchura leucogastroides*), which represented 14% of observed individuals, and Ashy tailorbird (*Orthotomus ruficeps*), which represented 10% of observed individuals. These three species are considered to be generalist species, with a primary diet consisting of grains. These three bird species were also observed in mixed garden land cover, agricultural land, and plantation forest land cover classes.

Carbo-Ramírez (2011) explained that several factors can affect the richness and abundance of bird species within a habitat, such as the surrounding landscape conditions and human disturbances, which is why habitat *patches* with narrow areas are more likely to display increased richness and abundance compared with larger habitats.

The TE value was positively correlated with the N value and negatively correlated with the H 'and S values, indicating that as the TE value increases, the abundance of individual birds increases but species diversity and bird species richness decrease, which can be observed in Figure 7. Figure 7 shows that patch 11 had the greatest TE value, whereas patch 2 had the lowest TE value. In patch 11, 12 generalist species were recorded, which are known to be less sensitive to environmental changes than specialist species.

Kaban (2018) stated that a region divided into several units of smaller-sized habitats promotes species abundance and diversity. However, some of the identified species may represent weed species, which are dependent on the impacts of human activities. Landscapes with relatively high numbers of *edges* support animals that prefer *edge* areas but pose a threat to animals that do not.

NP and PR values were positively correlated with individual abundance but negatively correlated with both species richness and diversity, indicating that increases in NP and PR values may increase individual abundance while simultaneously reducing species richness and diversity, which may be due to differences in the land covers surrounding the coffee agroforestry sample patches.

NP values indicate the number of *patches* found for each land cover. More *patches* indicate that more elements of the landscape are separated into small groups, suggesting the increased occurrence of fragmentation (see Figures 8 and 9).

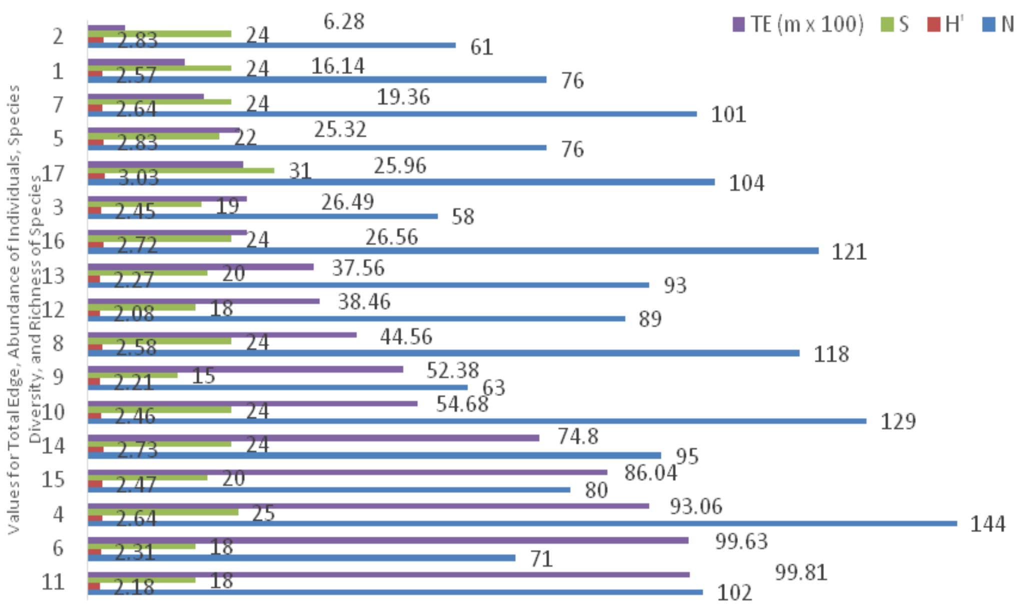

Figure 7. Values for Total Edge (TE), Abundance of Individuals, (N), Species Diversity (H'), and Richness of Species (S)

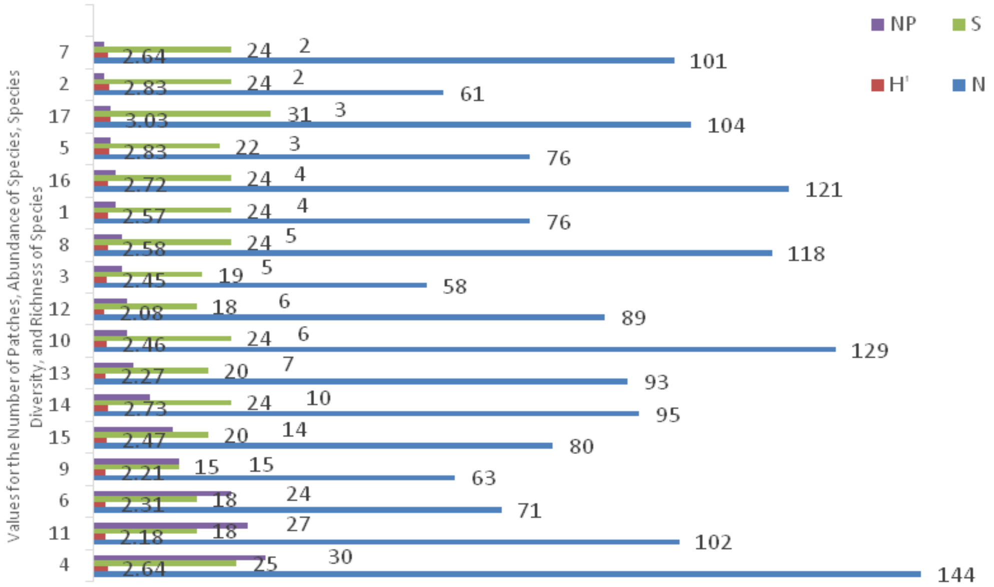

Figure 8. Values for the Number of Patches (NP), Abundance of Species (N), Species Diversity (H '), and Richness of Species (S)

As shown in Figure 8 and 9, patch 4 had the highest NP, PR, and N values, and 17 species of generalist bird species were recorded in patch 4, indicating that the types of birds found in patch 4 were able to use different types of habitats were more adaptable to landscape changes, and the highest NP value in patch 4 was for the settlement class. Dewi (2005) stated that habitat fragmentation can cause changes in bird species diversity. However, increases in bird species diversity may not be balanced because the number of generalist species is likely to be higher than that of specialist species.

The MPFD and MSI values illustrate the complexity of *patch* shapes in a landscape, and these variables were negatively correlated with bird species diversity and bird species richness, indicating that species diversity and species richness decreased with increasing MPFD and MSI values. Primack et al. (1998) explained increased fragmentation resulted in wider edge areas and middle areas moving closer to edge areas. High MSI and MPFD values indicate that complex land cover classes are associated with complex *patch* shapes, which can result in reduced habitat sizes.

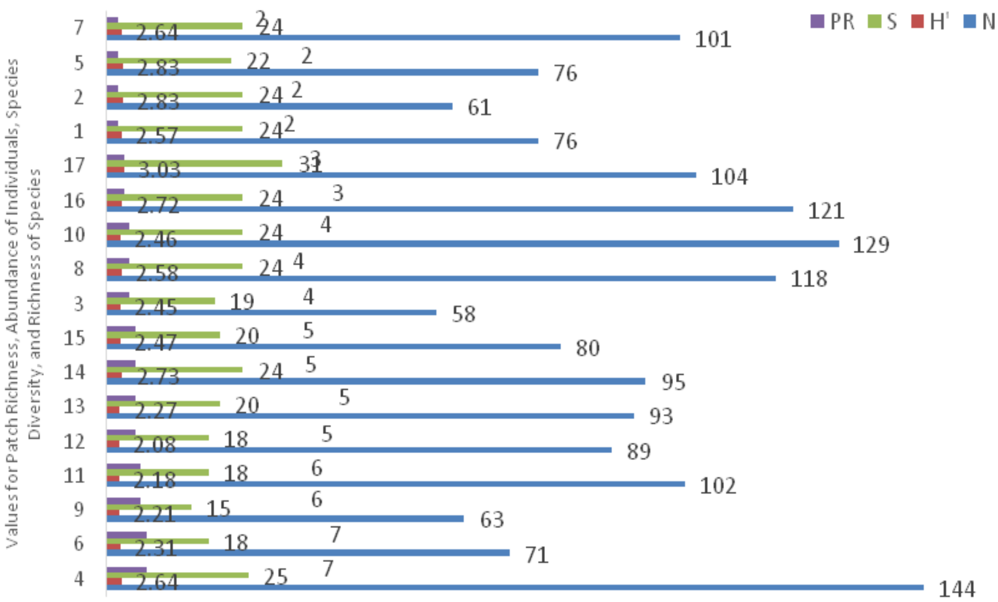

Figure 9. Values for *Patch Richness* (PR), Abundance of Individuals (N), Species Diversity (H '), and Richness of Species (S)

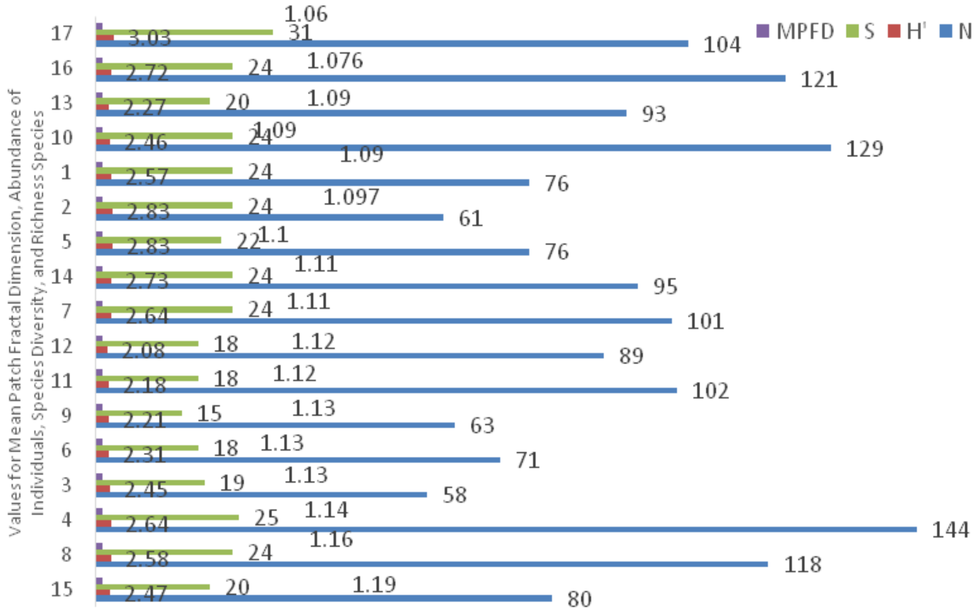

Figure 10. Values for Mean Patch *Fractal Dimension* (MPFD), Abundance of Individuals (N), Species Diversity (H ') and Richness of Species (S)

Based on Figure 10, the lowest MPFD values were found for patch 1. MPFD values showed a negative correlation with species diversity, which was classified as high in patch 17. In addition, 31 species of birds were observed in patch 17, consisting of 11 types of generalists and 20 types of specialists, indicating that patches with less complex forms and low levels of fragmentation may potentially support more specialist bird species than more complex patches. Kaban (2018) explained as landscape complexity increases, more edges are formed, allowing the area to be beneficial for most exterior species, such as generalist species, which are more tolerant of landscape changes. Praja (2016) explained that specialist types tend to utilize specific resources and are very vulnerable to human disturbances, in contrast with generalists, which can utilize various types of resources, such as feed, nest building materials, and nesting locations; in addition, generalists display high fecundity do not migrate. Mardiastuti (2014) stated that the presence of specialist bird species can act as an indicator of good environmental conditions.

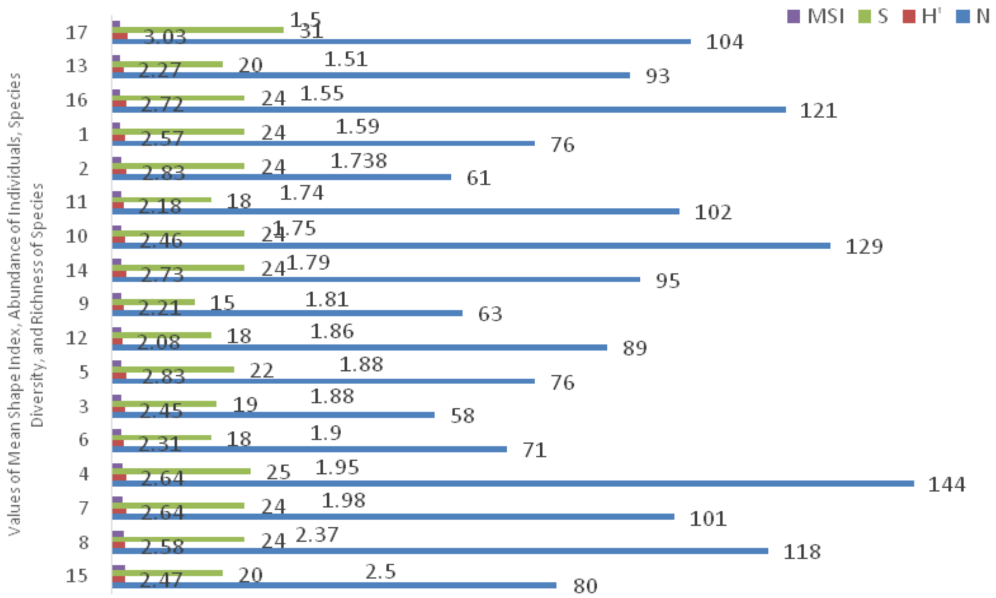

Figure 11. Values of Mean Shape Index (MSI), Abundance of Individuals (N), Species Diversity (H ') and Richness of Species (S)

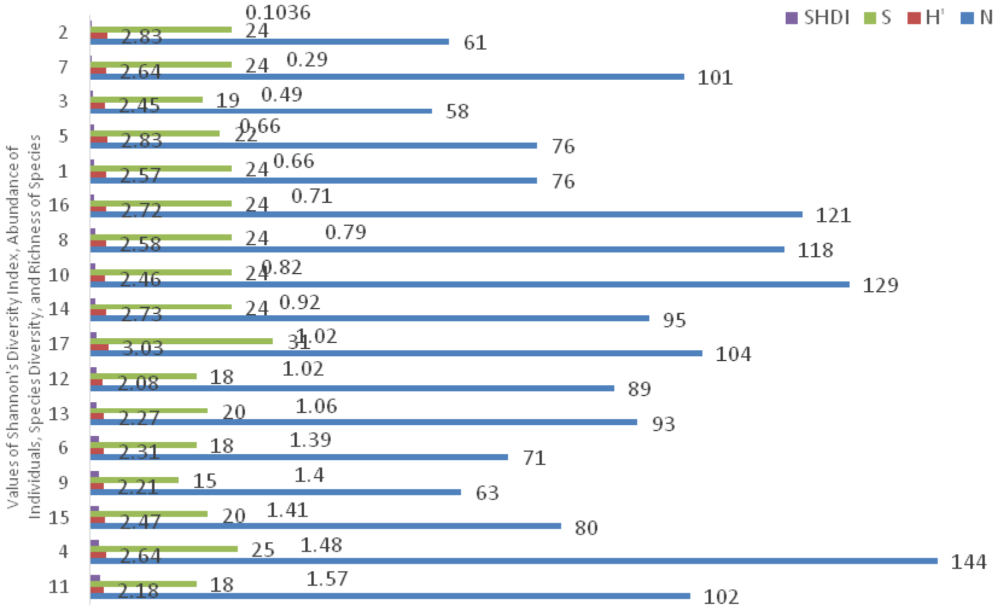

Figure 12. Values of Shannon's Diversity Index (SHDI), Abundance of Individuals (N), Species Diversity (H '), and Richness of Species (S)

Patch diversity was assessed based on the SHDI parameters, where individual abundance was positively correlated with SHDI values, but bird diversity and species richness were negatively correlated with SHDI values. The lowest SHDI value was found for patch 2 (Figures 11 and 12). The lowest SHDI size was 0, which indicates the presence of only one *patch* in the landscape. Conversely, SHDI values increase with increasing numbers of *patch* types (McGarigal 1994).

SHDI values for all patches were greater than 1, indicating habitat fragmentation. Kaban (2018) stated that habitat fragmentation in a landscape can increase the number of land patches and increase the SHDI value. As more land patches are formed, the average size of the patches decreases, and the complexity of the land increases. Smith et al. (2010) explained that the heterogeneity of the landscape can be a primary determinant of the richness and abundance of bird species. The heterogeneous landscape in this study differed based on the number of non-plant habitats, the land proportion, and the sizes of the patches. According to Redlich (2018), diversity at a landscape level does not influence bird species richness; however, landscape heterogeneity is associated with an increase in total bird abundance.

In conclusion, the characteristics of the landscape structure at the research site, which were assessed by measuring the area (TA), edges (TE), heterogeneity (SHDI), variability (NP and PR), and complexity (MSI and MPFD), indicated the occurrence of fragmentation among the natural forests, which were the natural habitats of birds. This fragmentation resulted in differences in individual abundance, species diversity, and bird species richness for each area, based on the adaptability of each species to habitat disturbances, which was also demonstrated by the larger numbers of generalist type individuals than specialist type individuals. The most common species of birds in all coffee plantations habitats were common second-growth or edge species. From the results of this study, it is clearly seen that coffee plantations play an important role in maintaining avian diversity. Thus, to ensure that coffee landscapes can continue to provide biodiversity benefits, several measures need to be taken by the coffee plantations' management, such as maintaining native canopy shade trees and forest cover.

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