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Correlations between human-modified landscape structure and bird diversity in Paseh Sub-district, Sumedang District, Indonesia

SUSANTI WITHANINGSIH[1,2,3,♥], MUHAMAD GALIH RAMDHANI[1], FIRMAN HADI[4], PARIKESIT[1,2,3]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran. Jl. Raya Bandung-Sumedang Km. 21, Jatinangor, Sumedang 45363, West Java, Indonesia. Tel.:+62-22-7796412 ext. 104, Fax.:+62-22-7795545, ♥email: susanti.withaningsih@unpad.ac.id

[2]Center for Environment and Sustainability Science, Universitas Padjadjaran. Jl. Sekeloa Selatan No. 1, Bandung 40213, West Java, Indonesia

[3]Graduate School of Environmental Sciences and Sustainability Science, Universitas Padjadjaran. Jl. Dipatiukur No. 35, Bandung, West Java Indonesia

[4]Department of Geodetic Engineering, Faculty of Engineering, Universitas Diponegoro. Jl. H. Prof. Soedarto, SH., Tembalang, Semarang 50275, Central Java, Indonesia

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Abstract. *Withaningsih S, Ramdhani MG, Hadi F, Parikesit. 2025. Correlations between human-modified landscape structure and bird diversity in Paseh Sub-district, Sumedang District, Indonesia. Biodiversitas 26: 1706-1719.* Various factors, including environmental conditions, human activities, and land use patterns, influence the diversity of bird species. The characteristics of each land use pattern will affect the diversity of bird species in a given area. The present study aims to investigate the correlations between human-modified landscape structures and bird diversity in the Paseh Sub-district, Sumedang District, West Java, Indonesia, highlighting how changes in land use and habitat composition influence avian species richness and distribution. Research on the relationship between bird species diversity and landscape structure in the Paseh Sub-district was conducted using the point count method for collecting bird data. Landscape structure was analyzed using Fragstats software, and the results were analyzed using Spearman correlation. The study recorded 74 bird species from 32 families, totaling 3,115 individuals. The Eurasian tree sparrow (*Passer montanus*) was the most abundant species, accounting for 38.1%. Bird diversity in Paseh Sub-district was assessed based on various land use patterns: settlements (H' = 1.47), mixed gardens (H' = 3.13), rice fields (H' = 2.65), and others (H' = 2.65). The overall bird species diversity was moderate (H' = 2.91). The landscape influenced bird diversity. Larger areas (TA), longer edges (TE), more patches (NP, PR), complex patch shapes (MSI, MPFD), and lower landscape heterogeneity (SHDI) were correlated with higher bird species diversity.

Keywords: Birds, diversity, landscape, land use, point count

INTRODUCTION

Birds play an important role in maintaining terrestrial ecosystems. Their role in the food chain comprises both primary consumers and apex predators. Additionally, the diversity of bird species in an area can serve as an indicator of the environment's quality, as birds are considered indicators of an ecosystem's health. Changes in bird populations and diversity can indicate declines in habitat quality, food availability, and other environmental factors (Molina-Marin et al. 2022). Vegetation cover is directly proportional to the diversity of bird species. This is because high vegetation cover, besides being used as nesting sites, plays a crucial role as a protective defense against predators (Igl et al. 2018). A source of water is also essential for bird diversity. As 70% of a bird's body is composed of water, and losing 10% of the water content can cause death, the nest location and the flight path are usually near a water source (Sheikh 2019). The habitat fragmentation that occurs in modern times due to changes in land use increases edge effects. However, this can have a positive impact on birds living at the edge of the habitat; the exposure to disturbances and predation may increase, ultimately affecting bird populations (Howell et al. 2021).

In addition to the abovementioned factors, humans indirectly influence the diversity of bird species. Each species of bird has a different level of tolerance for human activities. This tolerance is influenced by the bird's life history and the distance between the habitat and human activity. Bird species located near farms exhibit a higher level of tolerance to human activity compared to those in forests, resulting from adaptation and behavioral plasticity (Tryjanowski et al. 2019). Birds in agricultural environments play a crucial role in pest control. Various types of insectivorous birds can help control pest populations, and utilizing birds as natural predators is an environmentally friendly approach that reduces dependence on pesticides (Lees 2022). Quantitative analysis of landscape structures can be used to determine the characteristics of an area. Landscape measurement requires an overview of the landscape conditions obtained via satellite images. These images can also be used to assess the long-term effects of development on biodiversity, particularly due to changes in land use and habitat fragmentation (Teimouri et al. 2023).

The size of a landscape affects the diversity of bird species, as the greater the area, the more species the habitat can support. The edge of a landscape is an ideal habitat for many bird species. As the edge areas act as transition zones between habitats, species from multiple habitats will often coexist. The increase in biodiversity also results in high levels of resources, causing these areas to be utilized as bird habitats (Defriansyah et al. 2022; Muñoz-Sáez 2024). Increased development activities aimed at meeting human needs often lead to changes in land use, resulting in alterations to the local flora and fauna composition. Changes in land use and landscape features can occur in the form of alterations in size, shape, similarity, contrast, and other metrics that are incorporated into the landscape structure. The form of change can be characterized by environmental fragmentation (Santamaria-Rivero et al. 2016; Zhao et al. 2019).

Indonesia, there are several areas currently experiencing habitat fragmentation, one of which is Paseh Sub-district, Sumedang District, West Java, Indonesia. This fragmentation has occurred partly because of the construction of the Cileunyi-Sumedang-Dawuan (Cisumdawu) toll road. The existence of rice fields, mixed gardens, residential areas, and forests makes Paseh Sub-district contains suitable habitat for various types of birds. Understanding how land-use changes affect ecological balance, biodiversity conservation, and the ecosystem services provided by birds is crucial for maintaining essential services, such as pollination and pest control. Additionally, such research helps inform sustainable land management practices in Paseh Sub-district, ensuring coexistence between human activities and the preservation of avian biodiversity. Thus, the present study examined the influence of human-modified landscape structures on bird species diversity using a case study in Paseh Sub-district, Sumedang District, West Java, Indonesia.

MATERIALS AND METHODS

Study area

The research was conducted in Paseh Sub-district, Sumedang District, West Java, Indonesia. The Paseh Sub-district is one of the areas included in the Cisumdawu Toll Road project, which has resulted in changes in environmental factors and ecosystem conditions. Paseh Sub-district comprises 10 villages: Padanaan, Pasir Reungit, Bongkok, Cijambe, Legok Kidul, Paseh Kaler, Paseh Kidul, Legok kaler, Citepok, and Haurkuning (Figure 1). Bird data were collected from 15% of the overall study area. The survey area was divided into 450 count points, spread across three dominant land use patterns in each village: rice fields, mixed gardens, and residential areas. Observations were also made on several other types of land use that had the potential to become habitats for birds, such as forests, bushes, fields, cemeteries, rivers, and mining areas.

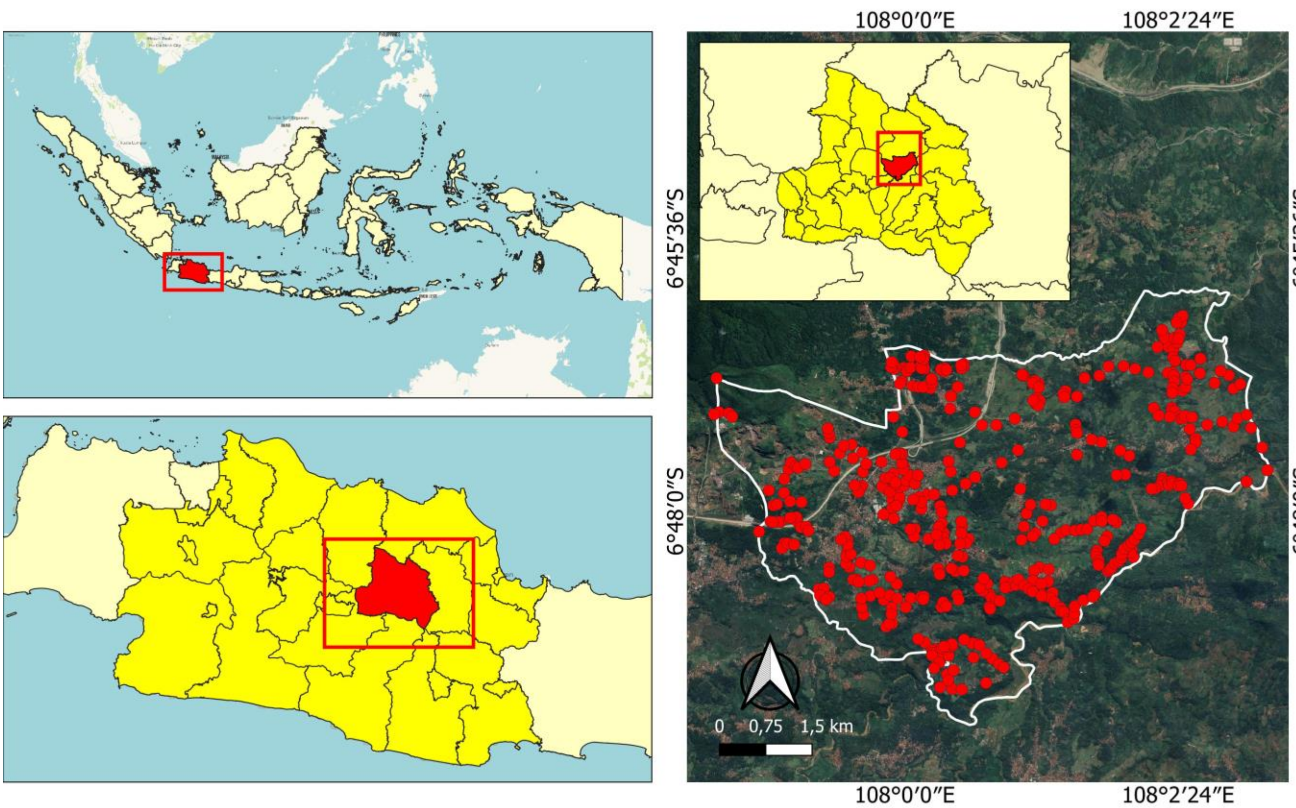

Figure 1. A map of the study area in Paseh Sub-district, Sumedang District, West Java, Indonesia

Procedures

The research consisted of two stages: primary and secondary data collection. Primary data collection was conducted through direct observations of birds at 450 count points in 10 villages of Paseh Sub-district, while secondary data collection, in the form of landscape structure, was carried out using satellite images. Bird data was collected using the survey method for point count data. The observations were made within a circle of a given radius centered on the observer's standing position. All birds detected within a 20-minute period were recorded. Each observation point was located at a distance of 150 to 200 meters and had a radius of 50 to 80 meters. These values were adjusted to the observation locations to avoid any overlap. A distance of 150 meters between points and a radius of 50 meters were applied to landscapes with limited visibility and dense cover, such as residential areas, mixed gardens, and secondary forests. A distance of 200 m between points and a radius of 80 m was applied to rice fields, agricultural fields, rivers, bushes, and mining areas. The point count technique was used to calculate the relative abundance of bird species, thereby determining the species diversity.

Data analysis

The Shannon-Wiener species diversity index value was calculated for each observation point. Satellite image data processing was carried out using Geographic Information System (GIS)-based software and ArcMap 10.8. Heat maps based on the value of the bird species diversity were used as a reference for determining buffer zones. Seventeen buffers, spread across five classes in the heatmap, were identified. Landscape analysis was carried out using spatial statistics. Land cover patterns were analyzed via rasterization to obtain images in TIFF format. The images were used to quantify landscape parameters using Fragstats 4.2 software. The 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), and Shannon Diversity Index (SHDI) (Prastiyo et al. 2018).

The relationship between landscape and bird species diversity was performed using Spearman correlation analysis in Past 4.0 software, with the program automatically ranking the results. To quantify the degree of landscape fragmentation, we developed a composite index that integrates multiple landscape metrics. This approach follows established methodologies in landscape ecology, combining individual metrics to create more comprehensive measures of landscape patterns (Hargis et al. 1998; Jaeger 2000; McGarigal et al. 2012).

Before integration, all metrics were normalized to a common scale (0-1) to ensure comparability:

$$X_{norm} = \frac{(X - X_{min})}{(X_{max} - X_{min})}$$

Where:
X : Original metric value
X_{min} and X_{max} : Metric's minimum and maximum values across all buffers, respectively

Based on ecological principles and previous studies, we assigned differential weights to each normalized metric to reflect their relative importance in characterizing landscape fragmentation:

$$FI = \Sigma\ wi \times X_{i,norm}$$

Where:
FI : Fragmentation Index
wi : Weight assigned to metric I
X_i, and $_{norm}$: Normalized value of metric I
The following weights were assigned:

- Number of Patches (NP): 0.25 (higher patch numbers indicate increased fragmentation)
- Total Edge (TE): 0.20 (greater edge density reflects landscape division)
- Mean Shape Index (MSI): 0.15 (more complex shapes often indicate anthropogenic fragmentation)
- Mean Patch Fractal Dimension (MPFD): 0.10 (higher complexity relates to fragmentation processes)
- Patch Richness (PR): 0.15 (diversity of patch types suggests landscape heterogeneity)
- Shannon's Diversity Index (SHDI): 0.15 (higher diversity may indicate fragmentation in natural landscapes)

In earlier research, these weights were determined from established correlations between these metrics and landscape fragmentation. The resulting index was adjusted to a 0-100 scale for simplicity interpretation:

$$FI_{scaled} = FI \times 100$$

To facilitate meaningful ecological interpretation, we classified fragmentation levels into three categories based on the statistical distribution of the index values:

- Low fragmentation: <(μ-σ)
- Moderate fragmentation: (μ-σ) to ($\mu + \sigma$)
- High fragmentation: >($\mu + \sigma$)

Where:
μ : Mean fragmentation index value across all buffers
σ : Standard deviation

Descriptive statistics were computed for the fragmentation index, including the mean, standard deviation, minimum, and maximum values. Furthermore, an analysis was conducted to assess the correlation between the computed fragmentation index and Shannon's diversity Index (H') in order to evaluate the relationships with ecological diversity. The resulting categorization of fragmentation was substantiated through comparisons with field observations and established literature concerning landscape pattern-process interactions relationships.

RESULTS AND DISCUSSION

Bird species diversity

Table 1 presents the results of the species richness analysis at 450 observation points distributed across the Paseh Sub-district landscape.

Table 1. Bird species richness and their conservation status in Paseh Sub-district, Sumedang District, West Java, Indonesia

Common name	Local name	Scientific name	Family	Number of individuals	Kr	Fr (%)	INP	Conservation status		
								IUCN	CITES	PP
Eurasian Tree Sparrow	*Burung Gereja Erasia*	*Passer montanus* (Linnaeus, 1758)	Passeridae	692	22.19%	11.0%	38.1%	LC	Non-Appendix	TDL
House Sparrow	*Kapinis Rumah*	*Apus nipalensis* (Hodgson, 1837)	Apodidae	394	12.63%	10.8%	25.0%	LC	Non-Appendix	TDL
River Kingfisher	*Cekakak Sungai*	*Todiramphus chloris* (Boddaert, 1783)	Alcedinidae	284	9.11%	12.9%	22.9%	LC	Non-Appendix	TDL
Javan Munia	*Bondol Jawa*	*Lonchura leucogastroides* (Moore, 1858)	Estrildidae	254	8.14%	7.7%	16.5%	LC	Non-Appendix	TDL
Peking Munia	*Bondol Peking*	*Lonchura punctulata* (Linnaeus, 1758)	Estrildidae	251	8.05%	2.2%	10.9%	LC	Non-Appendix	TDL
Javan Pond Heron	*Blekok Sawah*	*Ardeola speciosa* (Horsfield, 1821)	Ardeidae	132	4.23%	1.9%	6.3%	LC	Non-Appendix	TDL
Javan Kingfisher	*Cekakak Jawa*	*Halcyon cyanoventris* (Vieillot, 1818)	Halcyonidae	117	3.75%	7.1%	11.0%	LC	Non-Appendix	TDL
Spotted Dove	*Tekukur Biasa*	*Spilopelia chinensis* (Scopoli, 1786)	Columbidae	113	3.62%	4.5%	8.2%	LC	Non-Appendix	TDL
Olive-backed Sunbird	*Burung Madu Sriganti*	*Cinnyris jugularis* (Linnaeus, 1766)	Nectariniidae	107	3.43%	4.2%	7.7%	LC	Non-Appendix	TDL
Common Iora	*Merbah Cerukcuk*	*Pycnonotus goiavier* (Scopoli, 1786)	Pycnonotidae	78	2.50%	4.0%	6.5%	LC	Non-Appendix	TDL
Common Tailorbird	*Kekep Babi*	*Artamus leucorynchus* (Linnaeus, 1771)	Artamidae	73	2.34%	2.7%	5.1%	LC	Non-Appendix	TDL
Striated Swallow	*Walet Loreng*	*Cecropis striolata* (Schlegel, 1844)	Hirundinidae	70	2.24%	1.7%	4.0%	LC	Non-Appendix	TDL
Pacific Swallow	*Walet Sapi*	*Collocalia esculenta* (Linnaeus, 1758)	Apodidae	49	1.57%	2.1%	3.7%	LC	Non-Appendix	TDL
Black Drongo	*Kedasi Hitam*	*Surniculus lugubris* (Horsfield, 1821)	Cuculidae	39	1.25%	3.3%	4.5%	LC	Non-Appendix	TDL
Yellow-vented Bulbul	*Burung Madu Kelapa*	*Anthreptes malacensis* (Scopoli, 1786)	Nectariniidae	39	1.25%	1.6%	2.9%	LC	Non-Appendix	TDL
Bananaquit	*Cinenen Pisang*	*Orthotomus sutorius* (Pennant, 1769)	Sylviidae	37	1.19%	1.6%	2.8%	LC	Non-Appendix	TDL
Greater Coucal	*Cucak Kutilang*	*Pycnonotus aurigaster* (Vieillot, 1818)	Pycnonotidae	29	0.93%	1.3%	2.3%	LC	Non-Appendix	TDL
Rock Pigeon	*Jingjing Batu*	*Hemipus hirundinaceus* (Temminck, 1822)	Campephagidae	27	0.87%	0.6%	1.5%	LC	Non-Appendix	TDL
Black-capped Kingfisher	*Pelanduk Topi Hitam*	*Pellorneum capistratum* (Temminck, 1823)	Timaliidae	25	0.80%	1.1%	1.9%	LC	Non-Appendix	TDL
Grey-Crowned Yellow-Warbler	*Cinenen Kelabu*	*Orthotomus ruficeps* (Lesson, 1830)	Sylviidae	20	0.64%	0.9%	1.6%	LC	Non-Appendix	TDL
Common Sandpiper	*Caladi Tilik*	*Dendrocopos moluccensis* (J.F.Gmelin, 1788)	Picidae	18	0.58%	0.9%	1.5%	LC	Non-Appendix	TDL
Rock Dove	*Merpati Karang*	*Columba livia* (J.F.Gmelin, 1789)	Columbidae	18	0.58%	0.5%	1.1%	LC	Non-Appendix	TDL
Red-breasted Parakeet	*Kadalan Birah*	*Phaenicophaeus curvirostris* (Shaw, 1810)	Cuculidae	16	0.51%	1.0%	1.5%	LC	Non-Appendix	TDL
Common Bush Hen	*Pelanduk Semak*	*Malacocincla sepiaria* (Horsfield, 1821)	Timaliidae	15	0.48%	0.9%	1.4%	LC	Non-Appendix	TDL
Javan Magpie	*Cucak Kuricang*	*Pycnonotus atriceps* (Temminck, 1822)	Pycnonotidae	15	0.48%	0.7%	1.2%	LC	Non-Appendix	TDL
Scaly-breasted Munia	*Bondol Haji*	*Lonchura maja* (Linnaeus, 1766)	Estrildidae	15	0.48%	0.3%	0.8%	LC	Non-Appendix	TDL
Philippine Serpent Eagle	*Elang-ular Bido*	*Spilornis cheela* (Latham, 1790)	Accipitridae	13	0.42%	1.3%	1.7%	LC	Appendix II	DL
Little Pied Flycatcher	*Pijantung Kecil*	*Arachnothera longirostra* (Latham, 1790)	Nectariniidae	11	0.35%	0.7%	1.1%	LC	Non-Appendix	TDL
Red Junglefowl	*Bambangan Merah*	*Ixobrychus cinnamomeus* (Gmelin, 1789)	Ardeidae	11	0.35%	0.6%	1.0%	LC	Non-Appendix	TDL
Mountain Flycatcher	*Pijantung Gunung*	*Arachnothera affinis* (Horsfield, 1821)	Nectariniidae	10	0.32%	0.5%	0.8%	LC	Non-Appendix	TDL
Little Egret	*Kuntul Kecil*	*Egretta garzetta* (Linnaeus, 1766)	Ardeidae	10	0.32%	0.3%	0.6%	LC	Non-Appendix	TDL
Cattle Egret	*Alap-alap Sapi*	*Falco moluccensis* (Bonaparte, 1850)	Falconidae	8	0.26%	0.8%	1.1%	LC	Non-Appendix	DL
Buff-backed Bulbul	*Kerak Kerbau*	*Acridotheres javanicus* (Cabanis, 1851)	Sturnidae	8	0.26%	0.1%	0.4%	VU	Non-Appendix	TDL
Striped Swift	*Layang-layang Loreng*	*Cecropis striolata* (Schlegel, 1844)	Hirundinidae	7	0.22%	0.1%	0.3%	LC	Non-Appendix	TDL
Lesser Sand Plover	*Gemak Loreng*	*Turnix suscitator* (J.F.Gmelin, 1789)	Turnicidae	6	0.19%	0.5%	0.7%	LC	Non-Appendix	TDL
Black-winged Stilt	*Bubut Alang-alang*	*Centropus bengalensis* (Gmelin, 1788)	Cuculidae	6	0.19%	0.5%	0.7%	LC	Non-Appendix	TDL
Javan-Banded Pita	*Paok Pancawarna*	*Hydrornis guajanus* (Müller & Pls, 1776)	Pittidae	6	0.19%	0.4%	0.6%	LC	Non-Appendix	TDL
Worm-eating Flycatcher	*Sikatan Cacing*	*Cyornis banyumas* (Horsfield, 1821)	Muscicapidae	6	0.19%	0.2%	0.4%	LC	Non-Appendix	TDL
Redshank	*Caladi Ulam*	*Dendrocopos macei* (Vieillot, 1818)	Picidae	5	0.16%	0.4%	0.6%	LC	Non-Appendix	TDL
Grey-backed Shrike	*Bentet Kelabu*	*Lanius schach* (Linnaeus, 1758)	Laniidae	5	0.16%	0.4%	0.6%	LC	Non-Appendix	TDL
Grey Wagtail	*Wiwik Kelabu*	*Cacomantis merulinus* (Scopoli, 1786)	Cuculidae	5	0.16%	0.3%	0.5%	LC	Non-Appendix	TDL

Emerald Dove	*Delimukan Zamrud*	*Chalcophaps indica* (Linnaeus, 1758)	Columbidae	5	0.16%	0.3%	0.5%	LC	Non-Appendix	TDL
Spotted Wood Owl	*Takur Ungkut-ungkut*	*Megalaima haemacephala* (P.L.S.Müller, 1776)	Megalaimidae	5	0.16%	0.1%	0.3%	LC	Non-Appendix	TDL
Bamboo Wren	*Cikrak Bambu*	*Abroscopus superciliaris* (Blyth, 1859)	Sylviidae	5	0.16%	0.1%	0.3%	LC	Non-Appendix	TDL
Black-capped Wagtail	*Wiwik Uncuing*	*Cacomantis sepulcralis* (S.Muller, 1843)	Cuculidae	4	0.13%	0.4%	0.5%	LC	Non-Appendix	TDL
Crested Serpent Eagle	*Elang Brontok*	*Nisaetus cirrhatus* (Gmelin, 1788)	Accipitridae	4	0.13%	0.3%	0.4%	LC	Appendix II	DL
Rock Quail	*Puyuh Batu*	*Excalfactoria chinensis* (Linnaeus, 1766)	Phasianidae	4	0.13%	0.2%	0.3%	LC	Non-Appendix	TDL
Javan Bush Warbler	*Cica-koreng Jawa*	*Megalurus palustris* (Horsfield, 1821)	Sylviidae	4	0.13%	0.2%	0.3%	LC	Non-Appendix	TDL
Chili Plover	*Burung Cabai*	*Dicaeum trochileum* (Sparrman, 1789)	Dicaeidae	3	0.10%	0.3%	0.4%	LC	Non-Appendix	TDL
Great Reed Warbler	*Bubut Besar*	*Centropus sinensis* (Stephens, 1815)	Cuculidae	3	0.10%	0.3%	0.4%	LC	Non-Appendix	TDL
Eurasian Wryneck	*Uncal Kouran*	*Macropygia ruficeps* (Temminck, 1835)	Columbidae	3	0.10%	0.2%	0.3%	LC	Non-Appendix	TDL
Long-tailed Shrike	*Tepekong Jambul*	*Hemiprocne longipennis* (Rafinesque, 1802)	Hemiprocnidae	3	0.10%	0.2%	0.3%	LC	Non-Appendix	TDL
Rock Martin	*Layang-Layang Batu*	*Hirundo tahitica* (Gmelin, 1789)	Hirundinidae	3	0.10%	0.1%	0.2%	LC	Non-Appendix	TDL
Common Redstart	*Jinjing Petulak*	*Tephrodornis gularis* (Raffles, 1822)	Campephagidae	3	0.10%	0.1%	0.2%	LC	Non-Appendix	TDL
Jungle Pipit	*Cikrak Rimba*	*Phylloscopus plumbeitarsus* (Swinhoe, 1861)	Phylloscopidae	3	0.10%	0.1%	0.2%	LC	Non-Appendix	TDL
Javanese Woodcock	*Bubut Jawa*	*Centropus nigrorufus* (Cuvier, 1816)	Cuculidae	2	0.06%	0.2%	0.3%	VU	Non-Appendix	DL
Nutmeg Mannikin	*Kapasan Kemiri*	*Lalage nigra* (J.R.Forster, 1781)	Campephagidae	2	0.06%	0.1%	0.2%	LC	Non-Appendix	TDL
Striped-breasted Cuckoo	*Cinenen Belukar*	*Orthotomus atrogularis* (Temminck, 1836)	Sylviidae	2	0.06%	0.1%	0.2%	LC	Non-Appendix	TDL
Common Waxbill	*Burung Madu Belukar*	*Chalcoparia singalensis* (Gmelin, 1789)	Nectariniidae	2	0.06%	0.1%	0.2%	LC	Non-Appendix	TDL
Asian Palm Swift	*Walet-palm Asia*	*Cypsiurus balasiensis* (J.E.Gray, 1829)	Apodidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Eurasian Skylark	*Uncal Buau*	*Macropygia emiliana* (Bonaparte, 1854)	Columbidae	1	0.03%	0.1%	0.1%	LC	Non- Appendix	TDL
Common Sandpiper	*Trinil Pantai*	*Actitis hypoleucos* (Linnaeus, 1758)	Scolopacidae	1	0.03%	0.1%	0.1%	LC	Non- Appendix	TDL
White-throated Kingfisher	*Tiong-lampu Biasa*	*Eurystomus orientalis* (Linnaeus, 1766)	Coraciidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Grey-headed Flycatcher	*Sikatan Bubik*	*Muscicapa latirostris* (Raffles, 1822)	Muscicapidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Red-backed Kingfisher	*Raja-udangPunggung Merah*	*Ceyx rufidorsa* (Strickland, 1847)	Alcedinidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Green Imperial Pigeon	*Punai Lengkuak*	*Treron curvirostra* (J.F.Gmelin, 1789)	Columbidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Javan Flycatcher	*Pijantung Jawa*	*Arachnothera robusta* (S.Muller & Schlegel, 1845)	Nectariniidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Javan Cuckoo	*Opior Jawa*	*Lophozosterops javanicus* (Horsfield, 1821)	Zosteropidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Pacific Reef Heron	*Kokokan Laut*	*Butorides striata* (Linnaeus, 1758)	Ardeidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Asian Golden Weaver	*Kareo Padi*	*Amaurornis phoenicurus* (Pennant, 1769)	Rallidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Flowerpecker	*Kadalan Kembang*	*Phaenicophaeus javanicus* (Horsfield, 1821)	Cuculidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL
Grey Eagle	*Elang Kelabu*	*Butastur indicus* (Gmelin, 1788)	Accipitridae	1	0.03%	0.1%	0.1%	LC	Appendix II	DL
Black Eagle	*Elang Hitam*	*Ictinaetus malaiensis* (Temminck, 1822)	Accipitridae	1	0.03%	0.1%	0.1%	LC	Appendix II	DL
Brown Shrike	*Bentet Coklat*	*Lanius cristatus* (Linnaeus, 1758)	Laniidae	1	0.03%	0.1%	0.1%	LC	Non-Appendix	TDL

Note: 1. P.106/2018: Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia No P. 106 tahun 2018; 2. IUCN (International Union for Conservation of Nature) Redlist: EN: Endangered; VU: Vulnerable; NT: Near Threatened; LC: Least Concern; DD: Data Deficient; CR: Critically Endangered; 3. CITES (Convention of International Trade in Endangered Species of Wild Fauna and Flora)

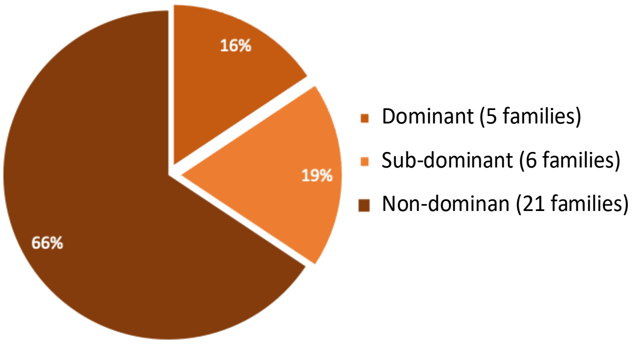

Figure 2. Percentage of bird dominance in Paseh Sub-district, Sumedang District, Indonesia

Table 1 revealed 74 bird species belonging to 32 families, with a total of 3,119 individuals identified. The dominant species belonged the Cuculidae family, with eight identified species: the Black-capped wagtail (*C. sepulcralis*), the Red-breasted parakeet (*P. curvirostris*), the Flowerpecker (*P. javanicus*), the Black-winged stilt (*C. bengalensis*), the Great reed warbler (*C. sinensis*), the Javanese woodcock (*C. nigrorufus*), and the Black drongo (*S. lugubris*).

The second most frequently encountered family was the Nectaridae, with six species recorded: the Mountain flycatcher (*A. affinis*), the Javan flycatcher (*A. robusta*), the Little pied flycatcher (*A. longirostra*), the Common waxbill (*C. singalensis*), the Yellow-vented bulbul (*A. malacensis*), and the Olive-backed sunbird (*C. jugularis*).

The abundance of these two bird families in the study area was likely due to the most common land use patterns in the Paseh Sub-district area, including rice fields, mixed gardens, and residential areas. These areas were dominated by bushes, small trees, and various types of plants suitable to the living habits of the Cuculidae and Nectaridae families (Sihotang et al. 2012). The percentage of bird dominance by families in Paseh Sub-district can be seen in Figure 2.

The most common individuals were from the Passeridae, Estrildidae, and Apodidae families, including 692 individuals of the Eurasian sparrow (*P. montanus*), 254 individuals of the Javan sparrow (*L. leucogastroides*), 251 individuals of the Peking sparrow (*L. punctulata*), and 394 individuals of House Sparrow (*A. nipalensis*). *Passer montanus* is a bird that is highly adapted to human habitats (Fithri et al. 2018). The Estrildidae family was often found in the Paseh Sub-district because of the large number of rice fields and mixed gardens that comprise the main habitat of this bird family.

Based on the Regulations of the Minister of Environment and Forestry of the Republic of Indonesia Number P.20/MENLHK/SETJEN/KUM.1/6/2018 concerning the Types of Protected Plants and Animals, six species of birds are classified as protected animals in the study area: the Cattle egret (*F. moluccensis*), the Black eagle (*I. malaiensis*), the Gray faced buzzard (*B. indicus*), the Philippine serpent eagle (*S. cheela*), Crested serpent eagle (*N. cirrhatus*) and the Javanese woodcock (*C. nigrorufus*).

Based on IUCN (International Union for Conservation of Nature) 2016, 72 species are classified as LC (Least Concern), and two bird species are included in the VU (vulnerable) category. The types of birds in the VU category include *C. nigrorufus* and *A. javanicus*. Four bird species in the study area are classified as Appendix II status based on CITES (Convention of International Trade in Endangered Species of Wild Fauna and Flora): *I. malaiensis*, *B. indicus*, *S. cheela*, and *N cirrhatus*.

Based on the results (Table 1), the relative abundance values of birds recorded in the study area were categorized into three groups:

Non-dominant species (Kr 0-2%)

In the study area, 83% (62 species) of the bird species were placed into this category, with Kr values ranging from 0.26 to 1.57%.

Subdominant species (Kr 2-5%)

In the study area, 9.4% (seven species) of the bird species were placed into this category, with Kr values ranging from 2.24% to 4.23%.

Dominant species (Kr >5%).

In the study area, 6.7% (five species) of the bird species found were classified into this category, with Kr values ranging from 8.05% to 22.19%. Carbó-Ramírez and Zuria (2011) explained that several factors can affect the richness and abundance of bird species within a habitat, including the surrounding landscape and human disturbance. This is why narrow habitat patches are more likely to display increased richness and abundance compared to larger habitats.

The five most abundant species at the observation locations were *A. nipalensis*, *L. punctulata*, *L. leucogastroides*, *T. chloris*, and *P. montanus*. *Lonchura punctulata* and *L. leucogastroides* were often found in bushes and rice fields. *T. chloris* was observed and found at observation points near water springs and/or perched on electric cables on several occasions. *Apus nipalensis* was often seen flying in groups in open areas and near residential areas, and *P. montanus* was often found perched on residential roofs, electric cables, and trees.

The observation of high numbers of these five bird species compared to other species indicated support from various environmental factors, such as adequate food sources, and other factors suggested a suitable habitat. These five species of birds are generalist species, meaning they can thrive in various types of habitats (Desantoro et al. 2020) and exhibit a greater ability to adapt to changes in environmental conditions or the presence of human disturbances (Devictor et al. 2008). This is in line with the conditions of the Paseh Sub-district, which has diverse land uses ranging from residential areas and rice fields to plantations.

The high abundance of generalist species in Paseh Sub-district indicated the presence of disturbance and changes in environmental factors at the observation sites. Generalist species are those that can use limited habitat elements (Hibbitts et al. 2013), whereas specialists are more sensitive to environmental disturbances (Mykrä and Heino 2017; Zhang et al. 2023). The results of the analysis showed that the highest Relative Frequency (RF) values were for *T. chloris* (12.92% and INP 22.9%), *P. montanus* (10.98% INP 38.1%), *A. nipalensis* (10.78% INP 25.0%), *L. leucogastroides* (7.73% INP 16.5%), and *H. cyanoventris* (7.12% INP 11%). Species with high-frequency values were due to the large number of encounters of that species at the observation sites (Withaningsih et al. 2020).

In contrast, the lowest RF values were for *L. cristatus*, *C. singalensis*, *A. superciliaris*, *P. plumbeitarsus*, *I. malaiensis*, *B. indicus*, and several other bird species with RF values of 0.10%. The low importance index value illustrates the rare presence of these birds at the observation sites and the low dominance values of those species.

A bird species evenness analysis was performed. The maximum species evenness will be obtained when the species have the same number of individuals. The Evenness Index (E) that we employed has values ranging from 0 to 1. When the value approaches 1, the birds are evenly distributed in that location (Wahyuningsih et al. 2019). The species evenness index was calculated for the entire set of Paseh Sub-district observation sites and categorized data based on the type of land use (Figure 3).

The value of the species evenness index in Paseh Sub-district, West Java, for the entire study area, was 0.67. Species Evenness Index values greater than 0.6 are classified as high, indicating stable ecosystem conditions (Withaningsih et al. 2020). Based on landscape use type, residential areas had an evenness index value of 0.491 and were classified as medium level. The highest evenness value was found for the mixed garden land use at 0.765, followed by other uses (rivers, cemeteries, bushes, sediments, and mining areas) at 0.735, and rice field land use at 0.719. The evenness indices tend to increase when the landscape becomes increasingly heterogeneous (Sandal et al. 2024). The species evenness values indicated that the Paseh Sub-district area, including its land uses, had medium to high stability. Various factors can influence the presence of birds, especially the composition and diversity of vegetation in a habitat, as the presence of vegetation affects the availability of food sources. This is supported by the presence of water sources, human activities, and climate (Desantoro et al. 2020).

Our analysis of bird species diversity indices, conducted in two parts across all observation sites in Paseh Sub-district and for each type of land use within these sites, has yielded significant findings. These findings not only reveal differences in species diversity across various land uses but also highlight the crucial link between bird diversity and landscape patterns. Species richness, a key indicator for quantifying biodiversity, has been shown to play a pivotal role in driving ecosystem functionality, as our research findings indicate. This emphasizes its significance beyond species turnover (Albrecht et al. 2021). The bird diversity indices for various types of land use are presented in Figure 4, further underscoring the significance of our research.

Residential areas had the lowest diversity index value of 1.47; this falls into the low species diversity category. This was due to various factors, particularly the limited availability and diversity of food sources, as well as the high level of human activity. Species of birds found in residential areas included *P. montanus*, *L. leucogastroides*, *A. nipalensis*, and *C. esculenta*. Large-scale changes can reduce both species richness and diversity due to disturbances in the availability of food and shelter necessary for birds, such as the fragmentation of land that serves as habitat for various bird species (Zhao et al. 2019).

The highest diversity value in Paseh Sub-district was for the mixed garden area, with a value of 3.131, indicating medium species diversity. The various types of plants, the presence of trees next to the gardens, and the abundance of insects make the mixed garden area a suitable habitat for birds. The species of birds found in the mixed garden area in Paseh Sub-district included *T. chloris*, *P. montanus*, *S. lugubris*, *P. goiavier*, and *A. leucorynchus*.

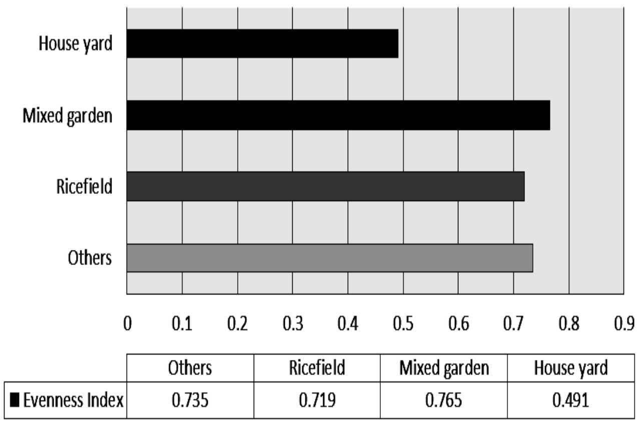

Figure 3. Comparison of bird Species Evenness Index in each type of land use in Paseh Sub-district, Sumedang District, Indonesia

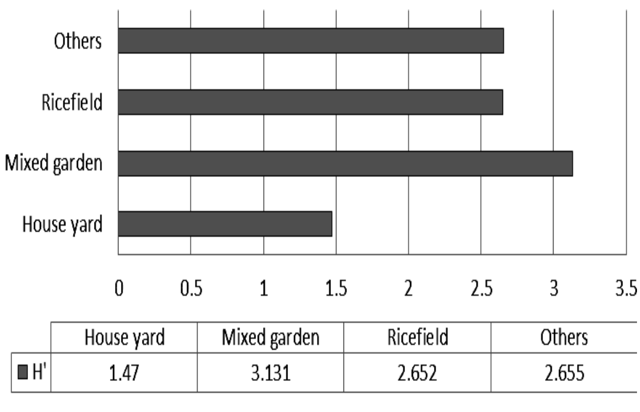

Figure 4. Comparison of Species Diversity Index values for each type of land use in Paseh Sub-district, Sumedang District, Indonesia

The rice fields in Paseh Sub-district had a diversity index value of 2.652 and were classified as areas of medium species diversity. The large amount of vegetation in this area as well as its proximity to water sources, meant that many birds gathered in this area. The species of birds observed here included *C. merulinus*, *C. striolata*, *S. chinensis*, *O. ruficeps*, *O. sutorius*, and several members of the genus *Lonchura*.

Apart from these three types of land use, other types, such as rivers, bushes, sediments, forests, cemeteries, and mines, occurred in much smaller areas. Collectively, these land uses had a biodiversity index value of 2.91 (classified as medium species diversity). Some of the bird species in this area were *F. mulucensis, L. schach*, *A. affinis*, *L. nigra*, and *H. hirundinaceus*. Overall, the observation sites in Paseh Sub-district, West Java, had a biodiversity index value of 2.918, indicating medium species diversity.

Bird species-diversity index values were also calculated for 17 buffer areas. This was done to perform a Pearson correlation analysis with the results of the landscape structure analysis. The species diversity values in the 17 buffer areas were largely categorized as medium and low (Table 2). The aim of analyzing biodiversity at a location is to determine the environmental conditions in that area. Based on literature references on bird species diversity, determining species diversity indices is the basis for understanding and managing the sustainability of habitat and ecosystem services at a location (Liu et al. 2022).

Landscape structure

The landscape structure analysis stage began by calculating the bird Species-Diversity Index value (H') at each observation site (450 points). The value of H' at each point was then processed using the heatmap feature in the geoprocessing section of the ArcGIS software. The resulting heatmap was then used with the reclass feature to generate class divisions by selecting the 'natural breaks' (Jenks) setting. This option was used to minimize internal variation within each group and maximize the differences between groups (Figure 5). The buffers formed were then rasterized and analyzed using Fragstat 4.2 software based on landscape structure parameters: Total landscape Area (TA), Total Edge (TE), Number of Patches (NP), Patch Richness (PR), Mean Shape Index (MSI), Mean Patch Fractal Dimension (MPFD), Shannon's Diversity Index (SHDI).

Table 3 lists the measurements of the landscape metrics in each research plot. The area measurements in each class were used to review the Class Area (CA) parameters. CA describes the total amount of land used by a landscape element. A high CA value indicates that the landscape element is dominant in a landscape. The presence of a matrix representing the most homogeneous habitat in a landscape is characterized by the largest CA value in that landscape area.

Next, the edges of the areas were measured using the TE parameter. The highest TE value was found in buffer 1, which was dominated by mixed garden land use. The higher the TE value, the more elongated the patch's shape. Conversely, a low TE value indicates that the patch's shape is more rounded. The area of the landscape was measured using the TA parameter. The TA value was obtained by measuring the area of the buffer area using a radius of 500 m so that with the buffer shape being circular, the area of each buffer was about 78.5152 Ha.

The two parameters used to measure variability in the landscape patch analysis were PR and NP. The PR value describes the richness and number of patches found in a landscape. A high PR value indicates that there are more types of land cover classes within the landscape. The largest PR value in this study was associated with buffer number 12, with nine land cover classes. The NP value indicates the number of patches within each land cover category. The analysis results indicated that buffer 12 (NP = 35) had the highest NP value, followed by buffer 8 (NP = 20). Meanwhile, buffer 4 (NP = 8) had the lowest NP value. The higher the NP value, the smaller the groups of patches and the greater the degree of fragmentation.

The value of SHDI reflects the level of heterogeneity of samples at varying spatial scales. In the Paseh Sub-district, the SHDI values ranged from 0.5996 to 1.5991. The SHDI values at the buffers represent a measure of variability related to the NP and PR values. Decreases in SHDI are proportional to decreases in the NP and PR values; thus, SHDI can be interpreted as showing that the lower the level of landscape heterogeneity, the smaller the class variation in a landscape.

Table 3. Landscape structure metrics in Paseh Sub-district, Sumedang District, West Java, Indonesia

Buffer number	H'	TA (ha)	NP	TE (m)	MSI	MPFD	PR	SHDI
1	2.26	78.5152	17	11708	2.1939	1.1514	6	0.9675
2	2.55	78.5152	18	8428	1.5991	1.0928	7	1.5991
3	2.4	78.5152	12	8868	1.8397	1.109	3	0.8562
4	1.9	78.5152	8	3236	1.4885	1.0865	5	1.2372
5	2.51	78.5152	14	9104	1.802	1.107	4	0.9388
6	2.42	78.5152	15	6100	1.9821	1.1749	6	1.2144
7	2.61	78.5152	10	6792	1.7539	1.106	5	1.1537
8	2.18	78.5152	20	6396	1.4914	1.1039	5	1.4301
9	1.69	78.5152	9	6604	1.7301	1.0986	3	0.8933
10	2.04	78.5152	16	9501	1.9834	1.1432	5	1.2441
11	2.08	78.5152	12	6424	1.7195	1.1269	4	1.1098
12	2.43	78.5152	35	7148	1.3502	1.0674	9	1.5138
13	2.17	78.5152	10	7940	1.8503	1.11	4	1.3240
14	2.18	78.5152	10	4916	1.6628	1.113	4	0.5996
15	2.59	78.5152	10	4828	1.5795	1.1031	5	1.0171
16	2.57	78.5152	13	8376	1.8001	1.1183	6	1.1046
17	1.94	78.5152	19	9460	1.6284	1.0921	7	1.4153

Table 2. Bird species-diversity index values in the buffer areas in Paseh Sub-district, Sumedang District, West Java, Indonesia

No buffer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(H') value	2.26	2.55	2.40	1.90	2.51	2.42	2.61	2.18	1.69	2.04	2.08	2.43	2.17	2.18	2.59	2.57	1.94

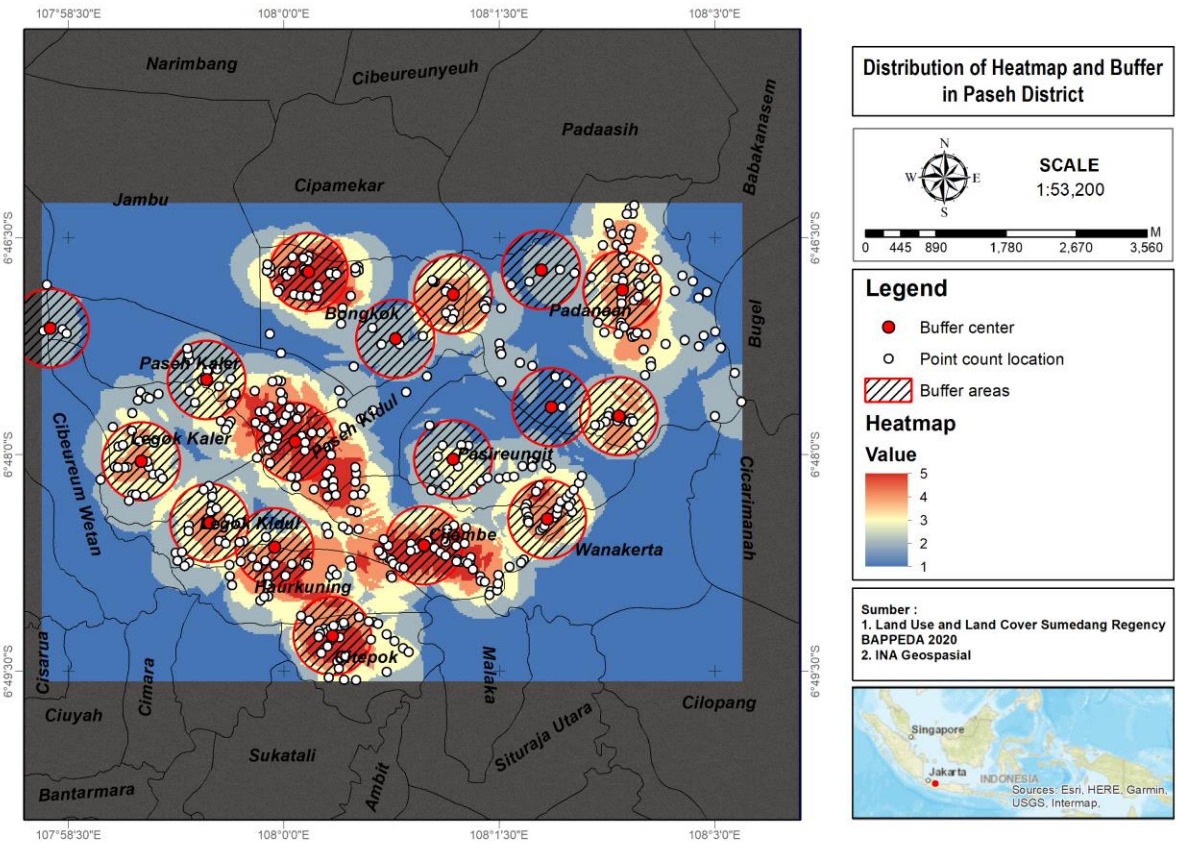

Figure 5. Heatmap and buffer distribution in Paseh Sub-district, Sumedang District, West Java, Indonesia

The complexity of patch shapes at the research location was measured by MSI and MPFD metrics. A complexity MSI value close to 1 indicates a patch with a perfect circular shape; conversely, when the MSI value is greater than 1, the patch will have an irregular shape. A high MSI value also reflects increasingly complex land cover, with patches having larger edges. The entire buffer had an MSI value greater than 1. Thus, the habitats around the observation sites were complex and irregularly shaped. In addition, the entire buffer had an MPFD value <1, suggesting that the study area was composed of patches with complex shapes. This is in line with the conclusion by Mardiastuti et al. (2014) that the more complex a habitat is, the greater the number of types of vegetation that can be used as food sources, nest locations, and niches for birds.

A highly complex habitat, with its increased edge effects, will display an increase in species heterogeneity in a landscape due to increased edge effects. This will be characterized by an increase in the number of generalist species and a decrease in the population of specialist bird species. While this situation can enhance the value of bird species diversity indices, it also poses a significant threat to the existence of certain bird species (Staude et al. 2021). Colles et al. (2009) noted that specialist types, with their reliance on specific resources, are more susceptible to human disturbances, unlike generalists, which can exploit a variety of resources for food, nest-building materials, and nesting locations. Moreover, generalists display high fecundity and generally do not migrate.

The relationship between human-modified landscape structure and bird species diversity

The relationship between landscape structure and bird species diversity was examined using Spearman correlation analysis, with bird species diversity as the dependent variable and landscape structure as the independent variable. The results can be interpreted through the resulting rho value (Table 4).

The analysis results revealed that the TA variable was not significantly correlated with bird species diversity. This finding, however, should be interpreted in the context of the study's limitations. For instance, the 17 buffers all had the same radius, leading to identical TA values. This limitation may have affected the measurement of the relationship between TA parameters and bird species diversity, making it less than optimal. The sizes of areas can have a profound impact on the diversity of bird species. This is a fascinating aspect of our study, as it is closely related to the theory of island biogeography. According to this theory, the number of species in an area (island) is influenced by the size of the island and the balance of local migration and extinction processes. For instance, increasing the size of the island by a factor of 10 can lead to a two-fold increase in species biodiversity, as demonstrated by Ruzzier et al. (2021) and Chen et al. (2024).

Large areas will provide fewer opportunities for geographic isolation and can harbor larger population sizes while increasing the opportunities for speciation and minimizing the risk of extinction. On a smaller spatial scale, a large landscape area can increase the opportunities for interactions between species and individuals, as well as provide greater opportunities for various prey species to thrive and serve as a source of food for birds.

In the study area, the overall TA value was consistent across all buffers (78.5152 ha), although the values for bird species diversity varied. For example, in buffer 5, the total abundance of bird species was relatively high (293 individuals), and the bird species diversity value was 2.51 (categorized as medium). Meanwhile, in buffer 4 with the same TA value, the total abundance of bird species was very low (16 individuals), and the bird species diversity value was 1.9. These differences individual abundance and diversity of bird species within buffers of the same Total Area (TA) value indicate the influence of various factors, including environmental conditions, human activities, and land use types. Buffers dominated by rice fields and mixed gardens consistently showed higher species diversity than those composed of residential areas. This study's findings underscore the intricate role of environmental conditions in shaping bird species diversity, highlighting the complexity of biodiversity research.

The results of the correlation analysis (Table 4) showed that H' was weakly positively correlated with the TE value. This means that bird species diversity increases along with the value of TE in the area. The TE values in each buffer are shown in Figure 6. The figure revealed that buffer 1 had the largest TE value, and the lowest TE value was in buffer 4. These results were directly proportional to the H' values of buffer 1 and buffer 4. The increase in species diversity in areas with high TE values is related to the concept of edge effects: areas with more edges will experience an increase in species diversity, especially regarding birds and insects, along with increasing habitat variation (Paquet et al. 2006). However, the increase in species diversity due to edge effects had a negative impact on the bird population in the area. Specialist species living in this area will face pressure from generalist species that arrive, ultimately creating competition for resources, and this can lead to increased rates of predation. Another example of the negative impact of high TE values is the reduction in nesting success by birds in edge areas due to higher levels of nest predation and parasitism (Chalfoun et al. 2002).

The high TE value in the observation buffer also shows that the Paseh Sub-district area has experienced habitat fragmentation. The development of green open land into residential areas and the construction of the Cisumdawu toll road project have increased habitat fragmentation. Habitat fragmentation will increase the presence of weedy species that are dependent on human activities. Increasing the total edge value in the landscape can increase the populations of birds that prefer edge areas, but at the same time, it threatens the existence of specialists that cannot compete with generalists in edge areas (Kaban et al. 2018).

The PR and NP values were positively correlated with bird species diversity. This result can be interpreted as indicating that the increase in PR and NP values enables greater species diversity in an area. A high NP value indicates a landscape with a large number of patches. In comparison, the PR value describes the richness or number of patch types in a landscape based on their composition and ecological characteristics. The PR and NP value analysis data are shown in Figures 7 and 8.

The highest NP value was in buffer 12 (NP = 35), while the lowest NP value was in buffer 4 (NP = 8). A high NP value indicates that there are numerous landscape elements grouped into several small areas within the buffer zones. Comparing H' values, it's surprising to find that buffer 12, as the area with the highest NP value, had a medium H' value (H' = 2.43). In comparison, buffer 7 (H' = 2.61), one of the areas with a low NP value, also had a medium H' value, which was even higher than that of buffer 12. This unexpected result challenges the conventional wisdom and suggests that high and low NP values cannot be used as primary indicators of the H' value, as the relationship between the two parameters is not linear, and many other factors also influence it. This surprising finding, in line with Bełcik et al. (2020) study, indicates that fragmentation in areas with high NP values can lead to either increases or decreases in bird species diversity, but it will increase the number of generalist birds and reduce the number of specialist species.

To gain a clearer understanding of the relationship between the Number of Patches (NP) and landscape fragmentation, we analyzed our data by categorizing buffers according to their level of fragmentation (Table 5).

Table 5. Summary by fragmentation category in Paseh Sub-district, Sumedang District, West Java, Indonesia

Fragmentation category	Average NP	NP range	Number of buffers	Average Fragmentation Index
Low	9.25	8-10	4	21.03
Moderate	14.30	10-20	10	42.52
High	22.67	16-25	2	60.77

Table 4. The results of Spearman correlation analysis between human-modified landscape structures and bird species diversity in Paseh Sub-district, Sumedang District, West Java, Indonesia

Landscape structure metrics	Spearman correlation values	Correlation description
Total landscape Area (TA)	0	No correlation
Total Edge (TE)	0.022	Very weak positive correlation
Mean Shape Index (MSI)	0.004	Very weak positive correlation
Mean Patch Fractal Dimension (MPFD)	0.055	Very weak positive correlation
Shannon's Diversity Index (SHDI)	-0.031	Very weak negative correlation
Number of Patches (NP)	0.159	Weak positive correlation
Patch Richness (PR)	0.318	Weak positive correlation

Table 6. Average Fragmentation Index by NP ranges

NP range	Average fragmentation index	Number of buffers
0-10	26.27	6
11-15	40.28	5
16-20	53.79	5
> 20	62.95	1

Table 7. Detailed data sorted by number of patches in Paseh Sub-district, Sumedang District, West Java, Indonesia

Buffer	NP	Total Edge (TE)	Mean Shape Index (MSI)	Fragmentation index	Fragmentation category
4	8	3236	1.4885	18.80	Low
9	9	6604	1.7301	22.94	Low
7	10	6792	1.7539	34.33	Moderate
13	10	7940	1.8503	39.18	Moderate
14	10	4916	1.6628	18.12	Low
15	10	4828	1.5795	24.27	Low
3	12	8868	1.8397	33.42	Moderate
11	12	6424	1.7195	33.49	Moderate
16	13	8376	1.8001	44.58	Moderate
5	14	9104	1.8020	38.71	Moderate
6	15	6100	1.9821	51.20	Moderate
10	16	9501	1.9834	55.18	High
1	17	11708	2.1939	64.17	High
2	18	8428	1.5991	53.30	Moderate
17	19	9460	1.6284	54.36	Moderate
8	20	6396	1.4914	41.94	Moderate
12	35	7148	1.3502	62.95	High

A detailed examination of each buffer's landscape metrics and the fragmentation index revealed a strong positive correlation (r = 0.75) between NP and the composite fragmentation index (Table 6). This confirms that higher NP values are generally associated with greater degrees of fragmentation, supporting the literature's finding that as NP values increase, the size of patch groups decreases, leading to a greater degree of fragmentation.

The detailed analysis of individual buffers (Table 7) indicated that buffers with high NP values, such as buffer 12 (NP = 35), buffer 1 (NP = 17), and buffer 10 (NP = 16), consistently exhibited high fragmentation indices (62.95, 64.17, and 55.18, respectively). In contrast, buffers with low NP values, such as buffer 4 (NP = 8) and buffer 14 (NP = 10), demonstrated significantly lower fragmentation indices (18.80 and 18.12, respectively).

These findings indicate that while NP alone provides valuable insights into landscape structure, the composite fragmentation index offers a more comprehensive evaluation by integrating multiple landscape metrics. The strong correlation between NP and the fragmentation index supports both methods, deepening our understanding of the intricate relationship between landscape structure and bird diversity in the study area. While NP is a significant indicator of fragmentation, other landscape metrics, such as Patch Richness (PR), provide critical insights into habitat composition and diversity. Combining these metrics in our fragmentation index allows a more nuanced analysis of landscape patterns and their ecological implications. Examining PR with NP and other metrics reveals how different aspects of landscape structure may influence biodiversity.

Based on the PR value, buffer 12 had the highest value (PR = 9), while buffer 9 had the lowest value (PR = 3). This suggests that buffer 12 was composed of patches that were much more diverse than buffer 9, which was directly proportional to the H' value in buffer 12 being higher than in buffer 9. High MSI values indicate increasingly complex land cover, with patch shapes that have larger edges and the shape of the landscape becoming increasingly rounded as the MSI value approaches 1. The MSI values for the entire buffer exceeded 1, indicating the high complexity of patches in the study area (Figure 9).

The results of the Spearman correlation analysis revealed a positive correlation between the MSI values and the bird species diversity indices. However, the correlation between the two parameters was very weak, so the MSI parameter could not be used as a determining factor for the value of bird species diversity at the observation sites.

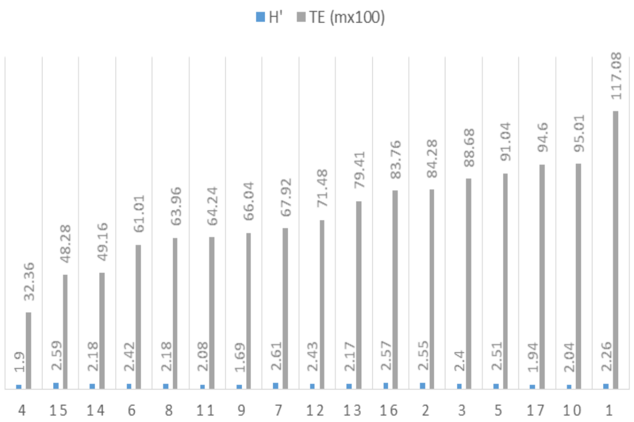

Figure 6. Comparison of the TE value with the bird species diversity value in Paseh Sub-district, Sumedang District, West Java, Indonesia

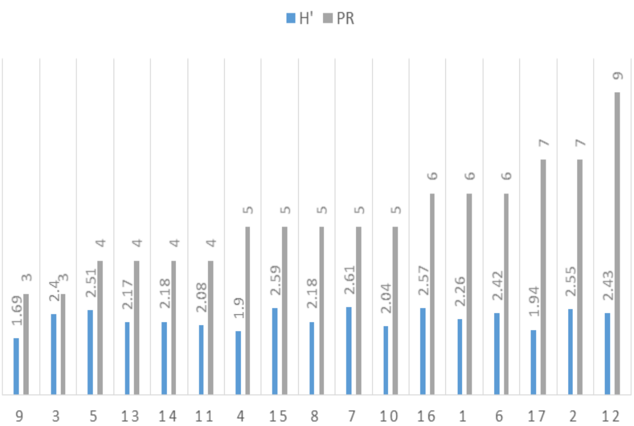

Figure 7. Comparison of PR values with bird species diversity in Paseh Sub-district, Sumedang District, West Java, Indonesia

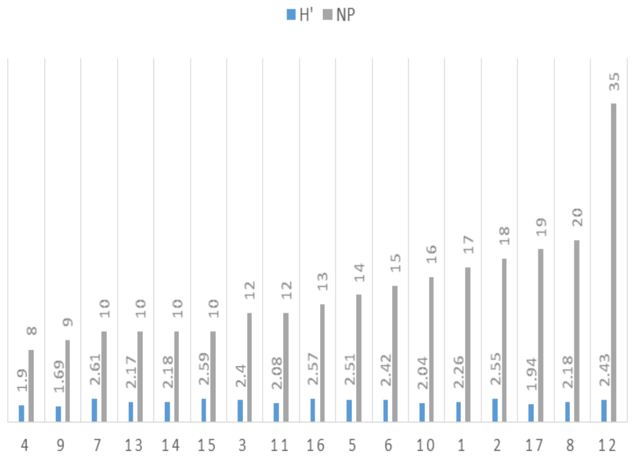

Figure 8. Comparison of NP values with bird species diversity in Paseh Sub-district, Sumedang District, West Java, Indonesia

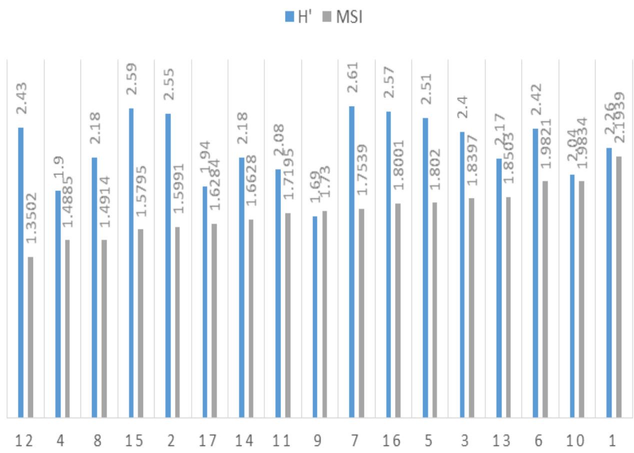

Figure 9. Comparison of MSI values with bird species diversity in Paseh Sub-district, Sumedang District, West Java, Indonesia

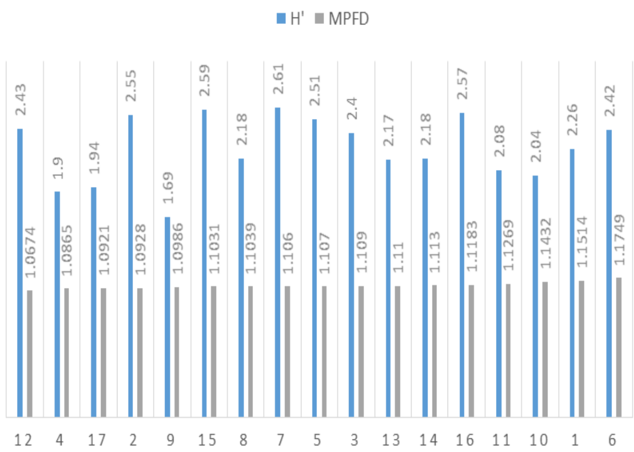

Figure 10. Comparison of the MPFD values with bird species diversity in Paseh Sub-district, Sumedang District, West Java, Indonesia

Buffer 1 had the highest MSI value (2.19), while buffer 12 had the lowest MSI value (1.35) (Figure 9). Buffer 12, with the lowest MSI value, had a higher H' value than buffer 1. However, in the other 15 buffers, the increase in the relative MSI value was associated with an increase in the species diversity. This indicates that the correlation between the two parameters was very weak, and an increase in bird diversity did not always accompany the complexity of the patch shape at the observation sites. Several factors could explain this, including high levels of habitat fragmentation and damage at observation sites, as well as the lack of supporting resources in areas with complex landscape forms.

The MPFD parameter value for the entire set of buffers was greater than 1. This illustrates that the study area consisted of patches with complex edges, characterized by high edge values and high levels of fragmentation. However, similar to the MSI parameters, the MPFD parameter measurements showed a very weak correlation. This can be seen from buffer 12, which had the lowest MPFD value (1.06), with a bird species diversity value that was almost the same as that of buffer 6, which had the highest MPFD value (1.17). The complete relationship is illustrated in Figure 10. Thus, it can be concluded that an increase in bird species diversity did not always accompany the complexity of patch shapes and patch edges in the study area due to various factors that influenced the complex habitats.

The diversity of a patch can be measured using the SHDI parameter. Based on Spearman correlation analysis, the SHDI value was found to be negatively correlated with the Shannon-Wiener species diversity index value. Thus, an increase in the SHDI value will cause a decrease in the value of H'. The range of SHDI values in the study area is shown in Figure 11.

The SHDI value for the entire set of buffers ranged between 0.599 and 1.599. The negative correlation between the SHDI value and bird species diversity at the observation sites may have been influenced by the effects of habitat fragmentation and human disturbance. This meant that an equivalent species diversity did not accompany patch diversity. The large number of patches also did not indicate a large area of land, which caused the average patch size to be smaller and the landscape to be more complex. As a comparison, the intricate interplay of factors in a landscape, such as the level of patch heterogeneity, the number of habitats, land proportions, and the size of the study area, can influence the abundance of bird species, but this is also influenced by the number of habitats, land proportions, and the size of the study area (Lu et al. 2024). This complexity was further confirmed by Redlich et al. (2018), who demonstrated that landscape heterogeneity is associated with an increase in total bird abundance but does not have a significant relationship with bird species richness. Spearman correlation analysis indicated that TA parameter measurements were not significantly correlated. Meanwhile, the TE, NP, PR, MSI, and MPFD parameters were positively correlated, and SHDI values had negative correlations, adding another layer of complexity to the research.

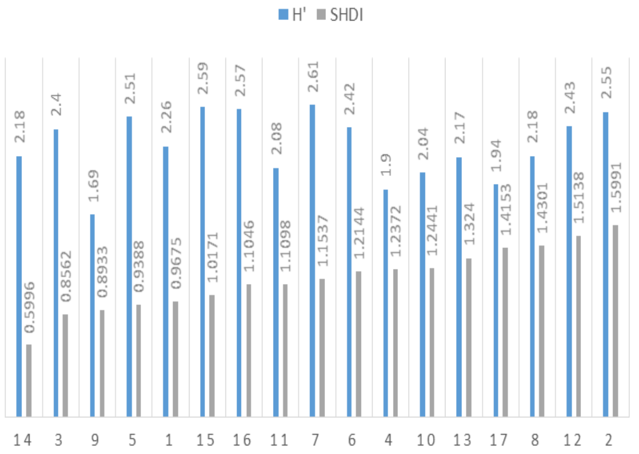

Figure 11. Comparison of SHDI values with bird species diversity in Paseh Sub-district, Sumedang District, West Java, Indonesia

Additionally, the fragmentation of natural habitat in the Paseh Sub-district affected species diversity to varying degrees, depending on each species' adaptability to habitat fragmentation and disturbance. High levels of fragmentation in the long term can lead to a decline in specialist bird populations and an increase in generalist bird populations, resulting from competition for natural resources and higher predation rates. The nature of specialist species, which utilize specific resources and are vulnerable to human disturbance, makes them susceptible to the threat of population decline and even extinction (Clavel et al. 2010). This study highlights the importance of mixed gardens and rice fields in preserving bird species diversity in human-modified landscapes, underscoring their value as biodiversity hotspots. Sustainable land-use practices that balance human activities with biodiversity conservation are essential, with mixed gardens deserving prioritization in landscape planning.

In conclusion, the present study evaluated the relationship between human-modified landscape structure and bird species diversity in Paseh Sub-district, Sumedang District, West Java. A total of 74 species of birds were identified, consisting of 32 families and 3,115 individuals. The highest to lowest bird species-diversity index values were associated with the following land uses: mixed gardens (H' = 3.13), rice fields and other land uses (H' = 2.65), and residential areas (H' = 1.47). A positive correlation was found between the value of bird species diversity and the value of landscape structure resulting from human modification, as reflected by six landscape parameters: TE, NP, PR, MSI, MPFD, and SHDI. The bird species diversity increased along with TE length, the number of patches (NP, PR), and patch shape complexity (MSI, MPFD), and decreased with the degree of landscape heterogeneity (SHDI).

These findings highlight the crucial role of mixed gardens and rice fields as vital habitats for preserving bird diversity in human-modified landscapes. These land uses provide a variety of resources, including food and nesting sites, that are vital for supporting a wide range of bird species. Mixed gardens, in particular, demonstrate their potential as biodiversity hotspots in anthropogenic environments and should be prioritized in landscape planning and management. Further research is needed to investigate the relationship between human-modified landscape structure and bird species diversity in other locations, by incorporating additional parameters to assess the long-term impact of development activities on biodiversity in general. Moreover, the relationship between specific landscape metrics and bird species diversity highlights the complex ways in which human-modified environments impact ecological patterns. Policymakers and urban planners should integrate these insights into development strategies, ensuring that ecological principles guide future modifications to landscapes to minimize biodiversity loss and enhance ecological resilience.

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