

Bird diversity in a human-modified geothermal landscape of Kamojang, West Java, Indonesia

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Abstract. Husodo T, Megantara EN, Rosandi Y, Wulandari I, Atsaury ZIA, Aminuddin SF, Suroso, Shanida SS, Tohir Y. 2025. Bird diversity in a human-modified geothermal landscape of Kamojang, West Java, Indonesia. *Biodiversitas* 26: 5679-5693. A geothermal power plant can significantly impact biodiversity through land-use changes. In general, human-induced habitat modifications alter environmental quality, affecting species composition and ecosystem stability. Due to their sensitivity to habitat changes, birds are bioindicators of ecological health. Therefore, this study aimed to assess trends in bird diversity in the Kamojang Geothermal Power Plant area, West Java, Indonesia, using point count and spotlighting methods. A total of 113 species from 37 families were recorded across various land cover types: natural forests, production forests, horticultural gardens, mixed lands, and replanting areas. Muscicapidae was also the most commonly recorded family. Although species richness has recently decreased due to the conversion of natural forests into horticultural fields, overall bird diversity relatively high. Shannon-Wiener diversity index values ranged from 2.663 to 2.995, indicating a moderate level of diversity. Several species served as bioindicators of habitat quality, including riparian specialists and predatory birds. Additionally, the presence of frugivorous, pollinator, and forest-dwelling birds demonstrates that Kamojang's natural woods continue to support pollination activities, provide suitable habitats, and facilitate seed dispersal, thereby promoting vegetation sustainability. Controlling the expansion of agriculture within the community is crucial to maintaining and enhancing bird diversity in a geothermal environment. Reforestation efforts that account for canopy stratification complexity can effectively restore damaged bird habitats by reintroducing native forest flora, thereby offering cover and helping sustain ecological balance in geothermal landscapes.

Keywords: Avian richness, habitat disturbance, spotlighting

INTRODUCTION

Industrial activities, including geothermal power plants, can negatively affect ecosystems (Budiharta et al. 2018). Although geothermal energy is often framed as sustainable with economic benefits, energy extraction from forest ecosystems still alters natural systems (Aji et al. 2022). In forests with geothermal activity, common impacts include fragmentation, poaching, illegal logging, and wildlife disturbance (Meijaard et al. 2019). Access roads built during exploration and construction are a primary driver of habitat change. In Indonesia, forest-cover change linked to geothermal projects is high: for every 100 MW produced, 5-10 km of access roads may be required, with environmental effects extending up to 1,000 m along riparian zones (Meijaard et al. 2019). Human activities also add noise and light that disrupt wildlife (Ciach and Frohlich 2019). Forest conversion further affects biophysical conditions and local socioeconomics and threatens habitats of protected species (UNPAD 2023 Unpublished Data).

Among Indonesia's geothermal fields, Kamojang is notable for its location in a montane forest, making it a strategic case for evaluating biodiversity impacts, particularly on birds. PT Indonesia Power Kamojang Power Generation O&M Services Unit (POMU) in West Java commits to environmental sustainability by managing and monitoring operations to reduce negative impacts and enhance positive outcomes for biodiversity around the Kamojang Geothermal Power Plant (UNPAD 2023 Unpublished Data).

Birds are widely used as bioindicators because they respond sensitively to ecosystem change and provide key ecological functions such as seed dispersal (Carlo and Morales 2016; Partasasmita et al. 2016). Their presence and diversity can indicate the extent to which human activities have altered habitat quality and broader biodiversity (Partasasmita et al. 2016). Monitoring birds is therefore suitable to assess industrial impacts in the energy sector, including geothermal projects. While geothermal is considered cleaner than fossil-fuel power (e.g., coal), its operational consequences for biodiversity remain

insufficiently documented. Land-cover change during development can modify both environmental quality and socio-economic conditions around project areas (Husodo et al. 2020).

Geothermal resources are typically aligned with volcanic belts that overlap forest ecosystems, including areas within Indonesia's protected-area network (Pambudi and Ulfa 2023). Approximately 57% of geothermal areas fall in forest zones, 22% in conservation forests, with the remainder in protection and production forests (Meijaard et al. 2019). The Kamojang plant sits in a West Java forest landscape recognized for high biodiversity and endemic species. Previous studies recorded mammals (Husodo et al. 2019, et al. 2024; Megantara et al. 2019), birds (Husodo et al. 2020), and herpetofauna (Erawan et al. 2021; Megantara et al. 2022, et al. 2025). In 2017, 82 bird species were documented, including the endangered, endemic Javan Hawk-eagle (*Nisaetus bartelsi*) (Husodo et al. 2020). Encounters with protected species listed by the IUCN underscore the landscape's role as refuge for wild birds (Kurnia et al. 2021). Despite these inventories, long-term, multi-habitat monitoring to evaluate avian diversity trends during plant operation has not been conducted.

The study aims to identify trends in bird diversity within the Kamojang Geothermal Power Plant area as baseline information on the ecological condition of its surrounding environment, particularly regarding biodiversity under current threats or disturbances. The findings can serve as a reference for future biodiversity management (Husodo et al. 2020). Species with low adaptability, often dependent on specific food and habitat types, are more vulnerable to disturbances and population decline, emphasizing the need for monitoring birds as indicators of habitat quality (Husodo et al. 2020). Bird diversity positively correlates with environmental quality (Li et al. 2019); higher vegetation diversity supports more bird species through increased prey availability and habitat complexity (Mrazova et al. 2019; Cabral et al. 2021; Sanderson et al. 2022). Conversely, poor management of biological resources poses serious threats to bird populations (Rohman et al. 2024).

MATERIALS AND METHODS

Period and study area

The study was conducted over 11 years, spanning the periods from July 2014 to October 2015, June 2016, July 2017, July 2018, April 2019, October 2020, February 2021, June 2022, June 2023, and April 2024. The Kamojang Geothermal Power Plant is in the Bandung District, West Java, Indonesia, with an altitude ranging from 1,640-1,750 m asl (Winarno et al. 2023). The temperatures in these lower mountain forests range from 18.5°C to 21°C with 93% relative humidity (Abdillah et al. 2023). This power plant has been producing electricity since 1978. The total installed capacity is currently about 235 MW (Kencana and Herdianita 2022), which consists of five generating units.

Specifically, Unit 1 has a capacity of 30 MW, while Units 2 and 3, with a combined capacity of 55 MW, are operated by PT Indonesia Power operates Units 4 and 5, which have capacities of 60 MW and 35 MW, respectively. Pertamina Geothermal Energy (Sufyana et al. 2023).

Land cover types in this area and its surroundings mainly include natural forests, production forests, mixed gardens or agroforestry systems, dry fields or shrublands, wet rice fields, fish ponds, residential areas, home gardens, and operational zones of PT Pertamina (Figure 1). From a landscape perspective, the distribution and size of each land cover type create patterns within the production forest matrix managed by PT Perhutani (Persero) and the agricultural land matrix. Based on land tenure, the area mainly consists of production forests managed by PT Perhutani (Persero) and cultivated lands, such as dry fields, horticultural gardens, mixed gardens, and home gardens owned by local communities. Some of the production forests have been converted by local communities for agricultural purposes, including fields, dry fields, and home gardens.

Procedures

Data were collected using point count and spotlighting methods. The observation was carried out every day in the morning, starting at 05.30-11.00 AM, in the afternoon, starting at 02.00-05.00 PM, and in the night at 07.00-11.00 PM (spotlighting) for a week by two observers, with one repetition, resulting in a total of 2,500 hours over the entire study period.

Point count surveys were conducted in each study area, within 5 to 10 sampling points per land cover type, every year. The distance between points was set at 150 m (Iswandaru et al. 2023), and each observation used a radius of 50 m (Iswandaru et al. 2023) to prevent duplicate counts of the same individuals, thus forming a transect line connecting each point. Each land cover type has a transect length using the point count method ranging from 750 m (for 5-point counts) to 1,500 m (for 10-point counts). Each point was surveyed for 30 minutes (Iswandaru et al. 2023) during which bird species and individual counts were recorded, including visual and auditory detections.

The spotlighting method was conducted to record nocturnal species using a flashlight (spotlight Krisbow Powerlite Led 5w 4xc) and a headlamp. Night-watching was repeated on the track that had been passed in the day or carried out at locations considered to have the potential to encounter the avifauna (Husodo et al. 2020). Data were collected on foot (± 2 km/hour) by recording visible bird species and/or only audible. This transect method was based on the proportion of the area observed and the time available for observation (Husodo et al. 2020). Nocturnal birds were documented using a Flash External Yongnuo Speedlite camera YN685. The species were identified using MacKinnon et al. (2010). The book 'Flora of the Javanese Mountains' by van Steenis et al. (2010) was used to determine plant species.

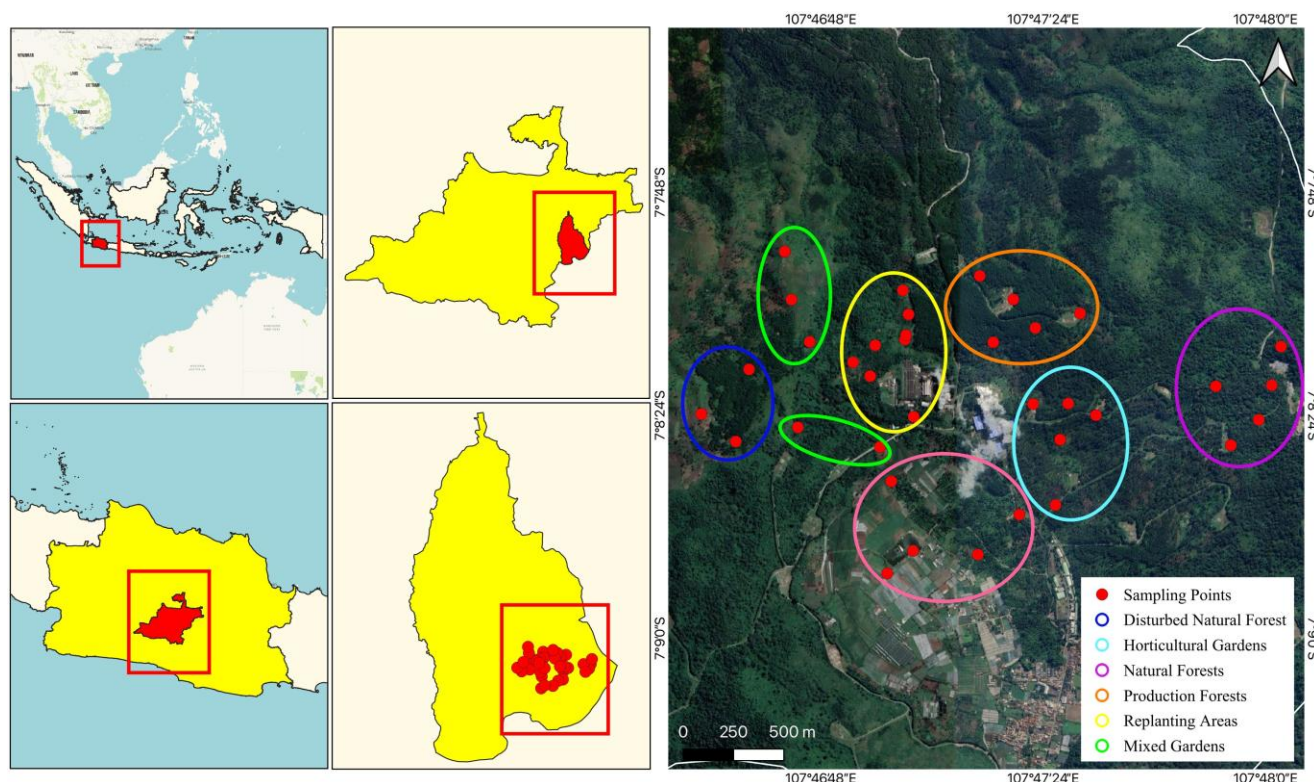


Figure 1. Study area in the Kamojang Geothermal Power Plant, Kamojang, West Java, Indonesia (7°8'24.20"S 107°47'3.05"E)

Observation points were recorded using a Global Positioning System (GPS) Garmin 64S Sea. Bird observations were conducted using Nikon Monarch 12x42 DCF binoculars and a voice recorder. Moreover, documentation was carried out using a Canon EOS 7D Mark I camera equipped with a Sigma 150-500 mm telephoto lens.

Data analysis

Species data were tabulated using Microsoft Excel and categorized by family and annual presence trends. The species were identified and their conservation status was determined using the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (www.iucnredlist.org) and national regulation (P.106/MENLHK/SETJEN/KUM.1/12/ 2018). The species was also identified using a checklist of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (<https://checklist.cites.org>). Additionally, species diversity and similarity indices were analyzed based on land cover type and year. Species diversity was assessed using Shannon-Wiener's diversity index (H') (Magurran 1988) and similarity index (S):

$$H' = - \sum_{i=1}^s p_i \ln p_i$$

$$S = \frac{2C}{A+B} \times 100\%$$

Where, H' is the species diversity index, s is the number of species, p_i is the proportion of individuals of each species belonging to the i th species of the total number of individuals, \ln is a natural logarithm, and Σ is the sum of calculations. Species diversity is categorized as high ($H' > 3$), moderate ($1 \leq H' \leq 3$), or low ($H' < 1$) (Magurran 1988). In the similarity index, A represents the number of species in community A, B represents the number of species in community B, and C is the total number of species shared by both communities. The results of the species similarity index are displayed as a heatmap to facilitate visualization of the similarity patterns of bird communities between land cover types during the period 2014-2024.

RESULTS AND DISCUSSION

Results

During 11 years of geothermal operation, 113 bird species from 37 families were recorded (Table S1). The family *Silviidae* was the most frequently encountered, comprising 16 species, followed by *Timaliidae* (10 species) and *Muscicapidae* (8 species), each with 7 species. *Muscicapidae* was also the most commonly recorded family in the Kamojang, Darajat, and Gunung Salak Geothermal Power Plants (Husodo et al. 2020). The result suggests that the Kamojang area is a suitable habitat for these species, providing an abundant and accessible food supply. Food availability significantly influences the

diversity of bird species in a habitat (Gómez-Catasús et al. 2019).

The lowest species count was 51 in 2024, while the highest count was recorded in 2017, with 72 species. Based on the annual diversity index (Figure 2), bird diversity in Kamojang was generally categorized as moderate, with the highest recorded index value of 2.995 in 2017 and the lowest value of 2.643 in 2020.

Regarding conservation status, 7 species have high conservation status (Endangered, Vulnerable, and Near Threatened) on the IUCN, with the Javan Hawk-eagle (*N. bartelsi*) being the most threatened species, classified as Endangered (Table S1). The remaining species are classified as Least Concern, with 10 species listed under CITES and 12 species also protected under Indonesian regulations (P.106/MENLHK/SETJEN/KUM.1/12/ 2018).

The various avifauna species in each study illustrate the state of diverse habitat conditions and land cover changes (Figures 4 and 5). Bird diversity indices fluctuated annually, depending on the land cover types (Figure 3 and Table 1).

According to the similarity index, values varied between years and land cover types, with some combinations showing relatively high similarity while others showed low similarity (Figure 6). This pattern confirms the existence of differences in bird community composition influenced by the ecological characteristics of each land cover type.

Discussion

Based on Figure 7, bird species in natural forests have an average diversity index of 3.139 (high). Forest habitats with more complex vegetation structures support greater bird diversity than plantation areas (Dinanti et al. 2018). Natural habitats consistently show higher biodiversity compared to human-modified environments (Tu et al. 2020). Sadam et al. (2021) reported that birds in plantation areas generally include fewer specialist species but higher species richness due to landscape heterogeneity. Extensive tree canopy cover provides a higher-quality habitat for specialist bird species (Gebremichael et al. 2022). Complex vegetation structures contribute to abundant and diverse food resources (Shafie et al. 2022), providing more nesting and foraging niches (Moudrý et al. 2021; Remeš et al. 2022), which ultimately enhance bird species richness (Moudrý et al. 2021; Remeš et al. 2022; Shafie et al. 2022). Furthermore, bird diversity is generally higher in habitats with more advanced successional stages, such as forests (Nugroho et al. 2023).

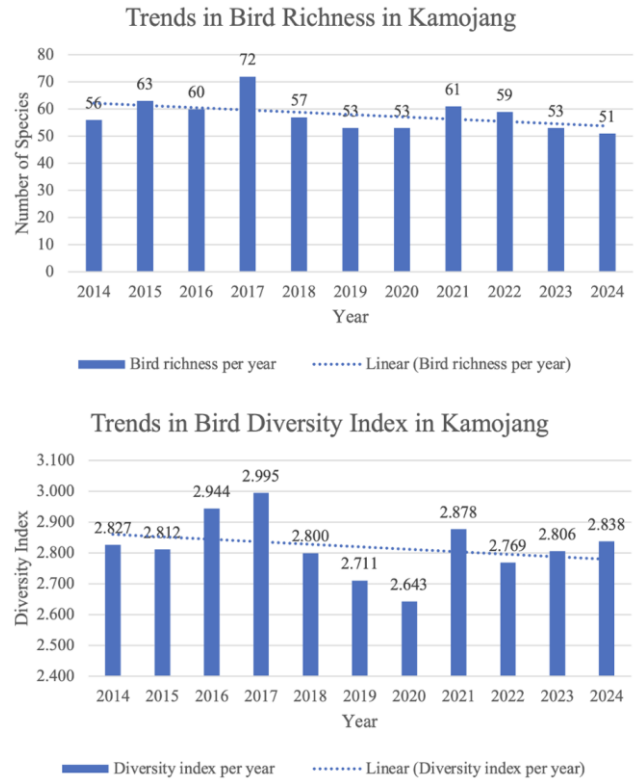


Figure 2. Trend of the number of species and the Shannon-Wiener diversity index per year. Source: Primary data (2014-2024)

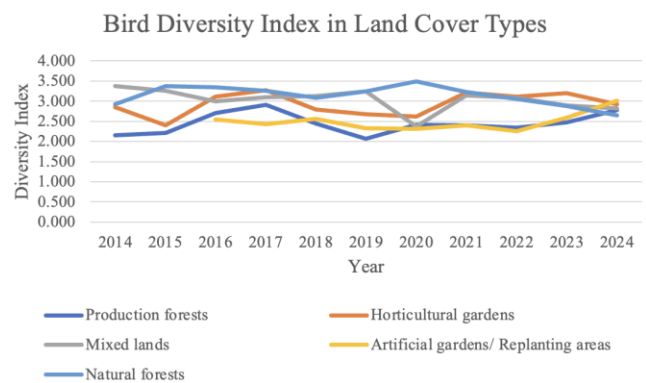


Figure 3. Trend of Shannon-Wiener diversity index on land cover types

Table 1. Details of Shannon Wiener diversity index based on land cover types

Land cover types	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Production forests	2.159	2.215	2.713	2.913	2.447	2.067	2.420	2.397	2.345	2.467	2.777
Horticultural gardens	2.846	2.400	3.118	3.267	2.789	2.676	2.621	3.216	3.116	3.197	2.925
Mixed lands	3.374	3.258	3.000	3.097	3.121	3.242	2.367	3.147	3.077	2.892	2.826
Replanting areas	-	-	2.547	2.433	2.555	2.330	2.320	2.403	2.260	2.590	3.013
Natural forests	2.929	3.375	3.344	3.264	3.088	3.239	3.486	3.226	3.048	2.883	2.648

Note: -: See the explanation in the Table 2

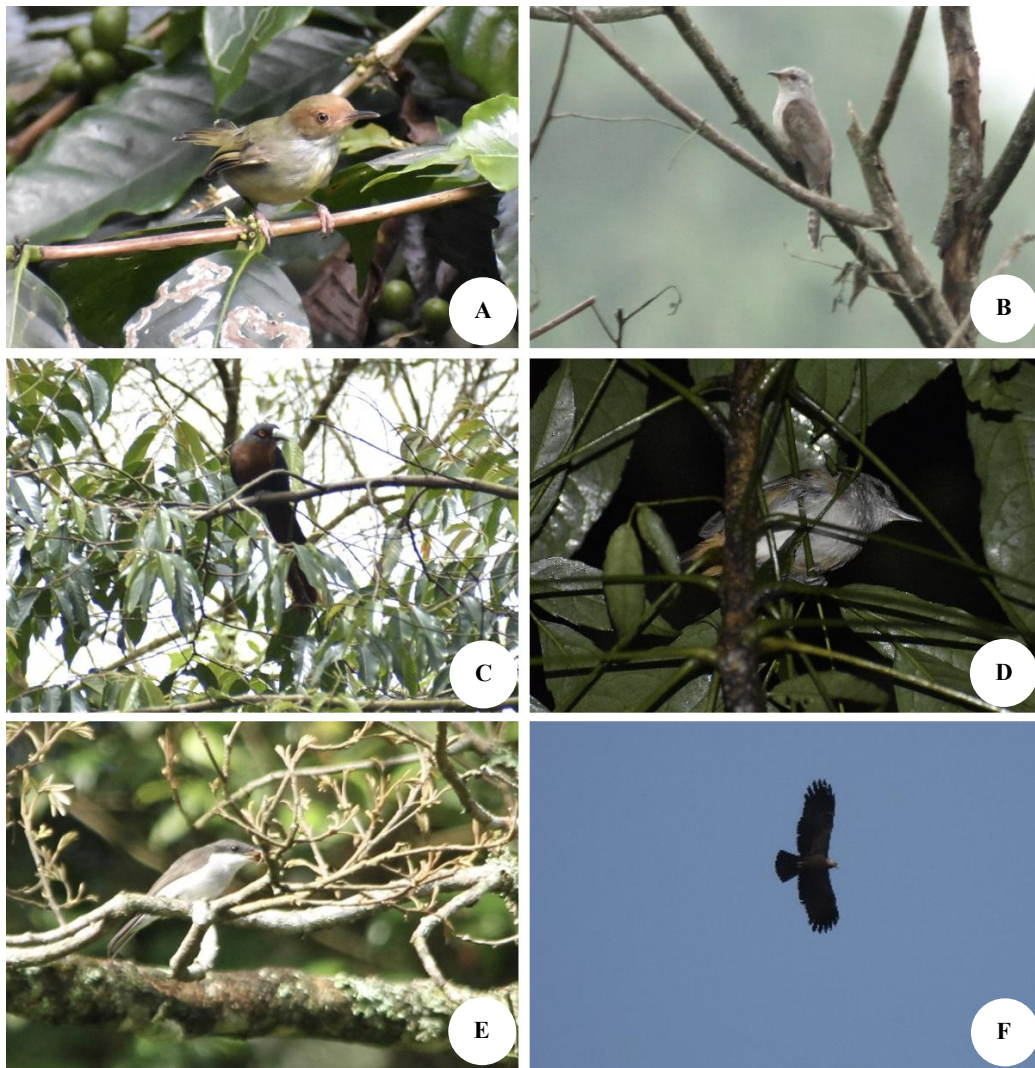


Figure 4. Bird documentation in the Kamojang Geothermal Power Plant, Kamojang, West Java, Indonesia. A. Olive-backed tailorbird (*Orthotomus sepium*), B. Plaintive Cuckoo (*Cacomantis merulinus*), C. Chestnut-breasted Malkoha (*Phaenicophaeus curvirostris*), D. Horsfield's Babbler (*Malacocincla sepiaria*), E. Black-winged Flycatcher-shrike (*Hemipus hirundinaceus*), F. Crested Hawk-eagle (*Spizaetus cirrhatus*)

Natural forests are covered by various plant species, including Javan Chestnut (*Castanopsis javanica*), Starry Distylium (*Distylium stellare*), Needlewood Schima (*Schima wallichii*), Bracteose Saurauia (*Saurauia bracteosa*), Serrate Engelhardia (*Engelhardia serrata*), Dense-flowered Syzygium (*Syzygium densiflorum*), Beaked Fig (*Ficus rostrata*), Ribes Fig (*Ficus ribes*), Blunt-leaved Fig (*Ficus fistulosa*), and Indian Pavetta (*Pavetta indica*). Bird species such as *N. bartelsi*, Crested Goshawk (*Accipiter trivirgatus*), Oriental Bay Owl (*Phodilus badius*), etc (Table S1).

The decline in the birds' diversity index from 2021 to 2024, reaching the lowest value compared to other land cover types, has significant ecological implications. For instance, Pasir Jawa, initially classified as a disturbed natural forest, has experienced significant changes. Initially classified as a natural forest, this area has been extensively converted into horticultural gardens and shrublands. This conversion has led to a significant decline in the diversity

index, as shown in Figure 3. The fact that natural forests consistently have a higher diversity index trend compared to other land covers underscores the importance of preserving these ecosystems. The conversion of Pasir Jawa into a motor trail route has further contributed to the lower diversity index. Heavily visited trails tend to have lower species richness and Shannon-Wiener diversity index compared to less frequented trails (Abdullah et al. 2024). According to the similarity index, production forest-horticultural gardens (81.08) had the highest value (Figure 6), followed by mixed lands-horticultural gardens (71.79) and production forest-mixed lands (68.00). This indicates that the vegetation structure and resource availability of the three land cover types are relatively similar. These land covers have a heterogeneous and open vegetation structure, dominated by shrubs and cultivated plants. These similarity values indicate that the bird species composition in these land cover types is highly similar.



Figure 5. Documentation of bird habitat in the Kamojang Geothermal Power Plant, West Java, Indonesia. A. Pine forests, B. Natural forests, C. Mixed gardens, D. Disturbed natural forests (Pasar Jawa), E-F. Replanting areas

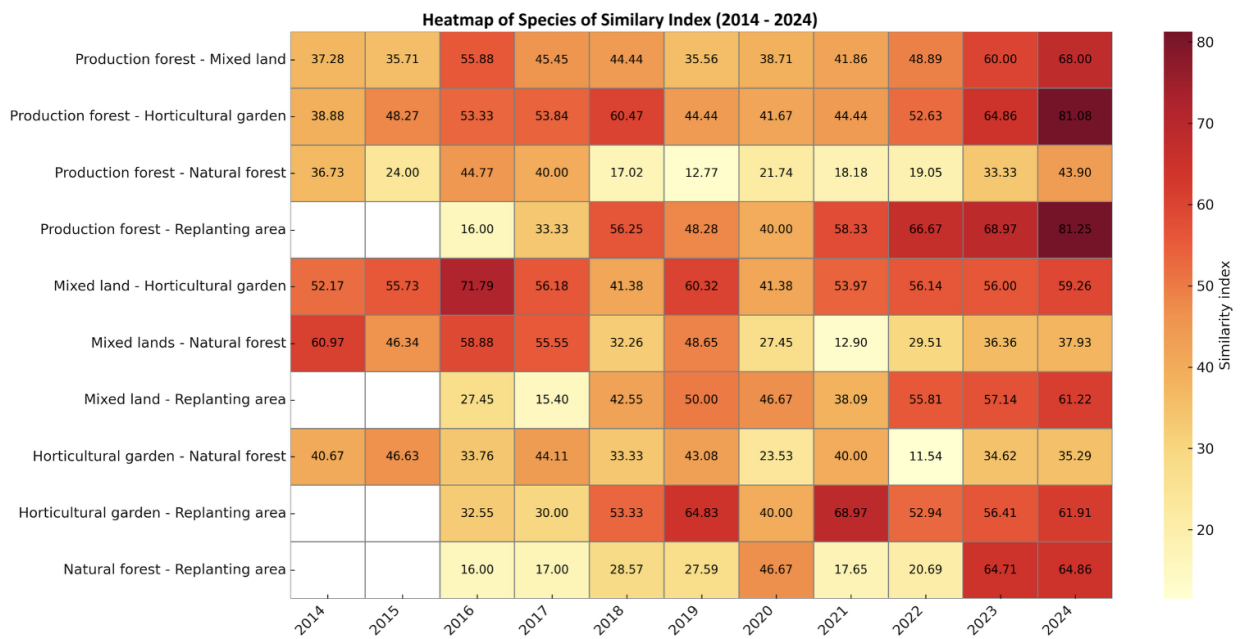


Figure 6. Heatmap of the species similarity index. Color Gradient: The higher the value, the darker the red; the lower the value, the lighter the yellow. Source: Primary data (2014-2024)

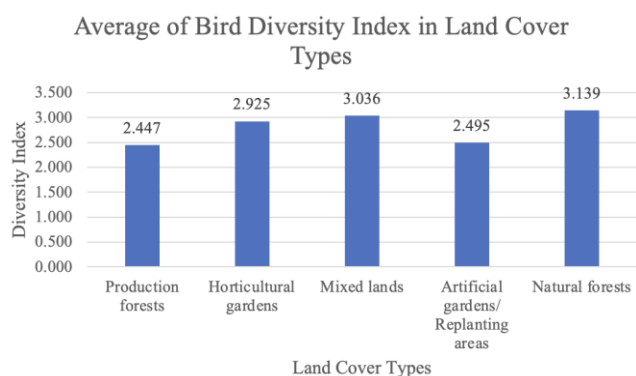


Figure 7. Average of the Shannon-Wiener diversity index based on land cover types

Table 2. Description of sampling areas in the Kamojang Geothermal Power Plant, West Java, Indonesia

Land cover types	Description
Production forests	It was located north of the office and consisted of pine forests intercropped with coffee, tobacco, and seasonal crops.
Horticultural gardens	It was located east of the office and consisted of mixed gardens. Over time, land has transitioned from coffee plantations to horticulture. Some areas are covered with shrubs and riparian vegetation.
Mixed lands	It was located west of the office and is dominated by riparian vegetation along the Cikaro River and Lake. Many resident fish in this area
Natural forests	It was located east of the office and consisted of secondary natural forests near geothermal craters. Human activities in this area include road construction, a motocross track, hunting, and the collection of non-timber forest products. One area, Pasir Jawa, is a disturbed natural forest. It was located west of the office and consisted of shrubs, pine forests, and horticultural gardens. In 2023, horticultural expansion led to the clearing of natural forests, allowing road access for vehicles. Farmers use this access road to transport agricultural commodities.
Replanting areas	It was located south of the office and had been conducted since 2016. These areas consisted of trees such as Indonesian cinnamon (<i>Cinnamomum burmanii</i>), moluccan albizia (<i>Falcataria moluccana</i>), and Sumatran pine (<i>Pinus merkusii</i>). Additionally, north of the office, pine forests and shrubs are present, along with revegetation plants. In 2024, some open areas were converted into horticultural gardens.

Horticultural garden-natural forest (11.54) has the lowest bird species similarity index in 2022 (Figure 6), followed by production forest-natural forest in 2019 (12.77) and mixed lands-natural forest in 2021 (12.90). Horticultural gardens, mixed lands, replanting areas, and production forests tend to be more homogeneous, dominated by cultivated plants (Table 2). Production

forests consisted of pine forests intercropped with coffee, tobacco, and seasonal crops. Replanting areas consisted of *C. burmanii*, *F. moluccana*, and *P. merkusii*. Mixed land comprises swamps with remnants of forests, settlements, and shrubs, while vegetable plantations and shrublands primarily cover horticultural gardens. Both areas are prone to environmental changes, making them more suitable for generalist bird species or those capable of adapting to diverse habitats.

In general, dominant bird species in the Kamojang Geothermal Power Plant area were primarily species that show high adaptability to human disturbances, such as the Yellow-vented Bulbul (*Pycnonotus goiavier*), Eastern Spotted Dove (*Streptopelia chinensis*), and Javan Munia (*Lonchura leucogastroides*). The dominant species in each location can serve as indicators of land-use characteristics. Differences in vegetation structure and type across various habitats influence the abundance of bird functional groups within a given environment. Each guild responds differently to environmental conditions caused by varying sensitivities to ecological factors (Katuwal et al. 2016).

The dominance of particular species over others suggests that these birds are relatively more adaptive to surrounding environmental conditions. *Pycnonotus goiavier* favors open areas, shrublands, roadsides, gardens, and secondary forests. This species often forms groups when foraging or perching, sometimes mingling with other *Pycnonotus* or even different bird species. It also roosts in groups on shrub branches or small trees, primarily feeding on insects and soft fruits, but also known to prey on caterpillars and small invertebrates, such as earthworms. In contrast to other bulbuls, this species spends more time foraging on the ground. The Pycnonotidae family is typically found in diverse habitats and plays a key role in preserving ecosystem balance (Ponpithuk et al. 2020). The diets are highly varied, with some species consuming insects and fruits, resulting in their classification as omnivorous (Eaton et al. 2021). The relative abundance of the *P. goiavier* is exceptionally high in residential areas, plantations, and forest-edge habitat (Husna et al. 2024).

Lonchura leucogastroides is a small granivorous bird that primarily feeds on rice and seeds. Due to the diet, this species frequently visits shrubs, grasslands, open vegetated fields, and gardens. It lives in pairs or small groups and is often observed flocking together while feeding on grass seeds or even foraging on the ground. This species also mixes with other *Lonchura*, such as the Scaly-breasted Munia (*Lonchura punctulata*), forming flocks while foraging. *Streptopelia chinensis* is commonly found in human settlements and open land, such as disturbed forests, replanting areas, and artificial parks. This generalist species is highly adaptable to fragmented and urban habitats (Lu et al. 2024; Tan et al. 2025). It shows high tolerance for human presence (Gendall et al. 2015).

During the study, 43 bird species were frequently observed, with an annual presence ranging from 9 to 11 times, while 30 other species were rarely encountered, with a presence of only 1 to 3 times per year. Within the Accipitridae family, species such as the Crested Hawk-eagle (*Spizaetus cirrhatus*) and the Crested Serpent Eagle

(*Spilornis cheela*) were consistently recorded throughout the year. In contrast, the Javan Hawk-eagle and the Crested Goshawk (*A. trivirgatus*) were rarely observed in the Kamojang area. These species are considered indicators of high-quality habitat. Carnivorous birds that hunt and prey on small animals, such as rodents, play a crucial role in controlling vermin populations, thereby maintaining balanced food chain structures through predation (Praptiwi et al. 2019). The presence suggests that certain predators help maintain ecosystem balance by regulating prey populations. An example of a predator, the Barred Eagle-owl (*Bubo sumatranus*), is rarely observed; hence, the low occurrence, particularly in controlling agricultural pests, may increase the risk of pest outbreaks, potentially reducing agricultural productivity in the area.

Alcippe pyrrhoptera and the Flame-fronted Barbet (*Megalaima armillaris*) were also frequently recorded each year. The presence of these species shows the high quality of the natural habitat. These species are commonly found in natural forests and primarily feed on forest fruits, such as Walen (*F. ribes*), Kamala Tree (*Mallotus* sp.), and Fig (*F. rostrata*) (Husodo et al. 2020). For these species, forests serve as essential habitat providing abundant food, water, and shelter for survival, and the loss of forests could lead to extinction (Krisanti et al. 2017). There is a strong correlation between bird presence and the flora. In general, birds prefer fruit-bearing trees, particularly those from the *Ficus* (Rohman et al. 2020). Various insects inhabit these trees, including those associated with banyan and *Ficus* species, further supporting avian populations (Mackay et al. 2018).

Most birds from the family Nectariniidae were seen in Kamojang, but the Streaky-breasted Spiderhunter (*Arachnothera affinis*) is the only species that serves as a pollinator. These species provide pollination and seed dispersal (Husodo et al. 2020). Praptiwi et al. (2019) noted that birds consume fruit from fruit trees, but since the seeds are not digested, they fall to the ground and can grow.

The White-crowned Forktail (*Enicurus leschenaulti*), showing riparian habitat quality (Husodo et al. 2020), was rarely recorded throughout the year. However, species from the Alcedinidae, such as the Javan Kingfisher (*Halcyon cyanoventris*) and the Collared Kingfisher (*Halcyon chloris*), which are also indicators of water quality (Husodo et al. 2020), were consistently observed year-round. This suggests that the water quality in Kamojang remains suitable as a habitat for the species. Other riparian-associated bird species recorded in the area include *L. leucogastroides*, Orange-spotted Bulbul (*Pycnonotus bimaculatus*), White-flanked Sunbird (*Aethopyga eximia*), Chestnut-fronted Shrike-babbler (*Pteruthius aenobarbus*), Lesser Shortwing (*Brachypteryx leucophrys*), *Ficedula westermanni*, and Pygmy Wren-babbler (*Pnoepyga pusilla*) (Husodo et al. 2020).

Land-use changes throughout the year directly affect species predominantly found in natural forests. The expansion of horticultural plantations has caused habitat loss, reducing the availability of shelter and food sources for forest-dependent birds. Natural forests provide essential ecosystem services for birds, as nesting sites and foraging

resources. Predatory birds, such as eagles, tend to inhabit natural forests and indirectly control agricultural pests. The Black Eagle (*Ictinaetus malaiensis*) and *S. cheela* are reliable indicators of habitat quality and play a critical role as apex predators in regulating food chains and contributing to ecosystem balance (Husodo et al. 2020). Changes in habitat structure or composition influence species diversity and distribution, including that of avifauna (Altaf et al. 2018). Declines in these species signal ecosystem imbalance and potential pest outbreaks. Therefore, maintaining and restoring natural forest cover, particularly within and around geothermal areas, is crucial to preserving sensitive species, sustaining ecological processes, and ensuring long-term biodiversity resilience under sustainable geothermal development.

In conclusion, over the 11-year monitoring period (2014-2024), a total of 113 bird species from 37 families were recorded in the Kamojang. Natural forest consistently supported the highest bird richness and diversity, with an average Shannon-Wiener index of 3.139. In contrast, areas undergoing conversion, such as Pasir Jawa, exhibited declining diversity trends. Significant changes in bird diversity were primarily driven by land-use conversion into horticultural plantations, which occurred outside of geothermal operations. Several bird species consistently serve as environmental bioindicators each year. The presence of a predatory bird indicates that natural population control mechanisms are still active, helping to maintain ecosystem stability. Additionally, certain species demonstrate good water quality, suggesting that water bodies within the geothermal area remain suitable habitats and water sources for wildlife. Several species of conservation concern were also identified, including the Endangered *N. bartelsi* and the Vulnerable *C. azurea*, highlighting the ecological importance and vulnerability of the remaining forest patches.

Limited agricultural activities within the community are essential for maintaining and even enhancing avifaunal diversity in a geothermal environment. Moreover, reforesting natural forests while considering canopy stratification complexity is necessary to restore degraded bird habitats by planting native forest vegetation that provides shelter and food sources. The structural heterogeneity and high diversity of plant species create ecological niches for many bird species, enabling them to coexist within the same habitat. Vegetation diversity influences bird species diversity in secondary forests (Erniwati et al. 2016). With proper habitat restoration, species that are currently rarely observed may gradually return to the Kamojang area.

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<i>Phaenicophaeus curvirostris</i>	Chestnut-breasted Malkoha	<i>Kadalan Birah</i>	0	3	3	6	1	4	3	2	7	4	4	3.36
<i>Cuculus saturatus</i>	Oriental Cuckoo	<i>Kangkak Ranting</i>	0	2	3	2	1	0	0	2	1	1	1	1.18
<i>Surniculus lugubris</i>	Square-tailed Drongocuckoo	<i>Kedasi Hitam</i>	0	0	0	1	0	0	0	0	0	1	1	0.27
<i>Cacomantis merulinus</i>	Plaintive Cuckoo	<i>Wiwik Kelabu</i>	0	1	0	8	2	3	2	1	0	0	4	1.91
<i>Cacomantis sepulcralis</i>	Brush Cuckoo	<i>Wiwik Uncuing</i>	31	18	2	14	2	4	1	5	4	20	19	10.91
STRIGIFORMES														
Tytonidae														
<i>Phodilus badius</i>	Oriental Bay Owl ^(NF)	<i>Serak Bukit</i>	0	0	0	0	0	0	1	0	0	0	0	0.09
Strigidae														
<i>Bubo sumatranus</i> ^(NT)	Barred Eagle-Owl	<i>Beluk Jampuk</i>	0	0	0	0	1	0	0	0	0	0	0	0.09
<i>Ketupa ketupu</i>	Buffy Fish Owl	<i>Beluk Ketupa</i>	0	0	1	0	1	1	0	0	0	0	0	0.27
<i>Otus lempiji</i> ^(II)	Sunda Scops-owl	<i>Celepuk Reban</i>	1	3	1	0	7	0	0	0	0	0	0	1.09
CAPRIMULGIFORMES														
Podargidae														
<i>Batrachostomus javensis</i>	Horsfield's Frogmouth ^(NF)	<i>Paruh-kodok Jawa</i>	0	0	0	0	0	0	0	0	0	1	0	0.09
Caprimulgidae														
<i>Caprimulgus pulchellus</i>	Salvadori's Nightjar ^(NF)	<i>Cabak Gunung</i>	1	4	2	0	0	0	1	0	0	0	0	0.73
<i>Caprimulgus affinis</i>	Savanna Nightjar	<i>Cabak kota</i>	0	0	0	0	0	1	1	1	1	0	0	0.36
APODIFORMES														
Apodidae														
<i>Apus nipalensis</i>	House Swift	<i>Kapinis Rumah</i>	0	0	0	0	0	0	1	0	0	0	0	0.09
<i>Collocalia vulcanorum</i> ^(J)	Volcano Swiftlet	<i>Walet Gunung</i>	0	0	0	0	0	0	3	0	0	0	0	0.27
<i>Collocalia linchi</i>	Cave Swiftlet	<i>Walet Linci</i>	0	1	0	0	0	2	11	0	0	0	0	1.27
Hemiprocnidae														
<i>Hemiprogne longipennis</i>	Grey-rumped Treeswift	<i>Tepekong Jambul</i>	0	3	0	0	0	0	0	0	0	0	0	0.27
<i>Hirundo tahitica</i>	Tahiti Swallow	<i>Layang-layang Batu</i>	10	3	2	0	1	1	2	2	0	6	5	2.91
<i>Cecropis striolata</i>	Striated Swallow	<i>Layang-layang Loreng</i>	0	5	2	0	0	0	0	1	1	1	1	1.00
CORACIIFORMES														
Alcedinidae														
<i>Halcyon cyanoventris</i> ^(JB)	Javan Kingfisher	<i>Cekakak Jawa</i>	2	6	5	10	2	6	3	6	11	10	10	6.45
<i>Halcyon chloris</i>	Collared Kingfisher	<i>Cekakak Sungai</i>	11	28	15	21	11	1	3	8	5	7	11	11.00
<i>Alcedo meninting</i>	Blue-eared Kingfisher	<i>Raja-udang meninting</i>	4	0	0	3	1	1	0	1	1	0	1	1.09
PICIFORMES														
Capitonidae														
<i>Megalaima lineata</i> ^(JB)	Lineated Barbet	<i>Takur Bultok</i>	0	0	0	1	0	0	0	0	0	0	0	0.09
<i>Megalaima corvina</i> ^(J)	Brown-throated Barbet ^(NF)	<i>Takur Bututut</i>	1	0	0	0	0	1	0	1	1	0	0	0.36
<i>Megalaima armillaris</i> ^(JB)	Flame-fronted Barbet	<i>Takur Tohtor</i>	1	2	2	2	2	3	1	2	3	1	1	1.82
<i>Megalaima javensis</i> ^(J)	Black-banded Barbet ^(NF)	<i>Takur Tulung-tumpuk</i>	0	0	0	0	0	0	2	0	0	0	0	0.18
<i>Megalaima haemacephala</i>	Coppersmith Barbet	<i>Takur Ungkut-ungkut</i>	2	4	4	0	0	0	0	0	0	0	0	0.91
Picidae														
<i>Dendrocopos moluccensis</i>	Sunda Pygmy Woodpecker	<i>Caladi Tilik</i>	2	3	11	4	0	0	2	3	3	1	2	2.82

<i>Dendrocopos macei</i>	Fulvous-breasted Woodpecker	<i>Caladi Ulam</i>	1	5	2	2	5	0	0	0	0	0	0	1.36
PASSERIFORMES														
Campephagidae														
<i>Hemipus hirundinaceus</i>	Black-winged Flycatcher-shrike	<i>Jingjing Batu</i>	8	2	0	25	2	20	2	3	8	8	20	8.91
<i>Pericrocotus miniatus</i>	Sunda Minivet	<i>Sepah hutan</i>	0	0	0	15	0	0	0	0	0	1	3	1.73
Chloropseidae														
<i>Aegithina tiphia</i> ^(JB)	Common Iora	<i>Cipoh Kacat</i>	1	0	0	0	0	0	0	0	0	0	0	0.09
Pycnonotidae														
<i>Pycnonotus bimaculatus</i> ^(NT)	Orange-spotted Bulbul	<i>Cucak Gunung</i>	0	0	1	0	0	0	0	0	0	0	0	0.09
<i>Pycnonotus aurigaster</i>	Sooty-headed Bulbul	<i>Cucak Kutilang</i>	4	2	33	28	12	12	21	17	34	21	11	17.73
<i>Pycnonotus goiavier</i>	Yellow-vented Bulbul	<i>Merbah Cerukcuk</i>	26	32	35	79	17	14	10	5	14	10	31	24.82
Dicruridae														
<i>Dicrurus macrocercus</i>	Black Drongo	<i>Srigunting Hitam</i>	2	0	0	3	1	0	0	0	0	0	0	0.55
<i>Dicrurus leucophaeus</i>	Ashy Drong	<i>Srigunting Kelabu</i>	2	1	2	12	8	4	1	8	5	5	6	4.91
Timaliidae														
<i>Alcippe pyrrhoptera</i> ^(J)	Javan Fulvetta	<i>Wergan Jawa</i>	1	7	23	21	8	11	1	4	14	5	13	9.82
<i>Timalia pileata</i>	Chestnut-capped Babbler	<i>Tepus Gelagah</i>	0	2	0	0	0	0	0	0	0	0	0	0.18
<i>Stachyris melanothorax</i> ^(JB)	Crescent-chested Babbler	<i>Tepus Pipi-perak</i>	7	2	8	21	6	3	1	7	6	3	12	6.91
<i>Napothera epilepidota</i>	Eyebrowed Wren-babbler	<i>Berencet Berkening</i>	0	0	0	2	5	0	1	0	0	0	0	0.73
<i>Malacocincla abbotti</i>	Abbott's Babbler ^(NF)	<i>Pelanduk Asia</i>	1	0	0	0	0	0	0	0	0	0	0	0.09
<i>Trichastoma pyrogenys</i>	Temminck's Babbler ^(NF)	<i>Pelanduk Bukit</i>	0	0	0	1	2	0	0	0	0	0	0	0.27
<i>Malacocincla septarium</i>	Horsfield's Babbler	<i>Pelanduk Semak</i>	7	3	0	11	5	5	1	2	2	4	4	4.00
<i>Pnoepyga pusilla</i>	Pygmy Wren-babbler ^(NF)	<i>Berencet Kerdil</i>	0	3	5	10	2	3	1	9	9	16	13	6.45
<i>Pteruthius flaviscapis</i>	Pied Shrike-babbler	<i>Ciu Besar</i>	0	4	11	7	1	1	1	2	2	1	0	2.73
<i>Pteruthius aenobarbus</i>	Chestnut-fronted Shrike-babbler	<i>Ciu Kunyit</i>	0	1	1	8	1	2	1	6	6	1	3	2.73
Turdidae														
<i>Cochoa azurea</i> ^{(J)(VU)(P)}	Javan Cochoa	<i>Ciung-mungkal Jawa</i>	0	0	0	1	1	3	0	2	1	0	0	0.73
Silviidae														
<i>Acrocephalus orientalis</i>	Oriental Reed Warbler	<i>Kerakbasi Besar</i>	0	1	0	0	0	0	0	0	0	0	0	0.09
<i>Acrocephalus stentoreus</i>	Clamorous Reed Warbler	<i>Kerakbasi Ramai</i>	1	0	0	0	0	0	0	0	0	0	0	0.09
<i>Cisticola juncidis</i>	Zitting Cisticola	<i>Cici Padi</i>	2	0	0	1	0	0	3	3	3	2	1	1.36
<i>Megalurus palustris</i>	Striated Grassbird	<i>Cica-koreng Jawa</i>	6	9	16	30	0	2	1	2	2	1	1	6.36
<i>Orthotomus sepium</i> ^(JB)	Olive-backed Tailorbird	<i>Cinenen Jawa</i>	32	32	10	8	7	34	6	6	4	13	16	15.27
<i>Orthotomus ruficeps</i>	Ashy Tailorbird	<i>Cinenen kelabu</i>	0	0	5	15	6	0	0	0	6	1	0	3.00
<i>Orthotomus sutorius</i> ^(J)	Common Tailorbird	<i>Cinenen Pisang</i>	0	0	3	19	0	2	3	9	9	6	11	6.20
<i>Prinia inornata</i>	Plain Prinia	<i>Perenjak Padi</i>	0	5	3	1	0	1	0	0	0	0	0	0.91
<i>Prinia familiaris</i> ^(NT)	Bar-winged Prinia	<i>Prenjak Jawa</i>	0	0	0	13	2	10	8	5	3	2	0	3.91
<i>Prinia flaviventris</i>	Yellow-bellied Prinia	<i>Prenjak Rawa</i>	0	0	1	1	0	0	0	0	0	0	0	0.18
<i>Phylloscopus trivirgatus</i>	Mountain Warbler	<i>Cikrak Daun</i>	2	0	0	18	1	2	0	2	2	1	3	2.82
<i>Phylloscopus borealis</i>	Arctic Warbler	<i>Cikrak Kutub</i>	1	4	1	0	0	0	0	0	0	0	0	0.55
<i>Seicercus grammiceps</i>	Sunda Warbler	<i>Cikrak Muda</i>	2	3	2	7	3	0	0	4	5	0	0	2.36
<i>Cettia vulcania</i>	Sunda Bush-warbler	<i>Ceret Gunung</i>	0	6	0	9	9	0	1	0	0	0	0	2.27
<i>Orthotomus cuculatus</i>	Mountain Tailorbird	<i>Cinenen Gunung</i>	0	8	3	4	2	3	1	7	4	2	2	3.27

<i>Tesia superciliaris</i> ^(D)	Javan Tesia	<i>Tesia Jawa</i>	2	2	0	4	3	1	2	6	3	3	3	2.64
Muscicapidae														
<i>Brachypteryx leucophrys</i>	Lesser Shortwing	<i>Cingcoang Coklat</i>	1	0	0	0	0	0	0	0	0	0	0	0.09
<i>Enicurus leschenaulti</i>	White-crowned Forktail	<i>Meninting Besar</i>	0	0	0	0	0	0	0	1	1	0	0	0.18
<i>Enicurus velatus</i>	Sunda Forktail	<i>Meninting Kecil</i>	0	0	1	0	0	0	0	0	0	0	0	0.09
<i>Ficedula westermanni</i>	Little Pied Flycatcher	<i>Sikatan Belang</i>	7	1	1	13	0	2	1	8	5	2	7	4.27
<i>Ficedula hyperythra</i>	Snowy-browed Flycatcher	<i>Sikatan Bodoh</i>	2	2	0	2	1	0	0	0	0	0	0	0.64
<i>Muscicapa dauurica</i>	Asian Brown Flycatcher	<i>Sikatan Bubik</i>	3	3	1	5	1	0	0	0	2	1	0	1.45
<i>Culicicapa ceylonensis</i>	Grey-headed Canary-flycatcher	<i>Sikatan Kepala-abu</i>	1	2	2	8	1	4	1	2	2	1	3	2.45
<i>Muscicapa sibirica</i>	Dark-sided Flycatcher	<i>Sikatan Sisi-gelap</i>	0	0	0	2	0	0	0	0	0	0	0	0.18
Rhipiduridae														
<i>Rhipidura phoenicurus</i> ^(D)	White-throated Fantail	<i>Kipasan Ekor-merah</i>	0	3	2	7	1	0	0	0	2	1	1	1.55
Aegithalidae														
<i>Psaltria exilis</i> ^{(D)(P)}	Pygmy Tit	<i>Cerecet Jawa</i>	0	0	0	17	10	9	0	1	0	0	2	3.55
Paridae														
<i>Parus major</i>	Great Tit	<i>Gelatik Batu Kelabu</i>	3	0	0	0	0	0	1	0	0	0	0	0.36
Sittidae														
<i>Sitta frontalis</i>	Velvet-fronted Nuthatch	<i>Munguk Beledu</i>	0	3	0	0	0	0	0	0	0	0	0	0.27
<i>Sitta azurea</i>	Blue Nuthatch	<i>Munguk Loreng</i>	1	4	16	20	1	1	1	7	7	1	7	6.00
Motacillidae														
<i>Motacilla cinerea</i>	Grey Wagtail ^(NF)	<i>Kicuit Batu</i>	0	0	0	0	0	2	0	1	0	0	0	0.27
Artamidae														
<i>Artamus leucorhynchus</i>	Artamus Leucorhyn	<i>Kekep Babi</i>	0	5	1	0	0	0	0	1	1	3	1	1.09
Laniidae														
<i>Lanius schach</i>	Long-tailed Shrike	<i>Bentet Kelabu</i>	11	21	4	17	6	0	0	6	7	9	9	8.18
Sturnidae														
<i>Acridotheres javanicus</i> ^(VU)	Javan Myna	<i>Kerak Kerbau</i>	0	2	0	0	0	0	0	0	0	0	0	0.18
<i>Aplonis panayensis</i>	Asian Glossy Starling	<i>Perling Kumbang</i>	0	0	0	1	0	0	0	0	0	0	0	0.09
Nectariniidae														
<i>Aethopyga eximia</i> ^(D)	White-flanked Sunbird	<i>Burung-madu Gunung</i>	1	4	1	4	2	1	1	2	1	1	1	1.73
<i>Cinnyris jugularis</i>	Olive-backed Sunbird	<i>Burung-madu Sriganti</i>	1	5	5	38	5	17	4	3	3	3	3	7.91
<i>Arachnothera affinis</i>	Streaky-breasted Spiderhunter	<i>Pijantung Gunung</i>	0	0	1	0	0	0	0	0	0	0	0	0.09
<i>Arachnothera longirostra</i>	Little Spiderhunter	<i>Pijantung Kecil</i>	1	5	2	3	1	4	2	2	1	1	1	2.09
Dicaeidae														
<i>Dicaeum trigonostigma</i>	Orange-bellied Flowerpecker	<i>Cabai Bunga-api</i>	7	0	2	8	3	2	0	3	0	0	0	2.27
<i>Dicaeum sanguinolentum</i>	Blood-breasted Flowerpecker	<i>Cabai Gunung</i>	2	2	3	8	0	1	1	3	6	10	10	4.18
<i>Dicaeum trochileum</i>	Scarlet-headed Flowerpecker	<i>Cabai Jawa</i>	5	8	2	10	0	0	2	2	0	5	5	3.55
Zosteropidae														

<i>Zosterops palpebrosus</i>	Oriental White-eye	<i>Kacamata Biasa</i>	9	2	19	17	0	1	2	0	0	1	0	4.64
<i>Heleia javanica</i> ^{(JB)(P)}	Javan Grey-throated White-eye ^(NF)	<i>Opor Jawa</i>	0	0	0	0	0	1	2	0	0	0	0	0.27
Ploceidae														
<i>Lonchura maja</i>	White-headed Munia	<i>Bondol Haji</i>	0	0	0	22	0	0	0	0	0	0	0	2.00
<i>Lonchura leucogastroides</i>	Javan Munia	<i>Bondol Jawa</i>	13	20	37	77	31	43	9	15	25	26	25	29.18
<i>Lonchura punctulata</i>	Scaly-breasted Munia	<i>Bondol Peking</i>	0	5	4	9	3	0	2	16	17	17	18	8.27
<i>Passer montanus</i>	Eurasian Tree Sparrow	<i>Burung-gereja Erasia</i>	7	13	1	20	7	1	4	10	23	15	9	10.00

Notes: AV: Average; (J): Endemic to Java Island, (JB): Endemic to Java and Bali Islands; IUCN Red List: (EN): Endangered, (VU): Vulnerable, (NT): Near Threatened, the remaining species is a least concern species; Checklist of CITES: (II): Appendix II; (P): Indonesian Regulation; (NF): Natural Forest