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# Single-station passive acoustic monitoring of bird diversity and vocal activity in Cikaniki, Gunung Halimun-Salak National Park, West Java

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## Abstract

**Background** Montane tropical forests support diverse avian communities, yet dense vegetation and rugged terrain limit conventional surveys.

**Objectives** This study aimed to assess bird species richness and vocal activity in Cikaniki, Gunung Halimun-Salak National Park, Java, using Passive Acoustic Monitoring (PAM).

**Methods** Acoustic recordings were collected continuously over 15 days (21 June–6 July 2023) using a fixed PAM station. Vocalizations were identified to species level, categorized as calls or songs, and measured for duration and frequency. Detection frequency across the sampling period was calculated to evaluate temporal patterns of vocal activity.

**Results** Forty bird species were detected, representing raptors, nocturnal birds, insectivores, frugivores, and nectarivores. Detection frequency varied from a single day to all 15 days. Raptors, such as the Crested Serpent Eagle (*Spilornis cheela*) and Black Eagle (*Ictinaetus malaiensis*), were recorded despite high-soaring behavior. Nocturnal species were also captured, showing temporal diversity in vocal activity. Call and song durations ranged from 0.15 to 34.29 s, with frequencies from 617 to 8,577 Hz. Highly vocal species included Blue-eared Barbet (*Psilopogon armillaris*), Pygmy Wren-Babbler (*Pneopyga pusilla*), and Orange-bellied Flowerpecker (*Dicaeum trigonostigma*).

**Conclusions** PAM effectively documents both common and elusive species in montane tropical forests. Quantitative acoustic data on detection frequency and vocal behavior provide a baseline for long-term monitoring, supporting adaptive management and conservation of avian communities in Cikaniki and similar habitats.

**Keywords** detection frequency | Gunung Halimun-Salak National Park | PAM | vocal activity

## Introduction

Gunung Halimun-Salak National Park (GHSNP) is the largest montane conservation area on Java Island, one of the most important strongholds of montane tropical forest biodiversity in western Java. Cikaniki Management Unit, hereafter referred to as Cikaniki, covering approximately 4,195 ha and ranging from 500 to 1,700 m above sea level, represents a key management unit within GHSNP (Ridwan *et al.*, 2014). Its heterogeneous topography and dense forest vegetation support high biodiversity, yet these same characteristics pose significant challenges for conventional wildlife surveys.

Biodiversity monitoring is fundamental for adaptive management of protected areas, but direct observation methods are often constrained by rugged terrain, limited accessibility, observer bias, and high operational costs (Sugai *et al.*, 2019). To overcome these limitations, passive survey methods such as camera trapping and acoustic monitoring have been increasingly adopted.

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Passive Acoustic Monitoring (PAM) employs autonomous recording devices to capture wildlife sounds continuously across space and time (Sugai *et al.*, 2019). PAM has proven especially efficient for vocally active taxa, such as birds, in dense tropical forests where visual detection is limited (Boullhesen *et al.*, 2021; Melo *et al.*, 2021). It is also non-invasive, generating permanent, achievable datasets while minimizing disturbance to wildlife (Sugai *et al.*, 2019).

Birds are particularly suitable for PAM because many species produce distinctive vocalizations that enable species-level identification and facilitate biodiversity monitoring across broad spatial and temporal scales (Pérez-Granados & Traba, 2021; Stowell *et al.*, 2019). Avian vocalizations are generally categorized into songs, long and structured sequences associated with territorial or reproductive behavior, and calls, shorter sequences serving communication functions such as contact or alarm. Acoustic parameters such as duration and frequency (Hz) are commonly measured to characterize vocalizations quantitatively (Zottesso *et al.*, 2018).

Species richness is a key indicator of ecological integrity and community structure (Kiester, 2013; Shafie *et al.*, 2023). A total of 276 bird species have been recorded in GSHNP, including 175 species documented within Cikaniki (Balai Taman Nasional Gunung Halimun-Salak, 2021). Although bird diversity in Cikaniki has been extensively documented through conventional field surveys, studies employing PAM remain limited, particularly with respect to bird vocal activity patterns and species detectability in montane forest habitats. Previous applications of PAM in the area have focused primarily on the Javan gibbon (*Hylobates moloch*) (Oktaviani, 2009; Ham *et al.*, 2016), while Ningrum (2025) provided a preliminary assessment of bird diversity.

The present study aimed to provide a baseline assessment of bird communities in Cikaniki, using PAM. Specifically, the objectives were to: (1) document bird species detected acoustically during a 15-day sampling period; (2) quantify key acoustic parameters of identified vocalizations, including call duration, start frequency, and end frequency; and (3) analyze species detection frequency to evaluate temporal patterns of vocal activity. By addressing these objectives, this study provides one of the first applications of PAM in Cikaniki and establishes a baseline for future long-term acoustic biodiversity monitoring programs.

## Methods

### Study Site and Research Period

GHSNP is the largest montane conservation area on Java Island. Since 2016, the park's area has been reduced from 113,357 ha to 87,699 ha, primarily due to land-use changes associated with population density and growth, land ownership patterns, and the expansion of settlements and agricultural areas. The Cikaniki covers approximately 4,195 ha at elevations ranging from 500 to 1,700 m above sea level and is characterized by hilly topography. The area encompasses core, wilderness, utilization, rehabilitation, and special-use zones within the national park, supporting high levels of biodiversity (Balai Taman Nasional Gunung Halimun-Salak, 2021).

This study utilized secondary acoustic data collected by Yayasan Konservasi Ekosistem Alam Nusantara (KIARA), a non-profit organization conducting ecological and bioacoustic research on the endangered Javan gibbon (*Hylobates moloch*) using PAM in Cikaniki. While the primary focus of data collection was gibbon vocalizations, the recordings also captured a broad range of wildlife sounds, including birds, which are the focus of this study.

An autonomous acoustic recorder was deployed at a fixed location in Cikaniki (06°44.561' S, 106°31.550' E; **Figure 1**) and operated continuously over 15 days from 21 June to 6 July

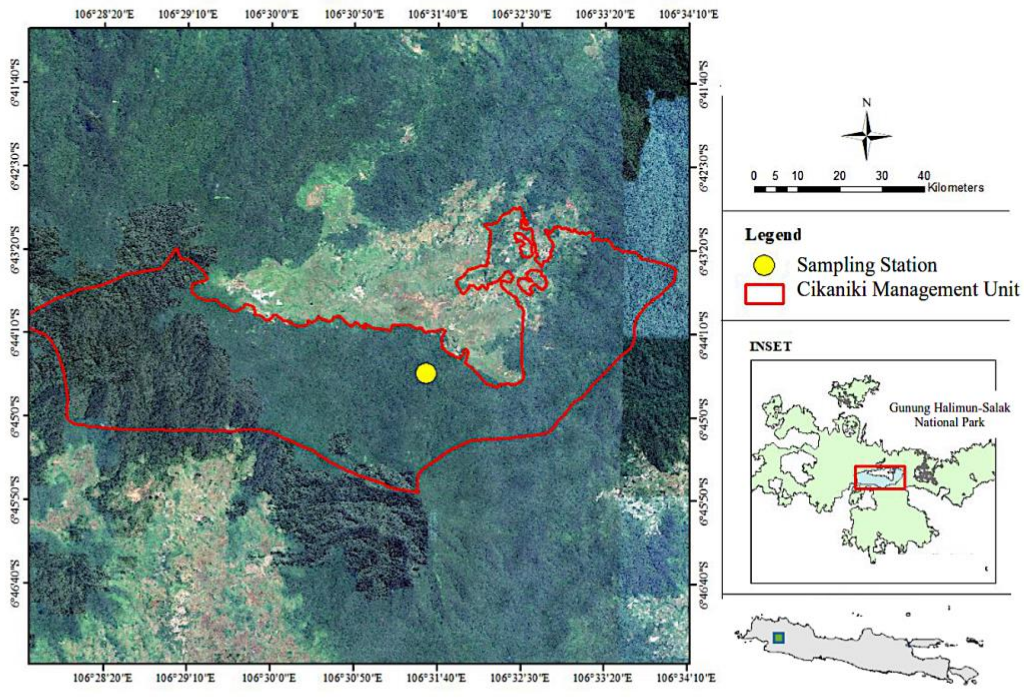


**Figure 1** Map showing the location of the study area and the sampling station in Cikaniki.

2023. For each species or vocalization type, acoustic measurements were obtained from a single vocalization with the highest signal quality and minimal background noise. The selected vocalization was considered representative of that species or vocalization type for descriptive purposes. Acoustic data processing and analysis were conducted between August and September 2024. Species identification followed field guides by Eaton *et al.* (2021), supplemented by reference recordings from Xeno-canto and eBird databases. Analyses were performed using Raven Pro version 1.6.0 (Cornell Lab of Ornithology).

**Acoustic Data Collection and Analysis**

Recordings were obtained using a SwiftOne autonomous recording unit (Cornell Lab of Ornithology), widely used in terrestrial passive acoustic surveys for its energy efficiency, time synchronization, adjustable recording settings, and high microphone sensitivity (Raiyardhi, 2023). The recorder was mounted on a tree trunk approximately 5 m above ground to optimize sound detection and minimize interference from ground-level noise.

The autonomous recorder operated continuously throughout the survey period, generating audio files of 40-minute duration. All recordings included in the analysis were manually reviewed using Raven Pro version 1.6.0 (Cornell Lab of Ornithology, Ithaca, New York, USA). Bird vocalizations were detected, annotated, and clipped for subsequent analysis. For species exhibiting multiple vocalization types, each vocalization type was treated separately. Acoustic measurements were obtained from a single representative vocalization of the highest recording quality for each vocalization type to minimize interference from background noise and overlapping sounds.

A total of 540 audio files were generated, each lasting 40 minutes, with a sampling rate of 48,000 Hz and a gain of 28 dB, providing broad frequency coverage and high-resolution spectrograms (Sugai *et al.*, 2019). Only recordings from the morning period (05:20–09:20 WIB) were analyzed, totaling 90 files (6 per day × 15 days). Although the analysis focused exclusively on morning recordings, occasional vocalizations of nocturnal species were detected during the early dawn period. No recordings collected outside the analyzed morning period were used for species identification or acoustic measurements. This period corresponds to the dawn chorus and early morning peak in avian vocal activity, when species detectability is generally highest, making it the most effective time window for bird acoustic surveys (Fontúrbel *et al.*, 2021). Bird species were identified using Eaton *et al.* (2021), and species names and taxonomic sequence follow this reference throughout the manuscript.

All recordings were screened for acoustic quality, excluding files with excessive background noise, such as heavy rain, strong wind, or dominant non-avian sounds (Darras *et al.*, 2018). Bird vocalizations were manually detected, annotated, and clipped to isolate individual calls and songs for spectrogram visualization and measurement.

Identified vocalizations were classified into two types: songs, long and structured sequences typically associated with territorial or reproductive behaviour, and calls, shorter sequences used for contact, alarm, or other communication. For each vocalization, three acoustic parameters were measured: duration, start frequency, and end frequency. Duration was defined as the interval from onset to termination of the vocalization (Pérez-Granados & Traba, 2021).

Species detection frequency was calculated as the number of days a species was recorded over the 15-day period, providing an indicator of temporal consistency in vocal activity. All identified species were compiled into a table with taxonomic information (order, family), common name, scientific name, and detection frequency.

Representative spectrograms of selected species were included to illustrate the diversity of vocalization patterns recorded during the survey and to provide visual support for species identification. Due to variation in recording quality and background environmental noise, the spectrograms are presented primarily as illustrative examples rather than detailed analyses of vocal structure. Quantitative analyses were therefore based on acoustic measurements (duration, start frequency, end frequency) and detection frequency.

## Results

**Bird Detection Frequency**

A total of 40 bird species were recorded across 15 sampling days, encompassing a diverse community of diurnal and nocturnal birds (**Table 1**). Representative spectrograms illustrating selected vocalization types are provided in **Figure 2**. Detection frequencies varied widely among species (**Figure 3**). Three species, namely Blue-eared Barbet (*Psilopogon armillaris*), Pygmy Wren-Babbler (*Pneopyga pusilla*), and Orange-bellied Flowerpecker (*Dicaeum trigonostigma*), were detected on all sampling days (100%), reflecting their high local abundance, frequent vocal activity, or both.

Conversely, species such as the Crested Serpent Eagle (*Spilornis cheela*), Javan Hawk-Eagle (*Nisaetus bartelsi*), Javan Owlet (*Glaucidium castanopterum*), and Javan Sunbird (*Aethopyga eximia*) were recorded only once (6.7%), suggesting lower local density or infrequent vocalizations. Intermediate detection frequencies were observed in species such as the Black Eagle (*Ictinaetus malaiensis*), Javan Partridge (*Arborophila javanica*), and Chestnut-fronted Shrike-Babbler (*Pteruthius aenobarbus*), which were detected on 20–46.7% of the sampling days.

Notably, several raptor species were detected, including the Crested Serpent Eagle, Black Eagle, and Javan Hawk-Eagle, despite their typical soaring behavior and extensive flight ranges. These observations suggest that either the species vocalized while perched or that our sampling area lies within a key part of their territorial or hunting range. Additionally, the Javan Owlet, a nocturnal species, was detected using PAM, confirming the utility of bioacoustic surveys for capturing elusive or crepuscular/nocturnal birds that are often missed in visual surveys.

**Vocalization Characteristics**

Bird vocalizations exhibited marked variation in both duration and frequency across species. Call durations ranged from brief, high-pitched notes, such as those of the

**Table 1** Detection frequency and acoustic characteristics of 40 bird species recorded in Cikaniki, West Java, over a 15-day survey period in Cikaniki. Detection frequency indicates the number of days each species was recorded, and percentage represents temporal consistency in vocal activity. Some species exhibited two vocalization types, indicated by the labels a and b

| No | Species name (latin name) | Detection frequency | % of sampling days | Duration (s) | Start freq (hz) | End freq (hz) | Type |
|---|---|---|---|---|---|---|---|
| 1 | Crested Serpent Eagle (*Spilornis cheela*) | 1 | 6.67 | 1.39 | 1883 | 2635 | Call |
| 2 | Black Eagle (*Ictinaetus malaiensis*) | 3 | 20.00 | 0.46 | 2100 | 2668 | Call |
| 3 | Javan Hawk-Eagle (*Nisaetus bartelsi*) | 1 | 6.67 | 0.56 | 1522 | 5198 | Call |
| 4 | Javan Partridge (*Arborophila javanica*) | 4 | 26.67 | 34.29 | 904 | 1370 | Song |
| 5a | Drongo Cuckoo (*Surniculus lugubris*) | 5 | 33.33 | 0.65 | 2134 | 2594 | Call |
| 5b | Drongo Cuckoo (*Surniculus lugubris*) | 5 | 33.33 | 11.71 | 1901 | 3041 | Song |
| 6 | Javan Owlet (*Glaucidium castanopterum*) | 1 | 6.67 | 11.26 | 1086 | 1285 | Song |
| 7 | Javan Trogon (*Apalharpactes reinwardtii*) | 1 | 6.67 | 2.67 | 977 | 1991 | Song |
| 8 | Orange-breasted Trogon (*Harpactes oreskios*) | 4 | 26.67 | 1.08 | 711 | 1778 | Song |
| 9 | Blue-eared Kingfisher (*Alcedo meninting*) | 1 | 6.67 | 1.53 | 6795 | 8186 | Call |
| 10 | Brown-throated Barbet (*Psilopogon corvinus*) | 2 | 13.33 | 10.33 | 617 | 823 | Song |
| 11a | Blue-eared Barbet (*Psilopogon armillaris*) | 15 | 100.00 | 5.18 | 815 | 1415 | Call |
| 11b | Blue-eared Barbet (*Psilopogon armillaris*) | 15 | 100.00 | 11.39 | 869 | 1466 | Song |
| 12 | Javan Banded Pitta (*Hydrornis guajanus*) | 3 | 20.00 | 5.94 | 1434 | 2092 | Song |
| 13 | Mountain Minivet (*Pericrocotus miniatus*) | 2 | 13.33 | 0.87 | 5973 | 8182 | Song |
| 14 | Blue-winged Leafbird (*Chloropsis moluccensis*) | 1 | 6.67 | 1.65 | 2577 | 4073 | Song |
| 15 | Ashy Drongo (*Dicrurus leucophaeus*) | 1 | 6.67 | 18.86 | 1971 | 3507 | Song |
| 16 | Javan Tit-Babbler (*Psaltria exilis*) | 1 | 6.67 | 1.45 | 2253 | 4301 | Song |
| 17 | Velvet-fronted Nuthatch (*Sitta frontalis*) | 2 | 13.33 | 0.15 | 4831 | 8577 | Call |
| 18 | White-browed Shortwing (*Brachypteryx leucophris*) | 11 | 73.33 | 2.59 | 2462 | 5033 | Song |
| 19 | Horsfield's Babbler (*Malacocincla sepiaria*) | 3 | 20.00 | 11.65 | 2820 | 4590 | Song |
| 20 | Pygmy Wren-Babbler (*Pneopyga pusilla*) | 15 | 100.00 | 3.48 | 5055 | 7377 | Song |
| 21 | Silver-eared Mesia (*Cyanoderma melanothorax*) | 1 | 6.67 | 1.19 | 1118 | 1507 | Call |
| 22 | Javan Fulvetta (*Alcippe pyrrhoptera*) | 13 | 86.67 | 1.06 | 2772 | 5034 | Song |
| 23 | White-bibbed Babbler (*Laniellus albonotatus*) | 12 | 80.00 | 15.90 | 1736 | 4036 | Song |
| 24 | Javan Whistler (*Pteruthius flaviscapis*) | 3 | 20.00 | 2.78 | 3238 | 4237 | Song |
| 25 | Chestnut-fronted Shrike-Babbler (*Pteruthius aenobarbus*) | 7 | 46.67 | 2.39 | 2099 | 4096 | Song |
| 26 | Javan Whistling Thrush (*Myophonus glaucinus*) | 1 | 6.67 | 2.10 | 2516 | 4082 | Call |
| 27 | Ashy Tailorbird (*Orthotomus sepium*) | 3 | 20.00 | 2.10 | 2070 | 4626 | Song |
| 28 | Bar-winged Prinia (*Prinia familiaris*) | 3 | 20.00 | 9.01 | 2532 | 4674 | Song |
| 29 | Asian Brown Flycatcher (*Muscicapa dauurica*) | 1 | 6.67 | 2.81 | 3899 | 4895 | Song |
| 30a | Indigo Flycatcher (*Eumyias indigo*) | 7 | 46.67 | 2.13 | 2728 | 3428 | Song |
| 30b | Indigo Flycatcher (*Eumyias indigo*) | 7 | 46.67 | 2.47 | 2755 | 3676 | Song |
| 31 | Snowy-browed Flycatcher (*Ficedula westermanni*) | 6 | 40.00 | 6.43 | 3311 | 4596 | Song |
| 32 | Grey-headed Canary-Flycatcher (*Culicicapa ceylonensis*) | 5 | 33.33 | 1.66 | 3194 | 4596 | Song |
| 33 | Long-tailed Shrike (*Lanius schach* | 1 | 6.67 | 4.66 | 3455 | 4993 | Song |
| 34 | Javan Sunbird (*Aethopyga eximia* | 1 | 6.67 | 4.02 | 3348 | 5651 | Song |
| 35 | Crimson Sunbird (*Aethopyga siparaja* | 2 | 13.33 | 1.74 | 6696 | 8303 | Song |
| 36 | Little Spiderhunter (*Arachnothera longirostra* | 4 | 26.67 | 9.49 | 2432 | 3846 | Song |
| 37 | Streaky-breasted Spiderhunter (*Arachnothera affinis*) | 6 | 40.00 | 6.78 | 3084 | 4842 | Song |
| 38a | Crimson-breasted Flowerpecker (*Prionochilus percussus*) | 10 | 66.67 | 1.62 | 4473 | 7333 | Call |
| 38b | Crimson-breasted Flowerpecker (*Prionochilus percussus*) | 10 | 66.67 | 1.54 | 6825 | 8510 | Call |
| 39 | Crimson-breasted Flowerpecker (*Prionochilus percussus*) | 10 | 66.67 | 10.79 | 4800 | 6446 | Song |
| 40 | Orange-bellied Flowerpecker (*Dicaeum trigonostigma*) | 15 | 100.00 | 1.68 | 5940 | 7373 | Call |

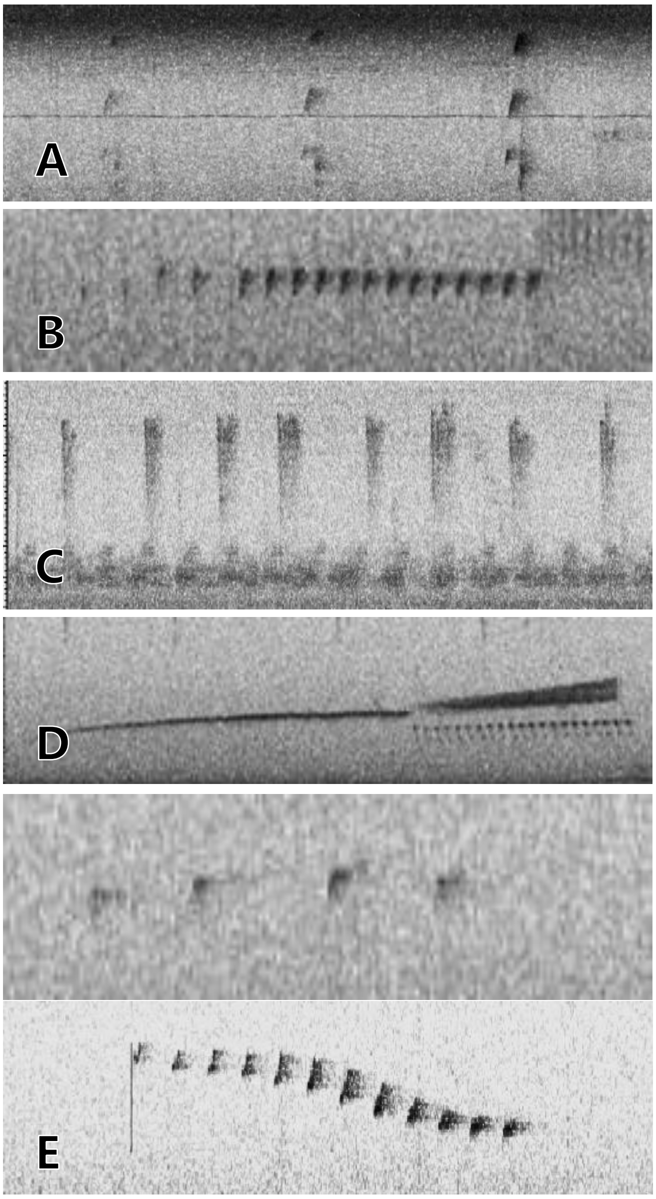


**Figure 2** Representative spectrograms of bird vocalizations recorded in Cikaniki. (A) Javan Hawk-Eagle (*Nisaetus bartelsi;* raptor), (B) Javan Owlet (*Glaucidium castanopterum*; nocturnal species, (C) Javan Tit-Babbler (*Psaltria exilis;* understory species), (D) Javan Partridge (*Arborophila javanica*; longest vocalization, ground bird), (E) Drongo Cuckoo (*Surniculus lugubris*, species exhibiting multiple vocalization types.

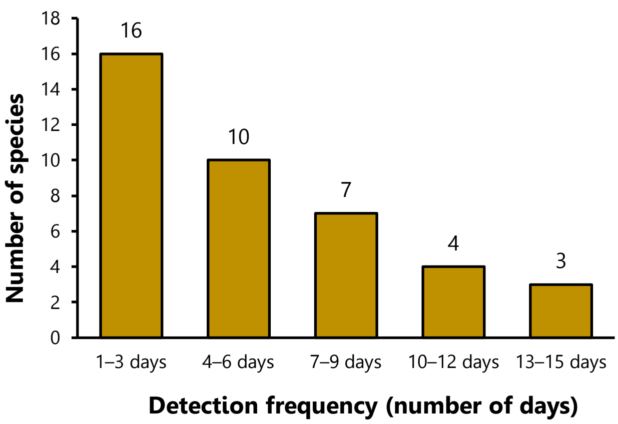


**Figure 3** Distribution of detection frequencies among the 40 bird species recorded during a 15-day PAM monitoring survey in Cikaniki.

Velvet-fronted Nuthatch (*Sitta frontalis*, 0.15 s), to extended, complex songs produced by the Javan Partridge (*Arborophila javanica*, 34.29 s). Start frequencies spanned from low-frequency notes in species such as the Brown-throated Barbet (*Psilopogon corvinus*, 617 Hz) to very high frequencies in species like the Orange-breasted Trogon (*Harpactes oreskios*, 6795 Hz). End frequencies similarly varied, with Blue-eared Barbet (*Psilopogon armillaris*) producing calls from 1901 to 3041 Hz, and Pygmy Wren-Babbler (*Pneopyga pusilla*) from 5055 to 7377 Hz.

Several species exhibited multiple vocal variants, indicating the use of distinct calls and songs for different behavioural contexts. For example, the Drongo Cuckoo (*Surniculus lugubris*) produced both short calls (0.65 s) and longer songs (11.71 s), with differing frequency ranges (2134–2594 Hz for calls; 1901–3041 Hz for songs). Similar patterns were observed in the Javan Banded Pitta (*Laniellus albonotatus*), Indigo Flycatcher (*Eumyias indigo*), and Crimson-breasted Flowerpecker (*Prionochilus percussus*), highlighting behavioral flexibility in vocal communication.

Nocturnal and crepuscular species, such as the Javan Owlet, produced low-frequency calls detectable at night, demonstrating that PAM can reveal temporal activity patterns not captured by traditional daytime surveys. Similarly, raptors, despite their wide-ranging behaviour, produced calls that were captured during early morning hours, likely associated with territorial or mating displays.

### Patterns Across Functional Groups

Analysis of detection and vocalization patterns revealed several ecological trends: (1) raptors and large birds of prey were generally detected infrequently but emitted low-frequency, long-range calls that were identifiable from considerable distances; (2) understory insectivores, such as the Pygmy Wren-Babbler and Horsfield's Babbler, were highly vocal and frequently detected, reflecting their dense forest microhabitat and reliance on acoustic signalling; (3) canopy and frugivorous species, including Blue-winged Leafbird and Javan Banded Pitta, produced moderate-frequency songs of varying duration, indicating a combination of territorial signalling and mate attraction; (4) nectarivores and flowerpeckers, such as the Javan Sunbird, Crimson Sunbird, and Orange-bellied Flowerpecker, displayed high detection rates and variable call frequencies, consistent with their active foraging behaviour across flowering patches.

Overall, the integration of detection frequency and vocalization data provides a comprehensive understanding of species-specific acoustic activity, temporal patterns, and habitat use. The results underscore the importance of bioacoustic monitoring for detecting rare, nocturnal, and wide-ranging species that are difficult to observe visually, as well as for characterizing the acoustic landscape of a biodiverse forest community.

## Discussion

### Patterns of Detection Frequency and Vocal Activity

Our study revealed substantial variation in detection frequency and vocalization patterns among the 40 recorded bird species. Previous bird surveys conducted in the Cikaniki area using conventional methods reported a substantially higher number of species than detected in the present study. However, direct comparisons should be interpreted cautiously because those surveys were conducted over broader spatial scales and employed different sampling methods. The present study was based on a single acoustic recorder and focused on vocal activity during the survey period, providing complementary information on species detectability and vocal behaviour.

Species such as the Blue-eared Barbet (*Psilopogon armillaris*), Pygmy Wren-Babbler (*Pneopyga pusilla*), and Orange-bellied Flowerpecker (*Dicaeum trigonostigma*) were detected consistently across all sampling days, indicating high local abundance and frequent vocal activity. In contrast, raptors,

including the Crested Serpent Eagle, Black Eagle, and Javan Hawk-Eagle, were detected only sporadically, which is consistent with their wide-ranging behavior and lower density (Morrison *et al.*, 2021; Prawiradilaga, 2006; Syartinilia *et al.*, 2015).

The presence of nocturnal species, such as the Javan Owlet (*Glaucidium castanopterum*), and crepuscular activity observed in some understory insectivores highlight the advantage of PAM for capturing temporal niches often overlooked by visual surveys (Sugai *et al.*, 2019). These findings demonstrate that acoustic surveys can effectively detect species across different activity periods, providing a more complete picture of forest avifauna.

The detection of raptors, particularly the eagles, is noteworthy because these species typically soar at high altitudes (Prawiradilaga, 2006; Syartinilia *et al.*, 2015), often beyond the visual detection range of standard point-count surveys. Their acoustic presence suggests that vocalizations may occur at lower altitudes, such as during perching or courtship activities, or may indicate the importance of the study area as part of the habitat used by these species. Previous studies have shown that raptor vocal activity can be highly context-dependent, often peaking during the early morning or breeding season (Morrison *et al.*, 2021). Therefore, integrating acoustic monitoring with spatial data can improve understanding of raptor habitat use in fragmented landscapes.

The patterns observed in Cikaniki are broadly consistent with findings from PAM studies conducted in other tropical montane forests, where understory insectivores and small forest-dependent passerines often exhibit high vocal activity and detection frequencies during morning recording periods. Similar studies have shown that species detectability is strongly influenced by vocal behaviour, habitat use, and vertical forest stratification, with acoustically active understory species generally being detected more consistently than highly mobile canopy species. These results support the value of PAM for documenting avian communities in structurally complex montane forests, where visual detection can be challenging due to dense vegetation and rugged terrain (Darras *et al.*, 2018; Pérez-Granados & Traba, 2021).

**Vocalization Variation and Behavioural Ecology**

The substantial variation in call and song characteristics among species reflects both ecological specialization and behavioural adaptations. Short, high-frequency calls, such as those of the Velvet-fronted Nuthatch (*Sitta frontalis*), are likely adapted for communication in dense understory environments, minimizing attenuation and masking by vegetation (Morton, 1975). In contrast, long-duration, low-frequency songs, as observed in Javan Partridge (*Arborophila javanica*) and Orange-breasted Trogon (*Harpactes oreskios*), can propagate over greater distances, facilitating territory defence or mate attraction across fragmented habitats (Catchpole & Slater, 2008).

Several species exhibited multiple vocal variants. For instance, the Drongo Cuckoo (*Surniculus lugubris*) and Indigo Flycatcher (*Eumyias indigo*) produced distinct calls and songs, suggesting context-specific signalling. Such multimodal acoustic strategies are common in tropical forest birds, often associated with territoriality, predator deterrence, or reproductive signaling (Slabbekoorn *et al.*, 2002).

Analysis of detection frequency and vocalization patterns across functional groups revealed clear ecological trends. Understory insectivores, such as the Pygmy Wren-Babbler and Horsfield's Babbler (*Malacocincla sepiaria*), were highly vocal and consistently detected, reflecting both dense habitat specialization and reliance on acoustic signalling for communication. Canopy frugivores and nectarivores, including Blue-winged Leafbird (*Chloropsis moluccensis*) and Javan Banded Pitta (*Laniellus albonotatus*), exhibited moderate detection rates, consistent with their mobility and feeding ecology (Holmes *et al.*, 2014). Flower-visiting species, such as Javan Sunbird (*Aethopyga eximia*) and Crimson Sunbird (*Aethopyga siparaja*), were actively detected during flowering periods, underscoring temporal variation in vocal activity linked to resource availability (Kissling *et al.*, 2010).

**Conservation Implications and Future Directions**

The present PAM survey detected 40 species, representing approximately 22.9% of the 175 bird species previously reported from the Cikaniki area. Although direct comparisons with previous inventories are difficult because they were conducted at different locations and spatial scales using different survey methods, the results demonstrate the potential of PAM to document bird diversity and vocal activity in tropical montane forests.

These findings have several implications for conservation and forest management. The detection of rare or infrequently encountered species, including raptors and nocturnal birds, highlights the value of acoustic monitoring for assessing species presence and habitat quality (Sugai *et al.*, 2019). Species with consistently high detection frequencies, such as understory insectivores and flowerpeckers, may also serve as useful indicators of ecological integrity. In addition, species-specific vocalization data can support the development of monitoring protocols for elusive or wide-ranging species that are often underrepresented in conventional field surveys.

Despite these advantages, PAM should be viewed as a complementary tool rather than a replacement for traditional survey methods. Species with low vocal activity, cryptic

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behavior, or infrequent calling may be under-detected, while environmental noise, weather conditions, and habitat structure can influence detectability (Darras *et al.*, 2018). Future studies integrating acoustic monitoring with point counts, visual observations, and multi-site sampling would provide a more comprehensive assessment of bird communities and allow a more robust evaluation of the effectiveness of different survey approaches.

## Conclusion

This study demonstrates that PAM is an effective approach for documenting both common and elusive bird species in montane tropical forests, including raptors, nocturnal birds, understory insectivores, and nectarivores. By combining species detection frequency with quantitative measurements of vocal duration and frequency range, the study provides robust baseline information on avian community composition and vocal behaviour in Cikaniki. These findings are valuable for long-term biodiversity monitoring, enabling the detection of temporal changes in species presence and acoustic activity. More broadly, the results highlight the potential of PAM to support adaptive management, ecological assessment, and conservation planning for bird communities in Cikaniki and other similar tropical forest habitats.

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**Author contribution** IPN: Data curation, analysis, and writing – original draft; YAM: Conceptualization, supervision, and writing – review & editing; AM: Conceptualization, supervision, writing – review & editing.

**Availability of data and materials** All data are available in the manuscript.

**Declaration of generative AI in writing process** During the preparation of this manuscript, the Authors used ChatGPT-5 to improve the English language and readability of the text. After using this tool, the Authors carefully reviewed, revised, and edited the manuscript as needed and take full responsibility for the content of the published article.

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