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Influence of forest configuration and bird exclusion on insect herbivory in Indonesian oil palm smallholdings

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Abstract. *Pradana DH, Winarni NL, Patria MP, Yasman. 2025. Influence of forest configuration and bird exclusion on insect herbivory in Indonesian oil palm smallholdings. Biodiversitas 26: 4640-4646.* The insect pest control services provided by birds may help address one biological challenge in oil palm plantations. Previous studies suggest that understory birds contribute to this ecosystem service and that forest configuration may influence their effectiveness. We investigated whether understory birds reduce insect pests and whether forest configuration affects their pest control services in six oil palm smallholdings in Indonesia. Understory birds were surveyed using the point count method at 0-200 m from adjacent forests. Herbivory rates, used as a proxy for insect pest activity, were assessed through a bird enclosure experiment. The indirect bird effect on herbivory rate was also evaluated using this experiment. We used binomial Generalized Linear Mixed Model (GLMM) to analyze the effects of understory bird abundance and forest configuration on herbivory rates. Results showed the herbivory rate ranged from 0.01 to 0.84 mm^2. A weak negative relationship between understory bird abundance and herbivory in control treatments (z: -1.65, n: 12, p-value<0.1) was found, suggesting a limited pest control effect. However, no significant influence of forest distance or remnant size on herbivory rates was observed. Functional trait analysis revealed that the bird community was dominated by gleaners, omnivores, and large-bodied species, which are typically associated with insectivores. The absence of strong effects may be linked to small forest remnant sizes, low pest abundance, and the structural limitations of smallholder oil palm understory that limit the use of this habitat by forest understory birds. While understory birds show some potential for insect pest control, their effectiveness appears constrained under current conditions. It is clear that urgent action is needed. Habitat enhancement through reforestation and vegetation management to increase habitat connectivity, and may be necessary to support more robust pest control by bird communities in oil palm landscapes.

Keywords: Forest configuration, herbivory rate, insect pest control, oil palm smallholdings, understory birds

INTRODUCTION

One of the primary biological challenges in oil palm plantations is pest infestation, mainly caused by rodents and insects. Rats have been reported to consume male oil palm flowers (Murgianto et al. 2022) and prey on the larvae of *Elaeidobius kamerunicus*, a key pollinator that inhabits male inflorescences (Siswanto and Soetopo 2020; Gintoron et al. 2023). Insect pests also pose a major threat, causing significant leaf damage (Desa et al. 2021; Egonyu et al. 2022; Ikhsan et al. 2024). Yield losses attributed to rats can reach up to 5%, while insect pests—such as *Oryctes rhinoceros* and various leaf-eating insects—can result in much higher yield gaps, ranging from 15% to 50% (Woittiez et al. 2017). An ecologically sound and promising strategy for managing these pests is biological control through the support of natural predators.

Several bird species are capable of dispersing into and inhabiting various types of cropland including coffee (Tscharntke et al. 2015; Maas et al. 2016), cacao (Maas et al. 2016), rubber (Zhang et al. 2017), rice fields (Pradana and Mustaqim 2019), coconut (Winarni et al. 2024), and oil palm plantations (Prabowo et al. 2016; Nursyamin et al. 2023; Tohiran et al. 2024). Among these, certain bird functional groups have shown potential as natural insect pest controllers. In oil palm landscapes, Koh (2008) reported that birds helped reduce insect herbivory in one-year-old seedlings, as plots excluding birds experienced greater damage than control plots. In contrast, Denmead et al. (2017) found no significant difference in herbivory between bird-excluded and control plots in smallholdings with 2-3-year-old palms. These differing results suggest that younger oil palms may be more susceptible to insect herbivory, highlighting the importance of focused research on avian pest control services, particularly in the early stages of plantation development.

Various ecological and functional traits shape the effectiveness of bird-mediated pest control. Notably, bird functional traits are a critical determinant of pest control efficiency (Philpott et al. 2009; van Bodegom and Price 2015). Philpott et al. (2009) highlighted that birds with gleaning foraging strategies, omnivorous diets, use of multiple vegetation strata, and smaller body sizes were more effective in controlling insect pests in coffee and cacao systems. In oil palm plantations, birds that forage in the understory (hereafter, understory birds) may play a similarly vital role. For instance, the Greater Coucal (*Centropus sinensis*) and Lesser Coucal (*C. bengalensis*) feed on leaf-eating pests such as *Setothosea asigna* (de Chenon and Susanto 2006) and are known as understory foragers (Payne 2020a, b). Nevertheless, empirical validation of their pest control contributions in oil palm systems remains limited.

Beyond functional traits, spatial landscape features such as forest configuration, including remnant size and proximity, can influence pest control dynamics. Nurdiansyah et al. (2016) found that pest control by insectivorous predators declined with increasing distance from the forest edge in oil palm smallholdings. Similarly, Gray and Lewis (2014) reported a weak negative correlation between forest remnant size and pest control efficacy. Both studies used dummy caterpillar experiments to assess predation pressure. In addition, forest area and isolation affect the diversity and abundance of understory insectivorous birds, which are particularly sensitive to habitat size and have limited dispersal capabilities (Powell et al. 2015).

A previous study by Pradana et al. (2024b) reported that forests supported higher overall abundances of insectivorous, omnivorous, and canopy-dwelling birds, whereas understory bird species more frequently inhabited oil palm smallholdings. This pattern suggests that understory birds may potentially play a particularly important role in providing pest control services within modified agricultural landscapes. Based on these findings, Pradana et al. (2024b) recommended that future research should explore how the quality and proximity of forest remnants influence herbivory rates and clarify the functional roles of different bird guilds in ecological pest management within oil palm systems. In response to this recommendation, the present study focused on evaluating the contribution of understory birds to insect pest control in oil palm smallholdings. Specifically, we investigated whether forest configuration, defined by the size and proximity of adjacent forest patches, affects the capacity of understory birds to reduce herbivory on oil palm seedlings. To address this, we implemented a bird enclosure experiment to directly measure avian pest control services in relation to landscape structure.

This study addresses the question of how forest configuration, specifically the size and proximity of forest patches, influences the role of understory birds in reducing insect herbivory in early-stage oil palm smallholdings. The research aims to (i) investigate the specific contribution of understory birds to insect pest control, (ii) assess the relationship between forest configuration and the presence and function of this bird group, (iii) provide ecological insights to support the development of bird-based Integrated Pest Management (IPM) strategies in oil palm landscapes. We hypothesize that oil palm smallholdings located closer to larger or more connected forest patches will support a higher abundance of understory birds, resulting in lower levels of insect herbivory compared to those farther from forest remnants.

MATERIALS AND METHODS

Study period and location

This study was conducted in six oil palm smallholdings: four in Bengkalis District, Riau Province, and two in Katingan District, Central Kalimantan Province, Indonesia (Figure 1). These two provinces have high oil palm smallholdings areas (Badan Pusat Statistik 2024) and have been experiencing high forest loss rates since 2005 (Tsujino et al. 2016). Fieldwork in Bengkalis took place from 14 September to 14 October 2022, while in Katingan it was conducted from 23 September to 20 October 2023.

Procedures

All smallholdings were adjacent (0 km) to relatively small forest remnants, ranging in size from approximately 0.34 to 35.41 ha. The smallholdings themselves were also relatively small, ranging from approximately 0.14 to 4.46 ha. These area estimates were obtained using satellite imagery via Google Earth Engine. We only measured the area of forest remnants adjacent to the smallholdings (within a 0.2 km radius). We used satellite images from Landsat. The minimum distance between sampling sites was 0.2 km. In Sumatra, smallholders did not apply fertilizers or insecticides, and the understory vegetation (weeds) was maintained at less than 1 m in height. In contrast, smallholders in Kalimantan applied fertilizers and insecticides once every six months, with a similar understory weed height of less than 1 m.

We used a bird enclosure experiment to assess the pest control service provided by birds. The exclusion treatment consisted of a 1-year-old oil palm seedling, approximately 1 m tall, placed inside a cage constructed from four 1.2 m wooden poles and covered with a polyethylene net (25x25 mm mesh size) (Figure 2). The mesh size was small enough to prevent understory birds from entering the cage. A seedling of the same age and height, left uncaged, served as the control treatment. At each smallholding, one bird enclosure and one control seedling were placed at the edge of the plantation and adjacent forest remnants (distance to forests was 0 m), and another pair at a distance of 200 m from the edge (Figure 3). The enclosures were checked for structural integrity at least three times a week.

On each seedling, 20 undamaged leaflets were randomly selected and marked at the base using a waterproof marker. The treatments lasted for three weeks at each site. At the end of this period, the marked leaflets were collected and photographed following Koh (2008) and Pradana et al. (2024a). The images were analyzed using ImageJ software (Rasband 2018) to quantify the area of missing lamina. Herbivory rate was calculated as the missing lamina area per leaflet per day. Pest control service by birds was quantified as the reduction in herbivory in control seedlings compared to enclosure treatments.

To assess the presence and activity of understory birds, the first author (who has had experience in bird surveys in Sumatra and Kalimantan) conducted point counts within a 50 m radius around each bird enclosure. Each observation lasted 15 minutes and was performed twice per site, in the morning (06:00-08:00) and in the afternoon (15:00-17:00), so that each bird enclosure was visited four times. All understory bird species seen or heard were recorded.

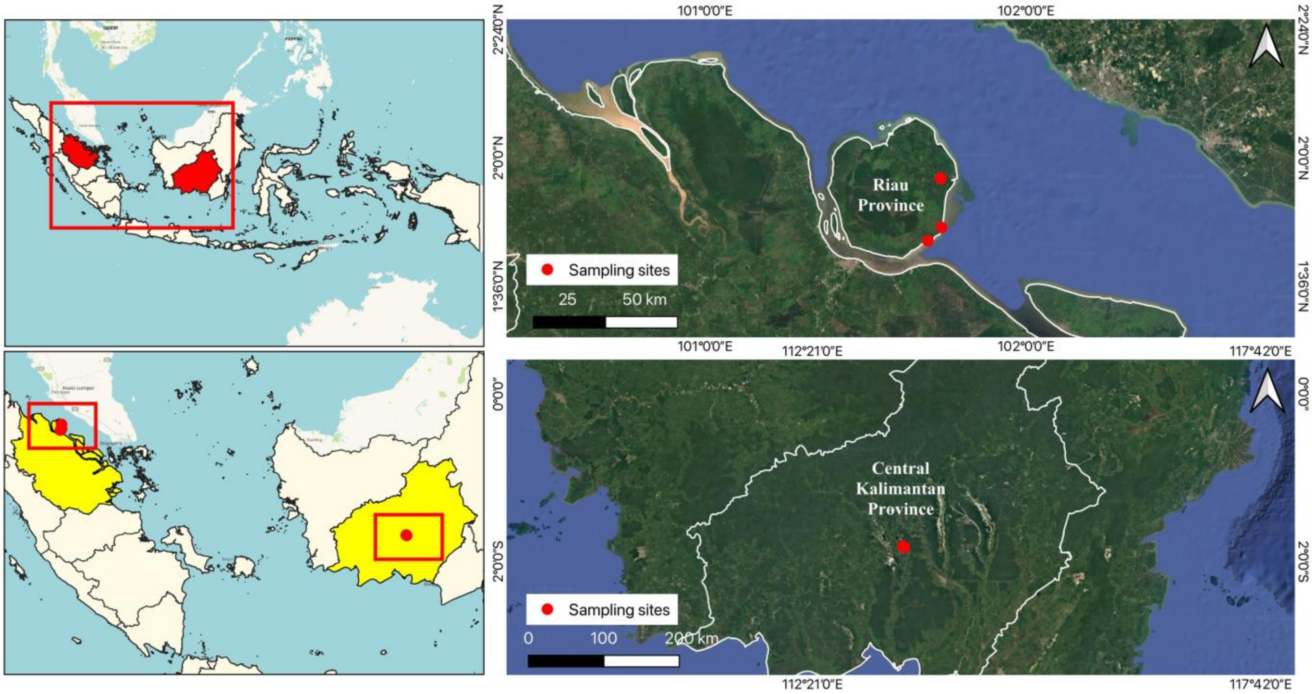

Figure 1. The smallholding sampling sites in Sumatra and Kalimantan (solid circles), Indonesia

Figure 2. Example of a bird enclosure used in the present study

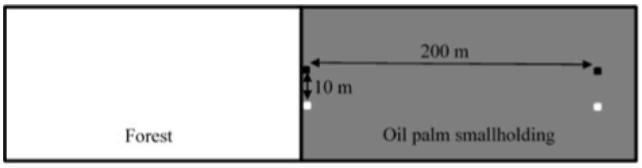

Figure 3. Illustration of bird enclosure (solid squares) and control treatment (hollow squares) configuration within each oil palm smallholding

Each recorded bird species was classified into functional groups based on foraging maneuver (gleaning or sallying), body mass (tiny, small, medium, large, or extra-large; Philpott et al. 2009), and diet (insectivore, omnivore, or carnivore) using data from Birds of the World (2022).

Data analysis

We visualized understory bird species and functional group data using the circlize package (Gu 2014) in R version 4.2.2 (R Core Team 2022). To analyze the effect of understory birds on herbivory, we used a Binomial Generalized Linear Mixed Model (GLMM) via the GLMM package (Knudson 2022). The response variable was the herbivory rate of the control treatment (which birds could access), with understory bird abundance as the fixed effect and sampling site as a random effect. To examine whether forest configuration (forest adjacent to the smallholding, i.e., 0 m from it) influenced the pest control service, we conducted another binomial GLMM with the herbivory rate of the control treatment as the response variable. The fixed effects included the interaction between understory bird abundance and forest configuration, and the sampling site was included as a random effect.

Lastly, we used a third binomial GLMM to test the direct effect of forest configuration on herbivory. Here, the response variable was the herbivory rate of both the bird enclosure and control treatments. Fixed effects included the interaction between treatment and forest configuration, with sampling sites treated as a random effect.

RESULTS AND DISCUSSION

We recorded 29 individual birds from nine understory species across the Bengkalis and Katingan Districts oil palm smallholding sites. Ten birds from four species (i.e., *Halcyon smyrnensis*, *Todiramphus chloris*, *Prinia flaviventris,* and *Acridotheres javanicus*) were found at Bengkalis, while 19 birds from eight species (i.e., *Phaenicophaeus sumatranus, C. sinensis*, *H. smyrnensis*, *Mixornis gularis*, *Macronus ptilosus*, *P. flaviventris, Lanius schach* and *A. javanicus*) were found at Katingan sampling sites. We did not observe any insects on the leaflets of the enclosure or control seedlings. Only signs of herbivory were observed, i.e., chewing on leaflets. Herbivory rates ranged from 0.01 to 0.84 mm^2 or 0 to 1.2% per leaflet per day. This rate is lower than previous studies by Koh (2008), who reported 0 to 21% herbivory rates, and by Denmead et al. (2017), who reported herbivory rates ranged from 0 to 4.8%. On average, herbivory in control plots was slightly higher (0.23±0.30 mm^2) than in bird exclusion plots (0.19±0.25 mm^2) (supplementary data can be accessed upon request from the first author). Although this suggests a trend toward reduced herbivory in the presence of birds, the difference was not statistically significant. A binomial GLMM showed a weak negative relationship between understory bird abundance and herbivory rate (z: -1.65, p-value: 0.09; Figure 4). While this result indicates only marginal support for bird-mediated pest suppression, the trend aligns with ecological expectations and warrants further investigation, especially under higher pest pressure scenarios. Bird predation has been shown to be more effective under moderate pest densities, but less so when prey availability is minimal (Mols and Visser 2002). This may partially explain the limited pest control signal detected in our study. It is possible that in areas experiencing higher pest pressure, the contribution of understory birds would become more evident.

Species richness was notably lower in Bengkalis District (4 species) compared to Katingan District (8 species), suggesting regional differences in habitat complexity and forest connectivity. Notably, the Collared Kingfisher (*T. chloris*) was observed exclusively in Bengkalis. At the same time, the Chestnut-bellied Malkoha (*P. sumatranus*), Greater Coucal (*C. sinensis*), Pin-striped Tit-Babbler (*M. gularis*), Fluffy-backed Tit-Babbler (*M. ptilosus*), and Long-tailed Shrike (*L. schach*) were found only in Katingan (Figure 5, Table 1). These contrasting species distributions are likely influenced by the availability and size of forest remnants in the surrounding landscapes, ranging from just 0.34 to 6.50 ha in Bengkalis, versus 30.44 to 35.41 ha in Katingan. Understory bird species are known to be particularly sensitive to habitat area, edge effects, and connectivity (Powell et al. 2015), which may explain the higher species richness and diversity in Katingan.

Of particular interest was the Greater Coucal (*C. sinensis*), which has been previously documented as a predator of *S. asigna*, a notable oil palm defoliator (de Chenon and Susanto 2006). Although only two individuals were recorded, both were observed in proximity to larger forest remnants. This is consistent with prior findings suggesting that *C. sinensis* is infrequently encountered in plantation areas, likely due to its reliance on denser, semi-natural vegetation (Payne 2020b). The Lesser Coucal (*C. bengalensis*), another species known to prey on oil palm pests, was not detected in this survey or the earlier study by Pradana et al. (2024b). Its absence may reflect local population constraints or the lack of suitable habitat conditions within the surveyed landscape.

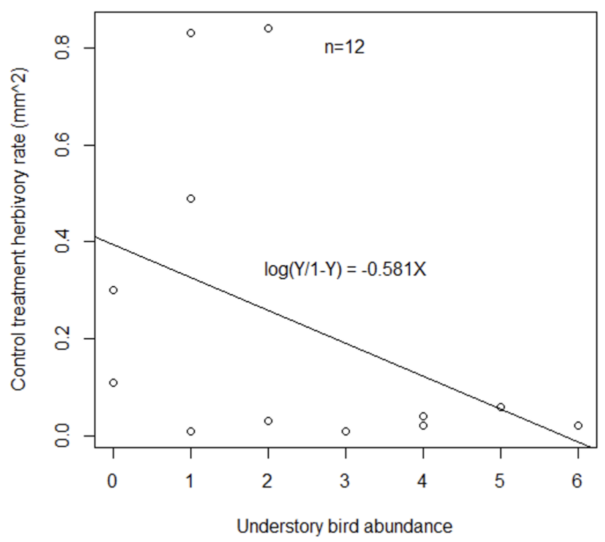

Figure 4. Relationship between herbivory rate and understory bird abundance

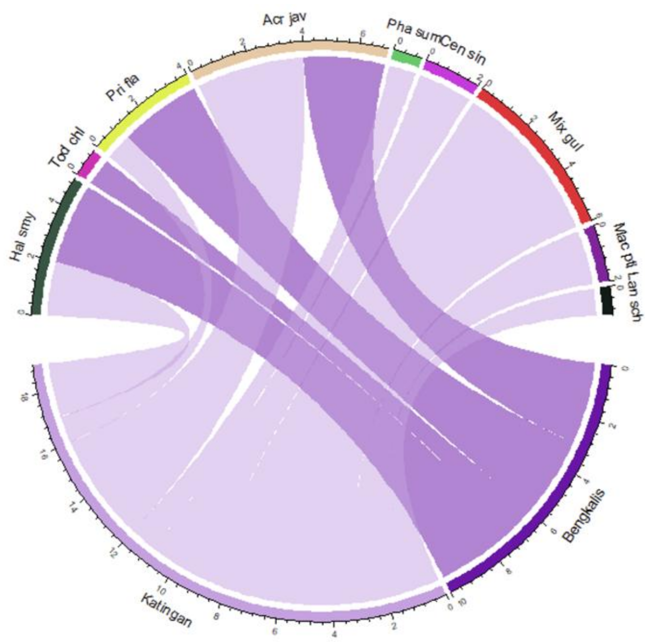

Figure 5. Chord diagram of understory bird species found at our sampling sites. The outer axis is bird abundance. Hal smy: *Halcyon smyrnensis*, Tod chl: *Todiramphus chloris*, Pri fla: *Prinia flaviventris*, Acr jav: *Acridotheres javanicus*, Pha sum: *Phaenicophaeus sumatranus*, Cen sin: *Centropus sinensis*, Mix gul: *Mixornis gularis*, Mac pti: *Macronus ptilosus*, Lan sch: *Lanius Schach*

Functional trait analysis revealed a dominance of gleaning omnivorous species with relatively large body sizes (Figure 6). This pattern supports the idea that these traits are particularly relevant for ecological pest suppression services. The Greater Coucal, for example, is both a large-bodied omnivore and a ground forager capable of preying on a variety of arthropods and small vertebrates, further suggesting its potential as a pest control agent (Payne 2020b). These functional traits, gleaning and omnivores, are recognized as critical for effective insectivores in agroecosystems, particularly in structurally simplified environments such as oil palm plantations (Karp et al. 2013; Maas et al. 2016).

However, neither forest distance nor remnant forest area, alone or in combination with bird abundance, significantly influenced herbivory rates (Table 2). This finding is consistent with studies by Nurdiansyah et al. (2016), who reported limited impacts of forest distance on avian pest control services in oil palm landscapes, and Gray and Lewis (2014), who found only marginal improvements in pest suppression with increasing riparian forest width. These outcomes may reflect the limited ecological capacity of small and isolated forest patches (<50 ha) to support sufficiently abundant and functionally effective bird communities. In contrast, Karp et al. (2013) demonstrated positive effects of large, contiguous forest areas (570,000 ha) on bird-mediated pest control in Costa Rican coffee systems, emphasizing the importance of landscape context and scale.

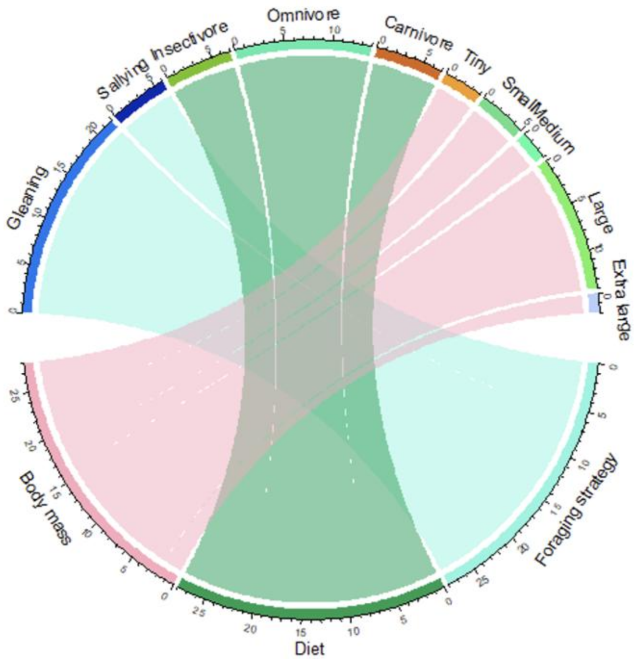

Figure 6. Chord diagram of understory bird's functional groups on the sampling sites. The outer axis is an individual number

Table 1. Functional group and abundance of understory bird species on the sampling sites

Species	Diet	Feeding strategy	Body size	Individual number	
				Katingan	Bengkalis
Phaenicophaeus sumatranus	Insectivore	Gleaning	Large	1	0
Centropus sinensis	Omnivore	Gleaning	Extra Large	2	0
Halcyon smyrnensis	Carnivore	Sallying	Large	2	3
Todiramphus chloris	Carnivore	Sallying	Large	0	1
Mixornis gularis	Omnivore	Gleaning	Small	6	0
Macronus ptilosus	Insectivore	Gleaning	Medium	2	0
Prinia flaviventris	Insectivore	Gleaning	Tiny	1	3
Lanius schach	Carnivore	Gleaning	Medium	1	0
Acridotheres javanicus	Omnivore	Gleaning	Large	4	3
Total individual number				19	10
Total species number				8	4

Table 2. Effect of forest configuration interaction with understory bird abundance and treatment on herbivory rate

Response ~ fixed effect: fixed effect	z	p	Random effect	z	p
Control herbivory rate ~ Understory: Far	-1.16	0.25	Sites	0.50	0.31
Control herbivory rate ~ Understory: Near	-1.07	0.29			
Control herbivory rate ~ Understory: Area	-1.12	0.26	Sites	0.81	0.21
Herbivory rate ~ Bird enclosure: Far	-1.56	0.11	Sites	0.55	0.29
Herbivory rate ~ Control: Far	-1.53	0.13			
Herbivory rate ~ Bird enclosure: Near	-0.79	0.43			
Herbivory rate ~ Control: Near	-0.93	0.36			
Herbivory rate ~ Bird enclosure: Area	-1.26	0.21	Sites	0.75	0.23
Herbivory rate ~ Control: Area	-1.23	0.21			

Another important factor is vegetation structure. In our study, forest remnants had understory vegetation exceeding 1 m in height, while vegetation within oil palm plantations was lower and less complex. Such vertical and horizontal structural differences may reduce habitat suitability for many understory birds, thereby limiting their foraging activity and effectiveness in pest suppression (Powell et al. 2015). However, excessive weed growth in oil palm can also foster pest outbreaks by providing alternative hosts (Rahutomo et al. 2023). Hence, maintaining a balance, promoting low yet diverse ground cover between rows, may help support avian activity while minimizing pest harboring conditions.

While this study offers valuable insights into the role of understory birds in pest control within oil palm smallholdings, several limitations should be acknowledged. First, the research was conducted in the same oil palm smallholdings as the previous study by Pradana et al. (2024b), which may limit the generalizability of the findings to other landscapes with different forest configurations. This restricted spatial context could partly explain the weak, non-significant negative relationship observed between understory bird abundance and herbivory rates. Second, the study's relatively small sample size and short duration may have constrained its ability to detect more nuanced ecological patterns. Additionally, bird surveys were limited to daytime observations, potentially overlooking crepuscular or cryptic species that may also contribute to pest suppression. Third, while the bird enclosure experiment provided useful data, it only captured short-term herbivory on young oil palm seedlings, which may not accurately reflect pest pressures over the entire crop cycle. The role of other natural enemies, such as arthropod predators and parasitoids, was also not assessed, making it difficult to isolate the contribution of birds to pest control. The enclosure may also exclude other vertebrate insect-predators such as bats. Lastly, differences in forest remnant quality, vegetation structure, and levels of human disturbance were not quantified in detail, which could have influenced bird activity and associated ecosystem services. Despite these limitations, the study's findings could significantly impact pest control strategies in oil palm smallholdings. Future research should address these limitations by incorporating longer-term studies, broader geographic sampling, multi-taxon assessments, and more detailed analyses of landscape and habitat complexity to better evaluate the full ecological role of birds in pest regulation.

In conclusion, this study provides some evidence that understory birds may contribute to insect pest suppression in oil palm smallholdings. Forest configuration, specifically remnant size and proximity, did not significantly affect avian pest control, likely due to small sample sizes, the small and possibly degraded nature of the forest remnants, low vegetation complexity within plantations, and generally low pest abundance at the study sites. Although some bird species with potentially relevant functional traits were recorded, these environmental constraints may have limited their effectiveness as natural enemies. To enhance avian-mediated pest control, efforts should focus on improving habitat quality, such as preserving larger forest remnants, increasing structural vegetation diversity, and incorporating non-host understory vegetation. Future research should expand to more heterogeneous landscapes, include longer-term data, and consider interactions with other natural enemies to evaluate better and optimize the role of birds in integrated pest management systems. Our study indicates that preserving small forests adjacent to oil palm smallholdings may not affect insect pest control service by understory birds. Retention of large adjacent forests may increase this service, and also make the oil palm production more sustainable.

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REFERENCES

Badan Pusat Statistik. 2024. Indonesian Oil Palm Statistics 2023. Badan Pusat Statistik, Jakarta. [Indonesian]

Birds of the World. 2022. Birds of the World. https://birdsoftheworld.org/bow/home.

de Chenon RD, Susanto A. 2006. Ecological observations on diurnal birds in Indonesian oil palm plantations. J Oil Palm Res (Special Issue-April 2006): 122-143.

Denmead LH, Darras K, Clough Y, Diaz P, Grass I, Hoffmann MP, Nurdiansyah F, Fardiansah R, Tscharntke T. 2017. The role of ants, birds and bats for ecosystem functions and yield in oil palm plantations. Ecology 98 (7): 1945-1956. DOI: 10.1002/ecy.1882.

Desa H, Dahari N, Hanani N. 2021. Knowledge level on bagworm in oil palm and its control using integrated pest management (IPM) practices among independent oil palm smallholders in Johor. Malays J Soc Sci Hum 6 (11): 296-305. DOI: 10.47405/mjssh.v6i11.974.

Egonyu JP, Baguma J, Martínez LC, Priwiratama Subramanian HS, Tanga CM, Anankware JP, Roos N, Niassy S. 2022. Global advances on insect pest management research in oil palm. Sustainability 14 (23): 16288. DOI: 10.3390/su142316288.

Gintoron CS, Mohammed MA, Sazali SN, Deka EQ, Ong KH, Shamsi IH, King PJH. 2023. Factors affecting pollination and pollinators in oil palm plantations: A review with an emphasis on the *Elaeidobius kamerunicus* Weevil (Coleoptera: Curculionidae). Insects 14 (5): 454. DOI: 10.3390/insects14050454.

Gray CL, Lewis OT. 2014. Do riparian forest fragments provide ecosystem services or disservices in surrounding oil palm plantations? Basic Appl Ecol 15: 693-700. DOI: 10.1016/j.baae.2014.09.009.

Gu Z. 2014. Circlize implements and enhances circular visualisation in R. Bioinformatics 30 (19): 2811-2812. DOI: 10.1093/bioinformatics/btu393.

Ikhsan Z, Syarif Z, Jaya AP, Aisyah S, Yudha PA, Rizki K. 2024. The effectiveness of fruit traps as a trap to oil palm leaf-eating caterpillars (OPLEC) in Dharmasraya District, Indonesia. IOP Conf Ser: Earth Environ Sci 1346: 012018. DOI: 10.1088/1755-1315/1346/1/012018.

Karp DS, Mendenhall CD, Sandi RF, Chaumont N, Ehrlich PR, Hadly EA, Daily GC. 2013. Forest bolster bird abundance, pest control and coffee yield. Ecol Lett 16: 1339-1347. DOI: 10.1111/ele.12173.

Knudson C. 2022. GLMM: Generalized Linear Mixed Model via Monte Carlo Likelihood Approximation. R Package Version 1.4.4. https://CRAN.R-project.org/package:glmm.

Koh LP. 2008. Birds defend oil palms from herbivorous insects. Ecol Appl 18: 821-825. DOI: 10.1890/07-1650.1.

Maas B, Karp DS, Bumrungsri S, Darras K, Gonthier D, Huang JC-C, Lindell CA, Maine JJ, Mestre L, Michel NL, Morrison EB, Perfecto I, Philpott SM, Sekercioglu CH, Silva RM, Taylor PJ, Tscharntke T, van Bael SA, Whelan CJ, Williams-Guillen K. 2016. Bird and bat predation services in tropical forests and agroforestry landscapes. Biol Rev 91: 1081-1101. DOI: 10.1111/brv.12211.

Mols CM, Visser ME. 2002. Great tits can reduce caterpillar damage in apple orchards. J Appl Ecol 39 (6): 888-99. DOI: 10.1046/j.1365-2664.2002.00761.x.

Murgianto F, Edyson E, Putra SK, Ardiyanto A. 2022. Role of the barn owl *Tyto alba* javanica as a biological agent for rat pest control in the oil palm plantation of Bumitama Agri Ltd. IOP Conf Ser: Earth Environ Sci 985: 012048. DOI: 10.1088/1755-1315/985/1/012048.

Nurdiansyah F, Denmead LH, Clough Y, Wiegand K, Tscharntke T. 2016. Biological control in Indonesian oil palm potentially enhanced by landscape context. Agric Ecosyst Environ 232: 141-149. DOI: 10.1016/j.agee.2016.08.006.

Nursyamin Z, Yahya MS, Atikah SN, Tohiran KA, Norhisham AR, Othman NW, Lechner AM, Azhar B. 2023. Identifying indicator bird species for sustainable oil palm plantation certification. J Clean Prod 415: 137852. DOI: 10.1016/j.clepro.2023.137852.

Payne RB. 2020a. Greater coucal (*Centropus sinensis*), version 1.0. In: del Hoyo J, Elliott A, Sargatal J, Christie DA, de Juana E (eds). Birds of the World. Cornell Lab of Ornithology, Ithaca. DOI: 10.2173/bow.grecou1.01.

Payne RB. 2020b. Lesser coucal (*Centropus bengalensis*), version 1.0. In: del Hoyo J, Elliott A, Sargatal J, Christie DA, de Juana E (eds). Birds of the World. Cornell Lab of Ornithology, Ithaca. DOI: 10.2173/bow.lescou1.01.

Philpott SM, Soong O, Lowenstein JH, Pulido AL, Lopez DT, Flynn DFB, DeClerck F. 2009. Functional richness and ecosystem services: Bird predation on arthropods in tropical agroecosystems. Ecol Appl 19: 1858-1867. DOI: 10.1890/08-1928.1.

Powell LL, Cordeiro NJ, Stratford JA. 2015. Ecology and conservation of avian insectivores of the rainforest understory: A pantropical perspective. Biol Conserv 188: 1-10. DOI: 10.1016/j.biocon.2015.03.025.

Prabowo WE, Darras K, Clough Y, Toledo-Hernandez M, Arlettaz R, Mulyani YA, Tscharntke T. 2016. Bird responses to lowland rainforest conversion in Sumatran smallholder landscapes, Indonesia. Plos One 11 (5): e0154876. DOI: 10.1371/journal.pone.0154876.

Pradana DH, Mustaqim WA. 2019. A purple heron *Ardea purpurea* with a rare type of the pigment deficiency 'dilution'. Birding ASIA 32: 126.

Pradana DH, Patria MP, Yasman, Winarni NL. 2024a. Bird functional groups can reduce insect pests in oil palm smallholdings in Rupat Island, Riau Province, Indonesia. J Oil Palm Res [in press]. DOI: 10.21894/jopr.2024.0053.

Pradana DH, Patria MP, Yasman, Winarni NL. 2024b. The spillover effect of bird functional groups on oil palm smallholdings in Indonesia. Biodiversitas 25 (12): 5055-5062. DOI: 10.13057/biodiv/d251243.

R Core Team. 2022. R: A Language and Environment for Statistical Computing. https://www.R-project.org.

Rahutomo S, Pradiko I, Farrasati R, Syarovy M, Donough CR, Sugianto H, Grassini P. 2023. Pocket Guide Book Indonesia Oil Palm Smallholders. Indonesian Oil Palm Research Institute and University of Nebraska-Lincoln, Lincoln.

Rasband WS. 2018. ImageJ Version 1.52a. https://imagej.nih.gov/ij/.

Siswanto, Soetopo D. 2020. Population of oil palm pollinator insect (*Elaeidobius kamerunicus* Faust.) at PTP Nusantara VIII Cisalak Baru, Rangkasbitung-Banten. IOP Conf Ser: Earth Environ Sci 418: 012045. DOI: 10.1088/1755-1315/418/1/012045.

Tohiran K, Nasir DM, Burhanuddin M, Nobilly F, Zulkifli R, Moslim R, Yahya MS, Norhisham AR, Lechner AM, Azhar B. 2024. First records of diurnal and nocturnal predatory birds from artificial hunting perch trials in oil palm plantations. BioControl 69: 635-646. DOI: 10.1007/s10526-024-10279-w.

Tscharntke T, Milder JC, Schroth G, Clough Y, DeClerck F, Waldron A, Rice R, Ghazoul J. 2015. Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales. Conserv Lett 8 (1): 14-23. DOI: 10.1111/conl.12110.

Tsujino R, Yumoto T, Kitamura S, Djamaluddin I, Darnaedi D. 2016. History of forest loss and degradation in Indonesia. Land Use Policy 57: 335-347. DOI: 10.1016/j.landusepol.2016.05.034.

van Bodegom PM, Price T. 2015. A traits-based approach to quantifying ecosystem services. In: Bauma JA, van Beukering PJH (eds). Ecosystem Services: From Concept to Practice. Cambridge University Press, Cambridge. DOI: 10.1017/CBO9781107477612.005.

Winarni NL, Mitchell SL, Anugra BG, Deere NJ, Yordan K, Immanuel B, Zakaria Z, Gaib MAW, Supriatna J, Struebig MJ. 2024. Bird diversity in the forests and coconut farms of Sulawesi, Indonesia. Oryx 58 (4): 427-436. DOI: 10.1017/S0030605323000315.

Woittiez LS, van Wijk MT, Slingerland M, van Noordwijk M, Giller KE. 2017. Yield gaps in oil palm: A quantitative review of contributing factors. Eur J Agron 83: 57-77. DOI: 10.1016/j.eja.2016.11.002.

Zhang MX, Chang C, Quang RC. 2017. Natural forest at landscape scale is most important for bird conservation in rubber plantation. Biol Conserv 210: 243-252. DOI: 10.1016/j.biocon.2017.04.026.