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Seasonal Activity of Fruit Bats in a Monoculture Rubber and Oil Palm Plantation in the Southern Philippines

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Abstract: The increasing expansion of monoculture plantations poses a major threat to Asian tropical biodiversity. Yet, in many countries such as the Philippines, the ability of species to persist within plantations has never been explored. We studied the seasonal activity and response of fruit bats in two types of monocultural plantations (rubber and oil palm) in the Southern Philippines from 2016–17 for 12 months. Our mist-netting and monitoring data showed that both plantations can support cosmopolitan species of fruit bats (*Cynopterus brachyotis*, *Eonycteris spelaea*, *Macroglossus minimus*, *Ptenochirus jagori*, and *Rousettus amplexicaudatus*), yet a significant variation in the abundance and guild distribution between plantations was observed. Rubber hosted a higher bat abundance than oil palm, which may be influenced by better habitat structure of the matrix (e.g., presence of orchard and fruit plantations) and practices occurring in the rubber plantation. We find that, among seasonal climatic variables, temperature showed significant negative effects on fruit bat abundance. Our results suggest that although monoculture plantations host low diversity (i.e., richness and endemism) they still support generalists which are still ecologically important species. Furthermore, wildlife-friendly commercial plantation practices could both enhance economic growth and biodiversity conservation in the Philippines. Our data both provide the potential for long-term monitoring in the Philippines and highlight the need for more comprehensive monitoring of other bat functional groups and their ability to transverse plantations to provide a more in-depth understanding of the roles and impacts of plantations and other land-use changes.

Keywords: agriculture; biodiversity; ecological indicators; land-use change; rapid-assessment

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1. Introduction

The destruction and degradation of natural ecosystems is a major driver of species loss, at both global and local scales [1–4]. The deforestation rates in Southeast Asia are amongst the highest of any region in the tropics, and as much as three-quarters of forests may be lost by the end of the century if rates of forest loss do not decrease [5,6]. Habitat loss is one of the main threats to tropical bats [7]. A substantial proportion of bat fauna is dependent on intact stands of forest for foraging and roosting, and thus the loss of forest is a major threat [7]. The conversion of natural habitats to agricultural use and its current expansion rate in previously forested or protected areas is a growing threat to tropical biodiversity, leading to both a direct loss of habitats and fragmentation of remaining intact habitats [8,9]. Numerous studies and models have shown evidence of the negative impacts of plantations on biodiversity and ecosystem service provision, yet the expansion of commercial plantations into native systems is continuing [5,10–12]. Monoculture plantations such as rubber and oil palm are major threats to intact ecosystems in the Indomalayan region [5,13–15]. In the Philippines, both rubber and oil palm are expanding [16], particularly in the Southern and Western parts of the Archipelago (Philippine Bureau of Agricultural Statistics, 2012).

Biodiversity within plantations is lower than more intact ecosystems such as primary forests [17,18]. Yet, plantations can host generalist bat species [17,19], and the ability of bats to pass through plantations is crucial to enabling their continued survival in increasingly fragmented landscapes. The existence of clear baseline data on the impacts of plantations on Philippine wildlife including bats is limited [16,20], and the understanding of the negative effects of these land modifications is often neglected [16,21]. A large proportion of mammal fauna (~48% of native species) in the Philippines consists of bats, and the majority depend on intact forest and cave systems [16]. Agricultural conversion is second to logging as a major threat to at least 71% and 48% of Philippine bats, respectively [16]. Nonetheless, roughly half of species (47%) occur in agricultural areas, yet their ability to persist long-term and their response to the environmental conditions requires further study [22,23].

Most monitoring in agricultural habitats involves insectivorous bat activities [24]. However, there are little Philippine bat call data, and the availability of sampling resources is limited, which hinders the ability to assess the impacts of land-use changes on bats [20,25]. Philippine fruit bats (Family: *Pteropodidae*) are the most well-known group because they are relatively well-studied [20] and widely distributed in agroecosystems, making their assemblage a useful indicator of impacts of monoculture habitats such as oil palm and rubber plantation [19]. In this paper, we aim to compare seasonal activities and responses of five common fruit bat species (*Cynopterus brachyotis*, *Eonycteris spelaea*, *Macroglossus minimus*, *Ptenochirus jagori*, and *Rousettus amplexicaudatus*) to seasonal changes of climate variables in two lowland monoculture plantations. We also discuss the effects of regional long-term atmospheric temperature, humidity, precipitation, and plantation types on species-specific abundance responses.

2. Materials and Methods

2.1. The Study Site

Philippine oil palm and rubber plantations are chiefly located in the Southern part of the Philippines [16]. We monitored and collected data for fruit bat abundance each month from May 2016 to May 2017 in two small-scale commercial monoculture plantations in Makilala (6°55′40.24″ N; 124°59′7.68″ E) and Tulunan (6°50′48.35″ N; 124°51′50.08″ E) for rubber and oil palm plantations, respectively (Figure 1). Two plantations in close vicinity were selected to reduce variability between sites (landscape structure, climate, access to caves and other roosts, etc.) which could have confounded assessments of the impact of the plantation on bat abundance and diversity. A paired assessment enables exploring the impact of crop-type alone, with minimal impact from variation in the surrounding landscape. Large contiguous plantations are not common in the region, therefore we selected our monitoring sites with at least $\geq$ 50-hectare land area of the same plantation age and management practices. Both plantations are private small-holdings in the lowlands of North Cotabato Province with similar climatic conditions, surrounding land-use types, and topography (Figure 1). The climate is dry from December to May and wet from June to November. During our sampling period (May 2016 to May 2017), the Philippines experienced El Nino Southern Oscillation (ENSO) [26,27], which severely affected the southern part of the country, and irregularities in weather patterns within the sampling period may affect our monitoring records (Figure 2). During this period, the provincial maximum temperature ranged from 30.18 to 34.06 °C (Figure 2) while the precipitation (i.e., rainfall) pattern fluctuated throughout the year. Maximum air temperature and precipitation showed a significant negative correlation ($\rho = -0.41$, $p < 0.001$).

Between the two plantations, the rubber plantation was surrounded by locally managed coffee plantation (*Coffea arabica*), rice paddies (*Oryza sativa*), and patches of fruit crops such as Jackfruit (*Artocarpus heterophyllus*), Pomelo (*Citrus maxima*), and Papaya (*Carica *papaya*), as well as bat pollinated plants such as Durian (*Durio zibethinus*). The sampling site for oil palm plantation is 16.6 km south of the rubber plantation and was characterised by cleared ground, potentially for further expansion. It was surrounded by small patches of banana plantations and other fruit crops such as Papaya and Pomelo. The invasive Spiked pepper (*Piper aduncum*) covers the edges and roadsides of the oil palm plantations. Canopy plants and vines have low levels of abundance or are absent in both plantations, whereas these were observed before the El Nino [28]. Furthermore, little or no ground vegetation exists in the plantations. Temporary streams and ponds exist but were dry for most months of the sampling period.

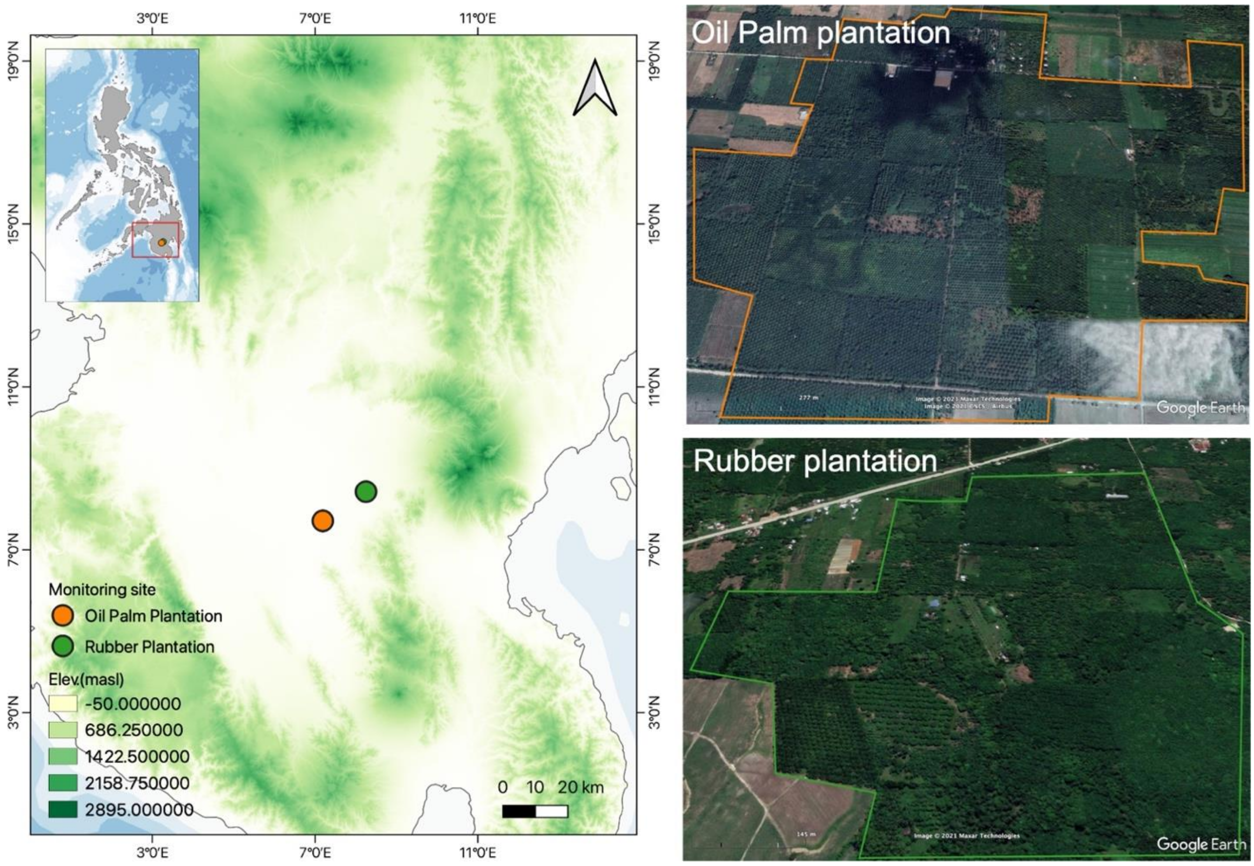

Figure 1. Map showing the monoculture oil palm and rubber plantation (right: marked aerial view) monitoring sites in North Cotabato province, Southern Philippines.

2.2. Sampling Design and Environmental Variables

We used 30 nets per night for three sequential nights per month in favourable weather. Nets were up between 1800 H and 0000 H, and 0400 H and 0700 H. We used 20 12 × 6 metre nets and 10 10 × 6 metre nets on each night to standardise capture effort [29,30]. Because of the limited area for contiguous plantations (>50 hectares) in the province, we sampled bats in a single plantation site for oil palm and rubber plantations. To reduce the bias of site replications, mist nets were redistributed to different parts of the plantation each month. We placed mist-nets with at least 50 m intervals in open areas which represented feasible flight paths such as pathways, roads, and plantation edges are more open than naturally forested areas. Mist nets were checked at least every 20 min from 1800 H to 0000 H and 0400 H to 0700 H to avoid injury and mortality of trapped fruit bats. The captured individuals were carefully untangled from the nets and placed in clean, moisture free cloth-bags for identification at the campsite. All captured bats were identified to species level using the keys of Ingle and Heaney [31], and were classified into two feeding guilds within the Old World fruit bats frugi-nectarivorous (*C. brachyotis*, *P. jagori* and *Rousettus amplexicaudatus*) or nectarivorous (*E. spelaea* and *M. minimus*) [32]. Since all were common and identifiable species, we included adults and juvenile individuals in the abundance calculations. After the bats were identified, individuals were marked with non-toxic nail polish on the right digits to avoid recounting any recaptured individuals. Insectivorous bats that were accidentally captured in the nets were immediately released.

We used records from the nearest weather station for the seasonal climatic changes to assess the effects of long-term provincial (i.e., monthly average temporal resolution) climatic conditions on fruit bat seasonal activities between plantations, e.g., Erickson and West [33] (Figure 2). We calculated minimum (min), mean, and maximum (max) daily historical daily air temperature (°C), relative humidity (%), and precipitation/rainfall (mm) (1 May 2016, to 31 May 2017) data from the nearest weather monitoring station in our study sites based in Weather Underground API using 'weatherdata' package in R studio [34].

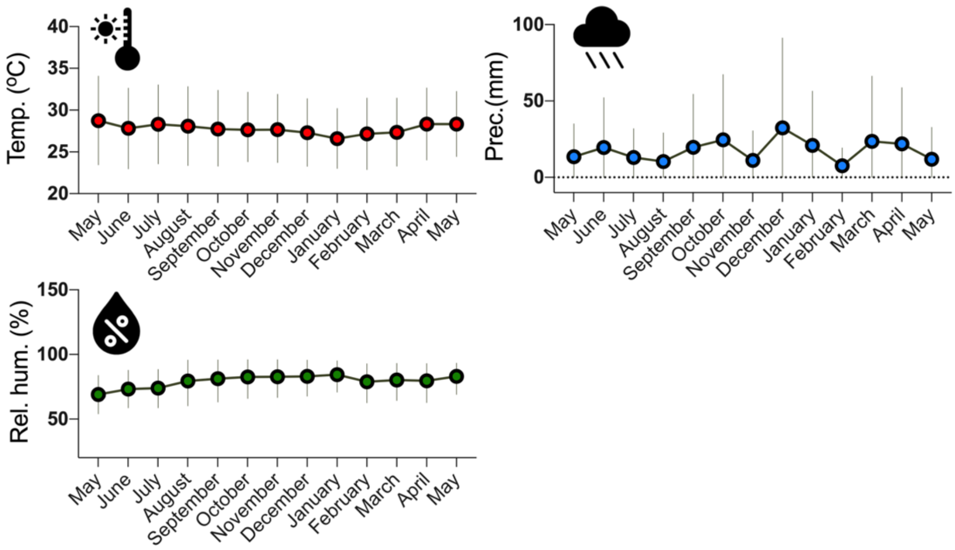

Figure 2. Seasonal monthly variation in seasonal changes in climate: temperature (°C), relative humidity (%), and precipitation (mm) during the sampling months in North Cotabato province, Southern Philippines. The circle (·) and error bars represent the monthly mean and min−max values respectively.

2.3. Data Analysis

We corrected and standardised our monthly total bat abundance data to individuals per mist net nights before data analysis. We tested data normality and performed data transformation (log_{10}) to improve distribution. However, the data normality was not consistent between plantations and seasons; therefore, we used a non-parametric test throughout the analyses. First, we implemented a Mann–Whitney U test to compare and determine the significant differences in overall capture rate and species-specific abundance (log_{10}) between plantations. We then used a Kruskal–Wallis test for each plantation to compare monthly species abundance (log_{10}) and evenness.

We used a generalised linear model (GLM) with Poisson distribution (log-link) to determine the link between seasonal bat activity and regional climatic data between plantations using the GAMLj module in the Jamovi program [35]. We used monthly mean values of air temperature (°C), humidity (%), and precipitation (mm) as covariates. Whereas guild, plantation type, and months were cofactors, we considered five models (Table 1) and selected the best model based on minimum values of corrected Akaike's Information Criterion (AICc) and Akaike weights (wAICc) [36]. We visualised and interpreted the effects in the best model by plotting the predicted effects at a 95% confidence interval. Using the same modelling approach, we modelled species-specific effects of temperature, precipitation, and plantation types. All other data analyses and visualisation were performed using the open software Jamovi 1.6 [37] and GraphPad Prism 8 [38], respectively. We set significance at $p < 0.05$.

3. Results

We captured a total of 2589 individual fruit bats of seven species, including *Cynopterus brachyotis*, *Eonycteris spelaea*, *Ptenochirus jagori*, *Macroglossus minimus* and *Rousettus amplexicaudatus,* in both plantations (Figure 3). Other fruit bat species (*Megaerops wetmorei* and *Haplonycteris fischeri*) that were occasionally captured in rubber plantations were excluded from analysis due to low sample sizes. Overall, the combined relative abundance of captured fruit bats was significantly different between oil palm and rubber plantations (Kruskal–Wallis: $\chi^2 = 10.57$, df = 1, $p < 0.001$), among species (Kruskal–Wallis: $\chi^2 = 69.13$, df = 4, $p < 0.001$), and feeding guild (Kruskal–Wallis: $\chi^2 = 36.7$, df = 1, $p < 0.001$). The rubber plantation (mean = 8.09 ± 4.86) showed an average of 31% more individuals overall than oil palm plantations (mean= 4.33 ± 3.40) (Figures 3 and 4).

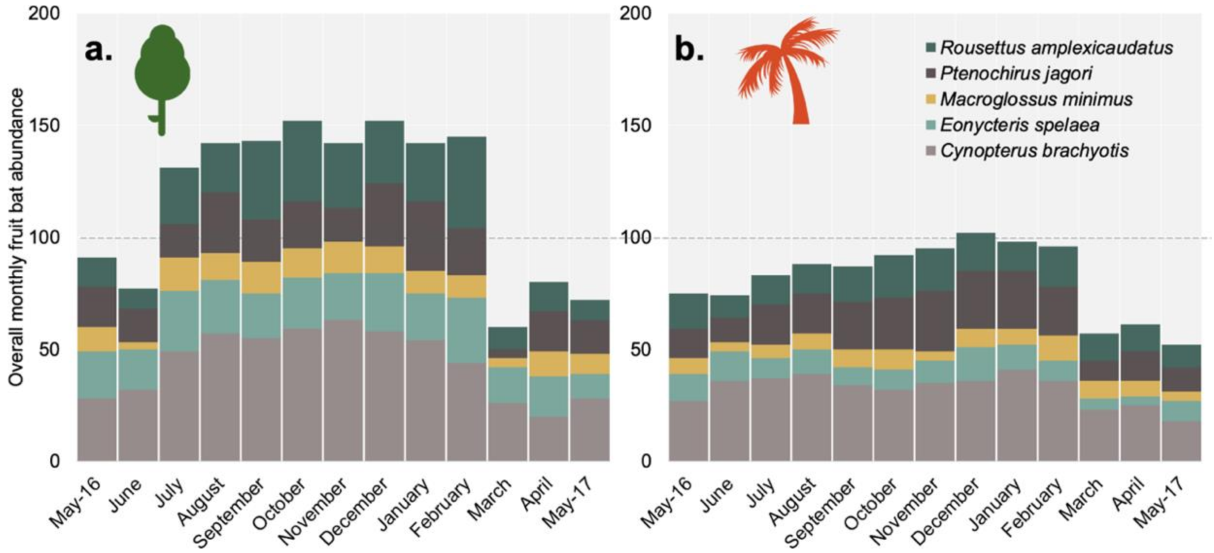

Figure 3. The species-specific proportion of overall monthly fruit bat abundance between two plantations ((**a**) rubber, (**b**) oil palm).

At a species level (Figure 4), only two species showed a significant difference between plantations (Figure 3). The frugivorous *C. brachyotis* was the most recorded species in both plantation types, but only marginally higher in the rubber plantation (mean = 15.14 ± 5) than in oil palm (mean = 11.14 ± 1.87) (Mann–Whitney U test: W = 39, $p = 0.06$). The nectarivorous *E. spelaea* was the second most abundant species and had a significantly higher abundance in rubber plantation (mean = 7.33 ± 1.31) than in oil palm plantation (mean = 3.39 ± 1.30) (Mann–Whitney U test: W = 0.00, $p < 0.01$). Similarly, the least recorded species, *M. minimus,* was significantly higher in rubber plantation (Mann–Whitney U test: W = 26, $p = 0.008$), whereas endemic frugivore *P. jagori* and *R. amplexicaudatus* did not show a significant difference in abundance between the two plantations (Figure 4).

Bat abundance peaked between September and February (Figures 3 and 4), when the temperature is relatively lower (Figure 4). This observation was supported by the best performing model showing seasonal changes in climate predicting bat abundance. We showed that temperature, precipitation, plantation types, and guild were linked to bat seasonal abundance (Table 2, Figure 5B). Both temperature and precipitation were negatively linked to bat abundance, although the regression slopes of temperature ($\beta = -0.18$, SE = 0.006, $p = 0.002$) showed higher in contrast to precipitation, which was not significant (precipitation: $\beta = -0.03$, SE = 0.02, $p = 0.151$). Similarly, with previous results, rubber plantation showed a significant positive seasonal change in abundance, which was higher than in oil palm plantation (Figure 5A). Frugi-nectarivorous bats showed a higher negative response to seasonal changes in climate than nectarivorous bats. In species-specific analyses (Figure 5B), precipitation did not show significant effects on all species, however, temperature only showed significant effects to *C. brachyotis* (β = −0.2, SE = −0.39, p = 0.02) and *Rousettus amplexicaudatus* (β = −0.32, SE = −0.59, p = 0.021). We found positive interactions between guild and plantations (β = 0.37, SE = 0.17, p = 0.029) and that rubber plantation performs better than oil palm plantation in supporting both guilds. Frugi-nectarivores are significantly more common compared to nectarivorous bats in both oil palm (Mann–Whitney U test: W = 32.50, $p < 0.01$) and rubber plantation (Mann–Whitney U test: W = 226, p = 0.02) (Figure 6). While comparing between guilds across plantations, only nectarivorous bats are significantly higher in rubber plantation compared to oil palm plantation (Mann–Whitney U test: W = 202.50, $p < 0.001$) (Figure 6).

Table 1. List of candidates generalised linear models showing the link between bat abundance to seasonal changes in climate (temperature (Temp), humidity (Hum), and precipitation (Prec)), plantation type (Plant), and guild (Gui).

Model	Terms	AICc	dAICc	RL	wAICDc
1	Mon + Temp + Hum + Prec + Guild + Plant + Plant × Gui	660.71	38.47	0.00	<0.001
2	Temp + Hum + Prec + Guild + Plant + Plant × Gui	623.59	1.35	0.51	0.335
3	Temp + Prec + Guild + Plant + Plant × Gui	622.24	0.00	1.00	0.658
4	Prec + Guild + Plant + Plant × Gui	630.19	7.95	0.02	0.012
5	Temp + Hum + Prec + Plant	712.33	90.09	0.00	<0.001
6	Temp + Hum + Prec + Gui	651.64	29.40	0.00	<0.001

Table 2. Results of the best generalised linear models (model 3) for bat abundance to seasonal changes in climate (temperature, humidity, and precipitation), plantation types, and guild. Relationships are visualised in Figure 5.

Effects	β	SE	z	*p*
(Intercept)	1.75	0.04	41.23	<0.001
Precipitation (mm)	−0.03	0.02	−1.44	0.151
Temperature (°C)	−0.18	0.06	−3.14	0.002
Guild (nectarivorous)	−0.76	0.08	−9.02	<0.001
Plantation (rubber)	0.46	0.08	5.48	<0.001
Guild × Plantation	0.37	0.17	2.18	0.029

4. Discussion

This study highlights the important role of spatial variation for bat abundance in rubber and oil palm plantations. Our monitoring showed that rubber significantly outperforms oil palm plantation in supporting seasonal abundance of fruit bats, with an apparent decrease in nectarivorous bats versus frugi-nectarivorous bats. Our modelling showed that seasonal changes in climate are associated with bat diversity, showing decreased patterns in abundance with the increasing temperature. We discuss each of these elements, including the conservation implications of monoculture expansion in the Philippines. Here, we showed the value of common and abundant species to indicate habitat disparities in both monoculture conditions. The observed overall patterns of fruit bat activity were similar to previous plantation studies in Malaysia, such as that from Syafiq et al. [19]; for example, frugi-nectarivorous (e.g., *Cynopterus brachyotis*) were more abundant compared to nectarivorous bats. However, our results differed from Azhar et al. [17], which did not record *Rousettus amplexicaudatus* and *Cynopterus* sp. in small-holder plantations, whereas *Macroglossus* spp. were absent in all plantations monitored. Rare species were only recorded in rubber plantation and, likewise, general abundance was higher, showing that they have a lower impact on species activity than oil palm.

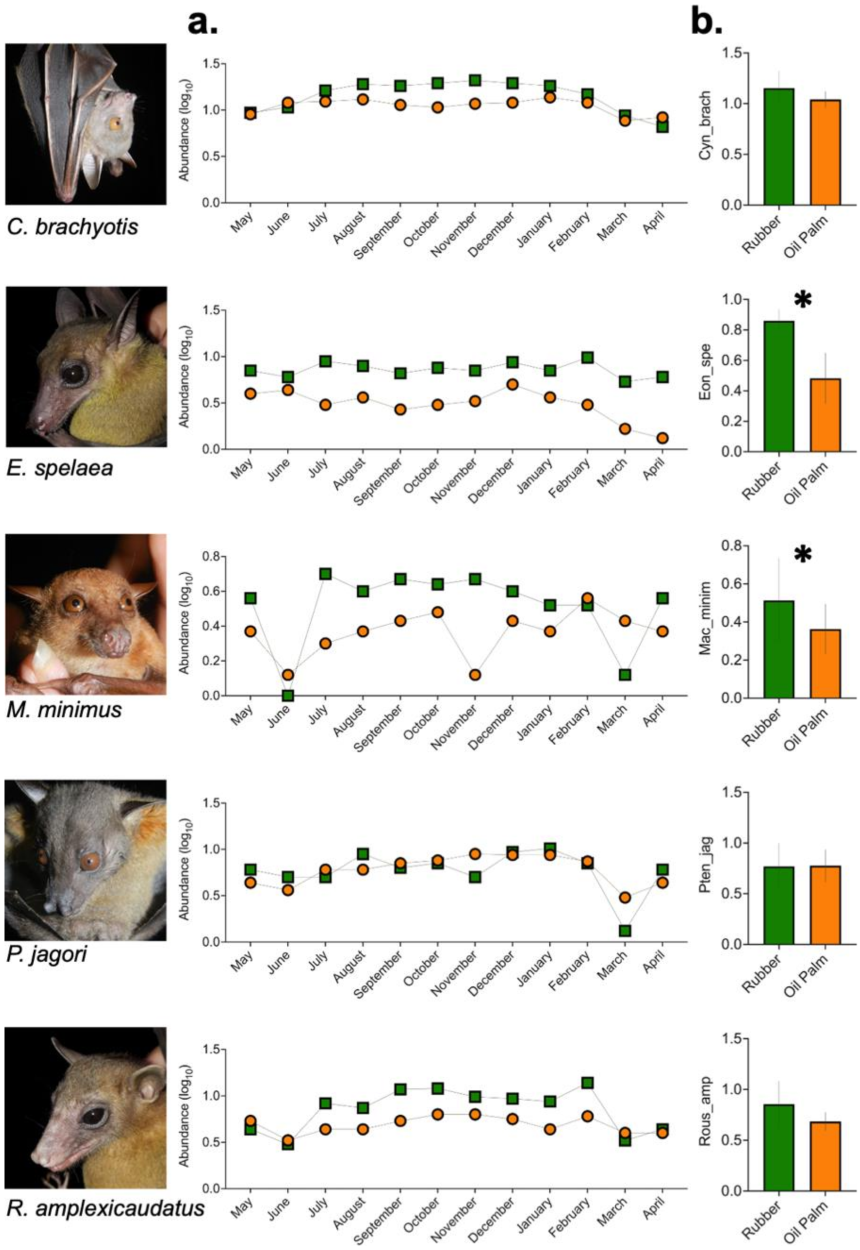

Figure 4. Species-specific comparison of seasonal fruit bat abundance across season (**a**) and between two plantations (**b**). The * indicates significance at $p < 0.05$.

Our study shows that the type of plantation compared to seasonal changes in climate has stronger effects on overall bat abundance and varies by species (Table 2, Figure 5B), suggesting that common species could potentially indicate the quality of not only contrasting habitats but also analogous habitats such as monoculture plantations. The rubber plantation supports higher bat abundance than oil palm plantation. This variation in abundance may relate to the availability of the common foraging resources and vegetation characteristics of the plantations (i.e., remaining patches within each system) [39]; for example, in our sampling sites, rubber plantation has relatively more understorey vegetation compared to oil palm, which is often bare due to frequent de-weeding. In Malaysia, polyculture smallholding plantations with more heterogeneous vegetation had 28% higher bat abundance and species richness than homogenous large-scale plantations [19]. Increased plantation crop density, the height of oil palm stands, and other direct activities have also been shown to have a negative relationship with birds and fruit bats in Malaysia [17]. In our oil palm site, we observed frequent clearings in ground vegetation and 'deleafing' (i.e., the processes of physically removing dead or excess palm oil leaves by the owners) every three-month interval, and these could contribute to a poor vegetation structure in oil palm plantation relative to rubber plantation, where some foraging plants and fruiting tress are still present. In our study, the rubber plantation performed better than oil palm plantation, however, few other studies have actively compared diversity in the two plantation types [40]. Although Phommexay et al. [41] demonstrated that insectivorous bat activity and diversity in rubber plantations is lower than in forested areas, due to lower insect biomass in rubber plantations. However, bats can show high abundance in plantations or agroecosystems by utilising various resources, for example, *Piper* species are abundant in edges of oil palm plantations where generalist frugivores are often observed foraging [42]. Additionally, fruit crops were often intercropped in rubber plantations, or they are surrounded by fruit orchards [28]. Between sites, we observed that generalist frugi-nectarivorous groups were significantly higher in relative abundance than nectarivorous species, and this may be explained by the lack of flowering plants. It may also suggest that the homogenous vegetation structure in plantation habitats reduces pollinator communities (i.e., low proportion of food-source for nectarivorous bats) [43]. Different guilds of fruit bats have varying abundances in the agroecosystems based on their functional traits [39], where more generalist species with broad foraging requirements can persist in extremely degraded habitats (i.e., with limited vegetation) compared to those with narrow requirements. The remaining agroecosystem matrices can support generalist bat species by providing foraging grounds and connecting intact habitats; additionally, intercropping enables bats to decrease their risk of predation whilst foraging [44].

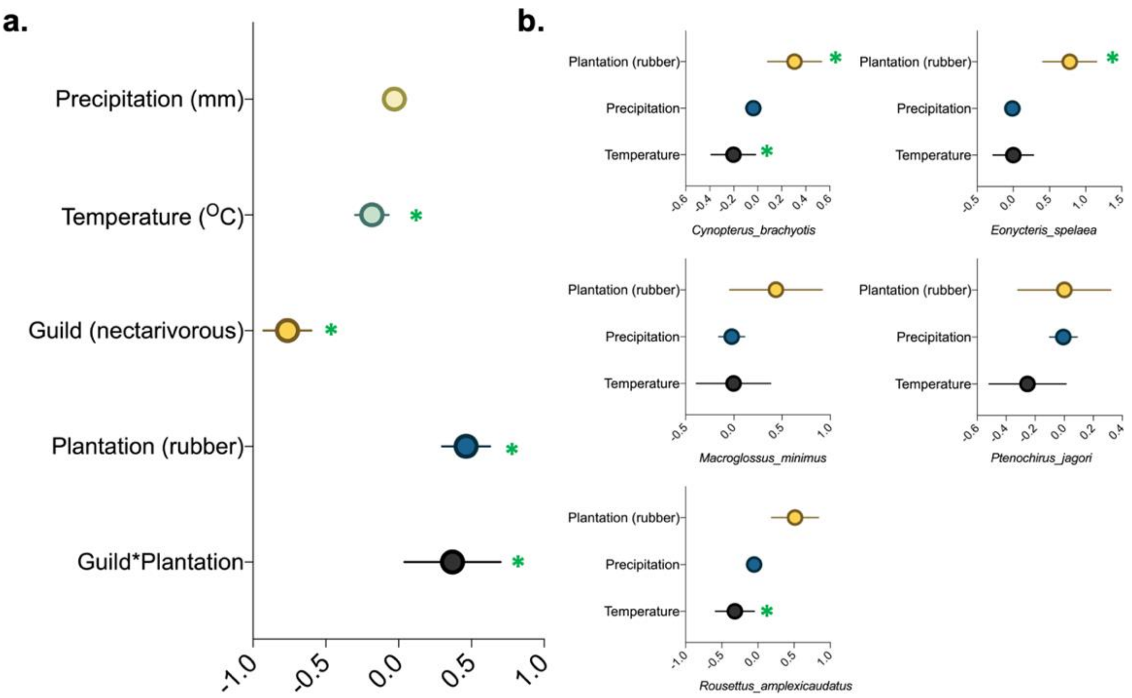

Figure 5. Visualised response of overall bat abundance (**a**) and species-specificities (**b**) to climatic variables (temperature and precipitation), plantation type, and guild. The * indicates significance at $p < 0.05$.

Wildlife using plantations may either be resident, commuting, or foraging, and the degree of tolerance and adaptability varies between species [40,44,45]. This highlights the importance of strategizing land-use management to promote more ‘wildlife friendly’ plantation systems (e.g., small-scale plantations that retain remnants) [40]. In Colombian oil palm plantations, species composition was drastically altered in landscapes with 45–75% oil palm cover relative to those with lower cover [45]. Alternatively, promoting small-scale plantations may also have less severe impacts than large-scale commercial plantations, as they are more likely to have natural areas between them; for example, fruit harvesting, fertilizer, and pesticides applications may occur at lower volumes and amounts in small-scale plantations [17]. Though lower efficiency of production could displace larger areas of forest.

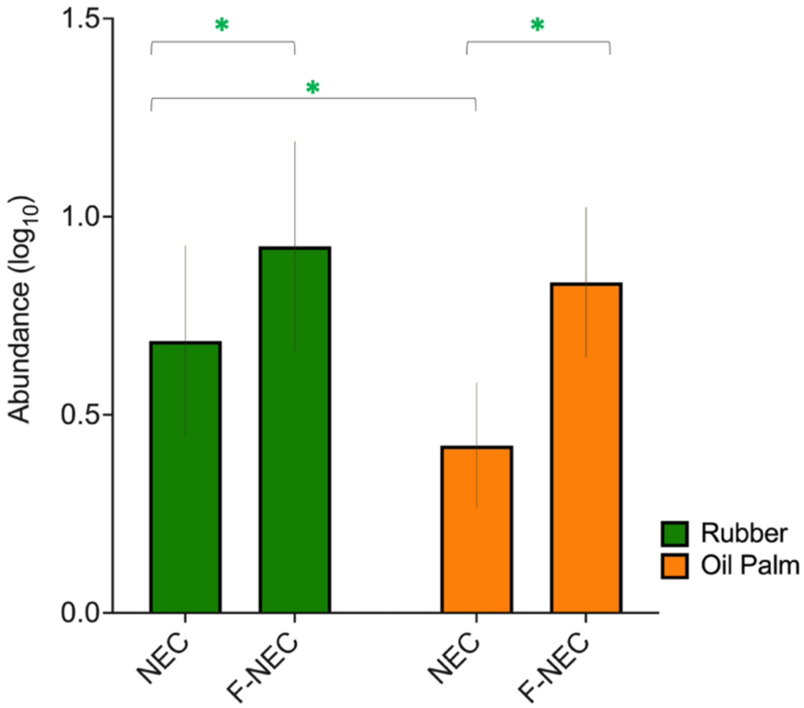

Figure 6. Comparison of captured rate (log_{10}) of two fruit bat guilds between (NEC: nectarivorous, F-NEC: frugi-nectarivorous) rubber plantation and oil palm plantation. The * indicates significance at $p < 0.05$.

The response of bats to seasonality is poorly understood in tropical systems [46] and, in the Philippines, most bat studies are community surveys conducted during favourable months (e.g., during dry summers), and do not account for seasonal differences. We found significant variation in seasonal abundance for some groups, as has been found in other studies in arid and temperate regions [24]. Although we did not find significant variation in bat activity across the year for some groups, this is likely due to the equatorial climate which enables a consistently high population. Furthermore, as hibernation is not known in these groups and inter-island migration would be challenging, we may expect populations to remain fairly consistent through the year if sufficient resources are available. Conversely, the temperature was negatively correlated to seasonal bat variation between plantations. This observation is contrary to patterns observed in tropical regions of Tanzania [47] and Brazil [48] which found that bat activity and foraging activity were positively correlated with temperature; however, as in our study, precipitation had no significant effect. The more generalist species, *Cynopterus brachyotis* and *Rousettus amplexicaudatus,* were the most abundant species in both plantation types. These medium fruit bats are widely recorded in lowland and urban areas and are abundant in agricultural areas and show a decreased abundance or occurrence in primary forests in North Cotabato Province [49,50]. Our study further supports our argument that variation in abundance of common species could provide potential indicators of environmental changes when more specialised species are typically absent.

Previous studies showed that bat activity responses vary depending on either localised or regional weather conditions (i.e., extreme conditions experienced by species or community). Erickson and West [33] showed that short-term weather conditions have less effect on bat activity than long-term climatic conditions such as extreme temperature rise or change in precipitation conditions. Similar to our findings, they found that bat activity is negatively correlated to temperature change. Previous studies showed that richness is slightly lower during the dry season and this difference is influenced by few resources in agricultural areas [46], which is predictable in cases of oil palm and rubber monoculture.

5. Conclusions: Implications to Conservation and Monoculture Expansion

The loss and modification of natural habitats is a major threat to tropical bats [51]. Extensive farming systems such as conversion to monoculture result in the reduction and removal of native vegetation that supports a wide range of species. Around 60% of the country's land area has been converted for agricultural use, these include plantations and agroecosystems. In 2000–2005 alone, 620 thousand ha or 8.7% of total forest cover annual change has been converted in the Philippines [52]. Monoculture oil palm and rubber plantations are rapidly expanding, particularly in the Southern Philippines' Island of Mindanao, with more than 200 thousand ha of rubber and oil palm plantation [53–55]. At present, the Philippines is not a major oil palm producer in the ASEAN region but has roughly 90 thousand hectares of commercial palm oil lands and is largely concentrated in Palawan and Mindanao Island, south of the Philippines [55–58]. However, monocultural areas will continue to increase in the future as the government supports economic growth through agricultural expansion. More than a quarter of Philippine bats are fruit bats, many of which are endemic (~60%) or threatened (~25%) [16,20]. Changing climate coupled with land-use changes may affect bat–plant interactions due to the altering of phenological patterns of plants or the reduction of mutualistic interactions. Fruit bats are widely distributed across the old-world tropics and provide crucial ecosystem services such as pollination and seed dispersal for hundreds of economically and ecologically important plant species [59].

Our monitoring shows that plantations can still support common fruit bat species such as those with more generalist environmental requirements. Between plantations, rubber typically has a more diverse matrix than oil palm that can potentially host better bat communities (e.g., especially nectarivores) than oil palm plantations. Seasonal changes in climate (e.g., temperature) can affect fruit bat persistence and usage of different parts of the landscape. We acknowledge that our study has some caveats, for example, the limited sampling sites and lack of data on night specific conditions such as moon phase or weather, and location-specific metrics such as vegetation cover and proximity to primary forest. However, we encourage more standardised monitoring and comparative wildlife census to serve as baseline evidence for establishing sustainable and wildlife-friendly plantations prior to further monoculture plantation expansion in the Philippines [16,53,60].

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