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Prey composition of insectivorous bats in Puting Bato Cave 1, Burdeos, Polillo Island, Quezon Province, Philippines

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ABSTRACT

Prey composition provides key insights into the trophic ecology of bats, helping to elucidate their ecological functions and inform effective conservation planning. We examined prey composition using morphological analyses of fecal samples from six insectivorous bat species in the Puting Bato Cave Complex, Polillo Island, Philippines. Culled fragments from the fecal samples of 58 bat individuals comprised 11 food items, classified into eight insect orders, two arachnid orders, and one plant category. Lepidoptera, Coleoptera, and Blattodea were the most commonly consumed food items, based on both percentage volume and frequency. The study also examined possible sex-based differences in diet; however, no significant differences were detected between males and females. While the majority of the diet aligns with previous studies, this study documents several additional prey items—specifically Sarcoptiformes, Araneae, and Odonata—that were not recorded in the earlier local study cited here. These findings contribute to a better understanding of the still poorly documented diets of Philippine bats.

INTRODUCTION

Diet is a fundamental aspect of bat ecology, as it reflects prey availability, habitat quality, and the roles bats play within ecosystems (Kunz et al. 2011; Jones et al. 2009; Bohmann et al. 2018). Some bats have evolved to specialize on arthropod prey, thereby exerting substantial pressure on arthropod populations. With their generally flexible foraging strategies and ability to consume insects amounting to more than half of their body mass—sometimes up to 70%—each night, insectivorous bats provide critical insect-regulation services that are particularly pronounced in agroecosystems (Kunz et al. 2011).

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These bat-arthropod interactions extend to broader ecological communities. By preying on insects, including herbivores that feed on plant material and saprophagous arthropods that consume dead organic matter, bats indirectly promote plant growth and alter litter inputs, thereby affecting plant communities, nutrient cycling, and ecosystem stability (Schmitz and Shuttle 2001; Kunz et al. 2011). Bats also facilitate energy transfer to confined ecosystems, such as caves, through guano excretion (Kunz et al. 2011).

Despite their ecological importance, insectivorous bats face threats that compromise both their populations and prey availability. In the Philippines, habitat loss due to logging, agriculture, and hunting poses a significant threat to more than half of the country's bat species (Tanalgo and Hughes 2019; Lama et al. 2023). Additionally, caves, which serve as critical roosting sites for many insectivorous bats, are increasingly exposed to disturbances. Activities such as guano collection, graffiti, treasure hunting, swiftlet nest collection, and tourism have been documented in the Philippines (Alviola et al. 2015; Tanalgo and Tabora 2015; Quibod et al. 2019), including on Polillo Island (Alviola et al. 2022). These disturbances may also reduce insect diversity and abundance by altering cave microclimates and modifying nearby arthropod assemblages, thereby reducing prey availability (Frick et al. 2019).

Puting Bato Cave 1, located in Burdeos, Polillo Island, hosts several insectivorous bat species belonging to the families Emballonuridae, Hipposideridae, Rhinolophidae, and Vespertilionidae (Alviola et al. 2022). The dietary composition of these bats is expected to reflect the local arthropod community, which is shaped by surrounding vegetation, cave-associated predators, and environmental pressures such as habitat change, overexploitation of natural resources, and pollution (Del-Claro et al. 2024; Zhu et al. 2024). Baseline data on bat prey composition in this cave indicate at least seven arthropod orders and reveal variability in consumed arthropod prey items per bat species (Alviola et al. 2023a). Accordingly, prey selection and resource

KEYWORDS

bat diet, fecal analysis, *Hipposideros*, *Miniopterus*, *Rhinolophus*

partitioning may be observed among bat species depending on their foraging habitat, echolocation and prey perception, flight performance, and wing morphology, among others (Norberg and Rayner 1987; Denzinger and Schnitzler 2013; Sedlock et al. 2014; Razak 2018; Sedlock et al. 2019). The bats documented in Puting Bato Cave 1 form a multi-species assemblage with potentially diverse prey-selection strategies. Further exploration of bat diets may reveal novel insect taxa that contribute to the bats' prey pool.

Understanding the feeding habits of these bats helps quantify the ecosystem services they provide and can also inform efforts to protect prey communities, which is necessary for chiropteran conservation. However, research on the dietary ecology of insectivorous bats in the Philippines remains limited, as reflected by the small number of published studies on the subject (Sedlock 2002; Balete 2010; Sedlock et al. 2014). While a previous study (Alviola et al. 2023a) explored bat dietary habits in one of the caves of Puting Bato, a more recent analysis could be a substantial contribution to understanding bats' dietary habits and their potential implications, especially amid timely and inevitable environmental changes.

The present study seeks to provide valuable insights into the current dietary composition of insectivorous bats inhabiting Puting Bato Cave 1, Burdeos, Polillo Island, Philippines. Specifically, this study aims to (1) identify arthropod prey items, preferably at the Order level, (2) determine the primary prey groups contributing to bat diets, and (3) compare the dietary composition across different insectivorous bat species. Thus, the study hypothesizes that insectivorous bats inhabiting Puting Bato Cave 1 will exhibit significant differences in dietary composition among species. It also posits that traditional visual examination of the percentage volume of insects in fecal samples will distinguish these differences. By expanding research coverage within the Puting Bato Cave Complex, this study also aims to contribute updated information on the dietary habits of insectivorous bats, especially since this study is the first to examine bat diets specifically in Puting Bato Cave 1 within the Puting Bato Cave Complex.

MATERIALS AND METHODS

Study site

The study was conducted in Puting Bato (PB) Cave 1 of the Puting Bato Cave Complex located in Burdeos, Polillo Island, Quezon Province (Figure 1). The complex comprises four caves: Puting Bato (PB) Cave 1, Cave 2, Cave 3-4 (previously considered as separate caves), and Cave 5. The caves are situated along the predominantly karst coastline on the eastern part of the island and are characterized by a landscape covered with forest growth over limestone (Alviola et al. 2023b).

All caves are surrounded by secondary forest, with some areas supporting vegetation such as papaya and coconut stands, and signs of cave disturbance, including guano sacks and old bamboo poles used for swiftlet nest collection (Alviola et al. 2022; Alviola et al. 2023b). The primary bat sampling site was at Puting Bato Cave 1(Figure 1C), chosen for its potential to house a variety of bat species and its size. At least twelve species of insectivorous bats have been documented in Puting Bato Cave 1 (Alviola et al. 2022). Additionally, at least seven orders of insects have been recorded in the area, with the following orders ranked by relative dominance: Diptera is the most dominant, followed by Lepidoptera, Hemiptera, Coleoptera, Hymenoptera, Blattodea, and Orthoptera (Alviola et al. 2023a).

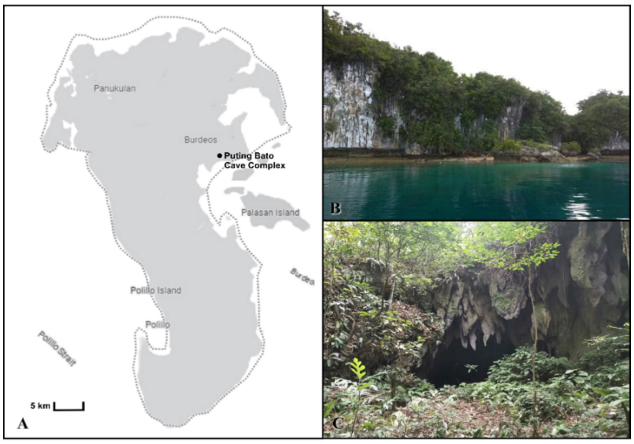

Figure 1: (A) Map showing the location of the Puting Bato Cave Complex; (B) photograph of the karst forest-over-limestone habitat of the complex (Burdeos Municipal Tourism Office, n.d.); and (C) entrance to Puting Bato Cave 1.

Bat sampling and fecal collection

Bat sampling involved setting up a 12-m mist net at the cave entrance between 4:00 am and 6:00 am on August 10 and 11, 2024. The nests were monitored continuously for the presence of intercepted bats. Bat sampling was conducted under the PHILBATS Gratuitous Permit Extension issued by the BMB-DENR (Biodiversity Management Bureau-Department of Environment and Natural Resources).

Bat morphometrics were first recorded to aid in species identification (Appendix I). Bats were then kept in separate cloth bags for two hours to collect five fecal pellets per bat (Alviola et al. 2023a). Afterward, the samples were stored in a zip-lock bag or vial with 95% alcohol, with each sample labeled according to species and individual.

Fecal analysis

Fecal pellets from each bat individual were teased apart, separated, and spread out evenly in a Petri dish lined with grids of 5.0 mm x 5.0 mm to facilitate visual estimation of prey parts. Examination of fecal pellets was conducted using a stereomicroscope to facilitate examination of culled remains. Only culled materials bearing diagnostic characters, such as wings and head parts, were considered, because these features are typically distinctive enough to enable accurate prey identification (Whitaker et al. 2009; de Guia and Quibod 2014; Alviola et al. 2023a). Culled insect remains were identified to the ordinal level (i.e., Blattodea, Coleoptera), whereas plant material remained unidentified. The proportion of insect remains occupying the squares of the Petri dish was also visually estimated.

For analysis, percentage volume and percentage frequency were estimated (Whitaker et al. 2009; Alviola et al. 2023a). Percentage volume pertains to the volume of each food category relative to the total number of 5.0 mm x 5.0 mm grids on the petri dish, expressed as a percentage. Percentage frequency refers to the proportion of individuals within each bat species in which a given prey category was recorded.

Statistical Analysis

Before analysis, the dietary data were arcsine-transformed. This transformation is commonly used for proportional or percentage data, as it normalizes their distribution (Lacey and Kaya 2007; Sheskin 2020). One-way ANOVA was used to compare the percentage volume and frequency of different food items within a bat species, with $\alpha = 0.05$ (McDonald 2014). This test was used to determine whether significant differences existed between the proportion of various food items consumed by a given bat species (Whitaker et al. 2009). Post hoc comparisons were conducted using the Tukey-Kramer test, which identified significant differences among groups, specifically among food items and/or taxonomic groups consumed by insectivorous bats. Lastly, the dietary preferences between the two sexes of insectivorous bat species were analyzed using the Student's two-sample t-test (McDonald 2014). For this analysis, only insect taxa with relatively high percentage-volume estimates were included for each bat species.

RESULTS AND DISCUSSION

Bat Captures

We collected prey items from the fecal samples of 58 individuals across six insectivorous bat species captured in Puting Bato Cave 1 (Figure 2). *Rhinolophus rufus* Eydoux & Gervais, 1836 comprised 53% of the captured bats, with 31 individuals, followed by *R. arcuatus* Peters, 1871 with 13 individuals, *R. philippinensis* Waterhouse, 1843 with seven individuals, and *Hipposideros coronatus* (Peters, 1871) with five individuals. Lastly, only one individual each of *H. diadema* (É.Geoffroy Saint-Hilaire, 1813) and *Miniopterus paululus* Hollister, 1913 was captured.

Figure 2: Insectivorous bat species captured from Puting Bato Cave 1, Aluyon, Burdeos, Polillo Island, Quezon Province, Philippines, from which fecal samples were obtained. (A) *Hipposideros coronatus* (Peters, 1871); (B) *H. diadema* (É. Geoffroy Saint-Hilaire, 1813); (C) *Miniopterus paululus* Hollister, 1913; (D) *Rhinolophus arcuatus* Peters, 1871; (E) *R. philippinensis* Waterhouse, 1843; (F) *R. rufus* Eydoux & Gervais, 1836.

Bat diet identification and analysis

Fecal samples from the 58 bats contained culled remains belonging to 11 distinct taxonomic groups (Figure 3). Eight of these groups are insects, while two belong to Arachnida (Table 1A and 1B). The insect groups consist of orders Blattodea, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Odonata, and Orthoptera, while the arachnids include the orders Sarcoptiformes and Araneae. We also documented an unidentified plant material from an unknown taxon. However, 28.32% of the samples from the six species of insectivorous bats remain unidentified. Although insects constituted the majority of dietary items, the detection of multiple insect orders together with arachnids and plant material indicates a broad dietary spectrum for these bats. This diversity underscores the ecological importance of bats in regulating arthropod populations (Kunz et al. 2011).

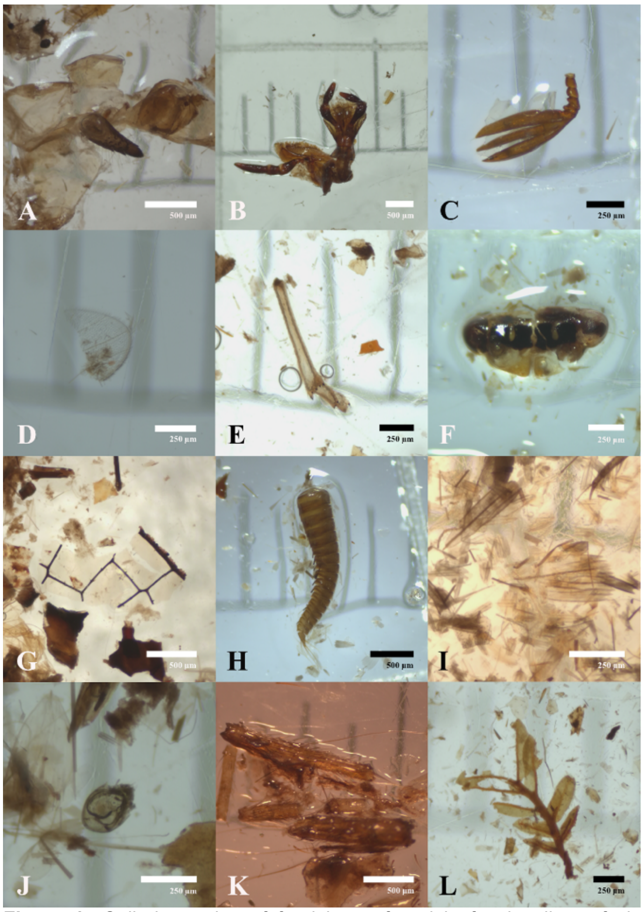

Figure 3: Culled remains of food items found in fecal pellets of six insectivorous bats species: insects—(A) Blattodea cercus; Coleoptera—(B) mouthpart and (C) antenna; (D) Diptera wing; Hemiptera—(E) leg and (F) head; (G) Odonata wing; Lepidoptera—(H) antenna and (I) wing scales; arachnids—: (J) acarine body, and (K) Araneae leg; and (L) plant material.

Comparison of percentage volume showed that the most abundant food items in the diets of the six insectivorous bats belonged to the orders Lepidoptera, Coleoptera, and Blattodea. Specifically, Lepidoptera comprised 33.90±30.98% of the volume, while Coleoptera accounted for 26.63±25.31%. Additionally, Blattodea made up 7.97±15.94% of the total volume. These three insect orders also had the highest percentage frequencies: Lepidoptera at 82.76%, Coleoptera at 79.31%, and Blattodea at 41.38% (Tables 1A and 1 B). While previous studies already identified these orders as prevalent food items for insectivorous bats (Pavey and Burwell 1997; Gonsalves et al. 2013; Sedlock et al. 2014; Alviola et al. 2023a), our findings document additional prey items for some bat species and differences in their relative proportions. However, we expect inevitable biases in the identification of food items, particularly for soft-bodied prey (Haarsma et al. 2016). For Diptera species, their relatively small, delicate body structures (Gibb and Oseto 2010; Alviola et al. 2023a) make them easily digestible by bats, hindering the identification of their remains in fecal samples through morphological analysis (Alviola et al. 2023a). Additionally, while Cecidomyiidae (Diptera) were conspicuously prevalent within the sampling area during collection, bat diets did not reflect this pattern in their proportional volumes. In the case of lepidopterans, although they are relatively easy to identify and quantify, their potential to remain in the digestive tract of a bat for extended periods could contribute to overestimation of recent consumption (Whitaker et al. 2009).

Table 1A: Percentage volume (Mean±SE) and percentage frequency of all food items identified in fecal samples from insectivorous bats captured in Puting Bato Cave 1, Polillo Island, Philippines. Generic abbreviations: H.- *Hipposideros*, M.- *Miniopterus*. Bat species preceded by the number of bats captured (in parentheses).

Food item	*H. coronatus* (5)		*H. diadema* (1)		*M. paululus* (1)	
	Vol	Freq	Vol	Freq	Vol	Freq
Araneae	0	0	0	0	0.83	100
Blattodea	16.13±22.69	60	6.67	100	0	0
Coleoptera	4.67±6.50	40	27	100	0	0
Diptera	0	0	0	0	0.67	100
Hemiptera	0	0	0	0	0.33	100
Hymenoptera	0	0	0	0	0	0
Lepidoptera	28.59±11.43	100	20	100	15.42	100
Odonata	0	0	0	0	0	0
Orthoptera	24.93±20.62	80	0	0	0	0
Plant material	0	0	0	0	0	0
Sarcoptiformes	0	0	0	0	0	0
Unidentified	25.68±19.32	100	46.33	100	83	100

Table 1B: Percentage volume (mean±sd) and percentage frequency of all food items identified in fecal samples (5 fecal pellets per individual) from insectivorous bats captured in Puting Bato Cave 1, Polillo Island, Philippines. Generic abbreviations: R.- *Rhinolophus*. Bat species preceded by the number of bats captured (in parentheses).

Food item	*R. arcuatus* (13)		*R. philippinensis* (7)		*R. rufus* (31)	
	Vol	Freq	Vol	Freq	Vol	Freq
Araneae	0.38±0.73	23.08	0	0	0	0
Blattodea	0.45±1	23.08	0	0	11.91±18.57	54.84
Coleoptera	23.77±15.92	100	2.39±6.30	14.29	37.67±27.08	90.32
Diptera	0.13±0.46	7.69	0	0	0.08±0.45	3.23
Hemiptera	0.45±0.94	30.77	1.43±3.78	28.57	0.61±2.71	3.23
Hymenoptera	0	0	0	0	0.08±0.45	3.23
Lepidoptera	50.50±14.62	100	75.21±17.12	57.14	19.51±30.13	87.10
Odonata	0	0	0	0	0.24±0.94	6.45
Orthoptera	0	0	0	0	0	0
Plant material	0	0	0	0	0.11	3.23
Sarcoptiformes	0.13±0.31	15.38	0	0	0	0
Unidentified	24.20±11.97	100	20.97±13.35	100	29.79±12.15	100

The presence of unidentified remains further highlights the limitations of the present method for characterizing the diet of insectivorous bats.

***Hipposideros coronatus* (Peters, 1871)**

Hipposideros coronatus accounted for five of the 58 bats collected. Endemic to the Philippines, the IUCN Red List of Threatened Species assessed this bat as Data Deficient in 2015 due to its rarity and the limited information on its biology, particularly its habitat and ecology (Phelps et al. 2016; Fernandez and Amarga 2020). The diet composition of this species includes four arthropod taxa, namely Blattodea, Coleoptera, Lepidoptera, and Orthoptera (Table 1.A). The presence of each food item varied among individual bats; however, there was no significant variation in the percentage volume of each item across fecal samples (Df=3, p-value=0.149). This species consumed Lepidoptera (28.59±11.43) most prominently among other identified insect orders, and which was significantly greater in percentage volume when compared with Blattodea (16.13±22.69), but not with Orthoptera (24.93±20.62). The volume of identified Coleoptera in the fecal pellets was relatively small (4.67±6.50), significantly lower than that of other food items. We observed the same trend for Blattodea (16.13±22.69), which differed significantly from Coleoptera, Lepidoptera, and Orthoptera.

In terms of percentage frequency, Lepidoptera (100%) was also the most frequent food item/taxon that we identified from the fecal samples of all individuals of *H. coronatus,* making it the dominant food item for this species. Other important dietary components of *H. coronatus* included Orthoptera (80%), Blattodea (60%), and Coleoptera (40%).

The dominance of Lepidoptera in *H. coronatus'* diet aligns with previous studies, as it occurred significantly more than other consumed insect taxa, including Diptera, Hymenoptera, and Orthoptera (Alviola et al. 2023a). The allotonic frequency hypothesis (AFH) likely influences the dominant occurrence of lepidopterans in the diet of this bat species. This observation indicates that eared moths, which can detect bat echolocation calls between 20 and 50kHz, are less accessible to syntonic bats that use frequencies within the moth's hearing range (Pavey and Burwell 1998; Waters 2003; Bailey et al. 2019). Some moths have developed tympanic organs that may detect bat ultrasonic calls and take evasive actions to avoid predation by bats (Ter Hofstede and Ratcliffe 2016; Kolkert et al. 2019). As a result, bats that constantly prey on these moths have adapted by modifying their foraging behavior to counteract the moths' defenses and improve prey capture efficiency (Ter Hofstede and Ratcliffe 2016). As the sensitivity of moths to frequencies above 65 kHz sharply decreases, their dominance within the diet of *H. coronatus,* which has a call frequency of 146–160 kHz, which is largely beyond the frequency range of the moths, becomes more plausible (Jacobs 2000; Taray et al. 2021; Alviola et al. 2023a). Noticeably, we did not observe Diptera and Hymenoptera from the diet of *H. coronatus,* which was previously recorded from the species in Polillo Island (Alviola et al. 2023). The absence or low detectability of Diptera may be due to their small sizes and soft bodies, which are readily digestible in bats' alimentary canals (Whitaker et al. 2009). Lastly, the set of food items for this species closely resembled those of other *Hipposideros* species in this study, i.e., *H. diadema*, except for the presence of Orthoptera.

Hipposideros diadema **(É.Geoffroy Saint-Hilaire, 1813)**

H. diadema is the largest insectivorous bat species in the country (Alviola et al. 2023a). Although most of the culled parts were unidentifiable, the fecal sample recovered from the single captured individual contained at least three food items (Coleoptera, Lepidoptera, Blattodea). Coleoptera comprised the majority of the identified prey items, followed by Lepidoptera (Pavey and Burwell 1997; Sedlock 2002; Alviola et al. 2023a). No statistical analysis was performed because only one fecal sample was available.

H. diadema primarily forages through perch-hunting and subsequent continuous flight, allowing them to intercept flying insects (Pavey 1998; Alviola et al. 2023a). Although *H. diadema* exhibits a call frequency higher than the range detected by eared moths at 67–71 kHz (Amberong et al. 2021; Alviola et al. 2023a; Duco et al. 2023), which theoretically allows these bats to overcome moth auditory defenses against their predatory mechanisms (Pavey and Burwell 1998; Waters 2003; Bailey et al. 2019), lepidopterans were less prevalent in the diet than coleopterans. These findings are consistent with previous reports showing a dietary preference of *H. diadema* for heavily sclerotized insects, particularly Coleoptera (Jacobs 2000; Dumont 2007; Weterings and Umponstira 2014; Ayala-Berdon et al. 2023).

Miniopterus paululus **Hollister, 1913**

As with *H. diadema*, we collected only one individual of *M. paululus* in this study. Inspection of culled parts in the fecal sample of *M. paululus* revealed four insect orders, compared with three orders recorded for *H. diadema*. However, most identified prey items in *M. paululus* occurred at low percentages, and a large portion (83%) remained unidentifiable, thereby limiting broader comparisons between the two species. Lepidoptera was the most dominant food item at 15.42%, whereas the other three orders accounted for relatively smaller percentages. Following Lepidoptera, Araneae ranked second in consumption at 0.83%, while Diptera ranked third at 0.67%. Hemiptera accounted for the smallest identified proportion among the identified orders. We also did not perform statistical testing because we collected only one individual.

The high occurrence of Lepidoptera in the diet of *M. paululus* could still be attributed to AFH, as its call frequency, 52–74 kHz (Amberong et al. 2021; Taray et al. 2021; Alviola et al. 2023a; Duco et al. 2023), may place much of its echolocation output beyond the most sensitive hearing range reported for many moths (Dumont 2007; Weterings and Umponstira 2014; Ayala-Berdon et al. 2023). Alviola et al. (2023a) also reported that the diet of this species includes a substantial portion of Lepidoptera, next to Hymenoptera, and small proportions of Coleoptera, Diptera, Orthoptera, and Osteichthyes. The detection of Araneae and Hemiptera in the diet of *M. paululus* expands the wide variety of prey items this species consumes, which further supports the species' apparently generalist feeding habit.

Rhinolophus arcuatus **Peters, 1871**

We identified seven arthropod taxa from the fecal samples of 13 *R. arcuatus* individuals in Puting Bato Cave 1. This species showed a preference for Lepidoptera, with a mean percentage volume of 50.50 ± 14.62 percent. *Rhinolophus arcuatus* also consumed Coleoptera in substantial amounts, averaging 23.77 ± 15.92. Although Coleoptera had the highest consumption among the other identified taxa, it did not dominate as strongly as Lepidoptera. This result is consistent with the findings of Sedlock (2002), Sedlock et al. (2014), and Alviola et al. (2023a). Studies on related *Rhinolophus* species also reported that Lepidoptera and Coleoptera were the primary food items of these species (Ahmim and Moali 2013; Berkovitz and Shellis 2018).

Additionally, across species, bats using a higher echolocation frequency consumed a greater proportion of eared moths and a lower proportion of non-eared insects such as beetles, flies, and termites (Jacobs 2000); this pattern possibly explains the dominance of Lepidoptera over Coleoptera in the diet of *R. arcuatus*. It is worth noting, however, that scales of lepidopterans tend to remain longer in bat gut, hence an overestimation of the recent consumption of lepidopterans can occur (Whitaker et al. 2009).

R. arcuatus' diet contained other prey items, including Sarcoptiformes, Araneae, Diptera, Blattodea, and Hemiptera, in much smaller quantities than the more frequently consumed taxa, Lepidoptera and Coleoptera. This study records Sarcoptiformes for the first time in the diet of *R. arcuatus.* Statistical analysis indicated significant variation in the percentage volume of prey taxa consumed by this species (Df = 6, p-value = 0.000).

In terms of percentage frequency, all samples contained both Coleoptera and Lepidoptera, each reaching 100%. Lepidoptera emerged as the most dominant food item consumed by *R. arcuatus*, as reflected in its percentage volume. While Coleoptera also showed a higher percentage volume compared to other food items, it was lower than that of Lepidoptera. Additional taxa, such as Hemiptera (30.77%), Araneae (23.08%), Blattodea (23.08%), Sarcoptiformes (15.38%), and Diptera (7.69%), occurred at lower but comparable frequencies. However, these values differed significantly from those of Coleoptera and Lepidoptera.

Approximately half of the food items recorded in this study matched those reported by Alviola et al. (2023a), with additional records of Sarcoptiformes, Araneae, and Hemiptera, and the absence of Hymenoptera and Orthoptera. The absence of Hymenoptera and Orthoptera among the identified prey items in this study may be influenced by prey abundance in the area, although prey abundance was not measured in this study. In Rhinolophidae bats, diets may vary with biogeographical seasons and regions, reflecting the types of food available in the area (Ahmim and Moali 2013). Moreover, apart from flying insects, which may include Lepidoptera, Diptera, Coleoptera, among others, *Rhinolophus* species may also capture spiders by gleaning them from webs, foliage, or the ground (Pavey 2021).

Rhinolophus philippinensis **Waterhouse, 1843**

Culled remains from the fecal sample of seven *R. philippinensis* individuals represented three orders: Lepidoptera, Coleoptera, and Hemiptera. Statistical analysis showed significant variations among these orders of food items (Df=2, p-value=9.17x10^-11). Overwhelmingly, this bat consumed predominantly lepidopterans (75.21±17.12) as its main diet, which is significantly different from both Hemiptera (1.43±3.78) and Coleoptera (2.39±6.30). In contrast, the latter orders did not differ significantly from each other. In terms of percentage frequency, Lepidoptera had the highest value at 57.14%, followed by Hemiptera at 28.57% and Coleoptera at 14.29%. This pattern was consistent with the observed percentage-volume data. While Hemiptera and Coleoptera showed relatively high percentage frequencies, their differences were not statistically significant.

Considering the maximum call frequency *R. philippinensis* (27–29 kHz) (Amberong et al. 2021; Alviola et al. 2023a), predation on tympanate moths would be expected to be less likely under the allotonic frequency hypothesis. However, this species clearly consumed lepidopterans as its primary food item. The Lepidoptera that this species consumed may not have been tympanate moths, which could explain their high abundance in its diet. In addition to Coleoptera, Orthoptera, and Neuroptera in their diet, this bat forages and intercepts flying moths during slow, fluttery flight (Pavey and Kutt 2008). These observations support the conclusion that *R. philippinensis* consumes Lepidoptera, but a more specific classification beyond the order level is needed to clarify the presence of tympanate moths in the fecal samples (Alviola et al. 2023a). Moreover, since the previous study of Pavey and Kutt (2008) was in Australia, the absence of Neuroptera and Orthoptera might be explained by the combined effects of factors such as spatial and temporal variation of food resources and environmental conditions of the trophic niche of the bats (Dai et al. 2023).

Rhinolophus rufus **Eydoux & Gervais, 1836**

We identified seven arthropod taxa and one type of plant material from fecal samples of 31 *R. rufus* individuals. Statistical analysis revealed that these food items were significantly different from each other (Df=7, p-value=0.000). The most dominant food item was Coleoptera (37.67±27.08), which differed substantially from the other identified food items. Lepidoptera (19.51±30.13) and Blattodea (11.91±18.57) were also present in substantial proportions, but they are not significantly different from each other. Diptera (0.08±0.45), Hymenoptera (0.08±0.45), plant material (0.11), Odonata (0.24±0.94), and Hemiptera (0.61±2.71) were also detected in small amounts in the fecal sample of *R. rufus,* but did not show significant differences among themselves. This study records Odonata for the first time in the diet of *R. rufus.*

In terms of percentage frequency, Coleoptera represented the most dominant food item consumed by *R. rufus*, accounting for 90.32%. Lepidoptera followed Coleoptera at 87.10%, Blattodea at 54.84% and Odonata at 6.45%. The remaining food items, each accounting for 3.23%, reflect the low frequency of Diptera, Hemiptera, and Hymenoptera, and plant material in the fecal samples.

While the abundance of Coleoptera contrasts with the data reported by Alviola et al. (2023a), where Lepidoptera predominated in the diet of this species, lepidopterans were still among the most frequently consumed taxa for *R. rufus* in this study. This pattern suggests that the relative ease of capturing lepidopteran prey, as well as possible prey preference, may contribute to their consistent presence in both the current and previous studies (Alviola et al., 2023a).

The peak frequency call of this species (39–42 kHz) (Amberong et al. 2021; Alviola et al. 2023a) falls within the known hearing range of lepidopterans, particularly those that had developed a tympanic membrane (Jia 2024). In theory, eared moths should be able to detect and evade bat predation at frequencies between 20 and 50 kHz (Pavey and Burwell 1998; Waters 2003; Bailey et al. 2019). However, lepidopterans were one of the most consumed taxa in the diet of *R. rufus*. Since the specific identification of tympanate moths in the diet of these bats cannot be verified through the morphological assessment in this study, their apparent prominence in the diet may reflect limitations of the present morphological approach or may indicate that this species does not conform neatly to the allotonic frequency hypothesis (Waters 2003; Alviola et al. 2023a).

Another possible explanation for the high Lepidoptera content in the diet is that the insects' scales may persist longer in the bats' digestive tracts, thereby delaying digestion. Thus, they tend to overaccumulate along with recently consumed scales (Whitaker et al. 2009). Most importantly, there is limited literature that directly addresses and explains certain aspects of diet composition of insectivorous bats in the country. This study is only the second conducted on the diet of *R. rufus* in the Philippines.

Sex-based variation analysis in bat diet

The diet composition was largely similar between sexes across species. Among the captured bats, 24 were male and 34 were female, indicating a female-biased sample, regardless of species. Among males, *R. rufus* accounted for 50% of the sample, followed by *R. arcuatus* at 21%, *Hipposideros coronatus* at 13%, *R. philippinensis* at 8%, and the remaining two species represented by single individuals at 8%. *Hipposideros diadema,* and *M. paululus* contributed 4% each to the total number of males among the sampled bats. Among the female samples, *R. rufus* comprised 56%, followed by *R. arcuatus* (23%)*, R. philippinensis* (15%)*, and H. coronatus* (6%)*.* Because we did not obtain female samples of *H. diadema* or *M. paululus*, we excluded these species from the analysis examining potential differences in dietary composition among the bat species.

The analysis was limited to food items with relatively high percentage volume (>3) for each bat species. The most abundant prey taxa across sampled male bats were Coleoptera (27.96±5.02), Lepidoptera (25.05±5.50), and Blattodea (9.09±3.03). Likewise, the most abundant taxa consumed by all sampled female bats were Lepidoptera (40.15±5.57), Coleoptera (25.69±4.48), and Blattodea (7.18±2.89), with Lepidoptera being the most dominant group consumed by bats, regardless of sex (Table 2).

Statistical analysis, however, indicated that bat diets of the six insectivorous species studied were similar across sexes. This absence of sex-based variation in the bat diet suggests that both sexes consume a similar prey base within the study area, indicating

Table 2: Sex-based variation in percentage volume (mean±SE) of the identified food item from fecal samples of insectivorous bats in Puting Bato Cave 1, Aluyon, Burdeos, Polillo Island, Quezon Province, Philippines. Generic abbreviations: H-*Hipposideros,* R-*Rhinolophus.*

Bat species	Arthropod taxa	Mean±SE	
		♂	♀
H. coronatus	Blattodea	24.67±15.76	3.33±3.33
	Coleoptera	3.33±3.33	6.67±6.67
	Lepidoptera	24.38±7.7	34.92±4.08
	Orthoptera	26.67±14.53	22.33±14.33
R. arcuatus	Coleoptera	19.00±1.52	26.75±7.09
	Lepidoptera	50.26±6.52	50.65±5.53
R. philippinensis	Lepidoptera	73.67±15.50	75.83±10.08
R. rufus	Blattodea	11.18±2.18	12.37±4.89
	Coleoptera	44.86±6.66	33.12±6.65
	Lepidoptera	7.84±5.09	26.89±7.86

overlapping foraging habits. Although sex-based dietary differentiation has been documented in other bat populations (e.g., Young et al. 2012; Haarsma et al. 2023), such patterns are likely site- and season-dependent and were not evident in this study. Future studies incorporating seasonal changes and prey availability may help determine whether sex-based variations in bat diet occur under different conditions.

CONCLUSION

This study provides insight into the dietary habits of six insectivorous bats from Puting Bato Cave 1, Aluyon, Burdeos, Polillo Island, Quezon Province, Philippines. Our findings revealed additional food items, further emphasizing the important role of bats in regulating insect populations, as they consume a wide range of taxa. Analysis of sex-based dietary variation showed no clear differences between male and female individuals, suggesting generally overlapping feeding patterns within the study area.

The current methodology also has limitations, including difficulty in identifying soft-bodied insects and highly digested remains, which underscores the need for further research to extensively understand their dietary ecology, especially with the use of a more advanced technique, such as molecular analysis of fecal samples to encompass all possible food items consumed without restrictions by the mentioned limitation. Future studies may also benefit from larger sample sizes and seasonal sampling to more thoroughly assess potential sex-based dietary variations in prey composition.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

RR Dimapasoc was the principal author, conducted the sampling, performed the statistical analyses, and drafted the manuscript. PA Alviola designed the study, participated in sampling, and revised the manuscript. MS Alviola contributed to the study concept, supervised laboratory activities, identified the arthropods, and revised the manuscript. MT Cantalejo assisted in laboratory activities, arthropod identification, and manuscript drafting.

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APPENDICES

Appendix IA: Morpho-metric measurement of the characteristics of insectivorous bats captured in Puting Bato Cave 1, Brgy. Aluyon, Burdeos, Polillo Island, Quezon Province, Philippines. Abbreviations: N-total number of bat individual, n-number of bat individual per species, SD-Standard deviation

Bat species	n	Parameters					
		Ear (mm)			Forearm (mm)		
		Mean	SD	Range	Mean	SD	Range
H. coronatus	5	15.60	0.89	15-17	50.60	0.55	50-51
H. diadema	1	25.00			81.00		
M. paululus	1	8.00			36.00		
R. arcuatus	13	19.77	0.93	18-21	46.54	0.66	46-48
R. philippinensis	7	33.29	1.70	30-35	56.29	0.95	55-57
R. rufus	31	28.42	1.75	24-32	70.58	1.20	68-73
N	58						

Appendix IB: Morpho-metric measurement of the characteristics of insectivorous bats captured in Puting Bato Cave 1, Brgy. Aluyon, Burdeos, Polillo Island, Quezon Province, Philippines. Abbreviations: N-total number of bat individual, n-number of bat individual per species, SD-Standard deviation

Bat species	n	Parameters					
		Hindfoot (mm)			Weight (g)		
		Mean	SD	Range	Mean	SD	Range
H. coronatus	5	9.60	0.55	9-10	10.20	0.55	8-11
H. diadema	1	12.00			37.00		
M. paululus	1	7.00			5.00		
R. arcuatus	13	10.85	1.52	9-15	7.54	0.78	7-9
R. philippinensis	7	10.00	0.58	9-11	10.43	1.90	7-12
R. rufus	31	16.13	1.89	14-25	27.35	4.15	23-36
N	58						