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Trophic ecology of insectivorous birds in agroforestry systems and Mountain Mesophilic Forest

Ecología trófica de aves insectívoras en sistemas agroforestales y Bosque Mesófilo de Montaña

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ABSTRACT

The purpose of the present study was to determine the diet of the insectivorous birds through the analysis of excreta and insect collection. From August 2018 to January 2019, search-intensive, branch cutting-shaking, mist-netting, scat analysis and insect identification were applied. Richness (Jacknife1), similarity (Jaccard) and diversity (Shannon-Wiener) were determined. Kruskal-Wallis, X^2, Poisson regression analysis (PRA) and canonical correspondence (CCA) were applied. Jacknife1 shows a mean of 39 families. Jaccard shows a similarity of 19.88 %. Shannon-Wiener shows a diversity of $H' = 3.09$. Kruskal-Wallis shows differences in richness (0.0423*) and diversity (0.0148*). The X^2 test shows that the richness of insect families theoretically present was not recorded ($P < 0.05$). PRAs show that six orders, two families, two insect types (cut and shake); one order, one family and one item (feces) have an effect on bird abundance. The CCAs show the conformation of seven (cutting and shaking) and six (feces) groups that show relationships between birds and the orders, families, insect type and items recorded. Trophic sympatry is exhibited in some of the birds recorded, favoring the biological control of pest and parasitic insects.

Keywords: avifauna, canonical-correspondence, biologic control, bird droppings, insects-pest.

RESUMEN

El propósito del presente estudio fue determinar la dieta del gremio de aves insectívoras mediante el análisis de excretas y colecta de insectos. De agosto 2018 a enero 2019 se aplicó búsqueda-intensiva, corte-sacudida de ramas, redes de niebla, análisis de heces e identificación de insectos. Se determinó riqueza (Jacknife1), similitud (Jaccard) y diversidad (Shannon-Wiener). Se aplicó Kruskal-Wallis, X^2, análisis de regresión poisson (ARP) y correspondencia canónica (ACC). Jacknife1 presenta una media de 39 familias. Jaccard muestra una similitud del 19.88 %. Shannon-Wiener presenta una diversidad de $H´ = 3.09$. Kruskal-Wallis evidencia diferencias en la riqueza (0.0423*) y diversidad (0.0148*). La prueba de X^2 muestra que no se registró la riqueza de familias de insectos teóricamente presentes ($P < 0.05$). Los ARP muestran que seis ordenes, dos familias, dos tipos de insectos (corte y sacudida); un orden, una familia y un artículo (heces) tienen efecto sobre la abundancia de aves. Los ACC muestran la conformación de siete (corte y sacudida) y seis (heces) grupos que muestran relación entre las aves y los órdenes, familias, tipo de insecto y artículos registrados. Se exhibe simpatría trófica en algunas de las aves registradas, favoreciendo al control biológico de insectos del tipo plaga y parásitos.

Palabras clave: avifauna, correspondencia-canónica, control-biológico, excretas, insectos-plaga.

INTRODUCTION

Worldwide, a total of 10,507 bird species are listed (Pulido *et al.,* 2020). However, human intervention has altered different ecological niches that affect the habitat of these species, forcing environmental processes that put their survival at a critical point and cause segregation of niches and competition for food and new spaces (Ramírez-Albores, 2010).

Bird species (1.076) have been recorded in Mexico (with 106 endemic species; Ortega-Álvarez *et al.,* 2021); however, due to various environmental alterations, nearly 26% are on the verge of extinction. There are 294 species and 98 subspecies recognized in some category of risk and another 429 that have declined in population (Ortiz-Pulido, 2018). Knowledge of how such disturbance impresses different bird species is still incipient (Alessio *et al.,* 2005). However, it is recognized that under these circumstances birds present a series of fluctuations, product of insect seasonality; being forced to resort to three possible actions: changing their diet, feeding on inactive insects or giving up their habitat and leaving in search of a new feeding niche (Pineda-Pérez *et al.,* 2014; Ortiz-Pulido *et al.,* 2016; Ortiz-Pulido, 2018).

The technique that some birds use to ensure their energetic ratio is described as optimal feeding (Elgin *et al.,* 2020). This theory points out that different organisms use capture methods that demand minimum energy expenditure and reward them with higher nutritional intake (González & Osbahr, 2013). Such behavior is the result of different coercions and natural selection events that determine survival and reproductive success. Under this principle, the breeding expenditure hypothesis mentions that during the reproductive period birds catch large prey that allows them to store energy to achieve their reproductive function (Tellez-Farfán & Sánchez, 2016).

Although the richness of insects in each of their life stages is apparently high, there is a lack of evidence demonstrating the impact on the spatiotemporal differentiation of this resource (García *et al.,* 2020). Therefore, evaluating trophic ecology as a function of the available resource and habitat is a topic of global interest for the study of ecosystems and species conservation. In this regard, different researchers have evaluated the relationship between birds and their habitat, trophic intake and capture of their prey through field observation, analysis of stomach contents, regurgitation, vomit or excreta (Alessio *et al.,* 2005). All this in order to know the resource and the optimal conditions that guarantee the conservation of the species.

Currently, as a mechanism for sustainable production and species conservation, ancestral production methods (agroforestry systems; González-Valdivia *et al.,* 2016) have been taken up again. In these systems, a series of factors interact that favor the conservation of species where birds could have a new habitat that provides food and shelter, performing important functions such as biological control of pests, seed dispersers, pollinators and vindicators of the environment (Cipriano-Anastasio *et al.,* 2020).

A traditional coffee production system (agroforestry system) immersed in a Mesophilic Mountain Forest is located in Huatusco municipality, Veracruz. In this system, birds could play a role in the optimal development of this productive model. However, despite being a multi-layered system, favorable for the maintenance and conservation of insectivorous birds. There are no studies that address the trophic ecology of these organisms and infer the stability of these species from feeding patterns.

The aim of this research was to determine the diversity of entomological components that determine the diet of birds through feces analysis in Huatusco, Veracruz, Mexico.

MATERIAL AND METHODS

The study area is located in Huatusco municipality, Veracruz, Mexico (19º 09' N and 96º 57' W at 1933 m a.s.l). For this study, three conditions were considered for evaluation: Traditional coffee (CT), Potrero (PT), and Mesophilic Mountain Forest (BMM), in a total area of 32.42 ha (Figure 1). In each condition evaluated, a systematic sampling was carried out at convenience with linear distances of 150 m between each point. Bird monitoring was conducted monthly from August 2018 to January 2019, employing mist-net trapping, fixed-radius point counts (Bayne *et al.,* 2016; Morales-Martínez *et al.,* 2018) and intensive searching (Alonso *et al.,* 2017; Parra Castillo & Cafiel Cuello, 2020). It should be noted that both schemes were employed jointly with the aim of reducing error due to identification of birds with still and silent behavior (Lavariega *et al.,* 2016; Travez & Yánez, 2017). Nets used were 12 m long by 2.5 m wide with a mesh size of 36 mm in diameter; they were placed from 07:00 to 16:00 h, the time of day when birds are most active foraging (Sánchez-Jasso *et al.,* 2013; Sánchez-Guzmán *et al.,* 2018). Captured specimens were placed in cardboard boxes in order to stress them and obtain their excreta, which were placed in jars with 70% alcohol for subsequent analysis (Whitaker, 1988). Found Insect fragments were identified using taxonomic keys proposed by Borror *et al.* (1989) and Sterhr (1987); while birds were identified from standard field guides (Peterson & Chalif, 1989; Peterson & Peterson, 2002). Bird recording was developed by generating an ID, which consisted of the first three letters of the genus, followed by the three letters of the species (e.g. *Volatinia jacarina* = VolJac).

Insect monitoring was applied in parallel to the method of fixed-radius point counting and intensive search, using cutting and shaking of branches. This scheme consisted of locating the birds that were feeding, then placing a plastic bag on the branch on which the bird was located and shaking it in order to collect the insects on which it could potentially be feeding. Insects were identified using the taxonomic keys mentioned above.

Observation Frequency (OF) and Relative Abundance Index (RAI) of the collected insects were determined. Insect richness was determined using the Jacknife index1 (it should be noted that due to project requirements, insect richness was obtained at the family level), similarity with the Jaccard index and diversity using Shannon-Wiener; these indices were obtained from Estimates software version 9.0. In order to establish possible statistically significant differences between the indexes evaluated and to infer whether the data recorded are those potentially found in the area, Kruskal-Wallis and X^2 tests were applied, since the assumptions of parametric statistics were not met; these analyses were obtained using the JMP statistical software in SAS version 8.0.

To determine the possible association between the abundance of birds and insects recorded, Poisson regression analysis (PRA) was applied using a generalized linear model (GML). This was done through a stepwise polynomial variable selection procedure, assuming a *Poisson* type distribution in the frequency of the data, for which a logarithm was applied as a link function (determining the standard error, z value and significance codes), the adjustment of the models was done with the minimum Akaike criterion in the program R.13 .0 (Akaike, 1969). In order to determine the degree of association between the abundance of birds with respect to the orders, families, and types of insects and items recorded, canonical correspondence analyses (CCA) were applied in the XLSTAT statistical software version 2018.7.

It should be noted that for all statistical analyses a significance level α=0.05 with a confidence interval of 95 % was applied.

Figure 1. Evaluated conditions of the study area

RESULTS

From the insects collected by cutting and shaking branches, 53 species, 9 orders, 40 families and 51 genera were recorded. Of the total number of insects collected, 41 were pests, 37 non-pests, 61 predators and 8 parasites; 3 eggs, 20 larvae, 2 nymphs and 140 adults.

In turn, 77 samples of excreta from the birds captured were recorded (37 from TC, 18 from PT and 22 in BMM).

According to the OF, the insect families with the highest frequency recorded (by cutting and shaking branches) were *Chrysomelidae* (16.66 %), *Cicadellidae* (6.66 %) and *Miridae* (5.86 %), the rest showed lower values.

Jacknife1 results showed average values of: CT = 27; PT = 18; BMM = 10 and CT-PT-BMM = 39 families. We know 26 %; 26 %; 17 % and 30 %, respectively, of the insect families theoretically present in the study area (Figure 2).

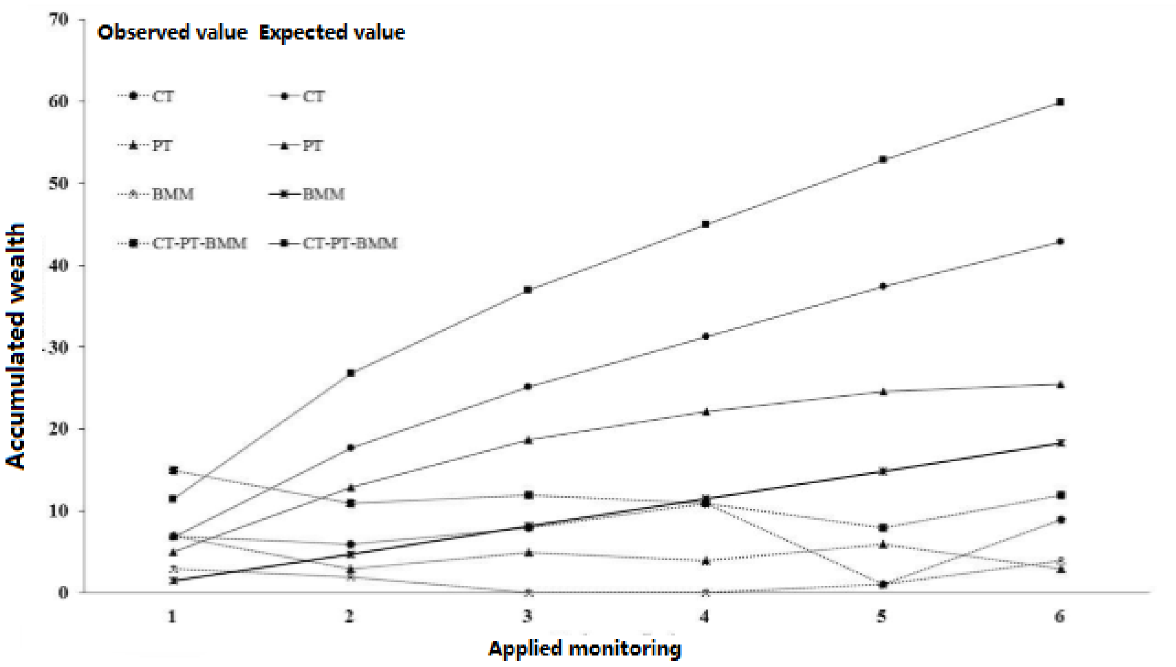

Figure 2. Jacknife1 for the wealth of insect families recorded by cutting and shaking branches

The relative abundance index presents average values of: CT = 0.03; PT = 0.05; BMM = 0.10 and CT-PT-BMM = 0.025 for insect families recorded by branch cutting and shaking.

Kruskal-Wallis shows significant differences in richness (p = 0.0423*) and diversity (p = 0.01*) recorded, but not in abundance (p = 0.52).

X^2 shows that abundance (p = 0.33) and diversity (p = 0.37) are those theoretically present in the evaluated area, but not for recorded richness (p = 0.02*).

The Jaccard estimator presents similarity percentages of: CT = 11.55 %; PT = 11.12 %; BMM = 0 % and CT-PT-BMM = 19.88 % for insect families recorded by branch cutting and shaking.

Shannon-Wiener presents minimum values of H' = 1.65; H' = 1.56; H' = 1.28; H' = 2.41 and maximum values of H' = 3.13; H' = 2.81; H' = 2.3; H' = 3.46; with average values of H' = 2.65; H' = 2.37; H' = 1.67 and H' = 3.09, respectively for the diversity of insects recorded by cutting and shaking branches.

The poisson regression analysis for the abundance of orders, families and types of insects recorded in branch cutting and shaking show values of AIC = 76.68, 76 and 119.23 (Table 1); for orders, families and items recorded in excreta they show values of AIC = 98.67, 98.65 and 98.67, respectively (Table 2). These GMLs show that only six orders, two families, two types of insects (cut and shaken), one order, one family and one item (excreta) have an effect on bird abundance in the conditions under study.

Table 1. Poisson regression for insects recorded by branch cutting and shaking

Coefficient	Estimated value	Standard error	Z value	Pr(>|z|)
		Orders		
(Intercept)	0.98	0.25	3.88	0 ***
Araneae	0.13	0.03	3.99	0.0000646 ***
Coleoptera	-0.56	0.21	-2.61	0 **
Hymenoptera	0.71	0.16	4.42	9.61E-06 ***
Lepidoptera	0.25	0.1	2.35	0.01 *
Orthoptera	0.46	0.07	6.48	8.94E-11 ***
Psocoptera	-0.51	0.1	-5.12	3.01E-07 ***
		Families		
(Intercept)	1.57	0.13	11.44	< 2e-16 ***
Apidae	1.64	0.24	6.78	1.15E-11 ***
Curculionidae	1.61	0.18	8.97	< 2e-16 ***
		Type of insect		
(Intercept)	1.47	0.16	8.76	< 2e-16 ***
Parasite	0.14	0.03	4.72	0 ***
Pest	0.09	0.02	4.31	0 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 2. Poisson regression for insects recorded by excreta analysis

Coefficient	Estimated value	Standard error	Z value	Pr(>|z|)
		Órdenes		
(Intercept)	-0.15	0.2	-0.74	0.45
Coleoptera	0.33	0.05	0.05	9.52E-11 ***
		Familias		
(Intercept)	-0.13	0.2	-0.69	0.49
Chrysomelidae	0.32	0.05	6.46	1.04E-10 ***
		ítems		
(Intercept)	-0.15	0.2	-0.74	0.45
Elytra	0.33	0.05	6.47	9.52E-11 ***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

CCA for orders, families, type of insects and items recorded, confirm percentages of accumulated inertia in their first two axes of: 88.28 % (figure 3); 62.89 % (figure 4); 95.40 % (figure 5); and 86.36 % (figure 6), respectively.

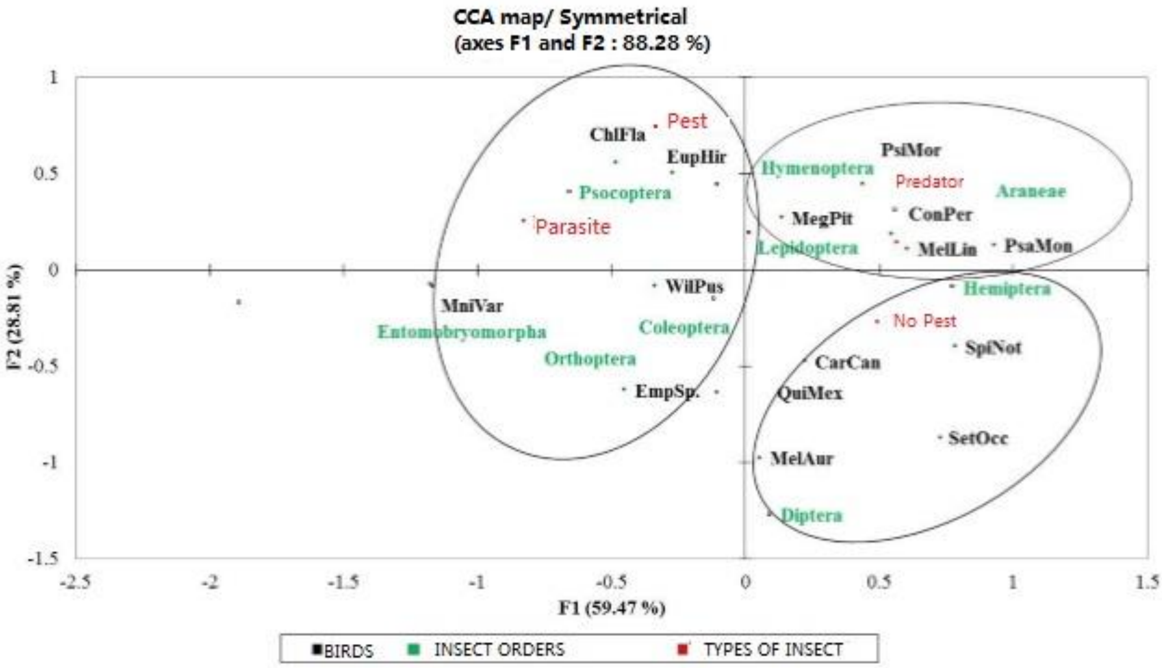

Figure 3. Inertia recorded among birds, orders and types of insects recorded by cutting and shaking branches

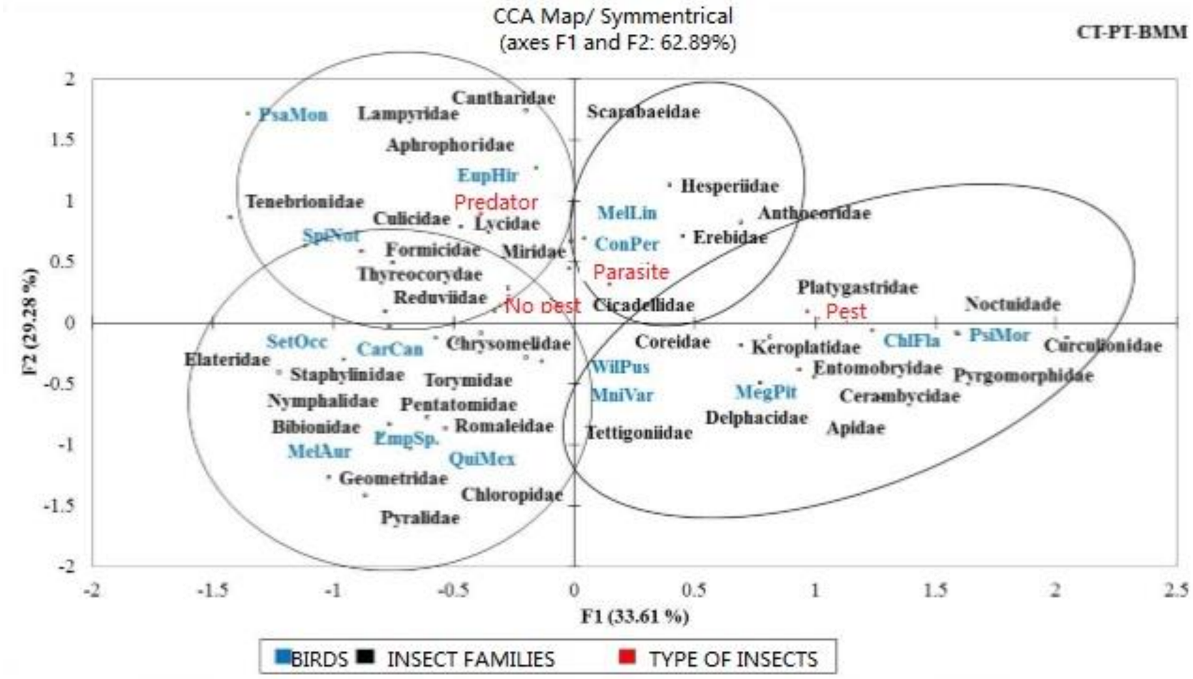

Figure 4. Inertia between avifauna and its relationship with families and types of insects recorded by cutting and shaking branches

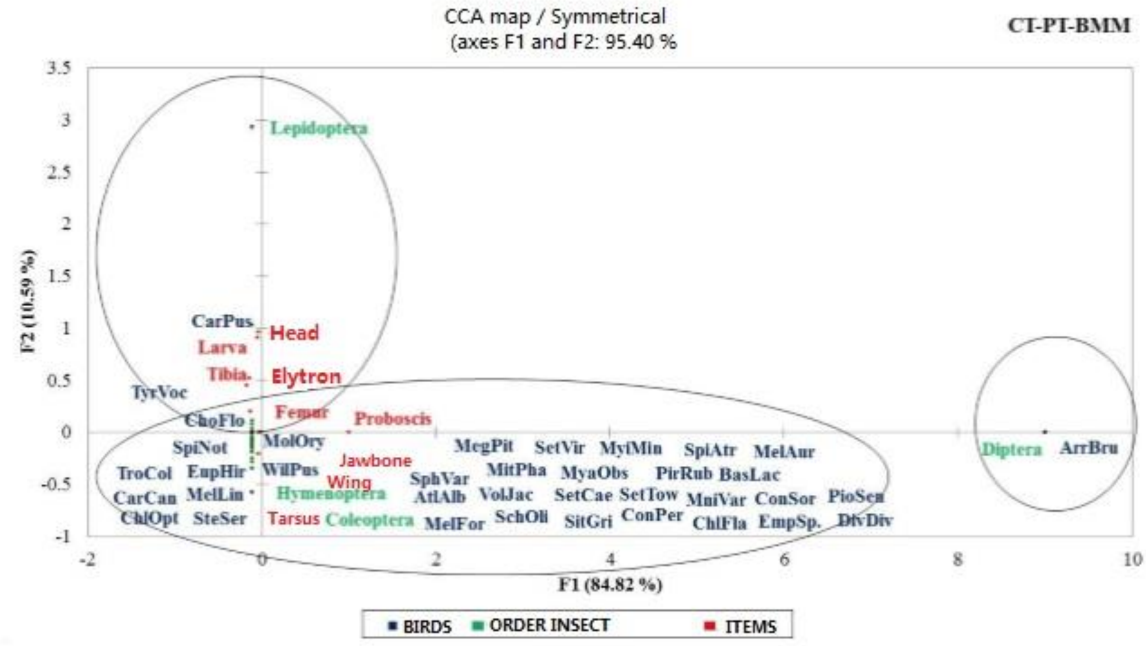

Figure 5. Inertia among birds and its relationship with orders and items of insects recorded in the analyzed excreta

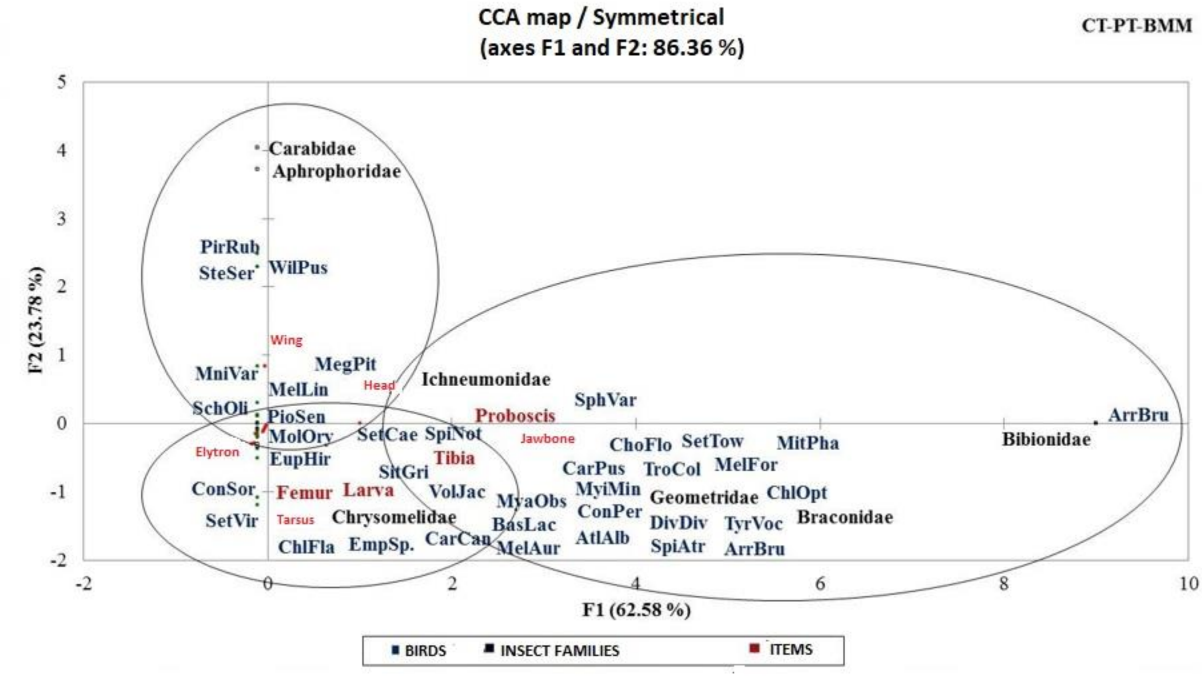

Figure 6. Inertia among birds and its relationship with insect families and items recorded in the analyzed excreta

DISCUSSION

The trend recorded for the feeding of the birds in the present study (feces and collected insects) agrees with that reported by Martínez *et al.,* (2019), Soto-Huaira *et al.,* (2019) and Liébana *et al.* (2020) who show similar results in other agroforestry production environments, indicating as the main trophic resource insects of the order Coleoptera. Followed by organisms of the order Araneae and Hymenoptera; likewise, it agrees with that reported by Hurtado-Giraldo *et al.* (2016) and Jedlicka *et al.* (2021) who determined the diet of insectivorous birds immersed in agroforestry systems in Colombia and Mexico, respectively. Their results show overuse of coleoptera by the avifaunal community; however, these organisms were of the pest type. The latter was also shown in the present study results and is consistent with the findings of García *et al.* (2018), Mosch *et al.* (2018), Escobar-Ramírez *et al.* (2019) and Rebollo *et al.* (2019) who have also developed studies in different agroforestry systems. It indicates that insectivorous birds function as biological control in agricultural and forestry crops, reducing up to 95% of this incidence. This behavior was corroborated in the present work by the sighting of birds in the arboreal stratum, feeding on insects that were later detected as pests; it can also be seen how certain individuals of *Megarhynchus pitangua* and *Icterus auratus* captured prey in PT and CT, controlling forest and fruit pests (citrus, bananas, avocados, and nuts, among others). All of the above is a sample of how agroforestry systems have food resources and utilization niches that allow the coexistence of diverse taxa, as pointed out by Figueroa-Sandoval *et al.* (2019) who applied an avifaunal study in agricultural production systems with conservation tillage. Jarrett *et al.* (2021) evaluated the incidence of insectivorous birds and other trophic groups in agroforestry systems in a certain region of Africa.

It is corroborated as the avifauna of these AFS, which contributes to regulate the incidence of pest insects as observed in certain individuals (*Euphonia hirundinaceae*, *Cardellina pusilla* and *Mniotilta varia*) of the lower stratum, feeding on larvae and adults of *Hypothenemus hampei* (coffee berry borer). It according to Bagny *et al.* (2020) and Olvera-Vargas *et al.* (2020) represents a problem that can reduce up to 50% of national coffee production. Thus it corroborates the importance of the results presented by Karp *et al.* (2013), Karp & Daily (2014), Martínez-Salinas *et al.* (2016), Milligan *et al.* (2016) and Jedlicka *et al.* (2021) who show how insectivorous birds from Mexico (Chiapas), Costa Rica and Africa immersed in coffee agroforestry systems contribute to the biological control of *Hypothenemus hampei*. However, the present research is a pioneer in addressing this issue by incorporating the trophic ecology of birds and their potential in the ecological balance of AFS insects immersed in Mesophilic Mountain Forest, in the particular region of Huatusco, Veracruz, Mexico.

In contrast, Miñarro Prado (2014), Newell *et al.* (2014a), Boesing *et al.* (2017), Olguín *et al.* (2017) and Hernández Guanche *et al.* (2020) point out that the greatest availability of insects of the arboreal stratum are of the order Araneae, Formicidae and Lepidoptera. It enhances the trophic support of birds that contribute to the control of pests in fruit trees and agricultural crops, reducing the incidence by up to 49%. This is due to their flight ability and low sensitivity to living barriers that allow the movement between different sites that provide food resources, favoring the resilience of ecosystems by the dispersal of seeds in degraded sites. In this study, certain individuals of *Pionus senillis*, *Psilorhinus morio* and some woodpeckers (*Melanerpes formicivorus*; *Melanerpes aurifrons*) were observed in the arboreal stratum collecting fruits that they transported to other places to consume their pulp and disperse their seeds, contributing to the resilience of these agroecosystems. Thus, Newell *et al.* (2014b), Leverkus & Castro (2017) and Banks-Leite *et al.* (2020) explain how birds are a key element in the resilience of fragmented ecosystems and areas (similar to AFSs) pointing out that thanks to their flight capacity these organisms are considered high mobility link species (HMLS). They fulfill the role of link between fragmented remnants and the connection between source and sinkhole areas. In such a way that Vaugoyeau *et al.* (2016) and Bateman *et al.* (2020) point out how the distance traveled by birds will be a function of their ability to acquire food and return to their home range. Therefore, there are species that only present utilization niches in areas considered edge effect as observed in some species that fed in PT, returning to their ecological niche once acquired their energetic proportion (BMM conserved condition). The TP is considered as a utilization niche where birds acquire food and provide the nutritional requirements that guarantee the survival of these species. All this agreeing with the reports of Montagnini (2020) and Morales Rozo *et al.* (2021) who point out that well-planned silvopastoral systems (similar to the evaluated TP) can contribute to the conservation of birds, offering opportunity niches where they find food and resources that allow their coexistence.

CONCLUSIONS

The diversity of entomological components that integrate the diet of insectivorous birds was determined through the analysis of excreta in the particular region of Huatusco, Veracruz, Mexico. Trophic sympatry is exhibited for certain bird species, favoring the biological control of pest and parasitic insects. The fundamental role played by birds in agroforestry systems is highlighted, maintaining the ecological stability and the good functioning of these means of production.

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Errata Erratum

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