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Activity of bats (Chiroptera) in extensive livestock systems in the Colombian Caribbean

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ABSTRACT

Introduction: Extensive cattle ranching in tropical dry forest areas (TDF) has caused the transformation of natural ecosystems and has altered the behavior of associated organisms, generating variation in activity patterns. In bats, the activity pattern is affected by the composition and vegetation structure of the ecosystem, and by the climatic season (dry and rainy). Therefore, it is expected that conventional extensive livestock systems, as opposed to silvopastoral systems where environmental heterogeneity is favored, determine the activity of bats.
Objective: To compare the activity patterns of bats in conventional management systems (CS) and silvopastoral (SPS) of extensive cattle ranching associated with TDF in the Colombian Caribbean.
Methods: The activity pattern of bats in TDF fragments associated with conventional and silvopastoral systems was compared within an annual cycle. The daily activity patterns of 11 species with records for over 10 days in both livestock management systems were determined.
Results: A total of 2 788 bats were captured, from six families, 22 genera, and 37 species. Greater bat activity was recorded during the rainy season. We found that although bats show behavioral adaptation to the different management systems (except for *Carollia perspicillata*, *Dermanura phaeotis* and *Glossophaga soricina*), in TDF fragments associated with SPS there is greater bat activity throughout the year, compared to the activity recorded in CS. Likewise, the only nectarivorous species evaluated, *G. soricina*, also presented the lowest overlap value between the two types of management SC and SSP.
Conclusion: The TDF fragments associated with SPS, due to the vegetation composition and structure, probably favor the constant supply of resources suitable for the bats' assemblage stability, especially flowers and fruits.

Key words: agroecosystems; caribbean colombian; *Glossophaga soricina*; temporal overlap.

RESUMEN

Actividad de murciélagos (Chiroptera) en sistemas de ganadería extensiva en el Caribe colombiano

Introducción: La ganadería extensiva en áreas de bosque seco tropical (bs-T) ha causado la transformación de los ecosistemas naturales, y ha alterado la conducta de los organismos asociados, generando variación en los patrones de actividad. En murciélagos, el patrón conductual se ve afectado por la composición y estructura vegetal del ecosistema, y por la época climática (seca y lluviosa). Por lo que, se espera que en los sistemas convencionales de ganadería extensiva a diferencia de los silvopastoriles donde se favorece la heterogeneidad ambiental, determine la actividad de los murciélagos.

Objetivo: Comparar los patrones de actividad de los murciélagos en sistemas de manejo convencional (SC) y silvopastoril (SSP) de ganadería extensiva asociados al bs-T en el Caribe colombiano.
Métodos: Se comparó el patrón de actividad de los murciélagos en fragmentos de bs-T asociados a SC y SSP durante un ciclo anual. Se determinó el patrón de actividad diaria de 11 especies con registros mayores a 10 días en ambos sistemas de manejo de ganadería.
Resultados: Un total de 2788 murciélagos fueron capturados, de seis familias, 22 géneros y 37 especies. Se registró mayor actividad de murciélagos durante la época de lluvias. Encontramos que a pesar de que los murciélagos presentan adaptación del comportamiento a los diferentes sistemas de manejo (excepto *Carollia perspicillata*, *Dermanura phaeotis* y *Glossophaga soricina*), en fragmentos de bs-T asociados a SSP se presenta mayor actividad de los murciélagos durante todo el año, con respecto a la actividad registrada en los SC. Igualmente, la única especie nectarívora evaluada, *G. soricina,* presentó también el menor valor de solapamiento entre los dos tipos de manejo SC y SSP.
Conclusión: Los fragmentos de bs-T inmersos en SSP debido a la estructura del paisaje, podrían estar favoreciendo la oferta constante de recursos adecuados para la estabilidad del ensamblaje de murciélagos, en especial flores y frutos.

Palabras clave: agroecosistemas; caribe colombiano; *Glossophaga soricina*; superposición temporal.

INTRODUCTION

The process of deforestation of the tropical dry forest (TDF) and its replacement by pastures for extensive cattle ranching has caused a decrease in fertility and increased soil compaction, a phenomenon that has generated desertification in many dry ecosystems in Colombia and the world, affecting the functioning of ecosystems and functional connectivity (Baguette & Van Dyck, 2007). These changes in plant structure and composition affect the activity patterns of different groups of associated species, such as mammals, closely related to TDFs (Pizano et al., 2014; Pizano et al., 2017). The replacement of vegetation cover has affected the bat assemblage (Ballesteros-Correa & Pérez-Torres, 2022), organisms sensitive to disturbance, which respond differentially by decreasing their richness and abundance of individuals (Williams-Guillén & Perfecto, 2011; Stahlschmidt & Brühl, 2012). The diverse ecological functions and functional traits, such as activity patterns, individual size, forearm length and body condition, which are related to energy expenditure and resources used (García-Morales et al., 2016; Chacón-Pacheco & Ballesteros-Correa, 2019; Castillo-Figueroa & Pérez-Torres, 2021) are sensitive to environmental changes (Kalko & Schnitzler, 1993).

Bats are recognized for their great trophic diversity and, because of that, are involved in many ecological processes, such as seed dispersal, plant pollination, ecological succession, and population control of insects (Delgado-Jaramillo et al., 2011; Vásquez-Parra et al., 2017; Ballesteros-Correa & Pérez-Torres, 2022). Therefore, due to their varied resource utilization strategies, the neotropical bat activity is correlated with habitat diversity, energetic requirements of the species, the food resource abundance, social interaction, and intra and inter-specific competition (Meyer et al., 2005), as well as with climatic variables such as temperature and precipitation (Santos-Moreno et al., 2010a; Santos-Moreno et al., 2010b). The resulting environmental variations such as resource supply and changes in landscape structure make bats's activity peaks present changes at the guild or functional group level (Santos-Moreno et al., 2010b), as a result of differential species responses and ecological adaptive capacity. This has allowed bats to be used as measurement tools in the evaluation of the impact of agricultural and livestock production projects (Meyer et al., 2005).

Bats in the Colombian Caribbean region face constant processes of anthropization and reduction of natural habitats as a result of the establishment of agricultural systems, so this

work sought to compare activity patterns of bats in conventional (CS) and silvopastoral (SPS) extensive livestock management systems.

MATERIALS AND METHODS

Study Area: This research was carried out within the framework of the doctoral thesis of the second author (JB-C) entitled "Effect of silvopastoral and conventional extensive livestock management on the bats assembly associated with fragments of tropical dry forest in Córdoba, Colombia" (Ballesteros-Correa, 2015). The field work was carried out during an annual cycle (August 2011 – July 2012) in four localities with TDF fragments with less than 100 ha, associated with two extensive livestock management systems, conventional (CS) and silvopastoral (SPS) in the department of Córdoba, in the Colombian Caribbean region. The territory has a tropical climate with an average temperature of 28 °C, average annual rainfall of 1 300 mm, and a bimodal distribution pattern with a dry season (December-March) and a rainy season (April-November) (Fig. 1). Two fragments are associated with extensive livestock SPS in Montería, Finca Las Palmeras (08°30'37.1" N & 76°06'12.9" W; 560 ha), and Los Córdobas, Finca San Lorenzo (08°53'20.0" N & 76°18'42.6" W; 860 ha) and two fragments associated with CS in Canalete, Finca Chimborazo (08°44'32.4" N & 76°19'23.4" W; 470 ha) and Buenavista, Finca Guacamayas (08°11'05.3" N & 75°31'49.2" W; 450 ha).

The TDF fragments of SPS are characterized by secondary forests in mixed stages of plant succession, surrounded by a matrix of extensive livestock system with natural polyspecific grasslands, stubble areas, pastures with abundant trees and shrubs, live fences, and agricultural practices. These have been under agroforestry management for more than 12 years, without the use of agrochemicals, where the tree, shrub and herbaceous vegetation is used to feed the cattle that freely graze the timber, forage, and fruit trees. Cattle enter the forest fragments during the dry season of the year; but during the rainy season they are not allowed looking for vegetation recovery, such as those plant species dispersed by fruit bats (*Guazuma ulmifolia*, *Spondia mombin*, *Ficus* sp., *Piper* sp., *Cecropia* sp., *Maclura tinctorea*,

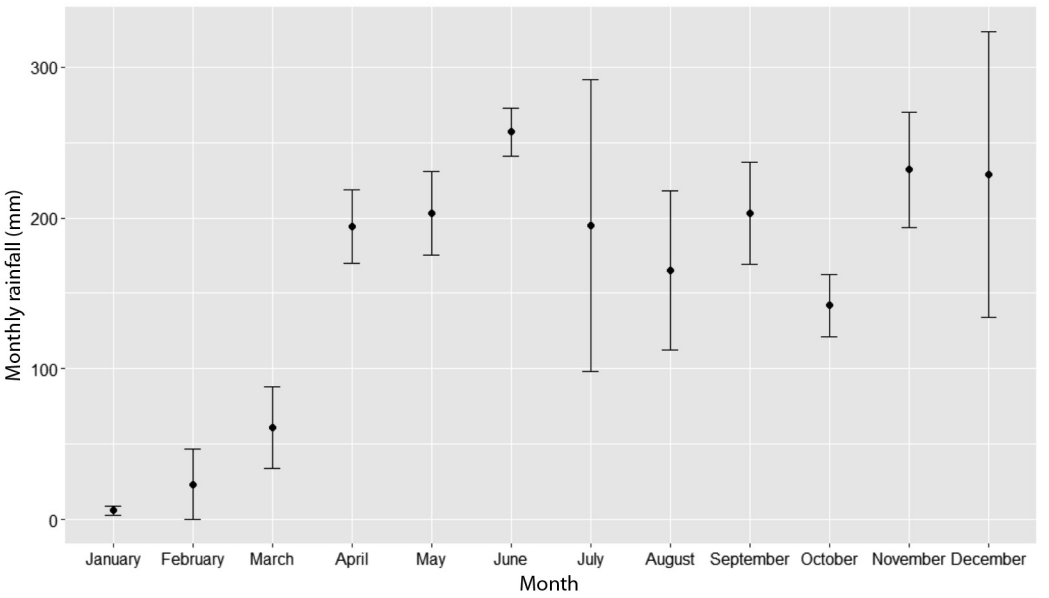

Fig. 1. Average monthly precipitation in tropical dry forest fragments (TDF) in extensive conventional (CS) and silvopastoral (SPS) livestock systems in the Colombian Caribbean region.

Aegiphila sp., *Solanum* sp., and *Vismia* sp., among others).

While the TDF fragments in CS are secondary forests in advanced succession stage (more than 50 years old), characterized by herbaceous, shrub, tree, and liana strata, where timber trees are selectively removed for timber extraction and its use in pasture fences. These fragments are connected to 6-year-old teak (*Tectona grandis*) plantations, an introduced species. Cattle ranching is carried out traditionally, in open pastures with monospecific pastures and few trees in the pastures, with rotational pasture management. During the dry season there is a significant decrease in forage supply, which reduces the carrying capacity of the system. Agrochemicals are frequently used to control herbaceous and shrub vegetation in the pastures (Glyphosate, 24-D, Paraquat), and to control livestock parasites (Pyrethroids, Ivermectin).

In the TDF fragments, 3378 individuals belonging to 242 plant species were recorded for the study period. Fifty-six taxonomic families were identified where Fabaceae (39), Rubiaceae (19), Bignoniaceae (12), Boraginaceae (12), Apocynaceae (9) and Moraceae (9) presented the highest species richness. TDF fragments associated with the SPS were dominated by Malvaceae (18.3 %), Boraginaceae (12.3 %), Fabaceae (10.8 %), Apocynaceae (6.9 %) and Euphorbiaceae (6.3 %). Meanwhile, in the fragments associated with the CS, the families Rubiaceae (13.2 %), Rutaceae (10.1 %), Fabaceae (7.6 %), Meliaceae (7.2 %) and Sapotaceae (6 %) presented the highest relative abundance. The diversity in taxonomic composition presented highly significant differences between SPS and CS (Shannon test, $P < 0.0001$); with a significantly higher alpha diversity in the SPS fragments (158 species) than in the CS fragments (142 species).

Bat sampling: Fifteen samplings of three consecutive nights per fragments were conducted at 24-day intervals, for a total sampling effort of 30 240 h-net-night, for a total of 45 nights in each fragment (7 560 h-net-night). A total of 14 mist nets were used to capture bats: 5 floor nets (0 - 4 m), 5 elevated nets (height > 4 m) inside the fragments; and 4 floor nets at the forest edge. The nets were deployed from 18:00 to 06:00 hours the following day and checked every 45 minutes. The nets were in the same place during the 15 samplings that were carried out in each fragment. The captured bats were processed *in situ* according to the protocol proposed by Kunz et al. (1996). Standard morphometric measurements, weight, sex, and relative age were recorded. The taxonomic keys were used for identification of Linares, 1998; Timm et al., 1999; and Gardner, 2008. Were marked on the propatagium with the help of a rabbit tattoo plier to avoid recounts. The taxonomic treatment of the Mammal Diversity Database and batnames was followed. For the genus *Sturnira* due to recent changes in the genus (Velazco & Patterson, 2014; Velazco & Patterson, 2019) following the treatment as *S. giannae*, although we recognize the need for revision. We obtained a reference collection (male and female) according to standardized techniques (Reynolds et al., 1996). Ethical, scientific, and administrative standards for animal research contained in Law 84 (Congreso de la República de Colombia, 1989) were considered, with research permission by The Regional Autonomous Corporation of the Sinú and San Jorge Valleys, CVS—Montería, Resolution N° 2-1033 (2015).

Data analysis: For the analysis of information on bat activity patterns. We used to catch as proxy of the activity the phyllostomids bats, considerate that echolocation system of these species reports low intensities and high frequencies that are often difficult to record in field (LaVal & Fitch, 1977) and are notoriously easy to catch with mist nets (Thies et al., 1998). We grouped the records by species, date and time, and according to the foraging preference of each species by their strategy (Soriano 2000). We applied a Kruskal-Wallis ANOVA to evaluate the activity of the species for their strategy, sedentary frugivorous, nomadic frugivorous and omnivorous-nectarivorous for each month.

Additionally, we applied a Kruskal-Wallis ANOVA of the activity of each species between the two management types of SC and SPS. For displaying activity patterns by species and foraging strategy, we estimated the overlap index (Δ) after pooling data by management type, we used the nonparametric Kernel density estimation method suggested by (Ridout & Linkie, 2009), where Δ values range from 0 (no overlap) to 1 (total overlap). We use a smoothing parameter of for species with more than 75 records, and was used for those species with less than 50 records in the livestock system with the lowest number of captures. For each overlap index we estimate its minimum and maximum value with a confidence interval of 95 % (1 000 bootstrap replicates). For the analysis we selected species with records in minimum 10 sampling days for the CS and SPS management types. We used the Overlap package (Meredith & Ridout, 2014) available in R.

RESULTS

A total of 2 788 bats were captured, from six families, 22 genera and 37 species grouped into eight foraging strategies (Table 1). We selected 11 species that met the minimum number of records for the two types of livestock management and were grouped as nomadic frugivorous, sedentary frugivorous, nectarivorous and omnivorous: *Artibeus lituratus* (409), *A. planirostris* (578), *D. phaeotis* (222), *Carollia perspicillata* (390), *C. castanea* (245), *C. brevicauda* (108), *Glossophaga soricina* (116), *Phyllostomus discolor* (222), *P. hastatus* (46), *Sturnira giannae* (98) and *Uroderma convexum* (175).

The 11 bat species analyzed showed temporal variation in activity patterns. Bats associated with TDF fragments in the SPS presented the highest peaks of temporal activity with respect to those found in the CS, with highest activity during the months of August, September, and December (Fig. 2).

The sedentary fruit bats presented temporal variation in the annual cycle (X^2 = 26.1, P < 0.05), *C. perspicillata* presented increased of activity during most of the year, with increased variation in June, September, and December; *Sturnira giannae*, *C. castanea* and *C. brevicauda* exhibited patterns with low activity early in the year, with increased variation in December. While nomadic bats did not show any significant variation (X^2 = 12.0, P = 0.36), *Artibeus lituratus* and *A. planirostris*, were most active in the August-October period; *Dermanura phaeotis* and *U. convexum* maintained constant activity patterns. Likewise, the bats

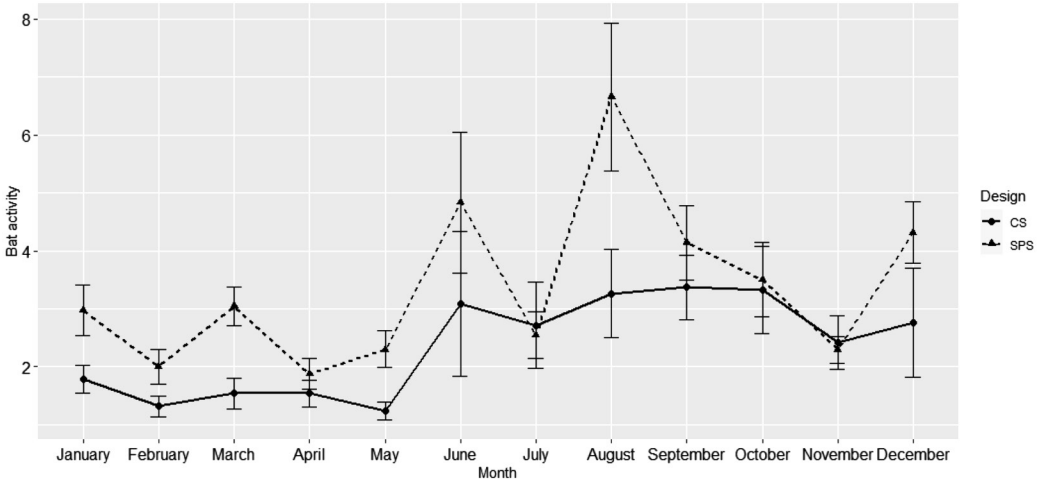

Fig. 2. Temporal activity patterns in the annual cycle of bats associated with tropical dry forest (TDF) fragments in the extensive conventional (CS) and silvopastoral (SPS) livestock systems in the Caribbean Colombian region.

Table 1
Bats species recorded in the extensive conventional (CS) and silvopastoral (SPS) livestock systems in the Caribbean Colombian region

Family	Genus	Species	FS	CS	SPS
Emballonuridae	*Saccopteryx*	*Saccopteryx bilineata*	IA	-	1
		Saccopteryx leptura	IA	4	9
Molossidae	*Mollossops*	*Molossops temminckii*	IA	2	-
	Molossus	*Molossus molossus*	IA	9	7
Mormoopidae	*Pteronotus*	*Pteronotus davyi*	IA	-	1
Noctilionidae	*Noctilio*	*Noctilio albiventris*	C	7	5
Phyllostomidae	*Artibeus*	***Artibeus lituratus***	**FN**	**103**	**306**
		Artibeus planirostris	**FN**	**300**	**279**
	Carollia	***Carollia brevicauda***	**FS**	**31**	**77**
		Carollia castanea	**FS**	**25**	**220**
		Carollia perspicillata	**FS**	**76**	**314**
	Dermanura	***Dermanura phaeotis***	**FN**	**31**	**191**
		Dermanura watsoni	FN	-	18
	Desmodus	*Desmodus rotundus*	H	5	18
	Glossophaga	*Glossophaga commissarisi*	N	1	2
		Glossophaga soricina	**N**	**29**	**87**
	Lionycteris	*Lionycteris spurrelli*	N	-	1
	Lonchophylla	*Lonchophylla robusta*	N	-	1
	Hsunycteris	*Hsunycteris thomasi*	N	1	-
	Lophostoma	*Lophostoma brasiliense*	IF	2	-
		Lophostoma silvicolum	IF	15	2
	Micronycteris	*Micronycteris hirsuta*	IF	-	1
		Micronycteris megalotis	IF	2	-
	Gardnerycteris	*Gardnerycteris keenani*	IF	2	1
	Phyllostomus	***Phyllostomus discolor***	**O**	**161**	**61**
		Phyllostomus hastatus	**O**	**26**	**20**
	Platyrrhinus	*Platyrrhinus angustirostris*	FN	3	-
		Platyrrhinus helleri	FN	7	14
		Platyrrhinus umbratus	FN	-	1
	Sturnira	***Sturnira giannae***	**FS**	**17**	**81**
	Trachops	*Trachops cirrhosus*	C	1	2
	Uroderma	***Uroderma convexum***	**FN**	**39**	**136**
		Uroderma magnirostrum	FN	1	5
	Vampyriscus	*Vampyriscus nymphaea*	FN	7	7
Vespertilionidae	*Myotis*	*Myotis* sp.	IA	1	-
		Myotis nigricans	IA	-	3
	Rhogeessa	*Rhogeessa io*	IA	2	7
Total				910	1 878

Foraging strategies (FS): (C) Carnivorous, (FN) Nomadic frugivorous, (FS) Sedentary frugivorous, (H) Hematophagous, (IA) Aerial insectivorous, (IF) Foliage insectivorous, (N) Nectarivorous, and (O) Omnivorous. Bold: species selected for analysis of activity patterns.

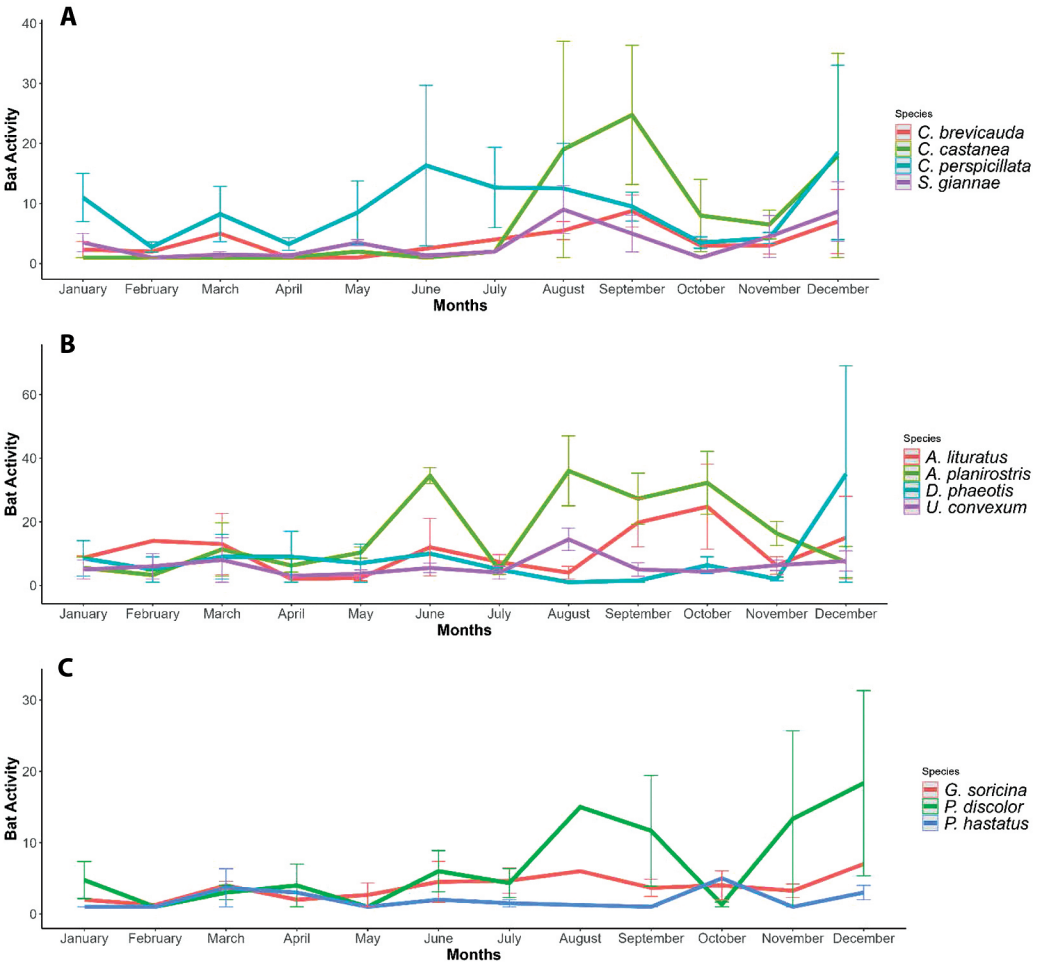

Fig. 3. Temporal activity pattern of bats according to foraging strategies in the extensive conventional (CS) and silvopastoral (SPS) livestock systems in the Caribbean Colombian region. (A) Nomadic frugivorous; (B) Sedentary frugivorous; (C) Nectarivorous (*Glossophaga soricina*) and omnivorous (*Phyllostomus discolor* and *P. hastatus*).

omnivorous-nectarivorous showed no significant variation, the activity of *Glossophaga soricina* was constant, *Phyllostomus discolor* showed a decrease in activity in the period from February to May and was most active from June-September and November-January; while *P. hastatus* maintained low activity throughout the year (Fig. 3).

According to foraging strategies, nomadic fruit bats, sedentary fruit bats and nectarivorous showed a bimodal activity pattern, and their abundance varied between the two periods of the night ≤ 00:00 hours and ≥ 00:00 hours (Fig. 4). While omnivorous *P. discolor* and *P. hastatus*, showed a pattern of activity associated with the first part of the night ≤ 00:00 hours (Fig. 5).

With respect to the Kruskal-Wallis ANOVA we found significant differences in activity between the two management types of CS and SPS for the species, *D. phaeotis* (X^2 = 5.24, P = 0.02), *C. perspicillata* (X^2 = 12.00, P < 0.05) and *G. soricina* (X^2 = 6.75, P < 0.05). The activity of the other species was not different between the two types of livestock management (P > 0.05). Nomadic and sedentary fruit bats

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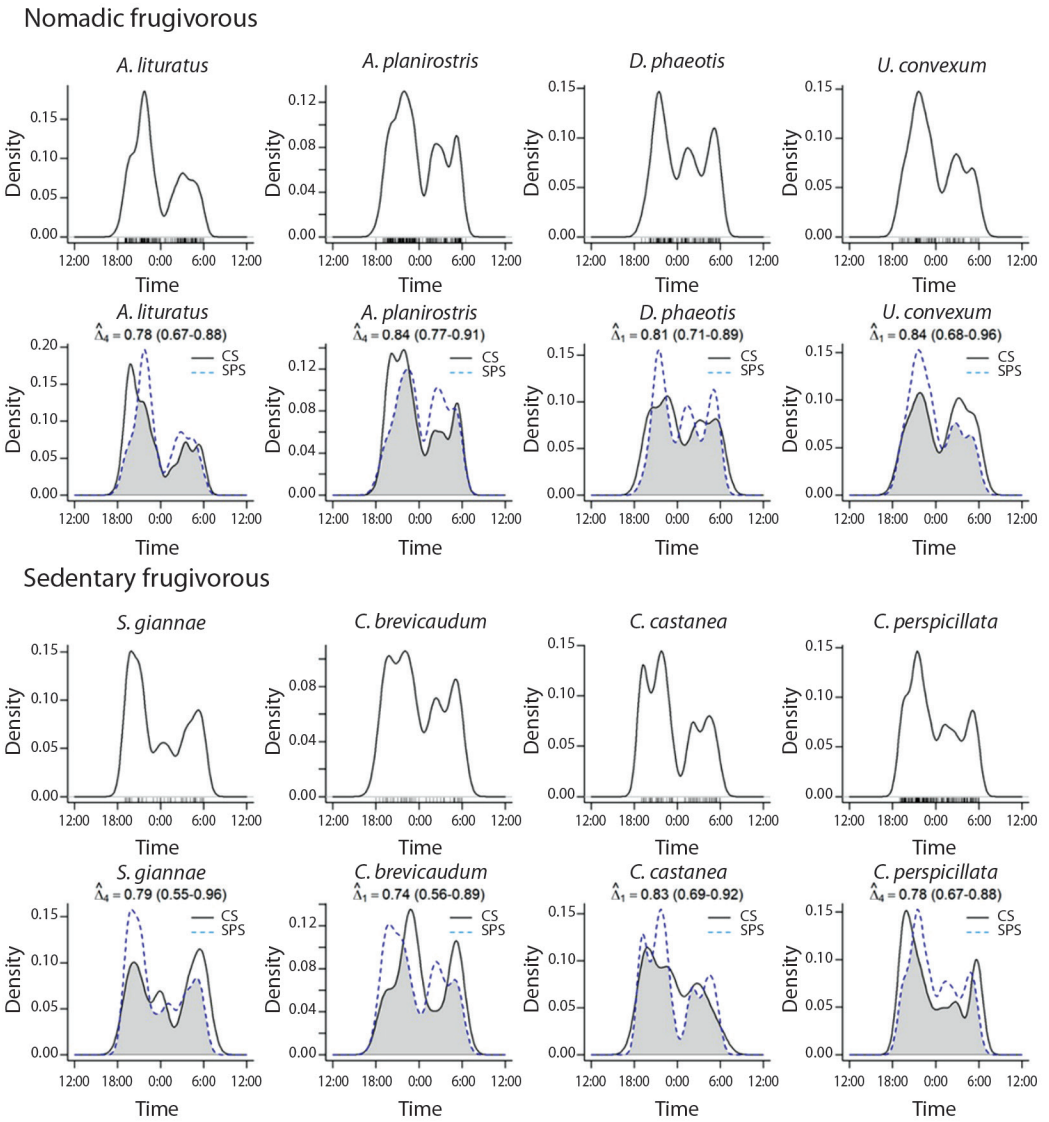

Fig. 4. Activity patterns average and the overlap index (Δ) for fruit bats in extensive conventional (CS) and silvopastoral (SPS) livestock systems in the Caribbean Colombian región. overlap index for species with more than 75 records and for those species with less than 50. Values in parentheses represent 95 % confidence intervals. The shadowed area indicates the overlap of activity for each species between the two management types CS and SPS. Top, nomadic frugivorous bats: *Artibeus lituratus*, *A. planirostris*, *Dermanura phaeotis* and *Uroderma convexum*. Bottom, bats: *Sturnira giannae*, *C. brevicauda, Carollia castanea* and *C. perspicillata*.

had an overlap between 0.74 and 0.84 (Fig. 4). *Glossophaga soricina* and *P. discolor* presented a temporal overlap of 0.64 respectively (Fig. 5). While the overlap index value (Δ) of *P. hastatus* between CS and SPS was lower 0.32 (0.22 - 0.40), with a peak of activity at 19:00 hours and decreasing activities around 00:00 hours for SPS. In contrast, for the CS, the peak of activity occurred around 20:30 hours, with a decrease in activity at 23:00 hours (Fig. 5).

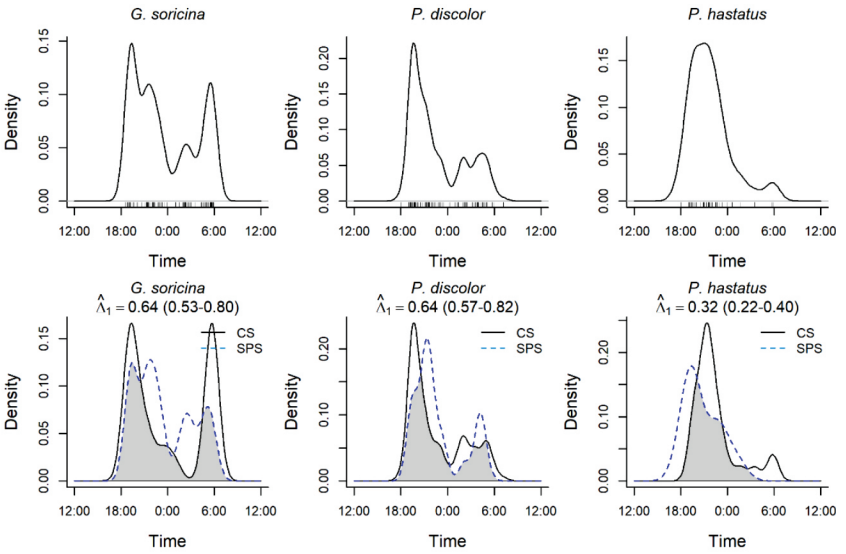

Fig. 5. Activity patterns average and the overlap index (Δ) for nectarivorous (*Glossophaga soricina*) and omnivorous (*Phyllostomus discolor* and *P. hastatus*) in extensive conventional (CS) and silvopastoral (SPS) livestock systems in the Caribbean Colombian region. overlap index for species with less than 50 records. Values in parentheses represent 95 % confidence intervals. The shaded area indicates the overlap of activities of each species between the two management types of CS and SPS.

DISCUSSION

This study becomes the first report that provides information on bat assemblage activity patterns in cattle ranching landscapes in Colombia, using the captures as a surrogate for the activity of phyllostomid bats. The effects of habitat modification on bats in tropical forests have been previously reported (Meyer et al., 2008; Verde et al., 2018; Rocha et al., 2020), and the effects of extensive ranching systems on the diversity of TDF bats associated with different extensive livestock management systems have been sparsely analyzed (Ballesteros-Correa & Pérez-Torres, 2022), but little is known about activity patterns.

Variation in bat activity patterns in TDF fragments associated with different extensive livestock management systems is probably due to differences in vegetation structure and composition in each livestock matrix (Ballesteros-Correa et al., 2019), and the different environmental conditions in each of the climatic periods in the annual cycle. In the SPS, greater activity of the entire bat assemblage was found throughout the annual cycle as compared to the CS, where the vegetation structure and composition in the SPS provide benefits in landscape connectivity, decreases the edge effect, and improves soil fertility (Arciniegas-Torres & Flórez-Delgado, 2018). These conditions allow greater availability of resources that favor richness, abundance and favor the body condition of bats (Chacón-Pacheco & Ballesteros-Correa, 2019).

The highest peaks in activity patterns for fragments associated with SPS and CS coincide with an increase in rainfall. This temporal variation in behavioral patterns is related to fruit production, in response to the marked temporal distribution of rainfall in the region (Avila-Cabadilla et al., 2014). Other authors, such as Kalacska et al. (2005) and Stoner (2005), indicate that these temporal variations favor the availability of resources such as flowers, fruits, insects, and suitable sites that allow a greater abundance of species in the SPS in the annual

cycle. The bat response to this temporal seasonality of resource supply in TDFs causes temporal changes in assemblages, especially in the abundance of frugivorous bats (Stoner, 2005; Avila-Cabadilla et al., 2009; Vleut et al., 2013), which is consistent with the results obtained in this study. As is the case of greater activity for the SPS of frugivorous and nectarivorous species (i.e. *C. perspicillata*, *D. phaeotis* and *G. soricina*) and less overlap between the two types of management as was the case for *P. hastatus*.

With respect to the analysis of the nocturnal bat activity, the results indicate that most of the species present bimodal activity patterns, as has been reported for species of the genera *Artibeus*, *Carollia*, *Platyrrhinus* and *Sturnira* in other geographic areas (Aguiar & Marinho-Filho, 2004; Vásquez-Parra et al., 2017; Verde et al., 2018). However, in bats it is common to observe a peak of activity in the early evening, as a response to the high energetic requirements associated with the high availability of resources in the first night hours. Additionally, between CS and SPS livestock systems the temporal overlap was higher for fruit bats, thus suggesting that there are no important changes or modifications in bat activity patterns between the two types of extensive livestock management. However, for the omnivorous and nectarivorous species the overlap index (Δ) was lower. This suggests that forest fragments associated with CS provide food resources for fruit bats, such as palms of the genera *Astrocaryum*, *Bactris* and *Sabal* (Chacón-Pacheco & Ballesteros-Correa, 2019; Ballesteros-Correa & Pérez-Torres, 2022). While TDF fragments associated with SPS provide opportunities for bats with higher energetic requirements and specialization, such as species of the genus *Phyllostomus*, bats considered indicators of habitat quality (Medellín et al., 2000).

Considering all this, we conclude that the bat activity pattern may be affected by extensive livestock management. SPS may be improving the stability of bat assemblage and activity patterns, because in TDF fragments associated with SPS, bat activity was favored throughout the annual cycle. However, other study methodologies need to be explored, such as acoustic sampling to reduce capturability effects on species behavior and analyze these activity patterns in complementary insectivorous bats species that are poorly represented in mist-net sampling (Bejarano-Bonilla et al., 2007). Likewise, more studies are needed about how bat activity patterns are affected in different TDF scenarios.

Ethical statement: the authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

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