Which Factors Affect The Flight Times Of A Moth Community In The Brazilian Pampa Grasslands?

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Abstract

The daily activity of a species can be affected by several biotic and abiotic factors. Since the activity patterns and flight times of Neotropical moths are both poorly understood, our goal was to record and analyze the flight times of moths from the Pampa biome, in the extreme south of Brazil, as well as its responses to climatic factors. We recorded hours of activity and investigated the influence of four climatic variables on the activity patterns of Arctiinae (Erebidae), Sphingidae, and Saturniidae. Data analysis showed that different species have different activity periods, and the abundance and richness of each taxa has its own patterns. Arctiinae had a higher abundance in the early evening, although it did not show a richness concentration at any hour. Saturniidae and Sphingidae had both abundance and richness concentrated in the middle of the night. Climatic variables related to abundance and richness differed between taxa and species. We provide evidence of possible niche partitioning and differential physiological adaptations between taxa, as well as differences in flight time strategy between potential competing species.

Introduction

An organism's daily activity is driven by several factors, such as climate, food availability, competition, and predation. Studies on the daily activity of species are relevant for answering both technical (such as determining the best moments to sample a given taxon) and scientific questions, such as temporal niche partitioning and co-occurrence patterns (Moreno et al. 2021). Although Insecta is the most diverse group of animals on the planet, studies focused on its daily activities are still scarce (Scherrer et al. 2013; Teston and Corseuil, 2004). Within insects, Lepidoptera is considered to be a megadiverse Order. In Brazil, there are 60,000 to 80,000 estimated species (Carneiro et al., 2024). In the Brazilian Pampas, Lepidoptera currently has 747 recorded species, mostly butterflies (Andrade et al. 2023). However, this proportion is due to a higher taxonomic understanding and sampling effort of Papilionoidea, and does not necessarily correspond to the real Lepidoptera diversity of the region.

Among the nocturnal lepidopterans, the subfamily Arctiinae (Lepidoptera: Erebidae) has approximately 11,000 species worldwide (Jacobson and Weller 2002) and 1,400 in Brazil (Ferro and Diniz 2010). These moths have nocturnal, diurnal and crepuscular habits. Arctiine caterpillars can feed on a wide variety of angiosperms and gymnosperms, as well as algae, fungi, lichens and bryophytes (Wagner 2009). Many Arctiinae species are wasp mimics or display aposematic colors that signal chemical defenses, those being generally sequestered from their host plants (Molina and Di Mare 2017; Zaspel et al. 2014). Despite its current subfamily status, Arctiinae comprehends species with great morphological contrast, from medium-sized species to very diminute ones.

The family Sphingidae, in contrast to Arctiinae, comprises medium to large-sized moths. This group also includes nocturnal, crepuscular and diurnal species. Many species in the family have a high ecological importance due to direct associations with sphingophilous plants, which are pollinated only by sphingids and are characterized by elongated flowering tubes or a dense array of stamens (Amorim 2008). More than 1,600 species of shingids are known worldwide, including 196 in Brazil (Carneiro et al. 2024; Corrêa 2017; Haxaire and Mielke 2019; Specht et al. 2008a).

The Saturniidae moths have a high richness in tropical regions (Heppner 1991). Approximately 3,500 species are known worldwide; of these, about 480 occur in Brazil (Carneiro et al. 2024; Nunes 2006). They can have vibrant colors or camouflage patterns, and many have wings with ocelli or translucent areas. Although most species are nocturnal, some Saturniidae are diurnal or crepuscular (Carneiro et al. 2024; Kawahara et al. 2018). Despite also being medium to large-sized moths, Saturniidae body and wing proportions have many distinctions when compared to Sphingidae. In sphingids, the wing area is relatively small compared to body size, a morphological trait that allows a vigorous and well-directed flight (Carneiro et al. 2024; Machado 2014). In Saturniidae, the body is much smaller compared to the wing area (Carneiro et al. 2024). Adult Saturniidae are characterized by lacking or having a non-functional proboscis (Costa Lima 1950). Consequently, adults do not feed and survive on energy stored in the body during larval stage (Janzen 1984). Differently, Arctiinae and Sphingidae adults possess functional proboscises, used on nectar feeding (with some exceptions).

Many factors can determine a species' hour of activity. It is known that species that compete for a resource can either mutually exclude each other from habitats or coexist, with one form of coexistence being the utilization of the same resource in a slightly different way (Begon et al. 2007). In this case, having different foraging times could be a way for species to share floral resources without direct competition. Similarly, the presence of predators can be a determining factor in a species' activity. Arctiinae and Sphingidae both comprise species with acoustic defenses against predators, either through eardrums for acoustic vigilance or through sound-producing mechanisms that hinder or inhibit predation by bats (Barber and Kawahara 2013; Dowdy and Conner, 2019; Dunning et al. 1992; Göpfert et al. 2002; Kawahara et al. 2019). Saturniids, on the other hand, do not have eardrums or sound production structures, and rely on a variety of morphological adaptations on body and wings for survival (Barber et al. 2015; Ntelezos et al. 2017; Zeng et al. 2011).

In addition to biotic factors such as competition and predation, abiotic factors (such as temperature, humidity, and rainfall) directly influence moth biology. In Arctiinae, there is a general tendency of a decreasing number of generations with the increase of latitude, a pattern also recorded for several species of Sphingidae (Wagner, 2009; Wiker et al., 2010). In Saturniidae, different species in the same region may present different numbers of generations per year (Janzen, 1987; Nath et al., 2021; Tikader et al., 2013). As insects are poikilothermic animals, there is a strong association with temperature, which is a determining factor for development, survival, and distribution on daily, local, or regional scales (Régnière et al., 2012).

The present study aimed to record the activity times of different moth species throughout the night in a Pampa region of southern Brazil, and to analyze the influence of abiotic factors on the activity times of these species. In addition to register which species occur in the area, we try to understand (1) how species composition differs throughout the night, (2) if different taxa respond distinctly to climate, (3) how the abundance/richness of each group relates to climatic factors, and (4) if it is necessary to sample throughout the whole night to obtain a representative sample of the community. We tested three hypotheses. The first is that different taxa would have different abundance/richness concentrations throughout the night. The second hypothesis is that smaller species (Arctiinae) would be concentrated in the early hours of the night, while larger species (Sphingidae and Saturniidae) would have a greater permanence capacity in the late night, given the higher heat retention capacity of moth with bigger bodies (Bartholomew and Heinrich 1973). The third is that climatic variables such as rain and wind would be more relevant for small species, since the impact of rain and wind is more significant on a smaller scale (Ortega-Jimenez and Dudley 2012). This work is the first to analyze the hours of activity in a moth community of the Pampa, a Brazilian biome with a reduced area, but highly diverse when considering its extension (Andrade et al. 2023).

Material and methods

Study area

The study was conducted on a series of private properties in the "Coxilha do Fogo" locality, in the municipality of Canguçu, Rio Grande do Sul, Brazil (Fig. 1). The region is part of the Pampa biome (IBGE 2024). The relief is undulating, with small hills and mountains, mostly covered by savannah-like grassland formations of true grasses and herbaceous plants (Boldrini, 2009; Minervini et al. 2023; Rambo, 1956). Denser, smaller forests are present in the narrow valleys between hills and in small patches across the landscape (Boldrini, 1997; Minervini et al. 2023). The altitude ranges from 200 to 500 m, and the climate is temperate in higher altitudes and subtropical in the lower regions (Boldrini, 1997). The average temperature of the warmest month (January) is 24°C, and in the coldest month (June) is 12.5°C (Girardi-Deiro et al. 2002). Precipitation is relatively well distributed throughout the year, with a monthly average of 125 mm; however, drought periods are common between December and March, while frosts occur between April and October (Caporal and Boldrini, 2007; Girardi-Deiro et al. 2002). The soil is gravelly and shallow (Boldrini, 1997). The main economic activity in the region is livestock farming of cattle and sheep (Bilenca and Miñarro 2004; Girardi-Deiro et al. 1994). A common practice is the slash-and-burn of shrub vegetation in order to expand the livestock grazing area (Boldrini, 1997).

Samplings

The samplings occurred in summer (December 13–19, 2023), during the new moon phase. Six sampling points were selected, all located on forest edges (Fig. 1). Trampling and grazing by animals (primarily sheep, but also goats, cattle and horses) were present through the whole area. To ensure an independent sampling, the minimum distance between points was 500 m. This distance is equivalent to 2.5 times the radius of attraction of the light source used in this study (Muirhead-Thompson 1991). Each point was sampled for one night, from dusk to dawn. The night was divided into 1-h periods, starting at 20:00 and ending at 04:59.

Moths were sampled using an active method (white sheet). The light source was a 250W mixed-light mercury lamp connected to an electric generator. The sheet was 2.40 m wide by 1.80 m high and hung at a height of 2 m. Adult moths belonging to the Arctiinae, Sphingidae, and Saturniidae were captured when landed on the sheet or in surrounding vegetation (approximately 2 m radius). Individuals were euthanized with a kill jar containing ethyl ether and stored in envelopes with corresponding sampling hours. Subsequently, specimens were pinned, labeled and identified through morphological characters of the wings, body and appendages with the help of bibliography (Camargo et al. 2018; Dowdy et al. 2020; Haxaire and Mielke, 2019; Kitching 2025; Martin et al. 2011; Nunes 2006; Pinheiro and Gaal-Haszler 2015; Specht et al. 2008a; Specht et al. 2008b; Vincent and Laguerre 2014) and through comparison with specimens from the UFRGS Lepidoptera Collection.

Climate data were recorded in situ, 30 minutes after the start of each hour using a digital thermo hygrometer and a portable weather station (**Table S. 1**). Three continuous variables were recorded: temperature, relative humidity and wind speed, the last one being the average between the maximum and minimum values recorded 30 minutes after the start of each hour. Precipitation was recorded categorically as nule, light, medium, or heavy.

Data analysis

The number of species in the study area was calculated using the Chao 2 and Jackknife 1 richness estimators. We performed circular analyses with Rayleigh test (Zar 1996) for the Total set of moth species and separately for Arctiinae, Sphingidae and Saturniidae using the Oriana software (Kovach 2013), aiming to visualize possible concentrations of abundance and richness in any specific hour.

To check relations between abundance and richness with climatic variables, Generalized Linear Models (GLMs) were performed in R software version 4.4.2 (R Core Team 2024) with the help of *ggplot2*, *stats*, *MASS*, *DHARMa*, and *stargazer* packages (Hartig 2024; Hlavac 2022; R Core Team 2024; Venables and Ripley 2002; Wickham 2016). GLMs were performed for all species (Total), for each taxon separately (Arctiinae, Sphingidae, and Saturniidae), and also for the 13 species with the highest abundance and/or occurrence in every hour of the night. Preliminary models were initially tested with two different statistical distributions (Poisson and Negative Binomial) and compared with the Akaike Information Criterion (AIC) to determine which model best suited the data. After choosing the distribution structure, models were built with the response variables *temperature*, *humidity*, *wind*, *precipitatio*n and *hours after sunset*, subsequently using ANOVA to remove non-significant variables. Negative binomial models were supported by ANOVA for most of the analyses performed; Poisson-distributed models were better suited in analyses where the data distribution peaked abruptly at specific hours.

The morphospecies *Lonomia* sp. was removed from the “Total” and “Saturniidae” GLM analysis since throughout its occurrence period, it was indifferent to precipitation and other climatic factors. Due to its apparent resilience to unfavorable climate, models built with the inclusion of *Lonomia* sp. had a high interference level and were not consistent with the general patterns observed in the other Saturniidae species.

Results

Abundance and richness of moths in the Coxilha do Fogo

We sampled a total of 1382 adult moths. Of these, 1318 were arctiines (95.4%), 39 sphingids (2.8%), and 25 saturniids (1.8%) (**Table S. 2**). Total species richness was 94 (74 species of Arctiinae, 12 of Sphingidae, and 8 of Saturniidae) (**Table S. 2**). Fourteen morphospecies were identified only to genus level, one was identified to subtribe level, and one to tribe level. The richness found represents approximately 95% of the estimated richness for the area (Chao 2 = 100.5; Jackknife 1 = 97.6). In total, 24.5% of the species were represented by only one individual (23 singletons) and 69 species (73.4%) by 10 or fewer individuals (**Fig. S. 1**). The five most abundant species were *Heliactinidia nigrilinea* (Walker, 1856) (235 individuals), *Eurata hilaris* Zerny, 1937 (99 individuals), *Bertholdia almeidai* Travassos, 1950 (85 individuals), *Ctenucha rubriceps* Walker, 1854 (83 individuals) and *Lamprostola pascuala* (Schaus, 1896) (69 individuals), all belonging to the Arctiinae (**Table S. 2**).

Moth abundance and richness varied between nights. The nights with the highest and lowest abundance had 551 and 69 individuals, respectively. The nights with the highest and lowest richness had 71 and 28 species, respectively. We detected a significant and positive relationship between abundance and richness ($R2 = 0.99$, $F = 959.80$, $p < 0.0001$).

Community structure throughout the night

For the Total sample, 22h was the time of higher abundance (221 individuals) and richness (46 species); the lowest abundance was at 20h (103 individuals) and the lowest richness at 04h (25 species) (Fig. 2). For Arctiinae, the time of higher abundance and richness was at 22h (205 individuals, 38 species); the lowest abundance was at 20h (101 individuals) and the lowest richness at 04h (23 species). In Sphingidae, the highest abundance (10 individuals) and richness (7 species) occurred at midnight; the hour of least abundance was at 20h (1 individual) and the times of lowest richness were at 20h and 03h (both with only one species each). In Saturniidae, the highest abundance was at 22h (10 individuals) and the highest richness occurred at 22h and 00h (both with 4 species). Saturniids were completely absent in the final hours of the night (03-04h).

For the community as a whole, only five species (5.32%) were active from dusk to dawn (Figs. 3 and 4). Thirteen species (13.83%) were found only in the early evening (20-22h); 15 species (15.96%) were sampled only in the middle of the night period (23-01h), and 12 species (12.77%) occurred only in the late evening (02-04h). The majority (28.72%) of the species remained active for only one hour during the night (**Fig. S. 2**). The second most frequent strategy was being active for 3 hours (20.21%), followed by 2 hours (14.89%).

Total abundance peaked in the early hours after dusk, decreasing and remaining relatively constant until the end of the night (Fig. 2). Circular analysis showed that abundance was concentrated over time for the Total sample, for Arctiinae, Sphingidae, and Saturniidae (Table 1, **Fig. S. 3**). The 22h time period was characterized by the highest richness for both the total sample and Arctiinae (46 and 38, respectively; Fig. 2). However, the richness distribution was dispersed throughout the night for Arctiinae (r = 0.06, Z = 1.025, p = 0.359) (Table 1), despite the significant concentration at 22h in the Total sample analysis. Saturniidae and Sphingidae had richnesses concentrated in the middle of the night period (23 and 00h, respectively; **Fig. S. 3**).

Table 1
Circular analyses of total moth abundance and richness (Total) and of each taxon separately.

	Variables	**Mean Vector (α)**	**Length of mean vector (r)**	**Circular Standard Deviation (SD)**	**Rayleigh Test (Z)**	**Rayleigh test of uniformity (P)**
Total	Abundance	82.284° (22h)	0.064	134.285°	5.687	0.003
	Richness	129.961° (23h)	0.101	122.689°	3.325	0.036
Arctiinae	Abundance	66.908° (22h)	0.058	136.69°	4.447	0.012
	Richness	114.737° (23h)	0.06	135.841°	1.025	0.359
Sphingidae	Abundance	152.893° (00h)	0.384	79.319°	5.738	0.003
	Richness	158.724° (00h)	0.358	82.111°	3.591	0.026
Saturniidae	Abundance	114.384° (23h)	0.466	70.81°	5.428	0.004
	Richness	127.336° (23h)	0.514	66.087°	3.965	0.016

Climatic influence

Relative humidity ranged from 66 to 94% over the six nights of sampling (**Table S. 1**), with an average increasing trend as the night progressed (74 to 89%). Temperature, on the other hand, showed little variation over the six nights of sampling (**Table S. 1**). The highest temperature recorded was 26.2°C and the lowest was 17.1°C; the largest fluctuation in one night was from 26.2 to 22.1°C, and the lowest from 23.9 to 23.2°C. Wind did not show a clear increasing or decreasing trend over time, although higher values were recorded at the beginning of the night and lower values at the end. Precipitation occurred only in the early hours of one of the sampling nights (20 and 21h), being completely absent on all other nights/hours.

There was a significant negative relationship between Total moth abundance with wind and precipitation (Table 2, **Table S.3**). However, there was no significant relationship between Total moth abundance with temperature, relative humidity, or hours after sunset. Similarly, Arctiinae abundance also showed a significant negative relationship only with wind and precipitation. Saturniid abundance was positively related to temperature and humidity, and negatively related to precipitation and hours after sunset. For Sphingidae, a positive correlation was found between abundance and temperature, although the explanatory power of the model was low (6%) (Table 2, **Table S.3**).

Table 2
Influential variables for abundance and richness of each taxon, according to Generalized Linear Model (GLM) analysis. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.0$

Táxon	**Dependent variables**	**Variables selected by GLM**	**R^2**
Total	Abundance	wind (-0.588**) precipitation (-1.823**)	0.209
	Richness	wind (-0.369*) precipitation (-1.382***)	0.210
Arctiinae	Abundance	wind (-0.591**) precipitation (-1.796***)	0.205
	Richness	wind (-0.364*) precipitation (-1.324***)	0.206
Sphingidae	Abundance	temperature (0.186*)	0.062
	Richness	temperature (0.155*)	0.049
Saturniidae	Abundance	temperature (1.147***) humidity (0.494***) wind (-2.175**) hours after sunset (-0.639***)	0.420
	Richness	temperature (0.888***) humidity (0.394**) wind (-2.042*) hours after sunset (-0.499**)	0.343

Wind was negatively correlated with the richness of Arctiinae, Saturniidae and the Total sample (Table 2, **Table S. 3**). Total richness was also negatively affected by precipitation, as was Arctiinae richness. Saturniidae richness was positively correlated with temperature and humidity, and negatively with hours after sunset. In Sphingidae, richness correlated positively with temperature, although it was barely significant ($R^2 = 0.049$).

The variable *hours after sunset* was significant for 10 of the 13 species analyzed individually, being non-influential only for *Cosmosoma centralis*, *Eurata hilaris* (Euchromiina) and *Bertholdia almeidai* (Phaegopterina) (**Table S. 4**). The second most present variable in the individual species GLM analyses was *humidity*, followed by *temperature* and *wind*. The species with the most significant environmental variables included in their final models was *Rhynchopyga meisteri* ($R^2 = 0.933$) and *Lamprostola pascuala* ($R^2 = 0.564$) (**Table S. 4**).

Discussion

Most of the moths sampled were arctiines. This is explained by the taxon being much more diverse (approximately 1,400 Brazilian species [Ferro and Diniz 2010]) than Saturniidae (488 Brazilian species [Carneiro et al. 2024]) and Sphingidae (196 Brazilian species [Haxaire and Mielke 2019]). In just six nights of sampling, we recorded approximately 22.5% of arctiines, 14.3% of sphingids, and 6.4% of saturniids from Rio Grande do Sul State (Ferro & Teston 2009; Nunes 2006; Specht et al. 2008a).

Climate effects/effects of climate

Given the high correlation between abundance and richness, the climatic factors that determined the abundance of each taxon also determined their respective richness. Furthermore, as expected, the variables that explained the temporal patterns of abundance and richness were the same for the entire moth assemblage and for Arctiinae, as the subfamily represents over 95% of the individuals sampled.

The activity of smaller moths (Arctiinae) was most influenced by wind and precipitation, which negatively impact flight. Rain and wind can prevent flight and decrease the abundance of both moths and other winged insects (Botero-Garcés & Isaacs 2004; Lawson and Rands, 2019; McGeachie 1989; Poulsen 1996). Wind can directly affect foraging patterns (Hennessy et al. 2020) and interfere in pheromone communication between males and females (Cardé 2016). Similarly to wind, the impact of rain is much more significant on small insects than on larger ones, destabilizing flight and damaging wing and body structures (Ortega-Jimenez and Dudley 2012). The accumulation of rainwater on the body can also affect thermoregulation, increasing the individual's mass and, consequently, the energy cost of flight (Lawson and Rands, 2019). The environmental noise of rain can also potentially interfere with the interpretation of audio, visual, and olfactory signals (Lawson and Rands, 2019).

For larger moths (Saturniidae and Sphingidae), climatic variables that influence flight physiology (air temperature and humidity) were more significant. Sphingidae was the taxon least affected by climatic variables, being influenced only by temperature (positively correlated). Camargo et al. (2016a) also observed that the activity of Amazonian sphingids was related to temperature. Moth's flight is an energetically expensive activity, and oxygen consumption during flight grows exponentially with the increase in the individual's mass (Bartholomew and Casey, 1978). When taking flight, many species need to reach specific body temperatures, which are achieved by warming their muscles through vibrations before flight (Dotterweich 1928; Heinrich 1993). The heat generated during flight by muscular activity depends on the individual's mass, wingbeat frequency and wing loading; in other words, larger, more robust moths producing more heat and losing it slowly, while smaller species heat and cool their bodies at faster rates (Bartholomew and Heinrich, 1973). From this perspective, although larger species could maintain body temperature for longer, smaller species would have a much lower energy cost to take flight, since larger individuals consume more oxygen to warm their muscles (Bartholomew and Casey, 1978). The correlation of saturniids and sphingids with temperature may, therefore, be directly related to their physiological needs for flight, since an environment with higher temperatures would make muscle warming easier. The sensitivity of saturniids to temperature and humidity may also be related to the fact that they do not feed as adults, and survive on stored energy acquired as larva (Braga and Diniz 2018; Janzen 1984). Although there are exceptions (e.g., Kafley & Smetacek, 2020), the lack of fluid intake in adult saturniids makes them especially susceptible to desiccation, a factor that likely explains the family's sensitivity to humidity and association with rainy seasons in other Brazilian biomes (Barcellos et al. 2022; Braga and Diniz, 2018).

It was suggested that moths with tympanic organs/ears have slower and less costly flights and, consequently, may have lower thoracic temperatures (Rydell and Lancaster, 2000). Moths without tympanic organs tend to have faster and more erratic flights than those who have it, probably due to the need to avoid predation by bats (Lewis et al. 1993). A higher wing loading is also observed in several moths without tympanic organs, a factor likely associated with higher thoracic temperatures during flight (Rydell and Lancaster, 2000). Arctiines do not respond erratically to bats and possess both ears and sound defense organs (Conner et al. 2009; Dowdy and Conner, 2019). In this context, by having both acoustic monitoring and defense mechanisms, it is possible that Arctiinae moths have less costly flights and require a lower body temperature to fly. These factors would explain the lack of correlation with temperature across the family as a whole. Furthermore, the volatile climate of the Southern Hemisphere, due to its proximity to large ocean masses, directly impacts the cold resistance strategies of a variety of insects (Sinclair et al. 2003). The high abundance of Arctiinae in the sample (95%) and the lack of correlation with temperature may be indicative of a set of factors that make the physiology of species in this subfamily well adapted to the Pampa environment, where a rapid response to favorable weather moments is extremely beneficial.

The effects of climatic variables also differ among species within the same clade. Some, such as the saturniid *Lonomia* sp., are tolerant to a wide range of climatic conditions. However, some species are highly climate-sensitive, having been observed foraging only within a specific range of climatic conditions. Furthermore, species within the same clade may respond differently to a given climatic variable. In Arctiinae, for example, a positive association with temperature was observed in *Eurata hilaris*, while *Heliactinidia nigrilinea* showed a negative correlation. In a climate change scenario, studies evaluating the effects of climate on activity schedules, population dynamics, interactions, and species development are increasingly important and urgent.

Temporal Structure of the Community

Moth activity patterns varied throughout the night. Arctiines followed a previously observed trend of occurring in a narrow time period, of no more than three hours (Moreno et al., 2021; Scherrer et al., 2013; Teston 2021). Higher abundance and richness of Arctiinae in the early evening are documented for the Amazon (Teston 2021) and the Brazilian Cerrado (Moreno et al., 2021; Scherrer et al. 2013). However, richness in the Amazon and Cerrado was concentrated in the early evening, whereas in our study, there was no significant concentration of richness at any time during the night.

The concentration of Saturniidae richness and abundance at 23h and their complete absence later in the night contrasted with that observed for Amazonian Saturniids, where abundance and richness are constant throughout the whole night (Lamarre et al. 2015). Flight activity in Saturniids is strongly related to mate searching, and peaks in male activity have been recorded coinciding with pheromone release by females (Toliver et al. 1979). A higher release of pheromones at a specific time may be driven by several factors, including a lower presence of predators or moments of higher fecundity.

The activity pattern of Sphingidae found in this study is similar to that observed in sphingids from the Malaysian rainforest, where an abundance symmetry occurs toward midnight (Beck and Linsenmair 2006). However, this pattern differed from that recorded in the Brazilian Atlantic Forest and the Amazon rainforest of French Guiana, where sphingids have a higher abundance and richness in early hours, gradually decreasing throughout the night (Lamarre et al. 2015; Machado 2014). This pattern is also recorded in the Brazilian Caatinga, where abundance is highest in the early evening, but richness remains stable (Costa 2020). In the Brazilian Amazon, however, sphingid abundance is documented as occurring in increasing peaks, with a constant richness throughout the night (Camargo et al. 2016a). This data indicates that the activity times of a given taxon can be heterogeneous between and within each biome, and may be associated with several factors such as conservation status and type of vegetation, food availability, competition, interactions with natural enemies, climate and nighttime duration. During summer, nighttime in the Pampas is shorter than in other Brazilian biomes due to its location at higher latitudes, a factor that results in summers with longer days and shorter nights (Mills 2008). Consequently, the nighttime window is narrowed, and the duration of optimal conditions for different moth species may be reduced or reorganized compared to environments at lower latitudes. Furthermore, taxa with different feeding habits may also exhibit contrasting activity patterns. Camargo et al. (2016b) found that sphingids have a tendency to have broader temporal niches of activity than saturniids, this being caused by sphingid feeding and foraging habits.

Our data shows that the Pampa moth fauna is highly represented by smaller species, occurring in low abundances and in very short windows of time. If sampling only occurred until midnight, we would have lost over 54% of the individuals and excluded species that are active only at the end of the night. Therefore, for faunistic inventories, we suggest sampling throughout the whole night. Sampling at specific hours may however be valid for studies focused on species that occur at restricted periods (e.g., *Rhynchopyga meisteri*) or for species that are active at all hours.

The Pampa biome, despite being highly modified, has only about 3% of its territory in protected areas (Ribeiro et al. 2021; Souza et al. 2020). As the Serra do Sudeste is a priority area for conservation in Brazil (Ministério do Meio Ambiente 2004), knowledge about species and their behaviours can serve as a basis for establishing biodiversity conservation strategies. Understanding the responses of different insect species and communities to climate, for example, is highly relevant in a scenario of global climate change and habitat alterations (see Ojija et al. 2025). Lack of knowledge about a species' natural history can, in certain cases, lead to methodological errors or flaws in conservation strategies (Nanglu et al. 2023). Besides affecting the physiology of individuals, climate change can affect the distribution of both species and their hostplants, ultimately leading to extinction (Bellaver et al. 2022). The Arctiinae moth *Heliactinidia nigrilinea*, despite being highly abundant in our sample, was associated with moderate temperatures, being less abundant when temperatures were higher. This being said, the species would be directly affected by a general increase in average temperature.

This research contributes significantly to the knowledge of moth diversity and ecology in a biome that remains understudied. Future studies with Pampa moths may provide insights about how climate affects the biology of these species, as well as detail life traits and interspecific dynamics. Such information may broaden our understanding of the nocturnal lepidopterans of the Pampa, and lead to a greater understanding of the southern Neotropics moths as a whole.

Declarations

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Contributions

Study conception and design: MES and VGF. Data sampling, processing and specimen identification: MES, IAB and VGF. Data analysis and figure/table production: MES. Supervision: VGF. Writing–original draft: MES. Writing–review and editing: MES and VGF. All authors read and approved the final manuscript.

Competing Interests

The authors declare no competing interests.

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Ethical Approval

Not applicable.

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Figures

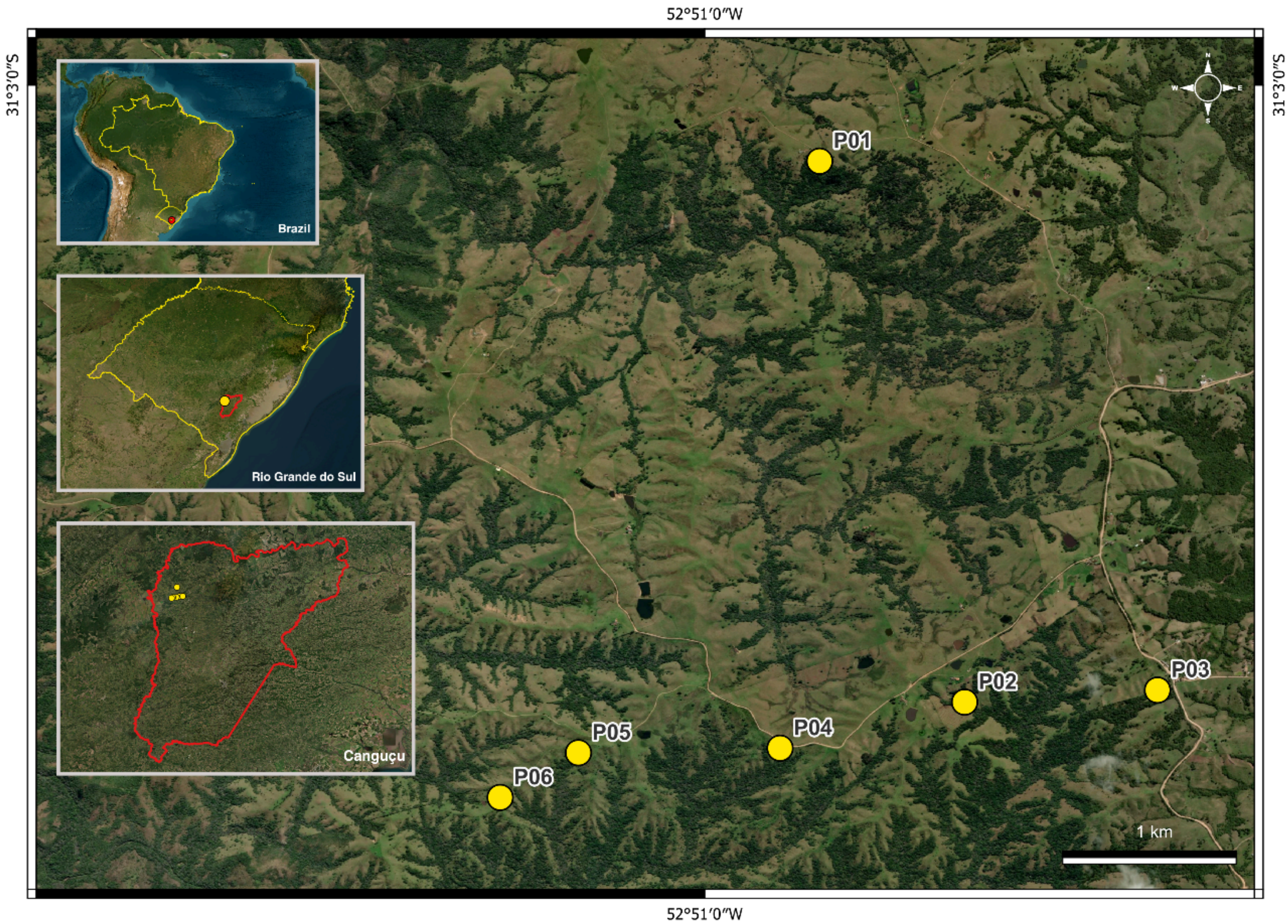

Figure 1

Location of the study area, in the municipality of Canguçu (marked in red), in the state of Rio Grande do Sul, Brazil, with the six sampling points highlighted in yellow

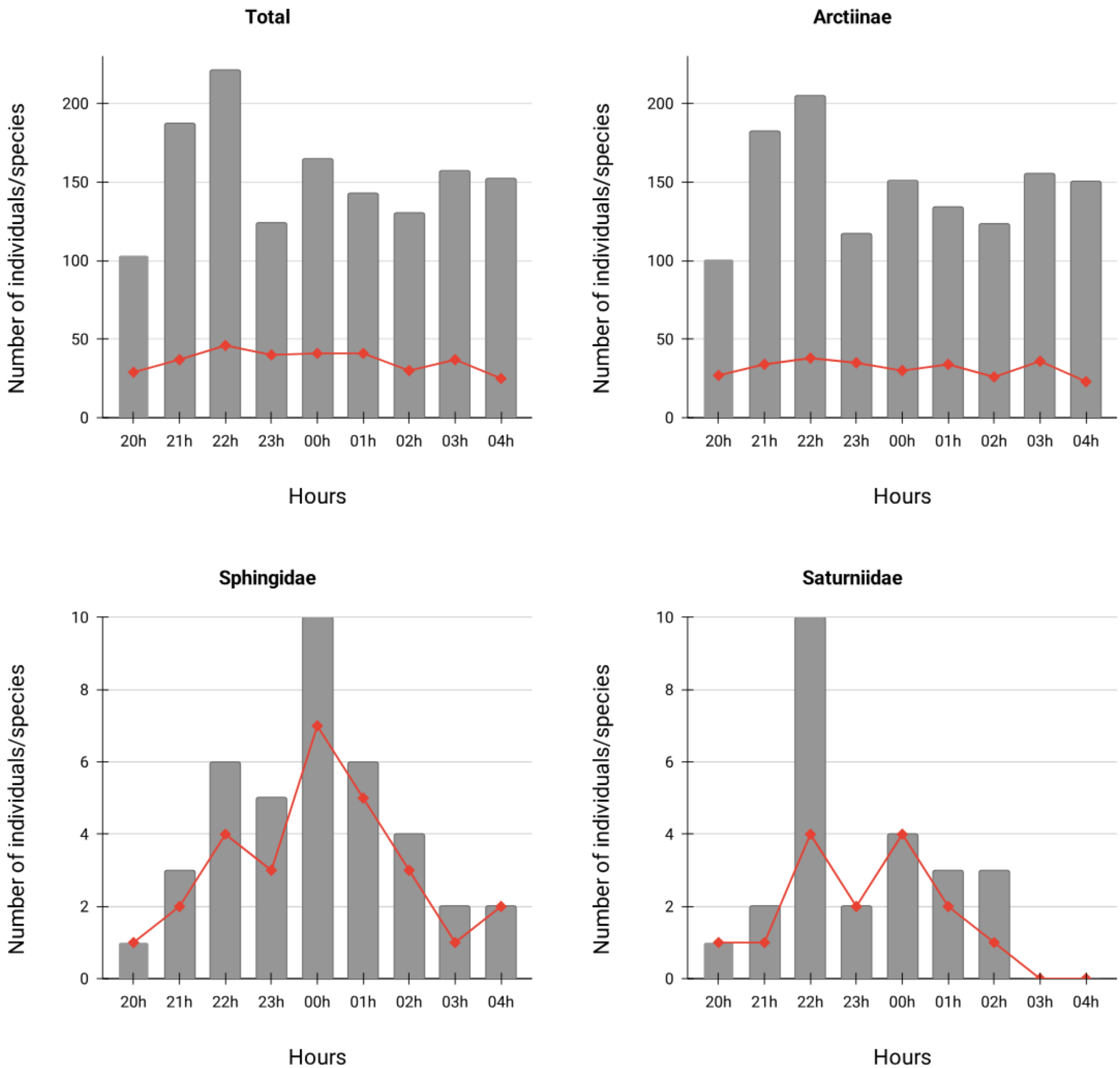

Figure 2

Abundance (grey bars) and richness (red lines) of moths throughout the night

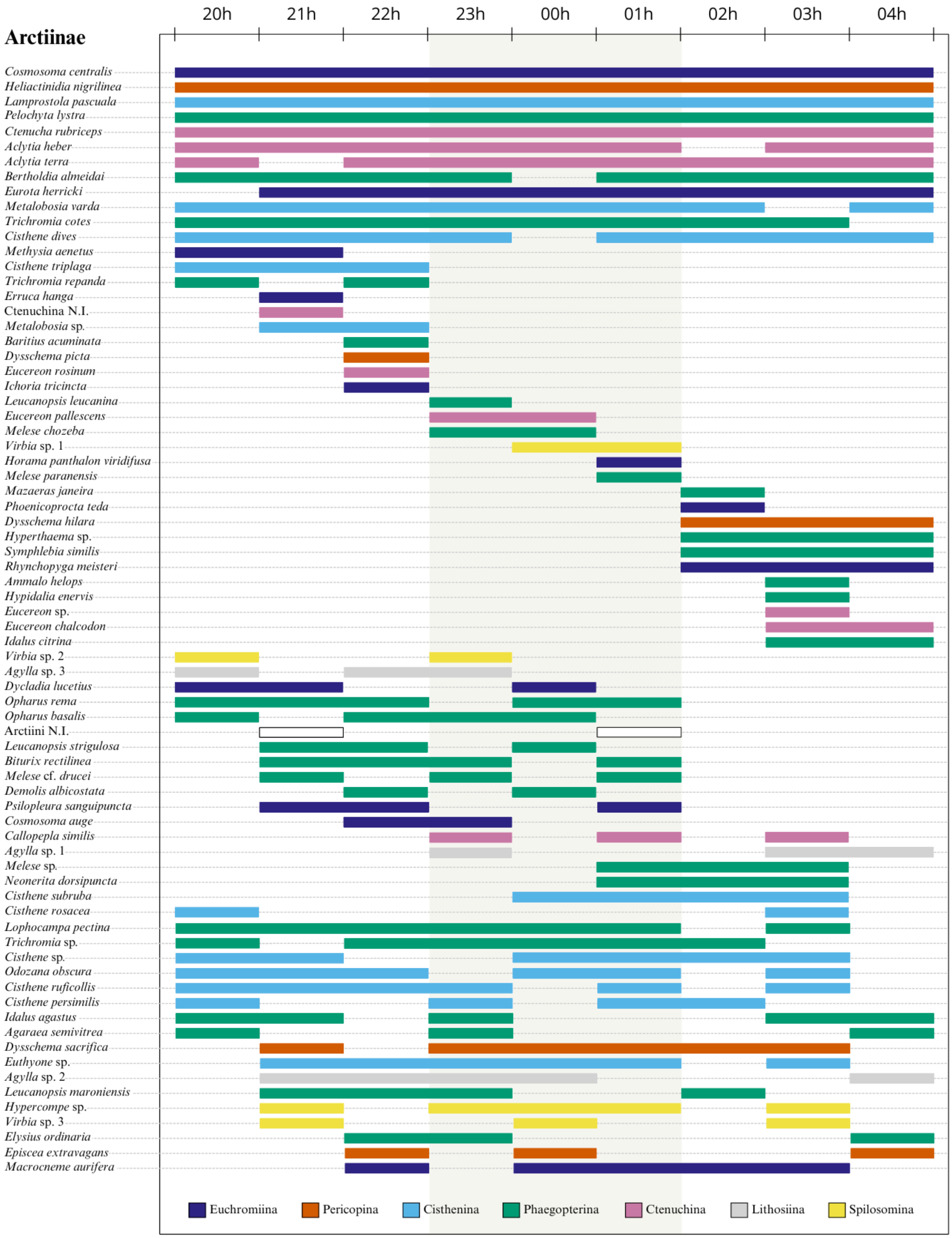

Figure 3

Hours of activity of Arctiinae moths sampled in December 2023 in the Coxilha do Fogo locality, Canguçu, RS - Brazil. Colors correspond to subtribes. The central region of the figure (marked in darker color) delimits the middle of the night period (23h to 01h)

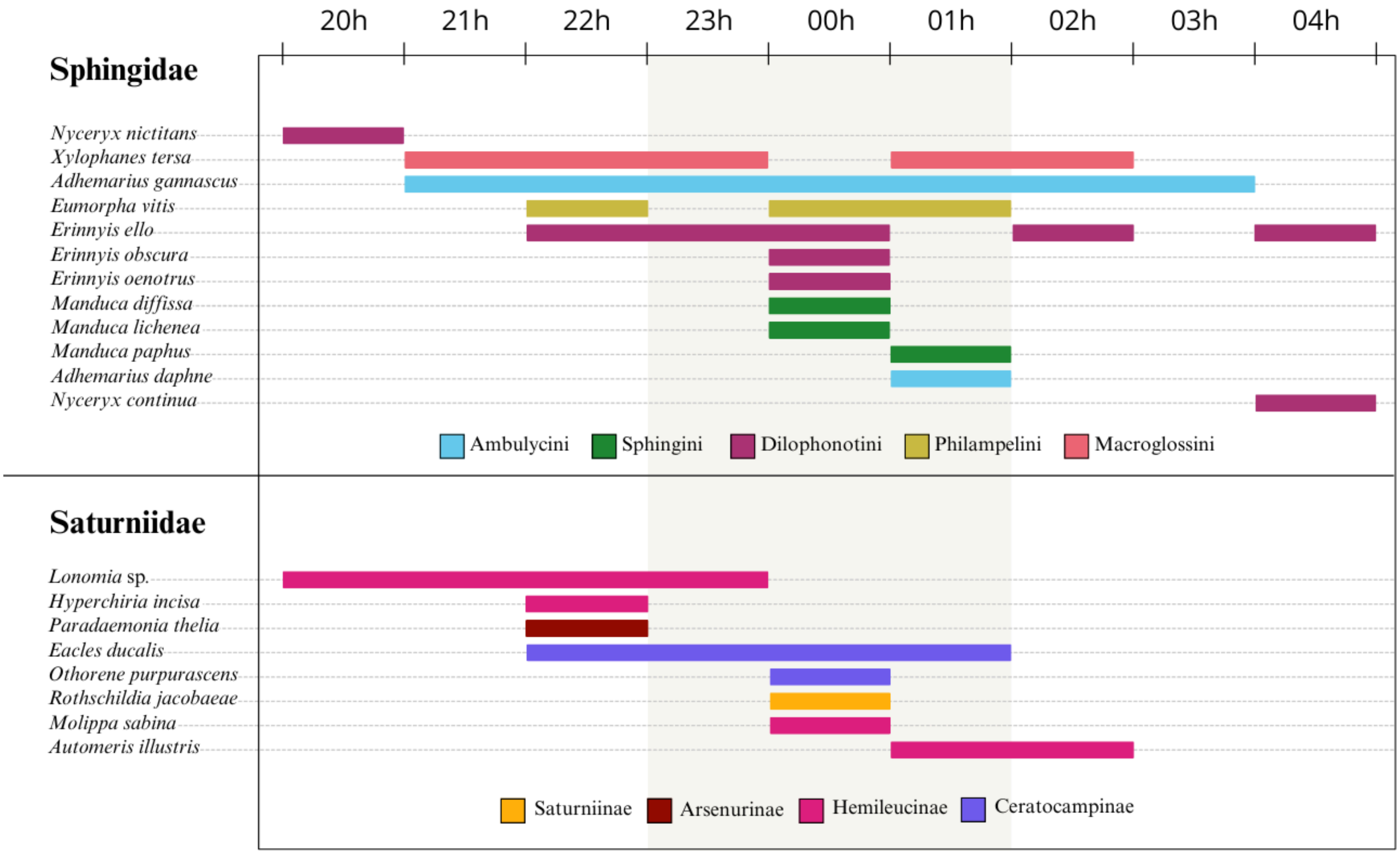

Figure 4

Hours of activity of Sphingidae and Saturniidae moths sampled in December 2023 in the Coxilha do Fogo locality, Canguçu, RS - Brazil. Colors correspond to subtribes. The central region of the figure (marked in darker color) delimits the middle of the night period (23h to 01h)

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