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Article

Population dynamics and seasonality of *Euspilotus* (*Hesperosaprinus*) *azureus* Sahlberg (Coleoptera: Histeridae: Saprininae)

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ABSTRACT. The effect of climatic conditions on the structure of populations has been perceived for different orders of insects and families of beetles. Here we described the population dynamics of *Euspilotus azureus* (Sahlberg, 1823) and determined its relationship with climatic variables. The specimens were collected monthly for one year in an area of Seasonal Semideciduous Forest, in Viçosa, Brazil. The seasonality of the population and of sexes was estimated through the absolute frequency of occurrence (AF) and the percentage frequency of occurrence (FO%) of the population and each sex, which were determined monthly. To test whether the changes in monthly AF of the population and of each sex are correlated with climatic variables, Spearman correlation tests were performed. To identify whether there are temporal fluctuations in the sex ratio, considering months and seasons, and within each season, we performed Chi-square tests. A total of 3,126 individuals (1,009 females and 2,117 males) were collected. The population had the highest abundance in spring and summer, and the lowest in autumn and winter. The highest AF and FO were found in December and January, and the lowest in June and July. The sex ratio of the population did not differ in the months of the year, but in the spring there was a marked predominance of males. For *E. azureus*, the temporal fluctuation in abundance of the population and in the sex ratio is related to the climatic variables of maximum temperature, humidity, and precipitation. Climatic variables, especially the temperature, provided a greater abundance of the population in the hottest and rainiest periods of the year for inducing reproductive activity and altering the population's sex ratio.

KEYWORDS. Atlantic Forest, ecology, Histerid beetles, natural history.

RESUMO. Dinâmica populacional e sazonalidade de *Euspilotus* (*Hesperosaprinus*) *azureus* Sahlberg (Coleoptera: Histeridae: Saprininae). O efeito das condições climáticas na estrutura das populações tem sido percebido para diferentes ordens de insetos e famílias de besouros. Nós descrevemos a dinâmica populacional temporal de *Euspilotus azureus* (Sahlberg, 1823) e determinamos sua relação com as variáveis climáticas. Os espécimes foram coletados durante um ano em uma área de Floresta Semidecidual Sazonal, em Viçosa, Brasil. A sazonalidade da população e dos sexos foi estimada através da frequência de ocorrência absoluta (FA) e da frequência de ocorrência percentual (FO%) da população, as quais foram determinadas mensalmente. Para testar se as mudanças mensais na FA da população e de cada sexo estão correlacionadas com as variáveis climáticas, testes de correlação de Spearman foram realizados. Para identificar se há oscilações temporais na razão sexual considerando meses e estações, e dentro de cada estação, foram realizados testes de Qui-quadrado. Um total de 3.126 indivíduos (1.009 fêmeas e 2.117 machos) foram coletados. A população teve maior abundância na primavera e verão, e menor no outono e inverno. As maiores FA e FO foram em dezembro e janeiro, e a menores em junho e julho. A razão sexual da população não diferiu nos meses do ano, mas na primavera houve uma predominância marcante de machos. Para *E. azureus*, a flutuação temporal na abundância da população e na razão sexual é explicada pelas variáveis climáticas de temperatura máxima, umidade e precipitação. As variáveis climáticas, especialmente a temperatura, propiciaram uma maior abundância da população nos períodos os mais quentes e chuvosos do ano por induzirem a atividade reprodutiva e a alterar da razão sexual da população.

PALAVRAS-CHAVE. Ecologia, histerídeos, história natural, Mata Atlântica.

In the natural environment, insect populations can fluctuate dramatically over time. One of the causes attributed to these population fluctuations are the abiotic conditions of an ecosystem, such as the climate (Schowalter, 2006; Begon *et al.*, 2007). This is because insects have abiotic tolerance ranges and, therefore, these climatic factors directly influence population systems, the seasonal distribution of species, and the structure of communities (Schowalter, 2006; Begon *et al.*, 2007; Johnson *et al.*, 2016).

The effect of climatic conditions on the structure of populations has been perceived for different insect orders (Schowalter, 2006; Figueiró *et al.*, 2014; Johnson *et al.*, 2016; Li *et al.*, 2017; Opoke *et al.*, 2018; Margatto *et al.*, 2019). Likewise, several families of beetles have shown patterns of seasonal variation (Noerdjito & Nakamura, 1999; Cherry, 2007) and have their abundance influenced by temperature, precipitation, and humidity (Martins *et al.*, 2009; Paro *et al.*, 2012; Aneni *et al.*, 2013; Kawakami

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et al., 2016; MARTINS *et al.*, 2016; BARRETTO *et al.*, 2018). However, for many taxa, the population dynamics and seasonality of the species are still poorly understood, as is the family Histeridae (Coleoptera: Staphyliniformia).

The Histeridae are found in almost all geographic regions and the great diversity of the family is concentrated in tropical areas (KOVARIK & CATERINO, 2001). Histerid beetles are known as generalist predators and they are trophically associated with ephemeral substrates, where they prey on other invertebrates, especially dipterans (KOVARIK & CATERINO, 2001, 2016). These beetles often disperse by flight (KOVARIK & CATERINO, 2001, 2016), and therefore abiotic conditions may influence the activity of these beetles (e.g., altering their capacity of displacement or accuracy to detect food resources). The majority of Histerid beetles appear to be highly thermophilic, and its peak abundance in temperate regions tends to coincide with the warmer months of the year (LEVESQUE & LEVESQUE, 1995; KOVARIK & CATERINO, 2016). For tropical regions, in the few studies that exist, the histerids flight activity starts in the rainy season and ends shortly after the rains ceased (LÖYTTYNIEMI *et al.*, 1989).

Euspilotus (*Hesperosaprinus*) *azureus* (Sahlberg, 1823) is a Histeridae species of medium to large size (length: 2.9–5.5 mm, width: 2.5–4.7 mm) with wide distribution in South America, recorded for Venezuela, French Guiana, Brazil, Peru, Argentina, and Chile (MAZUR, 2011; DEGALLIER *et al.*, 2012; ABALLAY *et al.*, 2013; ARRIAGADA, 2015). In Brazil, the species is known to Amazonas, Minas Gerais, Paraná, and Rio Grande do Sul (CELLI *et al*., 2015) but it can potentially be found throughout Brazil. This species is the most-collected Histerid beetle in faunistic surveys associated with carcasses in Brazil (SOUZA & LINHARES, 1997; MISE *et al.*, 2007, 2010; CORRÊA *et al.*, 2020), and is rarely recorded in feces (VIEIRA *et al.*, 2018). In carcass, the species has been recorded in the initial, medium, and final stages of decomposition (CELLI *et al.*, 2015), and it is considered a potential species to determine postmortem interval (PMI) in the application of forensic entomology (ALMEIDA *et al.*, 2015; CANEPARO *et al.*, 2017).

Recently, the knowledge about the biology (e.g., larval development and reproduction) of the species has advanced through laboratory studies (CANEPARO *et al.*, 2017). However, the influence of climate on the seasonal activity and population structure of the species *in situ* is completely unknown. Our objectives were, for the first time, (1) to describe the seasonal population fluctuation of the species; (2) to determine the sex ratio of the population and its temporal variation; and (3) to determine the influence of climatic variables on the seasonality of the species.

MATERIAL E METHODS

Fieldwork and study of specimens.

The studied material was collected in a fragment of a Seasonal Semideciduous Atlantic Forest (20°48'13"S/ 42°51'23"W, Mata do Paraíso Reserve), at the Universidade Federal de Viçosa (UFV), Viçosa city, state of Minas Gerais, Brazil. The fragment has about 200 ha and it is at a mean altitude of 650 m. This area has historical human occupation (e.g., introduction of pastures and coffee), however, since 1966 it has been undergoing vegetation restoration and is in an intermediate stage of regeneration (LIMA *et al.*, 2014).

According to the Köppen-Geiger classification, Viçosa has a warm temperate climate with dry winter and hot summer (Cwa). The annual mean precipitation ranges between 1250.1–1350 mm, while the mean precipitation in the seasons are: summer (December–March, rainiest season), 600.1–700 mm; autumn, 200.1–300 mm; winter (June–September, driest season), 25.1–50 mm; and spring, 300.1–400 mm. Throughout the year, the minimum, mean and maximum temperatures are: 16.1–17°C, 22.1–23°C, and 27.1–28°C, respectively (REBOITA *et al.*, 2015).

The specimens of *E. azureus* were collected using pitfall traps baited with decaying bovine meat and containing 70% alcohol as a preservative liquid (LEIVAS *et al.*, 2013). Five pitfalls were used, arranged every 30 m and in the form of a line. Once a week the Histerid beetles were taken out of the trap, the decaying meat was replaced in each trap, and then the traps were activated again. After each collection, the material was fixed in 70% alcohol. The sampling took place continuously for 12 months (06.v.2016 – 02.v.2017), totaling 361 days and 8,664 hours of exposure for each trap.

After collections were completed, the material was sent to the Laboratório de Pesquisas em Coleoptera (LAPCOL), Universidade Federal do Paraná to be pinned, labeled, and identified. The identification of the species was carried out based on DEGALLIER *et al*. (2012), ABALLAY *et al.* (2013), and CELLI *et al.* (2015). Subsequently, under a stereomicroscope, the specimens were sexed based on characters from the external morphology, in which females have anterior tarsi with spinous setae and males have anterior tarsi with spatulated setae. We deposited the voucher material at the Coleção Entomológica do Setor Palotina (CESP), Universidade Federal do Paraná.

Data analysis.

To determine the seasonality of the population and of males and females, the absolute frequency of occurrence (AF) and the percentage frequency of occurrence (FO%) of the population and each sex were determined monthly.

Spearman correlation tests were performed to test whether the changes in monthly AF of the population and of each sex are correlated with climatic variables, using the monthly AF of the population and each sex, and the environmental variables of monthly mean humidity (%), monthly accumulated precipitation (mm) and minimum, maximum and mean monthly temperatures (°C). Abiotic data were applied to the city of Viçosa (–20.76S; –42.86W, 712.20 m), measured daily, and was provided by the BDMEP (2019). In this study, the seasons of the year were defined as: summer (January to March), autumn (April to June), winter

(July to September) and spring (October to December). To identify whether there are temporal fluctuations in the sex ratio (males and females) considering months and seasons, and within each season, we performed Chi-squared tests. For this, we used (1) AF of females and males monthly, (2) AF of females and males of each season, and (3) AF of females and males of the months of the seasons. The adjustment to the 1:1 ratio was tested by the Chi-squares test (CALLEGARI-JACQUES, 2006). The analyzes were performed in the PAST program (HAMMER *et al.*, 2001) and the statistical significance was set a priori to $p < 0.05$ (CALLEGARI-JACQUES, 2006).

RESULTS

We collected 3,126 individuals (1,009 females and 2,117 males) and the species showed activity in all months of the year. The population had the highest AF and FO in December and January and the lowest in June and July (Fig. 1). Males had higher FO than females in all months of the year, except December to March and May when females had higher FO. However, when we observe the AF, males had higher AF than females in all months of the year (Fig. 1).

In general, the AF of the population, males, and females had a strong positive correlation with the climatic variables of precipitation, humidity, and maximum temperature (Tab. I). However, AF of males was poorly correlated with humidity (ρ = 0.1296). The AF of the population, males, and females, showed no correlation with the minimum and mean temperature variables (Tab. I).

Spring and summer were the seasons with the highest population abundance. Autumn and winter were the seasons with the lowest population abundance. Among the sexes, females and males follow the same pattern, with the highest abundance in spring and summer and the lowest abundance in autumn and winter (Tab. II).

Between the months and between seasons of the year there were no significant differences in the number of males and females ($x^2 = 18.22$; df = 11; p = 0.07 and $x^2 = 7.58$; df = 3; p = 0.05, respectively). Within each season, the number of males and females did not differ in the winter, summer, and autumn seasons, however, this difference was observed for spring, with a greater abundance of males (Tab. II).

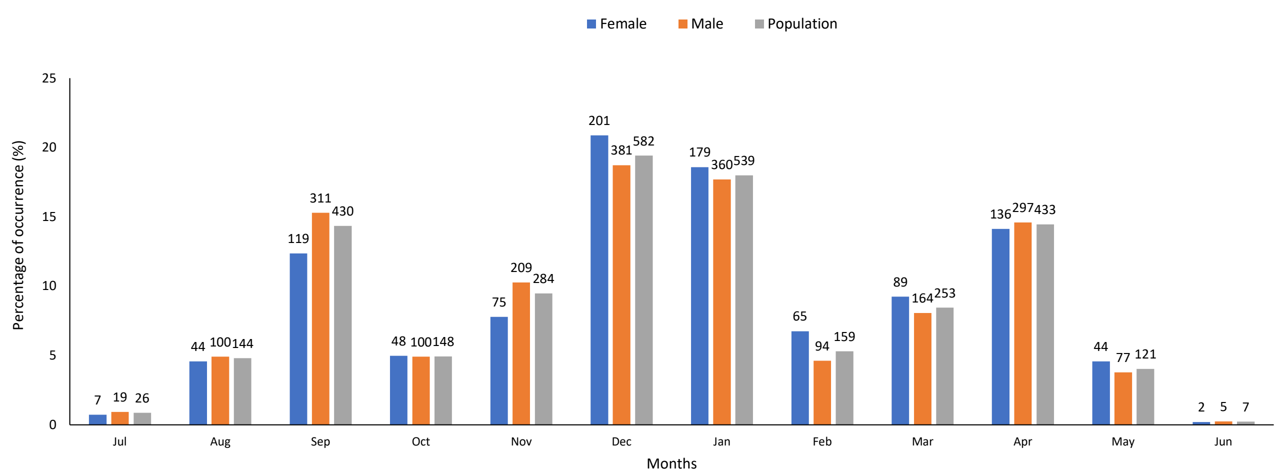

Fig. 1. Frequency of occurrence (FO) (bars) and absolute frequency (AF) (above the bars) of individuals collected and in each month of the population (gray), females (blue), and males (orange).

Tab. I. Values of the Spearman correlation coefficient (ρ) and the probability associated with the null hypothesis (P) with the AF of individuals in the population and for the sexes (males and females) and the environmental variables precipitation (Prec.), humidity (Humid.) and maximum (Max. Temp.), minimum (Min. Temp.) and mean (Mean Temp.) temperatures. Significant values ($p < 0.05$) are indicated by an asterisk (*).

Variable	Population		Males		Females	
	ρ	**P**	ρ	**P**	ρ	**P**
Prec.	0.8321	0.0007*	0.7600	0.0041*	0.8371	0.0006*
Humid.	0.7272	0.0073*	0.1296	0.0340*	0.7285	0.0072*
Max. Temp.	0.7552	0.0045*	0.6514	0.0002*	0.7530	0.0046*
Min. Temp.	0.4553	0.1368	0.3508	0.2634	0.4421	0.1501
Mean. Temp.	-0.2556	0.4224	-0.3157	0.3173	-0.2456	0.4416

Tab. II. Monthly abundance and in each climatic season of the population and of each sex and values of the x^2 test to indicate the sex ratio within each climatic season. Seasons where male and female abundance differ significantly are indicated by asterisk (*). Pop = population, Fem = female, Mal = male, Max T. = mean of the maximum temperatures for each month, Min T. = mean of the minimum temperatures for each month, Mean T. = mean of temperatures for each month, Prec. = precipitation for each month, and Hum. = mean of the humidity for each month.

Months	Pop	Fem	Mal	Max T. (°C)	Min T. (°C)	Mean T. (°C)	Prec. (mm)	Hum. (%)	Season	Pop	Fem	Mal	x^2
Jul	26	7	19	25.74	12.31	17.29	0	77.3					
Aug	144	44	100	27.49	12.61	18.56	0.35	69.4	Winter	600	170	430	0.46
Set	430	119	311	29.29	15.50	20.77	0.9	75.5					
Oct	148	48	100	27.86	17.62	21.72	1.92	79.5					
Nov	284	75	209	28.33	18.34	22.06	7.05	77.9	Spring	1014	324	690	5.81*
Dec	582	201	381	29.83	18.41	22.84	8.49	77.5					
Jan	539	179	360	31.29	19.12	23.66	2.02	74.5					
Feb	159	65	94	30.10	19.05	23.04	2.8	75.5	Summer	951	333	618	3.17
Mar	253	89	164	29.25	17.73	22.02	2.6	77.2					
Apr	433	136	297	28.14	16.78	21.08	1.45	81.5					
May	121	44	77	26.75	15.18	19.35	0.39	81.1	Autumn	561	182	379	1.10
Jun	7	2	5	23.80	12.95	16.87	2.6	83.8					
Total/Mean	3.126	1.009	2.117	28.16	16.30	20.77	2.55	77.56					

DISCUSSION

Our results indicate that the species has greater activity in the hottest and rainiest months and seasons of the year (spring and summer). This same seasonal activity was found in temperate areas of North America, where some Abraeinae (*Aeletes* Horn, 1873) and Histerinae (*Margarinotus* Marseul, 1853) had a greater flight activity during spring and summer, and Saprininae (*Geomysaprinus* Ross, 1940) a remarkable flight activity during the summer (LEVESQUE & LEVESQUE, 1995). Likewise, this pattern was observed by SUMMERLIN *et al.* (1993) where several species of Histerid beetles were also more active in spring and summer, including species of Saprininae (*Euspilotus* Lewis, 1907; *Geomysaprinus*; and *Xerosaprinus* Wenzel in Arnett, 1962).

In our study, the abundance of the population and of each sex of the species was related to precipitation, humidity, and maximum temperature. A seasonal study in North America also showed a greater abundance of several Histerid beetle species in temperatures between 35 and 37°C (similar to the maximum temperatures of the Viçosa region) and periods of the year with more rainfall, however, it was reported a reduction in abundance at low or very high temperatures (above 38° C) and low humidity (SUMMERLIN *et al.*, 1993). Therefore, the Histerid species seem to be not tolerant to very high temperatures and low humidity both in field study (SUMMERLIN *et al.*, 1993) and laboratory (CANEPARO *et. al.*, 2017).

The influence of precipitation, humidity, and maximum temperature on the species' activity in our study differs in part from that observed in other neotropical ecosystems. In Amazon Forest (Brazil), humidity and precipitation were positively correlated with the abundance and richness of Histeridae, while the temperature was negatively correlated with these factors. The little influence of temperature on the activity of Histeridae in this biome can be attributed to the small annual variation of temperature in the region, therefore, the rain and humidity are probably the main drivers that affect the dynamics of Histerid beetles in the Amazon region (CAJAIBA *et al.*, 2017). This difference compared to what we observed (positive correlation with maximum temperature) may indicate that regional climatic variables (e.g., between biome) are important for the biological activity of the species and seasonality of a population in neotropical ecosystems.

Our data demonstrate that the maximum temperature is important for determining the activity of the species on a considerable time scale (annual or in each season) of the population. SUMMERLIN *et al*. (1993) reported the influence of temperature on flight activity along the day (a short time scale) for saprinines (including *Saprinus* Erichson, 1834; *Xerosaprinus*, *Euspilotus*, and *Geomysaprinus*), and observed that the activity peak of the saprinines species occurred at mid-day between 11:00 and 13:00 hours. As a rule, this is the hottest interval of the day, which indicates an influence of the maximum temperature on the daily activity of the saprinines species. This also can help us understand the positive correlation of the maximum temperature for the activity of *E. azureus* reported in our study since patterns observed on a large time scale can be the result of the sum of short time scale behaviors.

The temperature also seems to have a great influence on the biological cycle of *E. azureus* and its reproductive activity. Under laboratory conditions, considering the number of eggs deposited, the number of eggs per mass of oviposition, and the viability of the eggs, the ideal temperature for *E. azureus* is around 25°C (CANEPARO *et al.*, 2017). Taking into account the observed seasonal activity of the species, the high abundance in the months of December and January is possibly a result of the high mean monthly temperatures in this period (above 22°C), since the reproductive activity is directly related to high temperatures. Likewise, the low abundance in the months with mean temperatures below 20°C (May to August) possibly lead to a reduction in the species' reproductive activity and, consequently, less abundance in the male and female populations. Thus, we believe that climatic variables, especially the maximum temperature influence the reproductive activity of the species, generating a seasonality in the abundance of the population with greater abundance in hot and rainy periods (spring and summer) and lower abundance and periods with lower temperatures of the year (autumn and winter).

The temperature variation between the months of the year also seems to influence the sex ratio of the population studied. Viçosa region presents in the warmer months (September to April) a mean temperature between 20.77 to 23.66, a temperature that biologically provides the largest hatching of males of *E. azureus*, since at temperatures between 20 and 25°C the expected rate of hatching of males is 57% for the species (Caneparo *et al.*, 2017). Similarly, in the months with lower mean temperatures (May to August), the temperature ranged from 16.87 to 19.35, a temperature that biologically provides the highest hatching of females of *E. azureus*, since at temperatures close to 15°C the expected hatching rate of females is 57% for the species (Caneparo *et al.*, 2017). Thus, we believe that possibly the predominance of males in the population (AF) is due to the high mean temperatures throughout the year (for eight months) that directly influence the higher hatching rate of males.

Alternatively, other explanations could be explored to understand the greater number of males compared to females. Insect populations with a 50:50 sex ratio generally indicate equally important roles for males and females (Schowalter, 2006), so we could assume a differentiated role division between males and females in the *E. azureus* population, however, we know nothing about the behavior of the species in the natural environment. During the breeding of *E. azureus*, Caneparo *et al*. (2017) fed the females with three times more larvae than males (3 daily larvae for females and 1 daily larva for males), due to their different consumption capacities. The abrupt difference in the proportion between males and females that compose the population of *E. azureus* could also be a result of an evolutive strategy to decrease the intraspecific competition for food resources since females are more voracious predators than males. However, besides climate conditions, division of roles, or strategy to reduce competition, we cannot ignore the possibility that other extrinsic factors (e.g., substrate quality, disturbances, vertical and horizontal structure, energy flow, and biogeochemical cycling) may be interfering with the sex ratio (Schowalter, 2006).

Assuming that climatic factors are factors that influence the proportion of males and females in the population, we observed that the variation in the hatching rate of males and females also produces a seasonality in the sex ratio of the population. We hypothesize that, possibly, the predominance of females between December and March is provided by the higher hatching rate of females during the months with lower temperatures (May to August), which increases the FO of the females in the warmer months. Likewise, the higher FO of males between April and November, except in May, is caused by the higher hatching rate of males during the months with the highest temperatures (September to April). In this sense, and if this pattern really exists, the seasonality of the sex ratio of the population may suggest that, in nature, the life cycle of the species may exceed 200 days, unlike that observed in the laboratory, which ranged from 63.4 to 105 days according to temperature variation (Caneparo *et al.*, 2017). This developmental delay can be a result of unfavorable developmental factors that cannot be controlled in a natural environment, such as variations in resource availability (food and habitat), photoperiod, microclimate, competition, and predation rate, however, our data do not allow a clear statement about this.

The adult population activity of *E. azureus* is maintained throughout the year and its population is made up of more males than females. Through climatic conditions, we can explain this difference in sex ratio because of the high mean temperatures throughout the year, which favor the hatching of males. The population dynamics of *E. azures* are positively correlated with precipitation, humidity, and maximum temperature, and the species has seasonality with population peaks in the spring and summer, and being less abundant in the autumn and winter.

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