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Relações entre a dinâmica populacional de noctuídeos
(Lepidoptera: Noctuidae) de importância agrícola no Brasil com
fatores ecoclimáticos e fenômeno El Niño

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Tese de Doutorado

Relações entre a dinâmica populacional de noctuídeos (Lepidoptera: Noctuidae) de importância agrícola no Brasil com fatores ecoclimáticos e fenômeno El Niño

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DEDICATÓRIA

Aos meus pais Oscar Fonseca Aburto, Amparo
Medrano Osorno e
Rodrigo Navarro Alvarado

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RESUMO

Relações entre a dinâmica populacional de noctuídeos (Lepidoptera: Noctuidae) de importância agrícola no Brasil com fatores ecoclimáticos e fenômeno El Niño

Considerando a importância dos noctuídeos-praga (Lepidoptera: Noctuidae) para a produção agrícola, esta tese objetivou fornecer subsídios ao entendimento das relações espaço-temporais entre as variações populacionais destes insetos com fatores climáticos e classificações ecoclimáticas (vegetação, clima, zonas de vida e biomas). Foram estudadas espécies de ampla distribuição no continente americano [*Anicla infecta* (Ochsenheimer), *Elaphria agrotina* (Guenée) e *Spodoptera frugiperda* (J.E. Smith)] cujas lagartas são polífagas, porém com hábitos diferenciados. As de *A. infecta* se alimentam preferencialmente do limbo foliar, as de *E. agrotina*, de tecidos vegetais secos e as de *S. frugiperda,* de tecidos vegetais em desenvolvimento ou reprodutivos. O primeiro estudo foi realizado em área agrícola no Distrito Federal durante quatro safras (de julho de 2013 a junho de 2017) analisando as variações populacionais das três espécies e o efeito de fatores climáticos e El Niño. O segundo estudo avaliou as variações populacionais de *A. infecta* em 12 locais do Brasil (Mojuí dos Campos, PA; Petrolina, PE; Rio Branco, AC; Porto Nacional, TO; Sinop, MT; Planaltina, DF; Uberaba, MG; Domingos Martins e Alegre, ES; Londrina, PR; Passo Fundo e Bagé, RS), durante as safras 2015-2016 e 2016-2017. As variações foram avaliadas empregando modelos lineares generalizados (GLM) como a regressão de Poisson; Testes não paramétricos como Kruskal-Wallis e Análise de Clusters. Os resultados do primeiro estudo evidenciaram que as três espécies apresentaram declínios populacionais anuais (porém não mensais) similares pelo menos nas três primeiras safras. Estas variações populacionais foram significativamente influenciadas pelos fatores climáticos e Índice Oceânico El Niño (ONI). No segundo estudo verificou-se que mariposas de *A. infecta* foram constantes (coletadas em mais de 50% dos meses amostrados) em praticamente todos os locais e suas populações variaram significativamente em função dos meses, dos locais, da vegetação, do clima, das zonas de vida e dos biomas. Os resultados indicaram uma maior associação entre número mensal de mariposas capturadas com o tipo de vegetação e zonas de vida (Coeficiente de Correlação Cofenética superior a 0,9) evidenciando a necessidade de considerar parâmetros destas classificações em estudos de monitoramento desta espécie.

Palavras-chave: Pragas agrícolas; *Anicla infecta*; Constância; *Elaphria agrotina*; ENSO; distribuição de insetos; noctuídeos; insetos polífagos; ecologia populacional; *Spodoptera frugiperda*

ABSTRACT

Relationships between population dynamics of noctuids (Lepidoptera: Noctuidae) of agricultural importance in Brazil with ecoclimatic factors and ENSO phenomenon

Considering the importance of noctuids-pests (Lepidoptera: Noctuidae) for agricultural production, this thesis aimed to provide information for the understanding of the space-time relationships between the population variations of these insects with climatic factors and ecoclimatic classifications (vegetation, climate, life zones and biomes). Widespread species were studied in the American continent [Anicla infecta (Ochsenheimer), Elaphria agrotina (Guenée) and Spodoptera frugiperda (J.E. Smith)] whose caterpillars are polyphagous, but with different habits. Those of *A. infecta* preferentially feed on the leaf blade, those of *E. agrotina*, of dry plant tissues and those of S. *frugiperda*, of developing or reproductive plant tissues. The first study was carried out in an agricultural area in the Federal District during four crops (from July 2013 to June 2017) analyzing the population variations of the three species and the effect of climatic factors and El Niño. The second study evaluated the population variations of *A. infecta* in 12 locations in Brazil (Mojuí dos Campos, PA; Petrolina, PE; Rio Branco, AC; Porto Nacional, TO; Sinop, MT; Planaltina, DF; Uberaba, MG; Domingos Martins and Alegre, ES; Londrina, PR; Passo Fundo and Bagé, RS), during the 2015-2016 and 2016-2017 seasons. Variations were evaluated using Generalized Linear Models (GLM) such as Poisson Regression; Non-Parametric Tests such as Kruskal-Wallis and Cluster Analysis. The results of the first study showed that the three species showed similar annual (but not monthly) population declines at least in the first three crops. These population variations were significantly influenced by climatic factors and the Oceanic Niño Index (ONI). In the second study, it was found that *A. infecta* moths were constant (collected in more than 50% of the sampled months) in practically all places and their populations varied significantly depending on the months, places, vegetation, climate, life zones and biomes. The results indicated a greater association between the monthly number of moths captured with the type of vegetation and life zones (Cophenetic Correlation Coefficient greater than 0.9), showing the need to consider parameters of these classifications in monitoring studies of this specie.

Keywords: Agricultural pests; *Anicla infecta; C*onstancy; *Elaphria agrotina;* ENSO; insect distribution; owlet moths; polyphagous insects; populational ecology; *Spodoptera frugiperda*

INTRODUÇÃO GERAL DA TESE

Todo ser vivo sobrevive, cresce e se reproduz, dependendo dos elementos bióticos e abióticos combinados em um período específico de tempo e local. Cada estágio do ciclo de vida dos insetos requer elementos diferentes para suprir as necessidades de evolução do organismo. Fatores como alimentos, níveis adequados de temperatura e chuva, presença de inimigos naturais, dimensão da área, entre muitos outros, definirão o tamanho da população de cada espécie em uma área e período de tempo. Nos insetos, diferentes estágios necessitam de condições específicas e podem ser mais ou menos resistentes. Quando as condições ambientais não são suficientes para o seu desenvolvimento, os insetos costumam migrar ou dispersar à procura de outro local que forneça as condições necessárias ao seu crescimento e reprodução. Além disso, as variações climáticas também influenciar o comportamento dos insetos. A temperatura é um dos fatores abióticos que exercem grande influência sobre a biologia do inseto e afeta a duração do ciclo de vida e, por consequência, o voltinismo e a densidade populacional (BALE *et* al., 2002).

Entre os lepidópteros de importância agrícola destacam-se os noctuídeos que apresentam diversas espécies-praga, caracterizadas por apresentarem lagartas polífagas, ciclo de vida curto, elevada fertilidade e capacidade de dispersão (Wagner et al. 2011). Neste estudo foram analisados diversos aspectos relacionados as variações populacionais de três espécies com potencial de se tornarem pragas agrícolas em situações específicas e suas relações com variáveis climáticas e fenômeno El Niño.

Para tanto foram escolhidas *Anicla infecta* (Ochsenheimer, 1816), *Elaphria agrotina* (Guenée, 1852), *Spodoptera frugiperda* (JE Smith, 1797) por apresentarem lagartas polífagas que atacam preferencialmente gramíneas. As lagartas de *A. infecta* consomem preferencialmente o limbo de folhas maduras (Teston et al. 2001), as de *E.*

agrotina preferem consumir tecidos mortos ou secos (Specht et al. 2014 enquanto que as larvas de *S. frugiperda* consomem preferencialmente tecidos jovens ou reprodutores com alto valor nutricional (Montezano et al. 2018).

Por outro lado, é importante mencionar que os insetos só podem ser considerados como pragas quando causam perdas significativas, atingindo Nível de Dano Econômico (SENAR, 2018). Todas as três espécies do presente estudo, especialmente *S. frugiperda*, em condições favoráveis podem se tornar pragas (Teston et al. 2001, Specht et al. 2014, Montezano et al. 2018).

O El Niño (ENSO - El Niño–Southern Oscillation) é um fenômeno climático oceano-atmosférico de larga escala, ligado ao aquecimento periódico das temperaturas da superfície do mar no Pacífico Equatorial Central e Leste-Central do Pacífico. O termo El Niño representa a fase quente do ciclo e o termo La Niña representa a fase fria. Sua alternância desencadeia variações climáticas cíclicas que interferem tanto na temperatura quanto na precipitação (NOAA 2019). Dessa forma este fenômeno gera grande impacto em todos os ecossistemas incluindo os agrícolas.

Para avaliar o efeito das condições climáticas e fenômeno El Niño sobre as variações populacionais destes três noctuídeos esta Tese foi estruturada em dois capítulos:

O primeiro: "Dinâmica populacional de três mariposas polífagas (Lepidoptera: Noctuidae) e a influência de fatores meteorológicos e o ENSO" apresenta um estudo que considerou os efeitos das variações climáticas e fenômeno El Niño, durante quatro safras agrícolas (julho de 2013 a junho de 2017) sobre as variações populacionais das três espécies, no Distrito Federal, Brasil. A principal hipótese deste capítulo é que devido as três espécies apresentarem preferencias alimentares distintas, provavelmente apresentarão respostas diferenciadas quando expostas as mesmas variações dos fatores climáticos e Índice Oceânico El Niño (ONI).

O segundo: "Variações populacionais de *Anicla infecta* (Lepidoptera: Noctuidae) de acordo com variáveis ecoclimáticas", aborda relações entre as variações populacionais de mariposas de *A. infecta* coletadas durante duas safras (Julho de 2015 a junho de 2017), com 12 locais de coleta no Brasil, com tipos de vegetação (Veloso & Góes), clima (Köppen-Geiger), zonas de vida (Holdridge) e biomas (   )". Adicionalmente, para avaliar se cada local ou categoria ecoclimática apresenta condições favoráveis ao desenvolvimento de *A. infecta* ao longo do tempo, avaliou-se a constância mensal de mariposas. Neste capítulo a principal hipótese se concentra em que as populações de *A. infecta* variam mensalmente em função das oscilações climáticas ao longo do ano e também em função dos locais e tipos de vegetação, clima, zonas de vida e biomas.

Este estudo tem como objetivo geral avaliar as relações entre as variações populacionais de três noctuídeos (Lepidoptera: Noctuidae) de importância agrícola no Brasil com fatores ecoclimáticos e fenômeno El Niño.

Como objetivos específicos destacam-se:

1. Avaliar e comparar as variações populacionais mensais de *A. infecta, E. agrotina* e *S. frugiperda* ao longo de quatro safras (julho de 2013 a junho de 2017)

2. Relacionar as variações populacionais de *A. infecta, E. agrotina* e *S. frugiperda* com fatores climáticos e fenômeno El Niño (Índice Oceânico El Niño - ONI).

3. Avaliar a constância e variações populacionais mensais de mariposas de *A. infecta* em duas safras agrícolas (julho de 2015 a junho de 2017) considerando 12 locais de coleta e diferentes classificações ecoclimáticas (Vegetação - Veloso & Góes; climática - Köppen-Geiger; Zonas de Vida - Holdridge e Biomas brasileiros).

4. Estimar relações entre as variações populacionais de *A. infecta* com pontos de coleta, tipos de vegetação, clima, zonas de vida e biomas.

1. The population dynamics of three polyphagous owlet moths (Lepidoptera: Noctuidae) and the influence of meteorological factors and ENSO on them

A dinâmica populacional de três mariposas polífagas (Lepidoptera: Noctuidae) e a influência de fatores meteorológicos e do ENSO sobre eles

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Resumo

As mariposas-coruja (Lepidoptera: Noctuidae) *Anicla infecta* (Ochsenheimer 1816), *Elaphria agrotina* (Guenée 1852) e *Spodoptera frugiperda* (J.E. Smith 1797) ocorrem em todo o continente americano. Essas mariposas polífagas têm preferência por gramíneas e têm diferentes hábitos biológicos. Neste estudo, as populações dessas três espécies foram avaliadas mensalmente com armadilhas luminosas na savana brasileira, variando em um período de quatro safras (de julho de 2013 a junho de 2017). Os dados populacionais foram analisados e correlacionados com as variáveis meteorológicas: temperatura máxima, temperatura mínima, umidade relativa e precipitação. Foram coletados 4.719 indivíduos nas seguintes porcentagens: *A. infecta* (n = 459; 9,73%), *E. agrotina* (n = 1.809; 38,33%) e *S. frugiperda* (n = 2.451; (51,94%). A abundância de todas as espécies caiu da primeira safra (2013/2014) para a terceira (2015/2016). Na quarta safra (2016/2017), as populações de *A. infecta* e *E. agrotina* se estabilizaram, mas a abundância de *S. frugiperda* sofreu uma diminuição adicional. O número de indivíduos das três espécies declinou quando a precipitação estava muito acima (safra 2014/2015) e abaixo (safra 2015/2016) do esperado da normal climatológica. Houve importantes mas diferentes graus de correlação, entre os fatores meteorológicos e o índice ONI (Oceanic Niño Index - indicador de monitoramento da oscilação El Niño-Sul ou "ENSO") em relação às variações mensais da população. Os resultados são discutidos de acordo com os princípios do Manejo Integrado de Pragas (MIP), tendo em vista a distribuição continental e importância agrícola das três espécies de mariposas estudadas.

Palavras-Chave: Pragas Agrícolas; Anicla infecta; Elaphria agrotina; ENSO; Spodoptera frugiperda

Abstract

The owlet moths (Lepidoptera: Noctuidae) *Anicla infecta* (Ochsenheimer 1816)*, Elaphria agrotina* (Guenée 1852) and *Spodoptera frugiperda* (J.E. Smith 1797) occur in the entire American continent. These polyphagous moths have a preference for grasses, and have different biological habits. In this study, the populations of these three species were evaluated monthly with light traps in the Brazilian Savannah, ranging a span of four crop seasons (from July, 2013 to June, 2017). The population data were analyzed and correlated with the meteorological variables: maximum temperature, minimum temperature, relative humidity and precipitation. A total of 4,719 individuals were collected in the following percentages: *A. infecta* (n=459; 9.73%), *E. agrotina* (n=1,809; 38.33%) and *S. frugiperda* (n=2,451; (51.94%). The abundance of all species went down from the first crop season (2013/2014) to the third (2015/2016). In the fourth crop season (2016/2017), the populations of *A. infecta* and *E. agrotina* stabilized, but the abundance of *S. frugiperda* experienced further decrease. The numbers of individuals of three species declined when precipitation was much above (crop season 2014/2015) and below (crop season 2015/2016) than expected by the climatological normal. There were significant, but different degrees of correlation, between the meteorological factors and the ONI index (Oceanic Niño Index - indicator for monitoring El Niño-Southern Oscillation or "ENSO") with respect to monthly population variations. The results are discussed in accordance with principles of the Integrated Pest Management (IPM) in mind, given the continental distribution and agricultural importance of the three owlet moth species studied.

Keywords: Agricultural pests; *Anicla infecta; Elaphria agrotina;* ENSO; *Spodoptera frugiperda*

1.1   Introduction

Insects are very diverse and play fundamental roles in ecosystems. Adult lepidopterans (butterflies and moths) are important pollinators of wild plants and also many food crops (Kondo, 2012). Their larvae, in contrast, have a great negative impact on plants, eating their leaves, flowers, fruits, seeds, branches and even roots (Weisse & Siemann, 2008). Out of their natural habitat lepidopterans can become important pests. The owlet moths, *Anicla infecta* (Ochsenheimer, 1816)*, Elaphria agrotina* (Guenée, 1852) and *Spodoptera frugiperda* (J.E. Smith, 1797) are good examples of this. They occur throughout the American continent and recently, *S. frugiperda* has also been detected in the African continent (Goergen et al., 2016), Europe (CABI, 2017) and India (Shylesha et al., 2018). Their caterpillars are polyphagous, with a strong preference for grasses (Teston et al., 2001; Casmuz et al., 2010; Specht et al., 2014; Montezano et al., 2018). The caterpillar of *A. infecta* feeds preferentially on the foliar limb of native and cultivated grasses such as oats, ryegrass, grasses, millet and corn (Teston et al., 2001). *Elaphria agrotina* stays in the soil and eats "debris/tillage" or dead plant structures of crops such as maize, including leaves, cobs, stigmas and dried seeds (Specht et al., 2014). *Spodoptera frugiperda* has a polyphagous caterpillar which can be a pest of many crops, including monocotyledonous and dicotyledonous plants. In cultivated Poaceae, it prefers young leaflets (attacking the maize, millet and sorghum husk), but also attacks reproductive tissues (such as corn ear or panicle of millet and sorghum) (Montezano et al., 2018). When their population numbers are high, they are considered pests due to their negative impact on the production of some crops (Capinera, 2008).

Lepidopteran pests cause losses not only by impairing plant production, but also by requiring expensive management (Paula-Moraes et al., 2017). The knowledge of the relationships between the population fluctuations of each species with the meteorological

variations can contribute with data for the development of forecasting systems, promoting the rationalization of their management (Zalucki & Furlong, 2005). In this way, this work presents and compares the population dynamics of *A. infecta, E. agrotina* and *S. frugiperda* in four crop seasons in Central Brazil, considering the Oceanic Niño Index (ONI) climatic pattern as a possible influence on it.

1.2   Materials and methods

1.2.1 Study area

This study was carried out in the area of 'Estação Experimental da Embrapa Cerrados', located in the city of Planaltina, Distrito Federal, Brazil, which is predominantly an agricultural area. It is located in the 'Cerrado' biome (Ab' Saber, 2003), also known as the Brazilian Savannah. According to the climate classification of Köppen-Geiger, it has a Tropical Wet-Dry Climate (Aw), with average temperatures around 17ºC in the coldest and 22ºC in the hottest months. The region is marked by two seasons, defined by the differences in rainfall accumulation. The rainy period starts in September and extends until April. The wettest months are November, December and January. The dry period starts in May and ends in September, resulting in a hot and rainy summer and mild and dry winter (Silva et al., 2017).

The sampled landscape is totally surrounded by native vegetation of Brazilian Savannah, but in the collecting point there are several agriculturally important crops, especially soybean, corn and wheat, which occupy about 25, 15 and 10% of the 400-meter radius from the collecting site. Part of the area is occupied with agricultural buildings (barns and greenhouses) and, to a lesser extent, crops of other species such as bluestem, coffee, cassava, rattleweed, gum, oil palm, panicgrass, passion fruit and sugar cane. Wheat, soybean and corn stand out because the former is restricted to the dry period,

while the other two are restricted to the rainy season. It is assumed that other crops do not affect the phenology of *A. infecta*, *E. agrotina* and *S. frugiperda* because they are perennial plants which are not preferential hosts for these species, and/or are cultivated in small areas. During four crop seasons the crops were repeated to avoid changing the availability of food for the owlet caterpillars.

1.2.2 Meteorological data and Oceanic Niño Index (ONI)

The meteorological data was obtained from the Estação Climatológica Principal da Embrapa Cerrados with meteorological sensors at a distance of 20 meters from the light trap. The variables analyzed were maximum (Tmax) and minimum (Tmin) temperature, relative humidity (RH) and precipitation (Precip). The Oceanic Niño Index (ONI) values were obtained in NOAA (2018). The Oceanic Niño Index (ONI) is NOAA's primary indicator for monitoring El Niño and La Niña, which are opposite phases of the climate pattern called the El Niño-Southern Oscillation or "ENSO" for short. NOAA considers El Niño conditions to be present when the ONI is +0.5 or higher, indicating the East-Central Tropical Pacific is significantly warmer than usual. On the other hand, La Niña conditions exist when the ONI is -0.5 or lower, indicating that the region is cooler than usual. Values over 0.5 correspond to El Niño and under -0.5 correspond to La Niña.

1.2.3 Insect collecting

The moths were collected with a Pennsylvania light trap (Frost, 1957) at the following coordinates 15°35′30″ S and 47°42′30″ W, altitude: 1007m a.s.l. This trap was equipped with a black fluorescent light model BL T8 15W (Tovalight) and was lit during five nights at each *novilunium*, to minimize the moonlight effects on trap efficiency. Each night is considered a repetition in the analysis, and the insects collected each night per

novilunium/month were individualized to calculate the means. This trap was placed three meters from the ground, inside the crop area.

In total, the trap was lit 50 times over a period of four years in *novilunium* to represent all months during that period. The collecting activities started in July when the harvest period starts and ended in June of the following year. Therefore, in the present study we considered four crop seasons, from June of 2013 to July of 2017. Crop season 1 (CS1) - July of 2013 to June of 2014; crop season 2 (CS2) - July of 2014 to June of 2015; crop season 3 (CS3) - July of 2015 to June of 2016 and crop season 4 (CS4) - July of 2016 to June of 2017.

Due to an excess of rainfall and a large number of Coleoptera, Hymenoptera and Isoptera attracted to the trap in November, 2013, the owlet moths were damaged to the point that their identification was not possible. For this reason, the samples collected on that month were not considered. In the months when there were two new moons, July 2015 and September 2016, the collecting process was considered a repetition. Therefore, instead of considering the usual five collections, we considered ten for the same month. The identification of insects during the sorting process was based on the literature (Angulo & Olivares, 1997; Pogue, 2002; Specht et al., 2014). The specimens were preserved in ethanol (96%), and representative vouchers were pinned and deposited in the Entomological Collection of Embrapa Cerrados.

1.2.4 Statistical analysis

Three separate analyses were conducted, one for each species: *A. infecta*, *E. agrotina* and *S. frugiperda*, for four years with entirely randomized design and five temporal repetitions. The analysis has two qualitative factors: crop season (four crop seasons) and months (twelve).

Normality of variances was tested annually using the Shapiro-Wilk. T-test was used to compare differences in the average abundance among the crop seasons. A Generalized Linear Model (GLM) Poisson Regression was used to determine how the mean expected value of a continuous response variable (abundance) depends on a set of explanatory variables (daily meteorological factors). To complement this, another similar analysis was conducted, comparing the monthly means of the populations of each species with ONI data (Oceanic Niño Index). The Poisson regression model takes into account discrete variables. The analysis using this regression model involved the total number of individuals of *A. infecta, E. agrotina* and *S. frugiperda* collected in each sample (McCullagh & Nelder, 1989). It works with non-normality distributions by modeling the data and identifying problems with discreteness in the outcomes (e.g. the "lump" of zeros) (Vittinhoff et al., 2004).

Data were analyzed and graphed using the R Software ver. 3.3.1, Action Stat Module.

1.3   Results

1.3.1 Abundance of species according crop seasons

In general, the results indicate that all populations of the three species decreased in numbers from CS1 to CS4 (Table 1, Figure 1) with significant between CSs ($p < 0.05$). There were two exceptions: non-significant variations in the number of individuals were observed for *A. infecta* between CS3 and CS4 ($p = 0.77$) and for *E. agrotina* between CS2 and CS4 ($p = 0.20$) and CS3 and CS4 ($p = 0.91$).

Regarding to the variations in populations per species during and among the crop seasons, the following results are notable:

The average number of individuals of *A. infecta* decreased from 24.7 (CS1) to 8.5 in CS2 and to 2.5 in CS3 (Figure 1). Similarly, and despite the fact that comparisons involving November's CS1 were not possible, significant monthly decreases in numbers of individuals were observed, particularly between CS1 and CS2, CS3 and CS4 (Table 2, Figure 2a).

The average number of *E. agrotina* individuals decreased from CS1 (126.3), to CS2 (12.3), to CS3 (4.6) and remained stable in CS4 (4.6) (Figure 1). With respect to the monthly fluctuations between crop seasons showed that July of 2013 (CS1) was the month when there were more individuals collected, with an average total of 106.3 moths per night (Table 2). In most cases, there was a decrease in abundance from one crop season to another, such as in July 2013, when there was a decrease of 96.05% in the average number of individuals (102.1) compared to CS2 and 99.81% (106.1) compared to CS3 and CS4 (Table 2). Significant decreases were also observed in at least half of the months, particularly in the comparisons between CS1 and the other crop seasons (Table 2).

Similarly, for four crop seasons, the total average of individuals of *S. frugiperda* progressively decreased from 111.4 in CS1 to 8.9 in CS4 (Figure 1). This decrease in

population numbers was significant between the harvests of most months, including comparisons with the last harvest (Table 2).

Another important aspect is that all species under study were present (were collected) in practically every month during all four crop seasons. However, the specific monthly abundance of each species, and the peaks in the population of each species, varied among the crop seasons. This is the case of *A. infecta,* which was more abundant in July, August and September of 2013; April, May and June of 2014. In the case of *E. agrotina*, the greatest numbers of individuals were collected only in July of 2013 and finally, for *S. frugiperda,* the population peak was reached in July of 2013, January, April and November of 2014 (Tables 1-2; Figure 2).

1.3.2 Relationship between meteorological factors and ONI on the specific abundances

According to our results, indicated by the Poisson coefficients and respective p-values, the climatological variables, except for the minimum temperature on *E. agrotina* and precipitation on *S. frugiperda*, influenced each one of the species in a significant and differential way (Table 3).

Our results indicate that the meteorological variables are negatively correlated with the population numbers of *A. infecta* and *E. agrotina*, meaning that lower population numbers were observed when precipitation, temperature and humidity were at their highest (Table 3).

To *S. frugiperda*, precipitation did not affect the populations in a significant way (Table 3). However, higher maximum temperatures, as observed for *A. infecta* and *E. agrotina*, contributed significantly to a decrease in the numbers of individuals of this species in our samples. The minimum temperature and relative humidity, in contrast, were positively associated with estimated values of abundance, meaning that, an increase in

the values of these parameters was significantly associated with increased abundance of *S. frugiperda* in samples (Table 3).

Beyond the meteorological factors, the numbers of individuals of all species were negatively correlated with the ONI values, the primary indicator for monitoring El Niño and La Niña events (Table 3).

1.4   Discussion

The consecutive decrease in the abundance of the three owlet moth species over the four crop seasons (Table 1; Figure 1) of this study are consistent with the results obtained for other owlet moth species, being *Chrysodeixis includens*, *Spodoptera albula*, *Spodoptera cosmioides* and *S. frugiperda,* in the same area, in the following crop seasons: 2013/2014, 2014/2015 and 2015/2016 (Piovesan et al., 2017; Santos et al., 2017).

Since this analysis was carried out in a Tropical Savannah (Cerrado) area with two very different seasons (a very long dry season and a very wet season), the temperature (maximum and minimum) fluctuated less than precipitation and relative humidity (Figure 2). Besides the variations in the observed precipitation values on each crop compared to the expected (Silva et al., 2014), there was a significant drop in precipitation in the fall of 2015/2016, associated with the El Niño. However, in the last crop season (CS4), even without the influence of the El Niño, precipitation and the consequent relative humidity were lower than the annual rainfall volume expected by the climatological normal (Silva et al., 2014, Figures 1 and 3).

Despite large variations in the volume of precipitation on each crop, according to the Climatological Normal 1974-2004 (Silva et al., 2014), it was not possible to find a connection between the observed decrease in the numbers of individuals of the three species and volume of precipitation (Table 1, Figure 1). Species' abundances declined

significantly (more than 50%) between the 2013/2014 harvest and the 2014/2015 one, when there was an increase of 19.8% (309.4 mm^3) in precipitation. The decrease in the number of individuals, at least in the case of *S. frugiperda*, was as expected, since the caterpillars, especially in the early life stages, tend to drown inside the corn's cartridge when precipitation is high (its main host plant) (García-Roa et al., 2002). Similarly, the neonate larvae of all the species are, directly or indirectly, highly vulnerable to the impact of raindrops, which can remove them from their host plants (Zalucki et al., 2002). Furthermore, high levels of precipitation, accompanied by high relative humidity, generally induce the occurrence of entomopathogenic epizooties (Ríos-Velasco et al., 2010).

The abundance of the three species continued to drop even more between the 2014/2015 and 2015/2016 crop seasons, when a reduction in precipitation was observed in 54.81% (-705.1 mm3), due to the El Niño phenomenon (Figure 3). That decrease can be attributed to the extreme water deficit, which among other things, affects the quantity and quality of food available for the insects (Zalucki et al., 2002). Despite this, the abundance decrease in crop season with reduced rainfall differs from the observations reported in the literature where, at least for *S. frugiperda*, the diminution in precipitation would lead to a considerable populational increase, since drier climates favor the larvae of this species (Corte et al., 1985; García-Roa et al., 2002).

In the following crop seasons, between the 2015/2016 and 2016/2017, only the abundance of *S. frugiperda* decreased significantly. It is important to highlight that, although the El Niño event lost its strength, precipitation remained relatively low during the fourth crop season 2016/2017 (1,136.8 mm^3) (Figures 1 and 3). Considering the size of the cultivated area and crop management (same quantity and type of chemical product) over four years and expressive non-intensive agricultural area (3000 ha) around the

collecting site, we inferred that the variations in population abundance are linked to other, non-quantifiable elements, such as natural biological control (Pereira et al., 2018).

The fact that the three species were sampled during practically every month of all crop seasons (Table 2, Figure 2) is conditioned to their multivoltinism, and by the presence, in the study area, of minimal biotic and abiotic conditions for their development and permanence. This also indicates that all species had initial populations (even in the dry season - June to September) that would allow rapid increases in abundance under favorable conditions. However, the monthly abundances of each species within each crop (Table 2, Figure 2) varied greatly, sometimes with coincident and sometimes antagonistic population peaks, attributed to the behavioral and developmental characteristics of the larvae of each (Kasten Jr. et al., 1978; Teston et al., 2001; Specht et al., 2014). Associated with these variations, the results indicate that the meteorological variables affected the decrease in the numbers of the three species in different ways (Table 3).

The caterpillars of each species have different habits and consume variable food resources (tissues): The caterpillars of *A. infecta* have cryptic coloration (green), rest all day on the leaf limbs and are exposed to daily climatic variations (warmer during the day and cooler at night). Plant tissues commonly consumed (leaves), especially native and cultivated grasses (oats, ryegrass, grasses, millet and corn) tend to be less nutritive (Teston et al., 2001). Since they stay close to the leaves, they are relatively more exposed to the attack of natural enemies. *Elaphria agrotina* caterpillars, however, prefer dry plant materials and stay in the soil feeding on debris / tillage or dead plant structures such as maize, including leaves, cobs, stigmas and dried seeds (Specht et al., 2014). Because caterpillars are usually close to the ground, they may or may not feed on nutrient-rich foods (depending on seed availability) and be less exposed to daily variations in temperature and relative humidity and are thus sheltered and protected from natural

enemies. At last, *S. frugiperda* caterpillars, although they remain hidden during the day (on the ground or between plant structures), are very mobile from birth and prefer to attack leaves that are starting to develop (attacking the maize, millet and sorghum (Harvey et al., 2008; Casmuz et al., 2010; Favetti et al., 2017). Because they are very mobile, *S. frugiperda* caterpillars are usually sheltered during the day and move out from dusk to early evening to eat, being protected from natural enemies most of the time. This greater mobility still allows their caterpillars (when available) to explore preferred hosts and plant tissues with higher nutritional value, including growing flowers, fruits, seeds or tissues.

Still regarding interspecific variations, the table data shows that the numbers of individuals of *A. infecta* and *E. agrotina* decreased in a similar manner on the three first crops (Table 1) and suffered negative influence of the meteorological parameters that were analyzed (Table 3); but showed differentiated monthly populational variations (Table 2). These divergences between specific monthly abundances were associated with the different degrees of influence of each meteorological parameter (Table 3). We attribute this discrepancy of population variations over time (four crops) and the level of meteorological influence to the different bioecological aspects of each species (Kasten Jr. et al., 1978; Teston et al., 2001; Specht et al., 2014).

It is important to point out in this context is that in the crop season that preceded the first crop of the present study (2012/2013), precipitation was 1,229.1mm^3, very similar to the value of crop season 1 (1,250.9 mm^3), before large precipitation oscillations (Figure 1) motivated especially by El Niño (NOAA, 2018). In this sense, several studies have shown that abrupt climatic variations lead to large population fluctuations of insects, including Lepidoptera (Woiwod, 1997; Cornelissen, 2011; Wilson & Maclean, 2011). In addition to the annual oscillations, one should pay attention to the monthly variations in precipitation (Figure 2) because it varied considerably in the same crop season from one

month to another, and in the same month in the different crop seasons, consequently influencing the other monthly meteorological factors differently. The result of this is that insect populations that have a relatively short life cycle were subjected to great climatic variations either directly or indirectly associated with the availability of host plants.

The significant correlation between meteorological factors and ONI with the specific abundance of the three species (Table 3) indicate that the direct relationship of the oscillation of ONI with cyclical climatic variations (Holmgren et al., 2001) including episodes of drought at the studied site (Figures 2 and 3), can be used to make predictions and proactive management of pests. To make more precise predictions, however, long-term studies in different places and monitoring both adult and immature forms are necessary (Summerville & Marquis, 2017). Beyond that, the different characteristics of the species and agroecosystems need to be considered, including dispersion capacity (Ferguson *et al*., 1991), the effects of the agricultural landscape on metapopulations (Mennechez et al., 2003; Colombo & Anteneodo, 2015), gene exchanges (Nagoshi et al., 2017), natural biological control (Pereira et al., 2018), phytosanitary products and cultural practices (Gallo et al., 2001).

The relationship (despite seasonal differences) of the population dynamics of *A. infecta*, *E. agrotina* and *S. frugiperda* with meteorological variables and ENSO indicate the possibility of forecasting related to increases or even population outbreaks, subsidize decision-making to their management. In order to increase the precision of the models associated to the forecasts, it is necessary to monitor these insects for a longer period, including more climatic variations episodes, especially the related to El Niño and La Niña events.

Conflicts of Interest

The authors declare no conflicts of interest.

1.5   References

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Table 1. Specific abundance of three owlet moth species in four crop seasons: July of 2013 to June of 2017 (CS1 - 2013/2014, CS2 - 2014/2015, CS3 - 2015/2016, CS4 - 2016/2017). T-test comparisons performed using mean number (five nights) of moths captured with light traps in each crop season (60 nights) at Embrapa Cerrados, Federal District, Brazil

Species	Specific abundance					P value					
	CS1	CS2	CS3	CS4	Total	CS1 x CS2	CS1 x CS3	CS1 x CS4	CS2 x CS3	CS2 x CS4	CS3 x CS4
Anicla infecta	296	102	30	31	459	0.00	0.00	0.00	0.02	0.04	0.77
Elaphria agrotina	1516	183	55	55	1809	0.00	0.00	0.00	0.02	0.20	0.91
Spodoptera frugiperda	1337	786	221	107	2451	0.00	0.00	0.00	0.04	0.00	0.02
Total	**3149**	**1071**	**306**	**193**	**4719**	-----	-----	-----	-----	-----	-----

Table 2. Monthly average abundance of *Anicla infecta*, *Elaphria agrotina* and *Spodoptera frugiperda* in four crop seasons (CS1 - 2013/2014, CS2 - 2014/2015, CS3 - 2015/2016, CS4 - 2016/2017).
T-Test comparisons performed with mean number (five nights) of moths captured in light traps by month (five repetitions) at "Estação experimental da Embrapa Cerrados", Federal District, Brazil

Month	Average abundance					Comparisons between crop seasons											
	CS1	CS2	CS3	CS4	Total	CS1 x CS2	P-val	CS1 x CS3	P-val	CS1 x CS4	P-val	CS2 x CS3	P-val	CS2 x CS4	P-val	C3 x C4	P-val
								Anicla infecta									
J	4.5	2.0	1.0	0	7.5	-2.5	0.00	-3.5	0.00	-4.5	0.00	-1.0	0.11	-2.0	0.00	-1.0	0.03
A	3.4	1.8	0.2	0.2	5.6	-1.6	0.06	-3.2	0.00	-3.2	0.00	-1.6	0.01	-1.6	0.01	0.0	1.00
S	3.8	1.5	0.6	0.5	6.4	-2.3	0.08	-3.2	0.01	-3.3	0.01	-0.9	0.11	-1.0	0.09	-0.1	0.80
O	1.7	0.8	0.6	0.8	3.9	-0.9	0.17	-1.1	0.10	-0.9	0.26	-0.2	0.74	0.0	1.00	0.2	0.79
N	---	0.3	0.0	0.2	0.5	----	----	----	----	----	-----	-0.3	0.19	-0.1	0.86	0.2	0.37
D	1.4	0.2	0.4	0.6	2.6	-1.2	0.11	-1.0	0.23	-0.8	0.33	0.2	0.63	0.4	0.37	0.2	0.73
J	1.0	0.1	0.8	0.8	2.7	-0.9	0.03	-0.2	0.70	-0.2	0.74	0.7	0.14	0.7	0.23	0.0	1.00
F	0.8	0.3	0.0	0.2	1.3	-0.5	0.11	-0.8	0.01	-0.6	0.08	-0.3	0.08	-0.1	0.70	0.2	0.37
M	0.8	0.3	0.2	0.6	1.9	-0.5	0.19	-0.6	0.11	-0.2	0.70	-0.1	0.62	0.3	0.56	0.4	0.41
A	4.4	0.7	1.8	0.6	7.5	-3.7	0.00	-2.6	0.02	-3.8	0.00	1.1	0.19	-0.1	0.73	-1.2	0.15
M	2.9	0.4	0.2	0.6	4.1	-2.5	0.00	-2.7	0.00	-2.3	0.00	-0.2	0.67	0.2	0.56	0.4	0.35
J	4.9	1.6	0.1	1.2	7.8	-3.3	0.00	-4.8	0.00	-3.7	0.00	-1.5	0.00	-0.4	0.33	1.1	0.00
								Elaphria agrotina									
J	106.3	4.2	0.2	0.2	110.9	-102.10	0.00	-106.1	0.00	-106.1	0.00	-4.0	0.00	-4.0	0.00	0.0	1.00
A	6.1	2.9	0.0	0.2	9.2	-3.19	0.02	-6.1	0.00	-5.9	0.00	-2.9	0.00	-2.7	0.00	0.2	0.37
S	2.3	1.7	0.0	0.0	4.0	-0.57	0.53	-2.3	0.00	-2.3	0.00	-1.7	0.06	-1.7	0.06	0.0	1.00
O	6.2	1.6	0.4	2.0	10.2	-4.60	0.04	-5.8	0.01	-4.2	0.05	-1.2	0.23	0.4	0.75	1.6	0.13
N	---	1.0	0.6	0.4	2.0	----	----	----	----	----	-----	-0.4	0.61	-0.6	0.34	-0.2	0.79
D	1.4	2.5	2.2	0.0	6.1	1.17	0.13	0.8	0.40	-1.4	0.01	-0.3	0.74	-2.5	0.00	-2.2	0.05
J	0.3	0.4	0.8	0.4	1.9	0.07	0.84	0.5	0.60	0.1	0.85	0.4	0.65	0.0	1.00	-0.4	0.65
F	0.5	0.0	1.8	0.2	2.5	-0.45	0.14	1.3	0.08	-0.3	0.47	1.8	0.04	0.2	0.37	-1.6	0.05
M	1.9	0.2	0.8	0.2	3.1	-1.68	0.00	-1.1	0.15	-1.7	0.00	0.6	0.40	0.0	0.94	-0.6	0.38
A	13.7	1.3	1.4	5.6	22.0	-12.43	0.01	-12.3	0.01	-8.1	0.16	0.1	0.86	4.3	0.33	4.2	0.34
M	8.0	0.7	0.6	1.6	10.9	-7.30	0.00	-7.4	0.00	-6.4	0.00	-0.1	0.89	0.9	0.10	1.0	0.12
J	3.9	1.0	1.6	0.2	6.7	-2.90	0.00	-2.3	0.02	-3.7	0.00	0.6	0.33	-0.8	0.08	-1.4	0.02
								Spodoptera frugiperda									
J	21.5	4.8	0.4	0.6	27.3	-16.7	0.00	-21.1	0.00	-20.9	0.00	-4.4	0.00	-4.2	0.00	0.2	0.58
A	7.2	0.0	0.8	1.4	9.4	-7.2	0.00	-6.4	0.00	-5.8	0.00	0.8	0.18	1.4	0.02	0.6	0.37
S	4.2	5.1	0.4	0.25	9.9	0.9	0.54	-3.8	0.00	-4.0	0.00	-4.7	0.00	-4.8	0.00	-0.2	0.68
O	5.8	0.0	0.2	2	8.0	-5.8	0.00	-5.6	0.00	-3.8	0.00	0.2	0.37	2.0	0.02	1.8	0.03
N	----	32.9	1.2	4.4	38.5	----	----	----	----	----	-----	-31.7	0.00	-28.5	0.01	3.2	0.11
D	12.4	7.7	14.0	4.2	38.3	-4.6	0.17	1.6	0.74	-8.2	0.03	6.3	0.16	-3.5	0.04	-9.8	0.05
J	22.9	9.7	7.4	1.4	41.4	-13.2	0.03	-15.5	0.02	-21.5	0.00	-2.3	0.47	-8.3	0.00	-6.0	0.10
F	8.1	2.5	3.2	0.8	14.6	-5.6	0.01	-4.9	0.04	-7.3	0.00	0.7	0.62	-1.7	0.02	-2.4	0.13
M	13.3	1.7	10.4	1	26.4	-11.6	0.00	-2.9	0.52	-12.3	0.00	8.7	0.05	-0.7	0.20	-9.4	0.04
A	29.2	3.3	2.2	1.4	36.1	-25.9	0.00	-27.0	0.00	-27.8	0.00	-1.1	0.07	-1.9	0.02	-0.8	0.20
M	0.2	2.0	0.6	3.0	5.8	1.8	0.02	0.4	0.35	2.8	0.19	-1.4	0.14	1.0	0.62	2.4	0.28
J	12.2	0.9	2.4	1	16.5	-11.3	0.00	-9.8	0.01	-11.2	0.00	1.5	0.17	0.1	0.82	-1.4	0.19

Table 3. Coefficients of Poisson Multiple Regression Model calculated for the montly variations in the mean number of moths collected, considered as predictor variables for climatic factors and ONI (Oceanic Niño Index). Est - Estimate, SE - Standard Error, P - P-value.

Predictor variables	*Anicla infecta*			*Elaphria agrotina*			*Spodoptera frugiperda*		
	Est	SE	P	Est	SE	P	Est	SE	P
Intercept	0.088	0.054	0.107	1.132	0.034	0.000	1.858	0.021	0.000
Maximum Temperature	-0.436	0.067	0.000	-1.112	0.035	0.000	-0.238	0.030	0.000
Minimum Temperature	-0.119	0.056	0.010	-0.009	0.031	1.000	0.154	0.030	0.000
Relative Humidity	-0.423	0.077	0.000	-0.756	0.042	0.000	0.100	0.036	0.001
Precipitation	-0.235	0.103	0.010	-0.271	0.051	0.000	0.024	0.018	1.000
Intercept	0.201	0.143	0.160	1.521	0.073	0.000	1.796	0.065	0.000
ONI	-0.355	0.175	0.042	-1.027	0.129	0.000	-0.141	0.069	0.040

Figure 1. Annual average abundance of *Anicla infecta* (black columns), *Elaphria agrotina* (grey columns) and *Spodoptera frugiperda* (white columns); cumulative precipitation in cubic millimeters per quadratic meter (black bars) in four Crop Seasons and expected precipitation according to Climatological Normal 1974-2004 (Silva et al., 2014). Moths captured with light traps at Estação Experimental da Embrapa Cerrados, Federal District, Brazil.
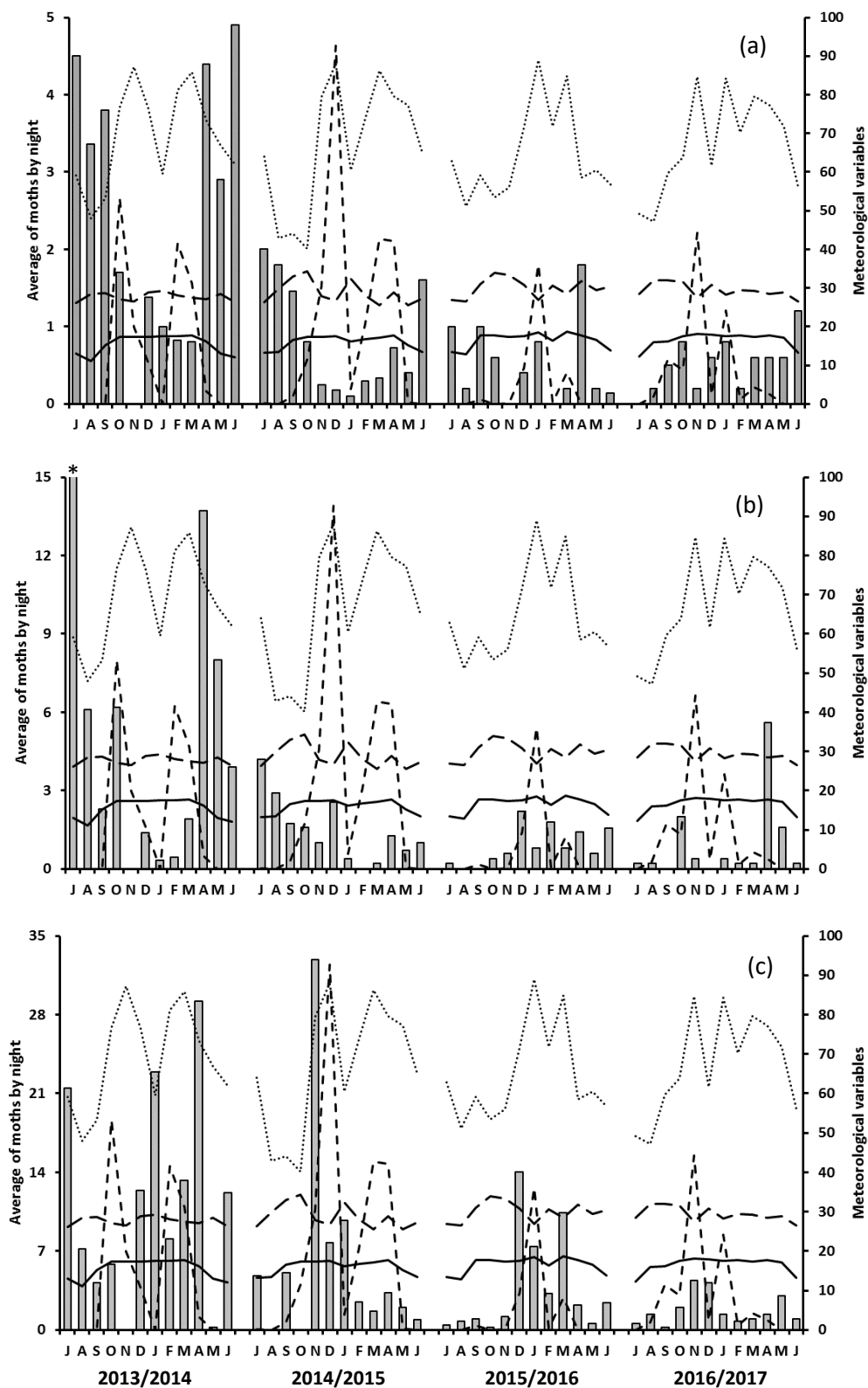
Figure 2. Average number of moths (a) *Anicla infecta*, (b) *Elaphria agrotina* and (c) *Spodoptera frugiperda* in four crop seasons according to meteorological variables: humidity - dotted line; maximum temperature - long dashed line; minimum temperature - continuous line and precipitation - short dashed line. Left columns have different scales and * [first column of *E. agrotina* (b)] represents 106.3 moths.

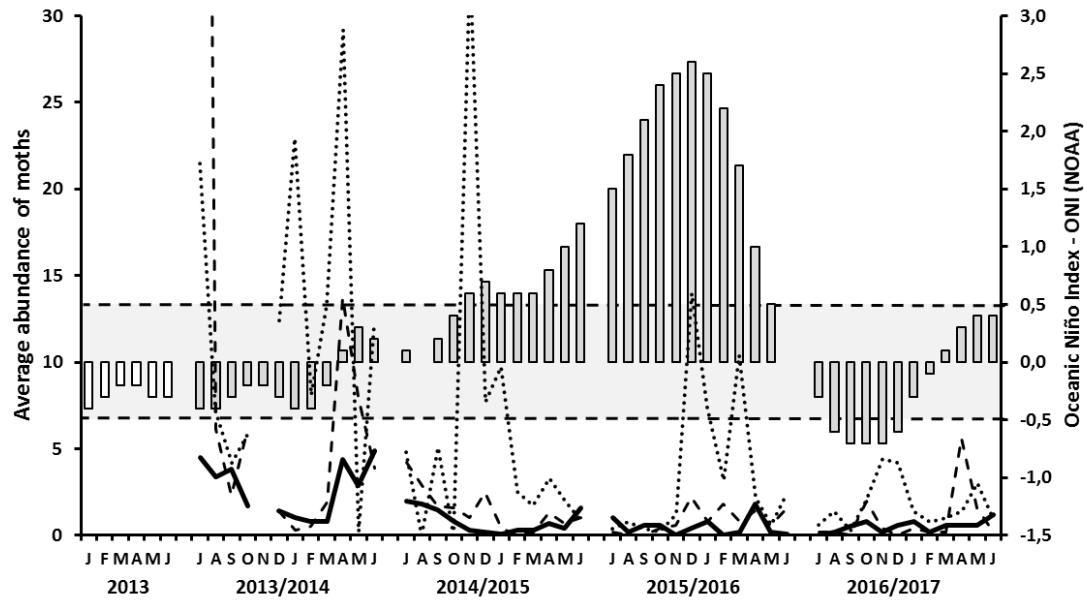**Figure 3.** Average number of *Anicla infecta* (continuous line), *Elaphria agrotina* (dashed line) and *Spodoptera frugiperda* (dotted line) in four crop seasons. Oceanic Niño Index - ONI; the white bars (left) represents six months before the beginning of the collections (gray bars). Values over 0,5 correspond to El Niño and under to -0,5 correspond to La Niña (NOAA, 2018)

2.   Population Fluctuation of *Anicla infecta* (Lepidoptera: Noctuidae) under the influence of Veloso & Góes Vegetation Classification, Köppen-Geiger Climate, Holdridge Life Zones and Brazilian Biomes

Flutuação populacional de *Anicla infecta* (Lepidoptera: Noctuidae) sobre a influência da Classificação da Vegetação de Veloso & Góes, clima de Köppen-Geiger, Zonas de Vida de Holdridge e Biomas Brasileiros

Resumo

Diversos fatores bióticos e abióticos como alimento, temperatura, precipitação, relacionam-se com o desenvolvimento e manutenção das populações das espécies. Os insetos representam organismos vulneráveis às condições ambientais e, portanto, para ocuparem diferentes ambientes e suportarem variações ambientais sazonais apresentam adaptações morfofisiológicas. As mariposas apresentam diversas adaptações como noturnalidade, polifagia, elevado potencial biótico e grande capacidade de dispersão que lhes permitem viver em ambientes diversos. *Anicla infecta* (Ochsenheimer, 1816) (Lepidoptera: Noctuidae) é uma espécie de ampla distribuição cujas características biológicas são descritas na literatura e permitem utilizá-la como um modelo para avaliar padrões populacionais de abundância e constância em diferentes ecossistemas. Este artigo objetivou descrever doze pontos não agrícolas em dez estados: 1- Mojuí dos Campos (Pará); 2- Petrolina (Pernambuco); 3- Rio Branco (Acre); 4- Porto Nacional (Tocantins); 5- Sinop (Mato Grosso); 6-Planaltina (Federal District); 7- Uberaba (Minas Gerais); 8- Domingos Martins (Espirito Santo); 9- Alegre (Espirito Santo); 10- Londrina (Paraná); 11- Passo Fundo (Rio Grande do Sul); 12- Bagé (Rio Grande do Sul) de acordo com a categorização da Vegetação de Veloso & Góes; classificação Climática de Köppen-Geiger; Zonas de Vida de Holdridge e Biomas Brasileiros. As análises foram obtidas por meio de Modelos Lineares Generalizados (MLG) como a regressão de Poisson; Testes Não Paramétricos como Teste de Wilcoxon, Teste de Kruskal-Wallis; Distribuição χ^2 (Qui quadrado) e Análise de Clusters. Dentre as conclusões podem-se mencionar que nenhum dos fatores ecoclimáticos determinou a abundância anual da espécie (p-valor > 0,05), a pesar dela ter flutuado significativamente por mês ao longo das safras; sua Ocorrência foi primeiramente constante e os Pontos de Coleta que mais se destacaram foram Mojuí dos Campos (PA) e Alegre (ES), que foram os únicos que apresentaram o p-valor significativo com respeito ao tipo de Vegetação e Zonas de Vida. No tocante ao resto dos fatores, pode-se dizer que a espécie apareceu em todos os locais, independentemente do tipo de categoria, o que leva a mais uma conclusão, a necessidade de continuar realizando este tipo de estudos de abundância de longo prazo em locais geográficos diversos para determinar fatores adicionais que poderiam estar beneficiando ou influenciando o aparecimento dela.

Palavras-chave: Zonas de Vida de Holdridge, Classificação de Köppen-Geiger, Ocorrência, Vegetação de Veloso e Góes

Abstract

Several biotic and abiotic factors such as food, temperature, precipitation, are related to the development and maintenance of species populations. Insects represent organisms that are vulnerable to environmental conditions and, therefore, to occupy different environments and withstand seasonal environmental variations, present morphophysiological adaptations. The moths have several adaptations such as nocturnal, polyphagy, high biotic potential and great dispersion capacity that allow them to live in different environments. *Anicla infecta* (Ochsenheimer, 1816) (Lepidoptera: Noctuidae) is a widely distributed specie whose biological characteristics are described in the literature and allow it to be used as a model to assess population patterns of abundance and constancy in different ecosystems. This article aimed to describe twelve non-agricultural points in ten states: 1- Mojuí dos Campos (Pará); 2- Petrolina (Pernambuco); 3- Rio Branco (Acre); 4- Porto Nacional (Tocantins); 5- Sinop (Mato Grosso); 6-Planaltina (Federal District); 7- Uberaba (Minas Gerais); 8- Domingos Martins (Espirito Santo); 9- Alegre (Espirito Santo); 10- Londrina (Paraná); 11- Passo Fundo (Rio Grande do Sul) and 12- Bagé (Rio Grande do Sul) according to the Veloso & Góes Vegetation categorization; Köppen-Geiger climate classification; Holdridge Life Zones and Brazilian Biomes. The analyzes were obtained using Generalized Linear Models (GLM) as the Poisson regression; Non-parametric Tests such as Wilcoxon Test, Kruskal-Wallis Test; Chi-square Distribution and Cluster Analysis. Among the conclusions, it can be mentioned that none of the ecoclimatic factors determined the annual abundance of the species (p-value> 0.05), despite having fluctuated significantly per month throughout the crops; its Occurrence was first constant and the Collection Points that stood out the most were Mojuí dos Campos (PA) and Alegre (ES), which were the only ones that presented a significant p-value associated to the type of Vegetation and Life Zones. Regarding to the rest of the factors, it can be said that the specie appeared in all places, regardless of the type of category, which leads to one more conclusion, the need to continue carrying out this type of long-term abundance studies in different geographic places to determine additional factors that could be benefiting or influencing its occurrence.

Keywords: Constancy, Insect distribution, Occurrence, Owlet moths, Polyphagous insects, Populational ecology.

2.1 Introduction

Anicla infecta (Ochsenheimer 1816) (Lepidoptera: Noctuidae: Noctuinae) or "green cutworm" (Crumb, 1929) was originally described by Ochsenheimer (1816) based on Hübner's misidentification of *Ochropleura praecox* (Linnaeus, 1758), from Europe. But, the occurrence of *A. infecta* is restricted to the American Continent (Poole, 1989). It occurs virtually throughout the American continent, with reports from northern North America, including Canada, to southern South America such as Uruguay, Argentina, and Chile (Crumb, 1956; Biezanko et al., 1957; Silva et al., 1968, Saunders et al., 1998, Lafontaine, 2004; Pastrana, 2004; Angulo & Olivares, 1997, Teston et al 2001; Wagner et al. 2011).

The green cutworm is a polyphagous owlet caterpillar that feed many cultivated and native herbs, preferring Poaceae representatives. It may be harmful to cereals and fodders of economic importance as barley, corn, millet, ryegrass, sorghum, sugar cane and wheat (Crumb, 1956, Silva et al., 1968; Angulo & Olivares, 1997; Teston et al 2001; Wagner et al. 2011).

The nocturnality (Daily & Ehrlich 1996), wide geographic distribution and polyphagia allows *A. infecta* to be found in very varied ecosystems with respect to edaphoclimatic and vegetative cover conditions (e.g. Teston et al. 2001, Lafontaine 2004). Associated with this, especially variable chromatic variations are described in both larvae and adults (Lafontaine 2004). The green cutworm can also vary its behavior and development depending on the temperature conditions, increasing or decreasing the number of generations, or, under unfavorable conditions, its moths can migrate to more suitable places (Fergusson et al., 1991; Wagner et al., 2011). These knowledges about its biology and biological plasticity makes *A. infecta* a potential model for ecologically based studies.

The differential abundance of a particular species in different places or times may address spatiotemporal adequations that impact in their development and survival (food resources, climatic adequacy, substrate for refuge before natural enemies' presence) (Santos et al. 2017, Piovesan et al. 2018a, 2018b, Pereira et al. 2018). When all of conditions are favorable the populations increase rapidly and result in outbreaks, both in natural and anthropogenic environments, see examples in Barbosa et al. (2018). But, the variation of these conditions determines the spatial and temporal differences on the abundance levels (Lu & Baker 2013, Maurer, 2018).

The constancy or temporal presence describe the proportion of time that a certain specie has conditions to survive in a certain place. In this way Bodenheimer (1955) categorized the constancy of a species is collected in one place as: constant - present in more than 50% of collections; accessory - present in 25% to 50% of collections and accidental - present in less than 25% of collections.

On the other hand, terrestrial ecosystems are permanently changing at a variety of spatial and temporal scales due to natural and/or anthropogenic causes (Martínez & Gilabert, 2009). Climate change is one of the causes resulting in land cover change (Lambin, Strahler, 1994). Evidence shows that there is a strong relationship between terrestrial vegetation coverage and climate variability (Kaufmann *et* al., 2003). Therefore, the present study includes Veloso & Góes Vegetation Classification (Veloso & Góes, 1982), based on Physio-ecological classification of neotropical formations according to RADAM Project (Brasil, 2019) as well as Köppen-Geiger Climate Classification, widely used to define climatic boundaries in such a way as to correspond to those of the vegetation zones (biomes). Finally, Holdridge Life Zones overcomes many weaknesses of available ecosystem classification systems and can be a useful tool for identifying ecological units (life zones). The process of constructing these types of maps often

involves circular reasoning. In the absence of comprehensive climatic information, vegetation is used *de facto* as a surrogate of climate. However, climate in turn is a driver of climax vegetation (Odum, 1945; Daubenmire, 1956; Whittaker, 1956 apud Lugo et al., 1999). Satellite images of land cover are excellent for assessing ecosystems at particular moments in time, but they require continuous updating because landcover and uses change constantly.

Due to the phytophagy of the lepidoptera representatives, the literature (Heppner, 1991) correlate biogeographic aspects, specially phytogeographic borders, with butterfly and moth diversity and distribution. In this way, through this article, we relate the population dynamic of *Anicla infecta* with four abiotic classification parameters: Veloso & Góes Vegetation Categories; Köppen-Geiger Climate Classification, Holdridge Life Zones and biomes.

2.2 Material and Methods

2.2.1. Study area

The experiment was performed in ten States: Acre (AC), Federal District (DF), Espirito Santo (ES), Mato Grosso (MT), Minas Gerais (MG), Pará (PA), Paraná (PR), Pernambuco (PE), Rio Grande do Sul (RS) and Tocantins (TO); twelve sites: 1- Mojuí dos Campos (Pará); 2- Petrolina (Pernambuco); 3- Rio Branco (Acre); 4- Porto Nacional (Tocantins); 5- Sinop (Mato Grosso); 6-Planaltina (Federal District); 7- Uberaba (Minas Gerais); 8- Domingos Martins (Espirito Santo); 9- Alegre (Espirito Santo); 10- Londrina (Paraná); 11- Passo Fundo (Rio Grande do Sul); 12- Bagé (Rio Grande do Sul) (Table 1). These collection points are non-agricultural areas located in different affiliates agencies of the Brazilian Agricultural Research Corporation (Embrapa), Advisory Institution of the Brazilian Ministry of Agriculture (Figure 1).

2.2.2 Ecoclimatic classifications of the collection points

2.2.2.1 Veloso & Góes Vegetation

In this study we have six types of vegetation according Veloso & Góes Classification (1982) (Table 1a): *i-Dense Ombrophilous*, where plants are capable of withstanding or thriving in the presence of much rain (Fapesp,2003); *ii-Steppical Savannah* that is formed by low trees and shrubs that usually lose their leaves in the dry season (deciduous species). It has three strata: arboreal (8 to 12 m), shrub (2 to 5 m) and herbaceous (below 2 m). The general appearance of the vegetation, in the drought, is of a thorny and wild forest (Rodal & Nascimento, 2006; Rodal et al., 2008; Bessa & Medeiros, 2011); *iii-Savannah*, during the hot summer months, when the rains are concentrated and the days are longer, everything is very green. In winter, on the contrary, the grass is yellow and dry; almost all the trees and shrubs, in turn, exchange the senescent foliage for a totally new one. But not all individuals do it at the same time, as in the northeastern caatingas. While some still keep their leaves green, others already have yellow or greyish leaves, and others have already taken off their leaves altogether. The woody species are deciduous but its vegetation is semideciduous (Sarmiento, 1984; Mendonça *et al*. 1998; Prado *et al*. 2004; Pennington, 2006). *iv-Semideciduous Seasonal Forest*; constituted by trees that will shed leaves in cooler months but may retain them in milder/warmer months; they may also be referred to as semi-deciduous if they lose their foliage for only a short period of time before regrowth or lose their foliage just as new growth emerges. It´s a term used if plants' periods of dormancy are dependent on certain weather conditions (Pagano & Leitão, 1987; Veloso, 1992); *v-Mixed Ombrophilous Forest* that occurs interspersed with savannah and steep areas (Seger, 2005; Kozera, 2006; Sonego et al., 2007; Silva, 2012); Finally, *vi-Steppe (Southern Fields)*, usually characterized by a semi-

arid and continental climate. Besides this huge difference between summer and winter, the differences between day and night are also very great. The term is also used to denote the climate encountered in regions too dry to support a forest but not dry enough to be a desert (Rambo, 1956; Boldrini, 1997; Waechter, 2002; Lohbeck *et al*. 2013) (Figure 2a).

2.2.2.2 Köppen-Geiger Climate Classification

We analyzed six types of climates (Table 1b) as follows: *i-Monsoon Climate (Am)*, where the temperature oscillates between 16,7ºC and 30ºC (Table 1e) with precipitation levels from 55mm to 149 mm (monthly average) (Table 1f). There are two periods of maximum temperature in association with the migration of the Sun's vertical rays. The monsoon climate tends to have its highest temperature just before rainy period. Once the rainy period starts, clouds block incoming solar radiation to reduce monthly temperatures (McKnight & Hess, 2000; Peel et al., 2007); *ii-Warm Semi-arid Climate (BSh)*, located further from the equator, which precipitation is dispersed throughout the year and it also means colder conditions. The temperatures oscillate between 22,7ºC and 33,4ºC (Table 1e) and the precipitation is from 2mm to 95mm (Table 1f) (Peel et al., 2007; Chen & Chen, 2013; Climate, 2019); *iii-Equatorial Climate (Af)*, characterized by the high temperatures throughout the year 32,4 °C, being the lowest temperature 21,8ºC (Table 1e) with plentiful precipitation: 89mm to 379mm (Table 1f), heavy cloud cover, and high humidity, with very little annual temperature variation. Wet equatorial regions lie within about 12° latitude of the Equator (Peel et al., 2007); *iv-Tropical Savannah (Aw)*, where there are two very different seasons: a very long dry season (winter), and a very wet season (summer). In the summer, there is lots of rain. It gets hot and very humid during the rainy season. Every day the hot humid air rises off the ground and collides with cooler air above and turns into rain. In the afternoons on the summer savanna the rains pour down for hours. In the coolest month the temperature reaches 12,5ºC and in the hottest

month, it could reach 27,9ºC (Table 1e). Its average monthly precipitation oscillates

between 7mm and 284mm (Table 1f) (Peel et al., 2007; Chen & Chen, 2013); *v-Subtropical Oceanic Highland Climate (Cwb)*, characterized by the Temperate, dry

winter and warm summer. The coldest month averaging above 10,7°C, all months with

average temperatures below 27,7 °C (Table 1e), and at least four months averaging above

10 °C. It rains at least ten times more in the wettest month of summer than in the driest

month of winter (9mm-347mm) (Table 1f) (McKnight & Hess, 2000; Peel et al., 2007;

Chen & Chen, 2013; Climate, 2019). Finally, we have *vi-Humid Subtropical Climate or

Warm Oceanic Climate (Cfa)*, where it could have cool but not cold winters and warm

summers. The annual temperature range of these areas is relatively narrow, except for

regions where the climate transits to subarctic, highland or continental climates, the mean

temperature during the coldest month is 10,3 °C or higher and below 29,6 °C (Table 1e)

in the warmest month. Summers are therefore cooler in oceanic climates as compared to

continental climates. The precipitation is sufficient, reliable, and evenly distributed

throughout the year. Regions with this climate lack a dry season. The precipitation falls

mainly in the form of rain, but some parts experience some snowfall every year during

winter (101mm-137mm) (Table 1f) (McKnight & Hess, 2000; Peel et al., 2007) (Figure

2b).

2.2.2.3. Holdridge Life Zones classification

The locals were inserted in seven life zones (Table 1c): *i-Tropical Dry Forest

Transition to Moist Forest (T-df∆)*, a zone where we can find both forests: Dry Forest and

Moist Forest. Moist Forest is a closed community of essentially but not exclusively

broadleaved evergreen hygrophilous trees, usually with two or more layers of trees and

shrubs. It includes the characteristic vegetation of the humid tropics, even when this has

a somewhat seasonal climatic regime, as well as those of moist elevated areas of the tropics (Whittaker, 1970; Madelon *et*. al, 2015; Neves *et*. al, 2015; Poorter *et*. al, 2017); *ii-Tropical Thorn Woodland Transition to Very Dry Forest (T-twΔ)* which is a mixed area of both classifications. The Tropical Thorn Woodland is a dense, scrub like vegetation characteristic of dry subtropical and warm temperate areas with a seasonal rainfall averaging 2 to 95 mm (Table 1f), is sometimes called Caatinga, and consists primarily of small, thorny trees that shed their leaves seasonally. Trees typically do not exceed 10 m in height, usually averaging between 7 and 8 m tall. In Contrast, the very dry forests are characterized by a long dry season with little rainfall. Many tree species are deciduous, losing their leaves at the onset of the dry season. Other plant adaptations are structured around water conservation and include spines, photosynthetic bark, waxy leaves, and tissues that can swell and store water collected during the rainy season (Mooney *et*. al, 1995; Rodal & Sampaio, 2002; Rodal & Nascimento, 2006); *iii-Tropical Moist Forests (T-mf)* that according to Holdridge are composed basically for Moist, Wet and Rain Forests. These regions are characterized for receiving annually high rainfall and often a cooler winter dry season (Lang & Knight, 1983; Seydack, 2000); *iv-Subtropical Premontane Moist Forest (SP-mf)*, characterized by low variability in annual temperature and monthly high levels of rainfall. Forest composition is dominated by semi-evergreen and evergreen deciduous tree species (Torres-Cuadros *et*. al, 2007; Pacheco *et*. al, 2010; Mastella *et*. al, 2019); *v-Boreal Subalpine Rain Forest (BS-rf)*, also known as Taiga, is dominated by shrubs (particularly Ericaceae), feather mosses, and in some areas lichens. There are a restricted number of commonly associated and highly characteristic herbs such as wintergreens. Areas of mire (bog, peatland muskeg) are widespread, and may be expanding or contracting. Its climate has extreme seasonal variation in insolation and temperature. In these regions the climate is characterized by very low winter temperatures

and fairly warm summers. The transition from winter to summer and vice versa is abrupt (Worrell, 1996; Lugo, 1999, DelaSalla *et*. al, 2011, Valério *et*. al, 2018)*; vi-Tropical Dry Forest (T-df),* which characteristics were mentioned previously, the only difference is the level of precipitation. In Tropical Dry Forests (T-df) rains lower than in Very Dry Forests, shortening in this way the period of the dry season (Murphy & Lugo, 1986; Sánchez-Azofeifa et al., 2005; Eliane *et*. al, 2006); *vii- Warm Temperate Lower Montane Moist Forest Transition to Wet Forest (WTL-mf∆)*, in this tropical zone, we can identify four clearly defined seasons, including a mild winter and a hot or cool summer that happens in mountain slopes. It is a transition area between Moist Forest and Wet Forest. The difference consists uniquely in the level of precipitation. In the Wet Forests rainwater seeps continually into the soil, the shade community lives under a closed canopy in a permanently moist and relatively cool environment (Jacobs, 1981; Valério *et*. al, 2018) (Figure 2c).

2.2.2.4. Biomes classification

The biomes are areas of extreme ecological importance when it comes of biodiversity and in this study, the collection points are found in five out of six Brazilian Biomes (Table 1d), excepting by Pantanal (1.76% of the national territory). They are: *i-Amazon,* that occupies approximately an area of 4.196.943km^2, representing 49.29% of Brazilian territory, its extension covers nine states (Acre-AC, Amapá-AP, Amazonas-AM, Pará-PA, Rondônia-RR, Roraima-RO and small parts of Maranhão-MA, Tocantins-TO and Mato Grosso-MT). It's considered the largest rain forest in the world, housing 20% of bird species, 20% of plant species and 10% of mammal species from around the world; *ii- Caatinga* occupies 844.453km^2 *and* 9.92% of Brazilian territory. It's located in the northeastern region of the country and it's characterized by vegetation adapted to the

dry climate and irregular rainfall patterns, with a warm and marked dry season (Brasil, 2020a). The term Caatinga is originally from Tupi-Guarani and means white forest. It is a unique biome because, despite being located in an area of semi-arid climate, it presents a great variety of landscapes, relative biological richness and endemism; *iii-Cerrado that* owns an extension of 2.036.448km² and 23,92% of Brazilian territory the second largest biome of South American covering 21% of the country (Klink & Machado, 2005; Scarano, 2007). Known as Brazilian Savannah is composed of habitats ranging from clean or open fields to closed forests. From the physiognomic point of view we have: the cerradão, the typical cerrado, the cerrado field, the dirty cerrado field, and the clean field that present height and plant biomass in decreasing order. Thus, the Cerrado basically contains two strata: an upper one, formed by trees and shrubs with deep roots that allow them to reach the water table, located between 15 to 20 meters; and an inferior one, composed of a carpet of grasses with low appearance, with shallow roots; *iv-Atlantic Forest, occupies* 1.110.182km² and represents 13,04% of the national territory. Historically, the Atlantic Forest has followed the entire Brazilian coast, from Rio Grande do Sul to Rio Grande do Norte. However, due to human occupation and deforestation, since the 20th century, this biome has been drastically reduced, being today considered one of the most threatened tropical forests in the world. The Atlantic Forest encompasses the most developed regions of the country, such as the state of São Paulo and Rio de Janeiro and, consequently, is under high anthropic pressure, with only 7% of its forest cover remaining in its original form. The Atlantic Forest can be seen as a diverse mosaic of ecosystems, presenting different floristic structures and compositions, due to differences in soil, relief and climatic characteristics existing in the wide area where this biome occurs in Brazil; Finally, we have *v-Pampa which extension is* 176.496km², representing 2,07% of the Brazilian territory. Its name comes from the indigenous term

"flat region". This denomination, however, corresponds only to one of the types of field, most found in the south of the State of Rio Grande do Sul, reaching Uruguay and Argentina. Other types known as fields in the high mountains are found in transition areas with the araucaria domain. In other areas, there are also fields of physiognomy similar to the savannah. They are soils, in general, of low natural fertility and quite susceptible to erosion (Brasil, 2010b). The only one that is not present in this study is

2.2.3 Insect collections

Based on the fact that the moonlight influences the flight activity of insects, the insect collection process was carried out ten days before and after the new moon. The main objective of this procedure is avoiding any additional distraction and attract as many insects as possible. The moths have been collected with a Pennsylvania light trap (Frost, 1957) as a collection method, set with a black fluorescent light model BL T8 15W (Tovalight) same that Silva et al. (2017).

The collections started in July when the harvest period starts and finished in June of the next year. Therefore, in the present study we considered two Crop Seasons, from June of 2015 to July of 2016: Crop Season 1 (CS1) and from July of 2016 to June of 2017: Crop Season 2 (CS2).

The identification of insects during the sorting process, was based on the literature (Angulo & Olivares, 1997; Pogue, 2002; Specht *et al* 2014). The specimens were preserved in ethanol (96%), and representative vouchers were pinned and deposited in the Collection of Insects at Embrapa Cerrados.

2.2.4 Data Analysis

Biotemperature and evapotranspiration data were obtained from the Instituto Nacional de Meteorologia (Inmet, 2017), Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (Incaper, 2017) and Clima database of Embrapa Cerrados. The variables analyzed for this chapter were maximum and minimum temperature, relative humidity and precipitation.

The period of time considered to analyze these variables is between January, 1996 and December, 2016 (20 years). The reasons that led to consider that period, is because the last Climate Normals data available for public and provided by Inmet included information from 1960-1990 and there is a big gap of time between 1990 and 2015. Through the sorting out insects' process of two years, a total of 1872 individuals of *A. infecta* were analyzed.

Shapiro-Wilk test (Shapiro & Wilk, 1965) was applied to examine the normality of variances, whose result showed the data was not normally distributed.

Wilcoxon test (Geoffrey & Streiner, 1998) for paired samples was used in order to assess whether their population mean ranks differed between the crops depending on the analysis (collection points; vegetation type; climate; life zones and biomes). Another rank-based non-parametric test such as Kruskal-Wallis (Ostertagová *et*. al, 2014) was also used to determine if the population mean ranks was statistically significant regardless the month and crop according to the category that was analyzed. The difference between these two statistical methods is that the latter can accommodate more than two groups.

The χ^2 (Chi-Square) test measured how well the observed data (Crop 1 and Crop 2) fitted the expected data. A small χ^2 (Chi-Square) affirms a relationship between them, not rejecting the Null Hypothesis (H_0). A large χ^2 (Chi-Square) means the opposite, an

absence of relationship, accepting the Alternative Hypothesis (H_1) (Greenwood & Nikulin, 1996; Ostertagová *et*. al, 2014).

The Probability value (p-value) analysis was applied as a parameter of comparison between the tests results and the results actually observed (abundance), where a p-value < 0.05 was considered statistically significant, showing enough evidence to reject the Null Hypothesis (H_0).

Data were analyzed and graphed using the R Software ver. 3.3.1 and statistical formulas in Excel (Microsoft Office).

To analyze and edit the spatial information was also used the geographic information system Quantum GIS, ver. 2.14.8.

For Holdridge Life Zones, it was calculated the biotemperature based on the formula:

$$Bio_{t} = t - \{[(3*lat)/100] * (t-24)^2\}$$

Where Bio_t is the Biotemperature that according to Holdridge (1966, apud Nogueira et al. 1987), is the required average temperature in Celsius Degrees (ºC) for the vegetation to grow. The formula is composed by two parts, the first one consists in multiplying the latitude by factor 3 and divided by 100 and the second part consists in subtracting from temperature the factor 24 and the result squared. All of this must be subtracted from the temperature to obtain the Biotemperature of the area.

For the averaging of the Potential Evapotranspiration $\overline{ETP}$ was used the formula: $\overline{ETP} = 58.93 * Bio_t$ (Lugo *et*. al, 1999; Tatlia & Dalfes, 2016).

$\overline{ETP}$ represents the amount of water that potentially could be used by the mature vegetation at a local with climatic association. Since both temperature and evaporation are directly correlated with rainfall, if other factor is equal, the annual $\overline{ETP}$ of any place,

could be determined, multiplying the annual biotemperature by the factor 58.93. Finally, the $\overline{ETP}$ relation is determined by: $R = \overline{ETP} / \overline{P}$, where $\overline{P}$ is the annual average of precipitation.

Another Analysis implemented was the Constancy of Occurrence (Bodenheimer, 1955; Dajoz, 1972 apud Gonçalves & Braga, 2008) through the following formula: $C=[(ni/N)*100]$; Where C= Constancy of Occurrence; ni= Number of Collections, where is occurred and N= Total Number of Collections.

The Constancy of Occurrence has the following categories: accidentals ($C \leq 25\%$), accessories ($25\% \leq C \leq 50\%$) and constants ($C \geq 50\%$).

Finally, a Cluster analysis was performed, which is a multivariate classification technique that aims to group data according to their similarities. It groups a heterogeneous data set into homogeneous groups using a fixed criterion. In the present study, we chose the hierarchical method with Euclidean distance and Ward's connection to group the studied elements (Hair et al., 1998). The value of the CoPhenetic Correlation Coefficient (CPCC) was verified for the generated groupings, greater than 0.8, indicating a good quality grouping. To perform the analysis, the "cluster package" was used in the R statistical software, version 3.5.2 (R Core Team 2018).

2.3 Results

2.3.1. Wilcoxon Analysis

The results after applying the Wilcoxon test did not show significant statistical differences between the means of the non-agricultural areas regardless of the category that was analyzed. In other words, neither the Collection Point, nor Veloso & Góes Vegetation Classification, nor Köppen-Geiger Climate Classification, nor Holdridge Life Zones and nor Biomes influenced the abundance of *A. infecta* between Crop Season 1 (CS1) 2015/2016 and Crop Season 2 (CS2) 2016/2017. Multiple analyses were made to reach that conclusion, among them we can mention the comparison made between the different collection points and same ecoclimatic category compared to each other in the same Crop Season (CS1 x CS1 or CS2 x CS2); different collection points and same category grouped by the same Crop Season and compared to a different Crop Season (CS1 x CS2) and same collection point and ecoclimatic category but different Crop Season compared to other points regardless the category and Crop Season (CS1 + CS2). In all the cases, the p-value was between 0.25 and 1.00 (p-value >0.05), considered not statistically significant and indicating weak evidence against the different categories having a degree of influence over the specie ($H_{0)}$.

2.3.2. Abundance and Constancy of the Collection Points

Taking Bagé (RS) as example, we can observe that in the first Crop Season (CS1) the average of individuals in February oscillated between 5.60 and 3.78; March between 7.20 and 1.92 and April between 4.50 and 3.32. In the second Crop Season, February abundance oscillated between 0.20 and 0.45; March between 6.20 and 1.48 and April between 5.80 and 2.59 (Table 2).

In Sinop (CS1) we have a variation in July from 20.40 to 10.88; in August from 71.80 to 11.12 and in September from 9.20 to 8.11. In Crop Season 2, these numbers oscillated between 5.60 and 6.43 in July, between 0.40 and 0.55 in August and finally we don´t have a number in September (Table 2).

Concerning the Constancy of occurrence of CS1, there were 2 states out of 12 categories as Accidental (16.67%); 1 Accessory (8.33%) and 9 Constant (75%). For CS2, we have 2 states under category Accessory (16.67%), 1 Accidental (8.33%) and 9 states as Constant (75%). For both seasons (CS1 and CS2), the presence of *A. infecta* was steady (Table 2).

Regarding the Monthly Chi-Square (χ^2) which in this study analyzed two independent samples (CS1 and CS2) to determine whether the differences in the samples constituted convincing evidence, all of the collection points showed a significant difference in the abundance between the crops. In this sense, Bagé (RS), Sinop (MT) and Alegre (ES) presented the highest Chi-Square (χ^2): 92.18, 71.54 and 64.45 respectively, all of them significantly important at 0.01. Only Petrolina (χ^2: 21.19[ns]) and Uberaba (χ^2: 25.47[ns]) showed a lack of statistical significance (Table 2).

Observing the Means Colum of CS1 (2015-2016), we can firstly see that Alegre presented more collected individuals (between 4.42 and 5.02), followed by Sinop (between 10.77 and 21.54) and Bagé (between 1.98 and 2.89). In CS2 (2016-2017), we can see Domingos Martins (between 1.63 and 1.68) and Alegre (between 1.63 and 1.78) (Table 3).

The Chi-Square (χ^2:195.60) of CS1 (2015-2016) and the Chi-Square (χ^2:136.80) of CS2 (2016-2017), evidenced statistical significance showing that the abundance of the specie was determined by the collection point. On the other hand, when we analyze the same collection points in different years, we can see that the means of individuals in

Mojuí dos Campos was higher in CS2 compared to itself in CS1, the opposite happened with Alegre, which its means was higher in CS1 compared to itself in CS2. Both of these points were the only ones statistically representative over the rest when different crops where compared (Table 3).

The Dendrogram of Dissimilarity, showed 5-Sinop (MT) less distant to 12-Bagé (RS) than 6-Planaltina (DF) and 1-Mojuí dos Campos (PA). The CoPhenetic Correlation Coefficient (CPCC) was 0.73, being that a CPCC equals to 1 means the groups belong to the same cluster and 0 means they belong to different clusters. The closer to 1 the less the dissimilarity (Figure 4).

2.3.3 Abundance and Constancy according Veloso & Góes Vegetation

Under the Steppe category in CS1, we can see that the abundance in February oscillated between 5.60 and 3.78 and in March between 7.20 and 1.92. The next season (CS2), the presence of individuals in February (CS2) changed to 0.20 ± 0.45 and in March to 6.20 ± 1.48 (Table 4).

During the first season (CS1) of Savannah we can see a variation in July from 1.00 to 1.31 and in August from 0.53 to 0.74. In the next season (CS2), July varied to 0.87 ± 1.19 and August to 0.20 ± 0.41.

Concerning the Constancy of Occurrence of CS1, there was 1 vegetation category out of 6 that presented an Accidental Occurrence (16.67%) and the remaining 5 categories showed to be Constant (83.33%). For CS2, we have 1 vegetation category as Accidental (16.67%) and 5 categories as Constant (83.33%). Regardless the Crop Season and the 6 vegetation categories, *A. infecta* showed to be present in 83.33% (Table 4).

Regarding the Monthly Chi-Square (χ^2), Steppe; Savannah and Mixed Ombrophilous showed the higher Chi-Squares (χ^2): 92.19; 46.71 and 45.97 respectively,

all of them statistically significant at 0.01, highlighting the variation of individuals between the Crop Seasons. Steppical-Savannah was the only category that did not show significant statistical data (Table 4).

The most important Means of CS1 (2015-2016) corresponded to Semidecidual Seasonal Forest which individual's presence oscillated in 1.98 ± 3.53 and Steppe with an average between 1.98 and 2.89. In CS2 (2016-2017), we can see primarily Steppe (1.92 ± 2.75) and Semidecidual Seasonal Forest (1.17 ± 1.58) (Table 5).

The Chi-Square (χ^2:82.53) of CS1 (2015-2016) and the Chi-Square (χ^2:73.19) of CS2 (2016-2017), evidenced statistical significance showing that the abundance of the specie was determined by the type of vegetation. In contrast, the 24-months Chi-Square (χ^2CS) showed that none of the results was statistically significant. In other words, the abundance of this specie may not be determined or significantly influenced by the crop season in vegetation categories (Table 5).

Analyzing the Dendrogram of Dissimilarity for both Crop Seasons (CS1 and CS2), we found 6-Semidecidual Seasonal Forest less distant to 3-Steppe than 5-Savannah. The CoPhenetic Correlation Coefficient (CPCC) was 0.90, highly close to 1, which means that both categories (3 and 6) could be close enough and sometimes belong to the same cluster (Figure 5).

2.3.4. Abundance and Constancy according to Köppen-Geiger Climate Classification

The first 3 months of Crop Season 1 in Tropical Savannah (Aw) leaded the number of individuals collected during that year, presenting the following oscillations: from 7.80 to 10.96 in July; from 24.40 to 35.21 in August and from 3.53 to 6.08 in September. In Crop Season 2, these oscillations varied from 2.47 to 4.19 in July; from 0.20 to 0.41 in August and finally from 0.07 to 0.26 in September. The other month that stressed by the

number of individuals and under the same category was May (CS2) which abundance varied between 1.86 and 1.46 (Table 6).

Another category to be considered is Humid Subtropical (Cfa), whose months of March and April showed the following variations in the first Season (CS1): 3.00 ± 3.48; and 2.21 ± 2.46; respectively (Table 6).

Observing the Constancy of Occurrence in both seasons (CS1 and CS2), we found 5 climate categories out of 6 as Constant (83.33%) and 1 category as Accidental (16.67%). Indicating a probability of Occurrence of the specie in 83.33% (Table 6).

The Monthly Chi-Square (χ^2) was significant only for two vegetation categories: Tropical Savannah (Aw) with 91.44 and Humid Subtropical (Cfa) with 69.73, both of them statistically significant at 0.01, validating the existing variation of abundance between the Crops (Table 6).

Among the Means of CS1 (2015-2016) that stand out, we find Monsoon Climate (Am) which abundance oscillated from 1.93 to 3.57; Humid Subtropical (Cfa) with a variation between 1.08 and 2.05 and Tropical Savannah (Aw) varying between 3.62 and 12.83. In CS2 (2016-2017), we can see Monsoon Climate (Am) (1.21 ± 1.64); Humid Subtropical (Cfa) (0.94 ± 1.87) and Tropical Savannah (Aw) (1.30 ± 5.40) (Table 7).

The Chi-Square (χ^2:60.60) of CS1 (2015-2016) and the Chi-Square (χ^2:56.88) of CS2 (2016-2017), evidenced statistical significance showing that the abundance of the specie was determined by the type of climate. In contrast, the 24-months Chi-Square (χ^2CS) showed that none of the results was statistically significant. As in the case of Veloso & Góes Classification, the abundance of this specie may not be determined or significantly influenced by the crop season in each Köppen-Geiger Climate classification (Table 7).

Analyzing the biennial Dendrogram of Dissimilarity (CS1 and CS2), we found that 5-Humid Subtropical (Cfa) is less distant to 2-Monsoon Climate than 1- Equatorial Climate (Af). The CoPhenetic Correlation Coefficient (CPCC) was 0.81, relatively close to 1, showing in this way that the groups (2 and 5) are close to each other (Figure 6).

2.3.5. Abundance and Constancy according to Holdridge Life Zones

In Crop Season 1, the Warm Temperate Lower-Montane Moist Forest Transition to Wet Forest (WTL-mfΔ) life zone showed a significant presence of the specie in the months of February (5.60 ± 3.78), March (7.20 ± 1.92) and April (4.50 ± 3.32), being March the most important. In Crop Season 2 (CS2), we can observe a decrease in February (0.20 ± 0.45) and March (6.20 ± 1.48) and an increase in April (5.80 ± 2.59) (Table 8).

Tropical Dry Forest (T-df) also showed a significant number of individuals in January (12.00 ± 5.05) and March (9.80 ± 10.57) of Crop Season 1. In Crop Season 2, those months showed a significant decrease, oscillating from 2.20 and 1.92 in January and from 1.80 and 1.30 in March (Table 8).

In CS1, we can see 2 life zones categories out of 7 considered Accidental (28.57%) and 5 categories as Constant (71.43%). For CS2, we have 1 category out of 7 as Accessory (14.29%), 1 as an Accidental (14.29%) and the remaining 5 as Constant (71.43%) (Table 8).

Four Life Zones categories were statistically significant at 0.01 and 1 significant at 0.05. Only Tropical Moist Forest (T-mf) (χ^2: 34.83^{ns}) and Tropical Thorn Woodland Transition to Very Dry Forest (T- twΔ) (χ^2: 34.83^{ns}) were not significant (Table 8).

Among the most representative means of CS1 (2015-2016) are Tropical Dry Forest (T-df) (4.42 ± 5.02); Warm Temperate Lower-montane Moist Forest Transition to Wet

Forest (WTL-mfΔ) (1.98 ± 2.89) and Boreal Subalpine Rain Forest (BS-rf) (1.09 ± 1.61). In CS2 (2016-2017), we can see Boreal Subalpine Rain Forest (BS-rf) (1.15 ± 1.48); Tropical Dry Forest (T-df) (1.63 ± 1.7) and Warm Temperate Lower-montane Moist Forest Transition to Wet Forest (WTL-mfΔ) (1.92 ± 2.75) (Table 9).

The Chi-Square (χ^2:154.85) of CS1 (2015-2016) and the Chi-Square (χ^2:103.18) of CS2 (2016-2017), show their statistical significance, indicating that the abundance of the *A. infecta* was determined by the life zone. By contrast, when we analyze the same life zones in different years, we can see that the average of individuals in Tropical Dry Forest (T-df) was higher in CS1 compared to itself in CS2. The same happened with Tropical Dry Forest Transition to Moist Forest (T-dfΔ), its average was higher in CS2 when compared to itself in CS1(Table 9).

Analyzing the Dendrogram of Dissimilarity (CS1 and CS2), we found that 3-Tropical Dry Forest (T-df) is less distant to 7- Warm Temperate Lower-montane Moist Forest Transition to Wet Forest (WTL-mfΔ) than 4- Tropical Dry Forest Transition to Moist Forest (T-dfΔ). The CoPhenetic Correlation Coefficient (CPCC) was 0.93, highly close to 1, inferring that both categories (3 and 7) could eventually belong to the same cluster (Figure 7).

2.3.6 Abundance and Constancy according to Biomes Categories

In Crop Season 1, Pampa Biome showed a significant presence of the specie in February (5.60 ± 3.78; subscript: ab), March (7.20 ± 1.92) and April (4.50 ± 3.32), being March the most important. In Crop Season 2 (CS2), we can observe a decrease in February (0.20 ± 0.45), March (6.20 ± 1.48) and April (5.80 ± 2.59). Cerrado Biome also showed a significant number of individuals in July of CS1 (1.19 ± 1.47) and August (0.53

± 0.74). In Crop Season 2, those months showed a decrease in July from 0.87 to 1.19 and in August from 0.20 to 0.41 (Table 10).

In CS1, 1 Biome out of 5 was Accidental (20%) and the remaining 4 biomes were Constant (80%). The same situation repeated in CS2, we found 1 category out of 5 as Accidental (20%) and 4 as Constant (80%). In both cases the presence of the specie was confirmed in 80% (Table 10).

The monthly Chi-Square (χ^2) shows that 2 biomes categories (Amazone χ^2:41.21 and Atlantic Forest χ^2:41.74) were statistically significant at 0.05; Cerrado (χ^2:49.04) and Pampa (χ^2:92.19) were significant at 0.01 and only Caatinga (χ^2:21.19[ns]) was not significant (Table 10).

In CS1 (2015-2016) the average of individuals for Pampa biome oscillated between 1.98 and 2.89 followed by the Atlantic Forest biome which average varied between 1.72 and 3.19. In CS2 (2016-2017), we can see that Pampa oscillated between 1.92 and 2.75 and Atlantic Forest varied from 1.05 to 1.48 (Table 11).

The Chi-Square (χ^2:76.41) of CS1 (2015-2016) and the Chi-Square (χ^2:67.89) of CS2 (2016-2017) evidenced statistical significance showing that the abundance of the specie was determined by the type of biome. By contrast, when we analyze the same collection points in different years, it´s not possible to find a stressed point indicating that the crop season did not influence the populational variation in each biome (See χ^2CS Colum in Table 9), therefore, we can (Table 11).

In the Dendrogram of Dissimilarity (CS1 and CS2), we found that 2- Atlantic Forest (T-df) is less distant to 5- Pampa than 3- Caatinga or 4- Cerrado. The CoPhenetic Correlation Coefficient (CPCC) was 0.89, relatively close to 1, concluding that both categories (2 and 5) are close to each other and could eventually belong to the same cluster (Figure 8).

2.3.7 Abundance of Crop Seasons 1 and 2

When we compare the abundance between Crop Season 1 (Figure 3a) and Crop Season 2 (Figure 3b), we can see a slightly difference. The collection points that experienced a significant change were: 1- Mojuí dos Campos (PA); 4 - Porto Nacional (TO); 8- Domingos Martins (ES); 9- Alegre (ES). Esta semelhança da abundância de *A. infecta* entre as safras em cada ponto de coleta determinou que a maioria das análises incluindo agrupamentos ecoclimáticos não encontrou diferenças significativas entre safras (Tables 3, 5, 7, 9, 11). Esta semelhança entre as safras motivou que as análises de dissimilaridade (dendogramas) fossem elaboradas incluindo os dados das duas safras.

2.4 Discussion

Analyzing only the Collections Points, we can say that Mojuí dos Campos (Pará) and Alegre (Espirito Santo) showed a significant p-value ($p < 0.05$) when we compared their annually abundance. The vegetation category for Mojuí dos Campos (Pará) was Dense Ombrophilous Forest and for Alegre (Espirito Santo) was Semidecidual Seasonal Forest and their life zones were Tropical Dry Forest Transition to Moist Forest (T-df Δ) and Tropical Dry Forest(T-df) respectively.

Regarding to the Constancy of *A. infecta* according to the collection points and four ecoclimatic categories (Veloso & Góes Vegetation; Köppen-Geiger Climate; Holdridge Life Zones and Biomes), it was found that in Crop Season 1 (CS1), its presence as Constant oscillated between 70.43% and 83.33%; as Accidental between 16.57% and 28.57% and as Accessory only 8.33%. In the second Crop Season, the specie was Constant between 71.43% and 83.33%; Accessory from 14.28% to 16.67% and Accidental varying from 8.33% to 20%. We can conclude that the specie was primarily Constant and secondarily could be either Accidental or Accessory. The fact that *A. infecta*

was constant in most places (and consequently in the ecoclimatic categories) during the two harvests indicates that this owlet moth finds favorable conditions for its development despite the ecoclimatic differences between all the places where it was sampled. This constancy is also related to the great biological plasticity of *A. infecta*, whose caterpillars are polyphagous, and therefore can feed on plants present in different locations (e.g. Crumb 1956, Teston et al. 2001, Angulo et al. 2008) in addition, the ability to disperse and fertility reported in previous studies stands out (Lafontaine 2004, Wagner et al. 2011).

Associated with specific constancy, with specimens collected in at least 50% of the sampled months, the significant population variations of *A. infecta* (Tables 2, 4, 6, 8, 10) reflects different responses to varied biotic and abiotic conditions on its development in most places. These associated results reflect the interactions between variations in local climatic factors, including all components related to ecoclimatic categories. These results associated with the previous study (Fonseca-Medrano et al. 2019) demonstrate that despite being a resilient species, with wide distribution and great reproductive capacity (Angulo & Olivares 1997, Teston et al. 2001, Lafontaine 2004), *A. infecta* like other owlet moths, it can be considered a good environmental indicator due to its great capacity to respond to climatic variations and ecological factors (Wagner et al. 2011).

The vegetation plays a fundamental roll for being a key component of any ecosystem and, as such, is involved in the regulation of various biogeochemical cycles, e.g., water, carbon, nitrogen (Baldwin *et al.* 2019) we can see that the results of vegetation (Table 5) and its relation with Climate, Life-Zones and Biomes explain the significant differences between ecoclimatic categories (Tables 7, 9, 11) (Heppner, 1991). This explains the different similarities between the population variations of *A. infecta* when comparing different ecoclimatic categories, which in a way overlap. On the other hand, the results indicated a greater association between the monthly number of moths captured

with the type of vegetation and life zones (Cophenetic Correlation Coefficient greater than = 0.9), showing the property of prioritizing the parameters of these classifications in studies of monitoring of this species. As this study focused only on the collection of adults, it was not possible to establish more precise links related to the occurrence of *A. infecta* and its preferred host plants (which still need to be defined) and its availability in time space. Anyway, this is the first study that spatially and temporally quantifies the distribution of *A. infecta* in a vast area such as Brazil.

Because of *A. infecta* as an insect being poikilothermic and vulnerable to desiccation (Child, 2007) explain the significative differences of populational abundance levels found between the months (Tables 2, 4, 6, 8 10). Despite of this population variations, it should be highlighted that *A. infecta* was present at all collection points along the year. These results relate to the fact that this specie shows a high biological plasticity that includes larval polyphagy; wide tolerance to different temperatures and variations; great dispersion capacity and high reproductive potential (Teston *et al*. 2001, Fonseca-Medrano *et al*. 2019). Survival and thriving at extreme physical conditions require peculiar adaptations and plastic responses and that is the case of *A. infecta* whose ideal ranges for its development oscillate between 10ºC to 34ºC and from weekly precipitation of 0 to 50mm³ (Fonseca-Medrano *et al*. 2019), what indicates its tendency to achieve higher peaks of abundance in drier environments than in humid ones.

Regarding to the number of *A. infecta*´s individuals collected in each growing season, we can say that this number did not vary significantly in the majority of the locations (CS1-2015/2016 and CS2-2016/2017) and it was much like to the result of Planaltina-DF already published in the same growing seasons (Fonseca-Medrano *et al*. 2019). This could indicate that despite the population varied significantly in previous growing seasons (2013/2014, 2014/2015, 2015/2016, 2016/2017) the ecoclimatic

conditions in both crops (2015/2016, 2016/2017) during the present study, continued similar for all the collection points. This observation, associated with the relationship established between the influence of climatic factors and El Niño on the population variations of *A. infecta* (Fonseca-Medrano et al. 2019) and other owlet moths under the same conditions (Santos et al. 2017, Piovesan et al 2018a, 2018b) demonstrates the need for long-term studies to increase the accuracy of the parameters to be used in modeling and forecasting population outbreaks.

To ensure the future of food demand, it´s necessary to continue carrying out entomological studies that provide information for the Integrated Pest Management (IPM) and in turn, increase yields on existing lands while protecting biodiversity and looking after the environment.

Author contributions

AS and MF-M - conceived and designed the study; AS - carried out field collection and laboratory experiments; AS and M F-M wrote the manuscript with input from all authors. JVM and M F-M performed the statistical analysis; all authors discussed the results and contributed to the final manuscript.

Conflicts of interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

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CONCLUSÕES GERAIS DA TESE

Capítulo 1

No primeiro estudo demonstrou-se que apesar das lagartas das três espécies (*A. infecta*, *E. agrotina* e *S. frugiperda*) apresentarem hábitos alimentares diferenciados, apresentaram variações populacionais similares quando expostas as mesmas condições climáticas e Índice Oceânico El Niño (ONI). Por outro lado, os efeitos dos valores médios de fatores climáticos mensais como temperatura mínima e precipitação, variaram de acordo com as espécies de mariposas.

A influência significativa de fatores meteorológicos e ONI sobre as variações populacionais de *A. infecta, E. agrotina* e *S. frugiperda* indica a possibilidade de sua utilização para fazer previsões úteis para o manejo de pragas.

Capítulo 2

O segundo estudo demonstrou que *A. infecta* encontra condições de se desenvolver em todos os locais amostrados no Brasil, independentemente do tipo de vegetação, clima, zona de vida ou bioma. Além disso, a presença de suas mariposas foi constante (coletada em mais de 50% dos meses) ao longo das safras.

Por outro lado, excetuando Petrolina – PE, que tem clima semi estépico, as médias de suas populações variaram significativamente entre meses.

Também demonstrou-se haver uma associação mais significativa (índice de correlação cofenética igual ou superior a 0,9) entre as variações populacionais mensais de mariposas de *A. infecta* com o tipo de vegetação e as zonas de vida.

Table 1. Collection Points (#) and respective: Brazilian states, municipalities, latitude, longitude, Veloso & Góes vegetation, Köppen-Geiger climate, Holdridge Life Zones, Biomes, Monthly average of temperature (°C) and precipitation (mm^3/m^2), and altitude meters.

#	State	Municipality	Latitude	Longitude	Veloso & Góes (a)	Köppen-Geiger (b)	Holdridge Life Zones (c)	Biomes (d)	Monthly Average Temperature (e)	Monthly Average Precipitation (f)	Altitude (g)
1	PA	Mojuí dos Campos	-2.6977	-54.5689	Dense Ombrophilous Forest[i]	Am[i]	T-df Δ[i]	Amazon[i]	16,7-30	55-149	114
2	PE	Petrolina	-9.1373	-40.3021	Steppical-Savannah [ii]	BSh[ii]	T-tw Δ[ii]	Caatinga[ii]	22,7-33,4	2-95	365.5
3	AC	Rio Branco	-10.0328	-67.7035	Dense Ombrophilous Forest[i]	Af[iii]	T-mf[iii]	Amazon[i]	21,8-32,4	89-379	183
4	TO	Porto Nacional	-10.1366	-48.3208	Savannah[iii]	Aw[iv]	SP-mf[iv]	Cerrado[iii]	12,5-27,9	7-284	270
5	MT	Sinop	-11.8671	-55.6006	Dense Ombrophilous Forest[i]	Aw[iv]	SP-mf[iv]	Amazon[i]	12,5-27,9	7-284	362
6	DF	Planaltina	-15.6068	-47.7451	Savannah[iii]	Aw[iv]	SP-mf[iv]	Cerrado[iii]	12,5-27,9	7-284	1169
7	MG	Uberaba	-19.6625	-47.9609	Savannah[iii]	Cwb[v]	SP-mf[iv]	Cerrado[iii]	10,7-27,7	9-347	784
8	ES	Domingos Martins	-20.3715	-41.0633	Semidecidual Seasonal Forest[iv]	Am[i]	BS-rf[v]	Atlantic Forest[iv]	16,7-30	55-148	542
9	ES	Alegre	-20.7532	-41.0633	Semidecidual Seasonal Forest[iv]	Am[i]	T-df[vi]	Atlantic Forest[iv]	16,7-30	55-149	277
10	PR	Londrina	-23.1897	-51.1719	Semidecidual Seasonal Forest[iv]	Cfa[vi]	SP-mf[iv]	Atlantic Forest[iv]	10,3-29,6	101-137	545
11	RS	Passo Fundo	-28.2436	-52.4047	Mixed Ombrophilous Forest[v]	Cfa[vi]	BS-rf[v]	Atlantic Forest[iv]	10,3-29,6	101-137	671
12	RS	Bagé	-31.3514	-54.0201	Steppe[vi]	Cfa[vi]	WTL-mf Δ[vii]	Pampa[v]	10,3-29,6	101-137	232

Table 2 - Monthly abundance of *Anicla infecta* (means of five samples) in 12 Brazilian localities in crop seasons (CS): 1 - 2015-2016 and 2 - 2016-2017. The 24-monthly means (χ^2 months) were compared by Kruskal Wallis test (P<0.05)

CS	X² months	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Constancy
	37.92**						1-Mojuí dos Campos - PA							
1		0.00 ± 0.00 c	0.20 ± 0.45 bc	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.50 ± 1.00 abc	0.00 ± 0.00 c	0.25 ± 0.50 abc	Accidental
2		0.00 ± 0.00 c	0.20 ± 0.45 bc	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.20 ± 0.45 bc	0.00 ± 0.00 c	0.20 ± 0.45 bc	1.00 ± 1.41 ab	1.60 ± 2.51 a	1.00 ± 1.00 a	Accessory
	21.19ns						2-Petrolina - PE							
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	Accidental
2		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	Accidental
	34.83**						3-Rio Branco - AC							
1		0.00 ± 0.00 d	0.00 ± 0.00 d	0.00 ± 0.00 d	0.00 ± 0.00 d	0.20 ± 0.45 cd	0.40 ± 0.55 abcd	1.00 ± 1.00 abc	2.00 ± 2.00 ab	0.80 ± 1.79 bcd	0.40 ± 0.55 abcd	0.80 ± 1.30 abcd	0.40 ± 0.55 abcd	Constant
2		0.80 ± 0.84 abc	0.80 ± 0.45 abc	0.40 ± 0.55 abcd	0.20 ± 0.45 cd	0.40 ± 0.89 bcd	0.20 ± 0.45 cd	0.00 ± 0.00 d	0.40 ± 0.55 abcd	0.00 ± 0.00 d	0.50 ± 1.00 bcd	2.00 ± 1.58 a	0.40 ± 0.55 abcd	Constant
	57.44**						4-Porto Nacional - TO							
1		1.80 ± 1.64 ab	0.80 ± 0.84 b	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.20 ± 0.45 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.20 ± 0.45 c	0.20 ± 0.45 c	Accessory
2		1.60 ± 0.55 a	0.20 ± 0.45 c	0.20 ± 0.45 c	-----	0.20 ± 0.45 c	0.00 ± 0.00 c	0.20 ± 0.45 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.20 ± 0.45 c	1.40 ± 1.52 ab	0.00 ± 0.00 c	Constant
	71.54**						5-Sinop - MT							
1		20.40 ± 10.88 ab	71.80 ± 11.12 a	9.20 ± 8.11 abc	0.80 ± 0.84 efghij	0.60 ± 0.89 ghij	0.80 ± 1.10 fghij	0.00 ± 0.00 j	0.20 ± 0.45 ij	0.00 ± 0.00 j	0.00 ± 0.00 j	1.50 ± 1.29 defgh	15.33 ± 4.04 abc	Constant
2		5.60 ± 6.43 cdef	0.40 ± 0.55 ghij	0.00 ± 0.00 j	1.20 ± 1.30 efghi	4.00 ± 4.00 cdefg	0.80 ± 0.84 efghij	0.20 ± 0.45 ij	1.20 ± 1.30 efghi	0.25 ± 0.50 hij	0.00 ± 0.00 j	2.00 ± 1.15 bcde	26.00 ± 25.31 abcd	Constant
	36.83**						6-Planaltina- DF							
1		1.20 ± 1.10 abc	0.60 ± 0.89 bcde	1.40 ± 1.52 ab	0.60 ± 0.89 bcde	0.40 ± 0.89 cde	0.40 ± 0.55 bcde	1.00 ± 1.00 abcd	0.00 ± 0.00 e	0.00 ± 0.00 e	0.80 ± 1.30 bcde	0.40 ± 0.55 bcde	0.20 ± 0.45 de	Constant
2		0.20 ± 0.45 de	0.00 ± 0.00 e	0.00 ± 0.00 e	0.20 ± 0.45 de	0.20 ± 0.45 de	0.60 ± 0.89 bcde	0.20 ± 0.45 de	0.20 ± 0.45 de	0.20 ± 0.45 de	0.40 ± 0.55 bcde	2.20 ± 1.79 a	1.40 ± 2.61 bcde	Constant
	25.47ns						7-Uberaba - MG							
1		0.00 ± 0.00	0.20 ± 0.45	0.00 ± 0.00	0.2 ± 0.45	0.20 ± 0.45	0.20 ± 0.45	0.20 ± 0.45	1.00 ± 2.24	0.00 ± 0.00	0.00 ± 0.00	0.40 ± 0.55	0.60 ± 1.34	Constant
2		0.40 ± 0.89	0.40 ± 0.55	0.20 ± 0.45	0.20 ± 0.45	0.20 ± 0.45	0.80 ± 1.79	0.20 ± 0.45	0.40 ± 0.89	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.20 ± 0.84	Constant
	39.39**						8-Domingos Martins - ES							
1		0.40 ± 0.89 de	0.80 ± 1.30 cde	1.00 ± 1.41 bcde	1.40 ± 1.52 bcde	0.40 ± 0.89 de	0.20 ± 0.45 e	0.20 ± 0.45 e	1.60 ± 2.61 bcde	3.20 ± 2.39 ab	1.60 ± 1.52 abcde	2.00 ± 1.41 abc	1.60 ± 1.14 abcd	constant
2		0.60 ± 0.89 cde	0.60 ± 0.89 cde	0.80 ± 0.84 bcde	1.80 ± 0.84 abc	1.60 ± 1.52 abcde	1.60 ± 1.94 bcde	3.60 ± 1.34 a	2.80 ± 2.68 abc	1.20 ± 0.45 abcde	2.60 ± 2.30 abc	2.00 ± 2.00 abcd	0.40 ± 0.55 de	Constant
	64.45**						9-Alegre - ES							
1		4.80 ± 1.92 cdefgh	2.20 ± 1.10 cdefgh	5.20 ± 4.55 bcdef	5.20 ± 3.27 abcd	1.40 ± 2.19 ghij	2.00 ± 1.58 defgh	12.00 ± 5.05 a	3.60 ± 3.28 bcdefg	9.80 ± 10.57 ab	1.60 ± 1.14 fghij	4.80 ± 3.56 abcde	0.40 ± 0.89 ij	Constant
2		2.60 ± 2.30 cdefgh	0.20 ± 0.45 j	1.20 ± 1.30 ghij	1.00 ± 1.22 hij	1.20 ± 0.84 fghij	4.80 ± 2.05 abc	2.20 ± 1.92 defgh	2.20 ± 1.48 cdefgh	1.80 ± 1.30 efghi	0.20 ± 0.45 j	1.40 ± 1.52 fghij	0.80 ± 1.30 hij	Constant
	44.51**						10-Londrina - PR							
1		0.00 ± 0.00 d	0.40 ± 0.55 bcd	0.40 ± 0.89 cd	0.00 ± 0.00 d	0.40 ± 0.55 bcd	0.00 ± 0.00 d	0.20 ± 0.45 cd	0.00 ± 0.00 d	0.00 ± 0.00 d	1.00 ± 0.71 ab	1.00 ± 1.41 abc	0.40 ± 0.55 bcd	Constant
2		0.00 ± 0.00 d	0.00 ± 0.00 d	0.00 ± 0.00 d	1.40 ± 0.89 a	0.20 ± 0.45 cd	0.20 ± 0.45 cd	0.00 ± 0.00 d	0.00 ± 0.00 d	0.40 ± 0.55 bcd	0.60 ± 0.89 bcd	0.00 ± 0.00 d	0.20 ± 0.45 cd	Accessory
	45.97**						11-Passo Fundo - RS							
1		1.60 ± 1.82 abc	0.00 ± 0.00 d	1.00 ± 1.00 abc	0.20 ± 0.45 cd	0.20 ± 0.45 cd	0.20 ± 0.45 cd	0.40 ± 0.89 cd	0.00 ± 0.00 d	1.80 ± 1.92 ab	4.20 ± 2.95 a	1.60 ± 1.14 ab	0.60 ± 0.89 bcd	Constant
2		0.80 ± 0.84 abcd	0.40 ± 0.89 cd	2.25 ± 2.06 ab	0.80 ± 0.84 abcd	0.40 ± 0.55 bcd	0.40 ± 0.89 cd	0.00 ± 0.00 d	0.60 ± 0.89 bcd	1.60 ± 1.14 ab	1.00 ± 1.22 abc	0.00 ± 0.00 d	0.00 ± 0.00 d	Constant
	92.18**						12-Bagé - RS							
1		0.20 ± 0.45 f	0.20 ± 0.45 f	0.00 ± 0.00 f	0.40 ± 0.55 ef	0.00 ± 0.00 f	3.00 ± 1.58 bc	0.80 ± 1.30 ef	5.60 ± 3.78 ab	7.20 ± 1.92 a	4.50 ± 3.32 abc	2.33 ± 1.53 bcd	0.20 ± 0.45 f	Constant
2		0.40 ± 0.55 ef	0.80 ± 1.30 ef	0.20 ± 0.45 f	0.00 ± 0.00 f	0.00 ± 0.00 f	1.60 ± 0.55 cd	0.40 ± 0.55 ef	0.20 ± 0.45 f	6.20 ± 1.48 ab	5.80 ± 2.59 ab	6.40 ± 2.61 ab	1.00 ± 1.00 de	Constant

Significance: ns - non significant; * - significant at 0.05 and ** - significant at 0.01

Table 3 - Monthly abundance of *Anicla infecta* (means) in **12 Brazilian localities** compared in two crop seasons (columns - small letters) and the two crop seasons (CS) in each locality (χ^2 CS - lines – capital letters) by Kruskal Wallis test (P<0.05)

Localities\Crop seasons	2015-2016 (χ2 195.60**)		2016-2017 (χ2 136.80**)		χ^2 CS
	Means	**Rank**	**Means**	**Rank**	
1-Mojuí dos Campos	0.07 ± 0.32 h **B**	249.76	0.33 ± 0.96 fg **A**	285.89	4.15*
2-Petrolina	0.00 ± 0.00 h	234.00	0.03 ± 0.18 g	237.53	1.98ns
3-Rio Branco	0.50 ± 1.03 efg	319.48	0.51 ± 0.84 ef	341.81	0.68ns
4-Porto Nacional	0.27 ± 0.74 gh	286.07	0.36 ± 0.75 ef	305.82	0.81ns
5-Sinop	10.77 ± 21.54 b	451.56	3.13 ± 9.18 cd	403.45	2.74ns
6-Planaltina	0.58 ± 0.91 def	351.51	0.48 ± 1.11 ef	319.08	1.49ns
7-Uberaba	0.23 ± 0.79 gh	275.06	0.33 ± 0.75 f	298.98	1.48ns
8-Domingos Martins	1.20 ± 1.58 bcd	402.87	1.63 ± 1.68 a	488.52	3.40ns
9-Alegre	4.42 ± 5.02 a **A**	555.63	1.63 ± 1.78 ab **B**	472.06	14.85**
10-Londrina	0.31 ± 0.62 fg	303.78	0.25 ± 0.57 fg	286.82	0.41ns
11-Passo Fundo	0.98 ± 1.65 cde	370.04	0.66 ± 1.04 de	355.97	0.37ns
12-Bagé	1.98 ± 2.89 bc	420.52	1.92 ± 2.75 bc	428.27	0.01ns

Significance: ns – non significant; * significant at 0.05 and ** significant at 0.01.

Table 4 - Monthly abundance of *Anicla infecta* (means of five samples) according to **Veloso & Góes Vegetation Classification** in crop seasons (CS): 1 - 2015-2016 and 2 - 2016-2017. The 24-monthly means ($\chi2$ months) were compared by Kruskal Wallis test (P<0.05).

CS	X² months	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Constancy
	21.19ns						Steppical-Savannah							
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	Accidental
2		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	Accidental
	41.21**						Dense Ombrophilous							
1		6.80 ± 11.53 bcd	24.00 ± 35.49 abc	3.0 ± 6.24 bcd	0.2 ± 0.59 cd	0.27 ± 0.59 cd	0.40 ± 0.74 cd	0.33 ± 0.72 cd	0.73 ± 1.44 bcd	0.36 ± 1.21 d	0.31 ± 0.63 cd	0.71 ± 1.14 bcd	4.08 ± 7.01 abc	Constant
2		2.13 ± 4.31 abc	0.47 ± 0.52 bcd	0.13 ± 0.35 d	0.47 ± 0.92 cd	1.08 ± 2.40 bcd	0.33 ± 0.62 cd	0.13 ± 0.35 d	0.53 ± 0.92 bcd	0.14 ± 1 0.36 d	0.50 ± 1.02 cd	1.86 ± 1.75 a	9.08 ± 18.20 ab	Constant
	92.19**						Steppe							
1		0.20 ± 0.45 f	0.20 ± 0.45 f	0.00 ± 0.00 f	0.40 ± 0.55 ef	0.00 ± 0.00 f	3.00 ± 1.58 bc	0.80 ± 1.30 ef	5.60 ± 3.78 ab	7.20 ± 1.92 a	4.50 ± 3.32 ab	2.33 ± 1.53 bcd	0.20 ± 0.45 f	Constant
2		0.40 ± 0.55 ef	0.80 ± 1.30 ef	0.20 ± 0.45 f	0.00 ± 0.00 f	0.00 ± 0.00 f	1.60 ± 0.55 cd	0.40 ± 0.55 ef	0.20 ± 0.45 f	6.20 ± 1.48 ab	5.80 ± 2.59 ab	6.40 ± 2.61 ab	1.00 ± 1.00 de	Constant
	45.97**						Mixed Ombrophilous							
1		0.20 ± 0.45 cd	0.00 ± 0.00 d	0.60 ± 0.89 bcd	1.60 ± 1.14 ab	4.20 ± 2.95 a	1.00 ± 1.00 abc	0.20 ± 0.45 cd	0.20 ± 0.45 cd	1.80 ± 1.92 ab	1.60 ± 1.82 abc	0.00 ± 0.00 d	0.40 ± 0.89 cd	Constant
2		0.40 ± 0.89 cd	0.40 ± 0.89 cd	0.00 ± 0.00 d	0.00 ± 0.00 d	1.00 ± 1.22 abc	2.25 ± 2.06 ab	0.40 ± 0.55 bcd	0.80 ± 0.84 abcd	1.60 ± 1.14 ab	0.80 ± 0.84 abcd	0.60 ± 0.89 bcd	0.00 ± 0.00 d	Constant
	46.71**						Savannah							
1		1.00 ± 1.31 ab	0.53 ± 0.74 abcd	0.67 ± 1.23 bcde	0.33 ± 0.62 cdef	0.13 ± 0.52 ef	0.20 ± 0.41 def	0.40 ± 0.74 cdef	0.07 ± 0.26 ef	0.00 ± 0.00 f	0.27 ± 0.80 def	0.53 ± 1.30 cdef	0.20 ± 0.41 def	Constant
2		0.87 ± 1.19 abc	0.20 ± 0.41 def	0.47 ± 0.74 bcde	0.10 ± 0.32 def	0.13 ± 0.35 def	0.27 ± 0.59 cdef	0.20 ± 0.41 def	0.13 ± 0.35 def	0.07 ± 0.26 ef	0.33 ± 0.62 cdef	1.33 ± 1.54 a	0.53 ± 1.55 cdef	Constant
	35.25*						Semidecidual Seasonal Forest							
1		1.73 ± 2.52 bcdefg	1.13 ± 1.25 abcdef	2.20 ± 3.41 abcdef	2.20 ± 2.98 abcdef	0.73 ± 1.389 efg	0.73 ± 1.28 defg	4.13 ± 6.37 abcdef	1.73 ± 2.71 bcdefg	4.33 ± 7.17 ab	1.40 ± 1.12 abcd	2.71 ± 2.78 a	0.80 ± 1.01 bcdefg	Constant
2		1.07 ± 1.75 bcdefg	0.27 ± 0.59 g	0.6 ± 0.98 cdefg	1.40 ± 0.99 abc	1.00 ± 1.13 bcdefg	2.20 ± 2.51 abc	1.93 ± 1.98 abcde	1.67 ± 2.06 abcdef	1.13 ± 0.99 abcdef	1.13 ± 1.73 bcdefg	1.13 ± 1.60 bcdefg	0.47 ± 0.83 fg	Constant

Significance: ns - non significant; * - significant at 0.05 and ** - significant at 0.01.

Table 5 - Monthly abundance of *Anicla infecta* (means) according to **Veloso & Góes Vegetation Classification** compared in two crop seasons (columns - small letters) and the two crop seasons (CS) in each vegetation (χ^2 CS - lines) by Kruskal Wallis test (P<0.05)

Vegetation\Crop seasons	2015-2016 (χ2 82.53**)		2016-2017 (73.19**)		χ² CS
	Means	**Rank**	**Means**	**Rank**	
Steppical-Savannah	0.00 ± 0.00 e	234.00	0.03 ± 0.18 c	237.53	1.98ns
Dense Ombrop.	3.56 ± 12.92 cd	337.28	1.28 ± 5.36 b	342.67	0.37ns
Steppe	1.98 ± 2.89 ab	420.52	1.92 ± 2.75 a	428.27	0.01ns
Mixed Ombrop.	0.98 ± 1.65 bc	370.04	0.66 ± 1.04 b	355.97	0.37ns
Savannah	0.36 ± 0.83 d	304.31	0.39 ± 0.89 b	308.01	0.13ns
Sem.Seas. Forest	1.98 ± 3.53 a	421.41	1.17 ± 1.58 a	415.80	1.25ns

Significance: ns – non significant; * significant at 0.05 and ** significant at 0.01.

Table 6 - Monthly abundance of *Anicla infecta* (means of five samples) according to **Köppen-Geiger Climate Classification** in 2 crop seasons (CS): 1 - 2015-2016 and 2 - 2016-2017. The 24-monthly means ($\chi 2$ months) were compared by Kruskal Wallis test (P<0.05).

CS	X^2 months	Months (July to June)												Constancy
		Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	
	34.83ns	AF (Equatorial Climate-Trop.Rain Forest)												
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.40 ± 0.55	1.00 ± 1.00	2.00 ± 2.00	0.80 ± 1.79	0.40 ± 0.55	0.80 ± 1.30	0.40 ± 0.55	Constant
2		0.80 ± 0.84	0.80 ± 0.45	0.40 ± 0.55	0.20 ± 0.45	0.40 ± 0.89	0.20 ± 0.45	0.00 ± 0.00	0.40 ± 0.55	0.00 ± 0.00	0.50 ± 1.00	2.00 ± 1.58	0.40 ± 0.55	Constant
	27.01ns	Am (Monsoon)												
1		1.73 ± 2.52	1.07 ± 1.28	2.07 ± 3.45	2.20 ± 2.98	0.60 ± 1.40	0.73 ± 1.28	4.07 ± 6.41	1.73 ± 2.71	4.64 ± 7.33	1.29 ± 1.27	2.27 ± 2.89	0.79 ± 1.05	Constant
2		1.07 ± 1.75	0.33 ± 0.62	0.67 ± 0.98	0.93 ± 1.10	0.93 ± 1.16	2.13 ± 2.56	2.00 ± 1.93	1.67 ± 2.06	1.07 ± 1.03	1.27 ± 1.79	1.67 ± 1.91	0.69 ± 0.95	Constant
	91.44**	Aw (Tropical Savannah)												
1		7.80 ± 10.96 a	24.40 ± 35.21 a	3.53 ± 6.08 ab	0.47 ± 0.74 cde	0.33 ± 0.72 cde	0.47 ± 0.74 cde	0.33 ± 0.72 cde	0.07 ± 0.26 de	0.00 ± 0.00 e	0.29 ± 0.83 cde	0.64 ± 0.93 bc	3.69 ± 6.85 bc	Constant
2		2.47 ± 4.19 ab	0.20 ± 0.41 cde	0.07 ± 0.26 de	0.70 ± 1.06 bcd	1.08 ± 2.36 cde	0.47 ± 0.74 cde	0.20 ± 0.41 cde	0.47 ± 0.92 cde	0.14 ± 0.36 cde	0.20 ± 0.41 cde	1.86 ± 1.46 a	7.93 ± 17.06 bc	Constant
	21.19ns	BSh (Warm semi-arid)												
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	Accidental
2		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	Accidental
	69.73**	Cfa (Humid Subtropical)												
1		0.13 ± 0.35 gh	0.20 ± 0.41 fgh	0.33 ± 0.72 fgh	0.67 ± 0.98 efgh	1.53 ± 2.53 defg	1.33 ± 1.63 bcde	0.40 ± 0.83 efgh	1.93 ± 3.37 cdef	3.00 ± 3.48 abcd	2.21 ± 2.46 ab	0.92 ± 1.38 defg	0.33 ± 0.62 efgh	Constant
2		0.27 ± 0.59 fgh	0.40 ± 0.91 fgh	0.07 ± 0.26 h	0.47 ± 0.83 efgh	0.40 ± 0.83 efgh	1.29 ± 1.38 abcd	0.27 ± 0.46 fgh	0.33 ± 0.62 efgh	2.73 ± 2.79 a	2.40 ± 2.92 abc	2.33 ± 3.33 bcde	0.40 ± 0.74 efgh	Constant
	25.47ns	Cwb (Subtropical Oceanic)												
1		0.00 ± 0.00	0.20 ± 0.45	0.60 ± 1.34	0.40 ± 0.55	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 2.24	0.20 ± 0.45	Constant
2		0.80 ± 1.79	0.40 ± 0.55	1.20 ± 0.84	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.40 ± 0.89	0.40 ± 0.89	0.20 ± 0.45	Constant

Significance: ns - non significant; * - significant at 0.05 and ** - significant at 0.01.

Table 7 - Monthly abundance of *Anicla infecta* (means) according to **Köppen-Geiger Climate Classification** compared in two crop seasons (columns - small letters) and the two crop seasons (CS) in each climate (χ^2 CS - lines) by Kruskal Wallis test (P<0.05).

Climate\Crop seasons	2015-2016 (χ2 60.60**)		2016-2017 (56.88**)		χ²CS
	Means	Rank	Means	Rank	
Af	0.50 ± 1.03 bc	319.48	0.51 ± 0.84 bc	341.81	0.68ns
Am	1.93 ± 3.57 a	405.35	1.21 ± 1.64 a	416.94	0.08ns
Aw	3.62 ± 12.83 b	359.89	1.30 ± 5.40 bc	342.09	0.96ns
BSh	0.00 ± 0.00 d	234.00	0.03 ± 0.18 d	237.53	1.98ns
Cfa	1.08 ± 2.05 b	364.18	0.94 ± 1.87 b	357.02	0.28ns
Cwb	0.23 ± 0.79 cd	275.06	0.33 ± 0.75 c	298.98	1.48ns

Significance: ns – non significant; * significant at 0.05 and ** significant at 0.01. Climate Categories: Af (Equatorial Climate); Am (Monsoon); Aw (Tropical Savannah); BSh (Warm Semi-arid); Cfa (Humid Subtropical); Cwb (Subtropical Oceanic).

Table 8 - Monthly abundance of *Anicla infecta* (means of five samples) according to **Holdridge Life Zones** in crop seasons (CS): 1 - 2015-2016 and 2 - 2016-2017. The 24-monthly means ($\chi2$ months) were compared by Kruskal Wallis test ($P<0.05$).

CS	X² months	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Constancy
	45.85**					**BS-rf (Boreal Subalpine Rain Forest)**								
1		0.30 ± 0.67 f	0.40 ± 0.97 f	0.80 ± 1.14 bcdef	1.50 ± 1.27 abc	2.30 ± 2.87 abcde	0.60 ± 0.84 bcdef	0.20 ± 0.42 f	0.90 ± 1.91 cdef	2.50 ± 2.17 a	1.60 ± 1.58 abcd	1.00 ± 1.41 bcdef	1.00 ± 1.15 abcdef	Constant
2		0.5 ± 0.85 def	0.5 ± 0.85 def	0.40 ± 0.70 ef	0.90 ± 1.10 abcdef	1.30 ± 1.34 abcde	1.89 ± 1.90 abc	2.00 ± 1.94 ab	1.80 ± 2.15 abcd	1.40 ± 0.84 ab	1.70 ± 1.89 abcd	1.30 ± 1.64 abcdef	0.20 ± 0.42 f	Constant
	63.68**					**SP-mf (Subtropical Premontane Moist Forest)**								
1		4.68 ± 9.23 a	14.76 ± 29.47 ab	2.32 ± 4.93 abc	0.36 ± 0.64 defg	0.28 ± 0.61 efgh	0.28 ± 0.61 efgh	0.28 ± 0.61 efgh	0.08 ± 0.28 gh	0.00 ± 0.00 h	0.39 ± 0.77 efgh	0.78 ± 1.31 bcde	2.22 ± 5.35 cdef	Constant
2		1.64 ± 3.45 abcd	0.20 ± 0.41 efgh	0.28 ± 0.61 efgh	0.70 ± 0.98 bcde	0.65 ± 1.82 efgh	0.36 ± 0.64 defg	0.16 ± 0.37 fgh	0.32 ± 0.75 efgh	0.17 ± 0.38 efgh	0.32 ± 0.63 efgh	1.17 ± 1.43 ab	4.71 ± 13.41 defg	Constant
	64.45**					**T- df (Tropical Dry Forest)**								
1		4.80 ± 1.92 abc	2.20 ± 1.10 cdefgh	5.20 ± 4.55 bcdef	5.20 ± 3.27 abcd	1.40 ± 2.19 ghij	2.00 ± 1.58 defgh	12.00 ± 5.05 a	3.60 ± 3.29 bcdefg	9.80 ± 10.57 ab	1.60 ± 1.14 fghij	4.80 ± 3.56 abcde	0.40 ± 0.89 ij	Constant
2		2.60 ± 2.30 cdefgh	0.20 ± 0.45 j	1.20 ± 1.30 ghij	1.00 ± 1.22 hij	1.20 ± 0.84 fghij	4.80 ± 2.05 abc	2.20 ± 1.92 defgh	2.20 ± 1.48 cdefgh	1.80 ± 1.30 efghi	0.20 ± 0.45 j	1.40 ± 1.52 fghij	0.80 ± 1.30 hij	Constant
	37.92*					**T-df Δ (Tropical Dry Forest Transition to Moist Forest)**								
1		0.00 ± 0.00 c	0.20 ± 0.45 bc	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.50 ± 1.00 abc	0.00 ± 0.00 c	0.25 ± 0.50 abc	Accidental
2		0.00 ± 0.00 c	0.20 ± 0.45 bc	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c	0.20 ± 0.45 bc	0.00 ± 0.00 c	0.20 ± 0.45 bc	1.00 ± 1.41 ab	1.60 ± 2.51 a	1.00 ± 1.00 a	Accessory
	34.83ns					**T- mf (Tropical Moist Forest)**								
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.40 ± 0.55	1.00 ± 1.00	2.00 ± 2.00	0.80 ± 1.79	0.40 ± 0.55	0.80 ± 1.30	0.40 ± 0.55	Constant
2		0.80 ± 0.84	0.80 ± 0.45	0.40 ± 0.55	0.20 ± 0.45	0.40 ± 0.89	0.20 ± 0.45	0.00 ± 0.00	0.40 ± 0.55	0.00 ± 0.00	0.50 ± 1.00	2.00 ± 1.58	0.40 ± 0.55	Constant
	21.19ns					**T- twΔ (Tropical Thorn Woodland Transition to Very Dry Forest)**								
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	Accidental
2		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	Accidental
	92.19 **					**WTL-mfΔ (Warm Temperate Lower-montane Moist Forest Transition to Wet Forest)**								
1		0.20 ± 0.45 f	0.20 ± 0.45 f	0.00 ± 0.00 f	0.40 ± 0.55 ef	0.00 ± 0.00 f	3.00 ± 1.58 bc	0.80 ± 1.30 ef	5.60 ± 3.78 ab	7.20 ± 1.92 a	4.50 ± 3.32 abc	2.33 ± 1.53 bcd	0.20 ± 0.45 f	Constant
2		0.40 ± 0.55 ef	0.80 ± 1.30 ef	0.20 ± 0.45 f	0.00 ± 0.00 f	0.00 ± 0.00 f	1.60 ± 0.55 cd	0.40 ± 0.55 ef	0.20 ± 0.45 f	6.20 ± 1.48 ab	5.80 ± 2.59 ab	6.40 ± 2.61 ab	1.00 ± 1.00 de	Constant

Significance: ns - non significant; * - significant at 0.05 and ** - significant at 0.01.

Table 9 - Monthly abundance of *Anicla infecta* (means) according to **Holdridge Life Zones** compared in two crop seasons (columns - small letters) and the two crop seasons (CS) in each vegetation (χ^2 CS - lines) by Kruskal Wallis test (P<0.05)

Life Zone\Crop seasons	2015-2016 ($\chi2$ 154.85**)		2016-2017 (103.18**)		χ^2 CS
	Means	Rank	Means	Rank	
BS-rf	1.09 ± 1.61 b	386.45	1.15 ± 1.48 a	422.80	1.00ns
SP-mf	2.25 ± 10.00 c	331.02	0.88 ± 4.18 b	321.73	0.32ns
T-df	4.42 ± 5.02 a **A**	555.63	1.63 ± 1.7 a **B**	472.06	14.85**
T-dfΔ	0.07 ± 0.32 d **B**	249.76	0.33 ± 0.96 bc **A**	285.89	4.15*
T-mf	0.50 ± 1.03 c	319.48	0.51 ± 0.84 b	341.81	0.68ns
T-twΔ	0.00 ± 0.00 d	234.00	0.03 ± 0.18 c	237.53	1.98ns
WTL-mfΔ	1.98 ± 2.89 b	420.52	1.92 ± 2.75 a	428.27	0.01ns

Significance: ns – non significant; * significant at 0.05 and ** significant at 0.01. Life Zones: BS-rf (Boreal Subalpine Rain Forest); SP-mf (Subtropical Premontane Moist Forest); T- df (Tropical Dry Forest); T-df Δ (Tropical Dry Forest Transition to Moist Forest); T- mf (Tropical Moist Forest); T- twΔ (Tropical Thorn Woodland Transition to Very Dry Forest); WTL-mfΔ (Warm Temperate Lower-montane Moist Forest Transition to Wet Forest)

Table 10 - Monthly abundance of *Anicla infecta* (means of five samples) according to **Brazilian Biomes** Classification in crop seasons (CS): 1 - 2015-2016 and 2 - 2016-2017. The 24-monthly means (χ^2 months) were compared by Kruskal Wallis test (P<0.05)

CS	X² months	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Constancy
	41.21*						Amazon							
1		6.80 ± 11.53 bcd	24.00 ± 35.49 abc	3.07 ± 6.24 bcd	0.27 ± 0.59 cd	0.27 ± 0.59 cd	0.40 ± 0.74 cd	0.33 ± 0.72 cd	0.73 ± 1.44 bcd	0.36 ± 1.20 d	0.31 ± 0.63 cd	0.71 ± 1.14 bcd	4.08 ± 7.01 abc	Constant
2		2.13 ± 4.31 abc	0.47 ± 0.52 bcd	0.13 ± 0.35 d	0.47 ± 0.91 cd	1.08 ± 2.40 bcd	0.33 ± 0.62 cd	0.13 ± 0.35 d	0.53 ± 0.92 bcd	0.14 ± 0.36 d	0.50 ± 1.02 cd	1.86 ± 1.77 a	9.08 ± 18.20 ab	Constant
	41.74*						Atlantic Forest							
1		1.21 ± 2.25 defg	0.85 ± 1.18 bcdefg	1.80 ± 3.04 abcdef	2.05 ± 2.66 abcd	1.60 ± 2.37 abcdef	0.80 ± 1.20 cdefg	3.15 ± 5.74 abcdefg	1.35 ± 2.43 bcdefg	3.70 ± 6.32 a	1.45 ± 1.28 abc	2.00 ± 2.67 abcd	0.70 ± 0.98 defg	Constant
2		0.90 ± 1.59 defg	0.30 ± 0.66 g	0.50 ± 0.89 efg	1.05 ± 1.05 abcde	1.00 ± 1.12 abcdef	2.21 ± 2.37 ab	1.55 ± 1.85 abcde	1.45 ± 1.85 abcde	1.25 ± 1.02 abcd	1.05 ± 1.54 abcdefg	1.00 ± 1.45 abcdefg	0.35 ± 0.75 fg	Constant
	21.19ns						Caatinga							
1		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	Accidental
2		0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.45	0.20 ± 0.45	0.00 ± 0.00	0.00 ± 0.00	Accidental
	49.04**						Cerrado							
1		1.19 ± 1.47 ab	0.53 ± 0.74 abcd	0.67 ± 1.23 bcde	0.33 ± 0.62 cdef	0.13 ± 0.52 ef	0.20 ± 0.41 def	0.40 ± 0.74 cdef	0.07 ± 0.26 ef	0.00 ± 0.00 f	0.27 ± 0.80 def	0.53 ± 1.30 cdef	0.20 ± 0.41 def	Constant
2		0.87 ± 1.19 abc	0.20 ± 0.41 def	0.47 ± 0.74 bcde	0.10 ± 0.32 def	0.13 ± 0.35 def	0.27 ± 0.59 cdef	0.20 ± 0.41 def	0.13 ± 0.35 def	0.07 ± 0.26 ef	0.33 ± 0.62 cdef	1.33 ± 1.54 a	0.53 ± 1.55 cdef	Constant
	92.19 **						Pampa							
1		0.20 ± 0.45 f	0.20 ± 0.45 f	0.00 ± 0.00 f	0.40 ± 0.55 ef	0.00 ± 0.00 f	3.00 ± 1.58 bc	0.80 ± 1.30 ef	5.60 ± 3.78 ab	7.20 ± 1.92 a	4.50 ± 3.32 abc	2.33 ± 1.53 bcd	0.20 ± 0.45 f	Constant
2		0.40 ± 0.55 ef	0.80 ± 1.30 ef	0.20 ± 0.45 f	0.00 ± 0.00 f	0.00 ± 0.00 f	1.60 ± 0.55 cd	0.40 ± 0.55 ef	0.20 ± 0.45 f	6.20 ± 1.48 ab	5.80 ± 2.59 ab	6.40 ± 2.61 ab	1.00 ± 1.00 de	Constant

Significance: ns - non significant; * - significant at 0.05 and ** - significant at 0.01.

Table 11 - Monthly abundance of *Anicla infecta* (means) according to **Brazilian Biomes** Classification compared in two crop seasons (columns - small letters) and the two crop seasons (CS) in each vegetation (χ^2 CS - lines) by Kruskal Wallis test (P<0.05)

Biome\Crop seasons	2015-2016 (χ2 76.41**)		2016-2017 (67.89**)		χ^2 CS
	Means	Rank	Means	Rank	
Amazon	3.56 ± 12.92 b	337.28	1.28 ± 5.36 b	342.67	0.16ns
Atlantic Forest	1.72 ± 3.19 a	407.54	1.05 ± 1.48 a	401.03	1.30ns
Caatinga	0.00 ± 0.00 c	234.00	0.03 ± 0.18 c	237.53	1.98ns
Cerrado	0.38 ± 0.87 b	306.18	0.39 ± 0.89 b	308.02	0.06ns
Pampa	1.98 ± 2.89 a	420.52	1.92 ± 2.75 a	428.27	0.01ns

Significance: ns – non significant; * significant at 0.05 and ** significant at 0.01.

Bodenheimer F. S. (1955) Precis D'ecologie Animale. Payot, Paris
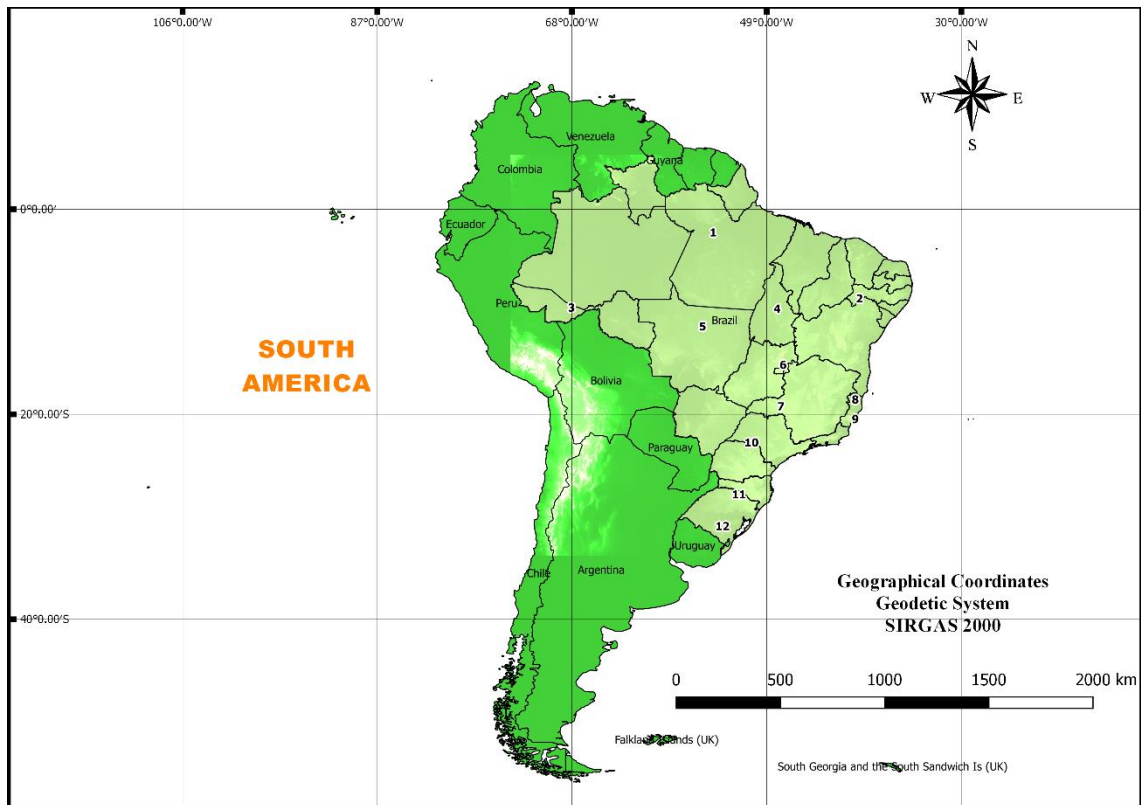
Figure 1. Collection Points: 1- Mojuí dos Campos (Pará); 2- Petrolina (Pernambuco); 3- Rio Branco (Acre); 4- Porto Nacional (Tocantins); 5- Sinop (Mato Grosso); 6-Planaltina (Federal District); 7- Uberaba (Minas Gerais); 8- Domingos Martins (Espirito Santo); 9- Alegre (Espirito Santo); 10- Londrina (Paraná); 11- Passo Fundo (Rio Grande do Sul); 12- Bagé (Rio Grande do Sul).
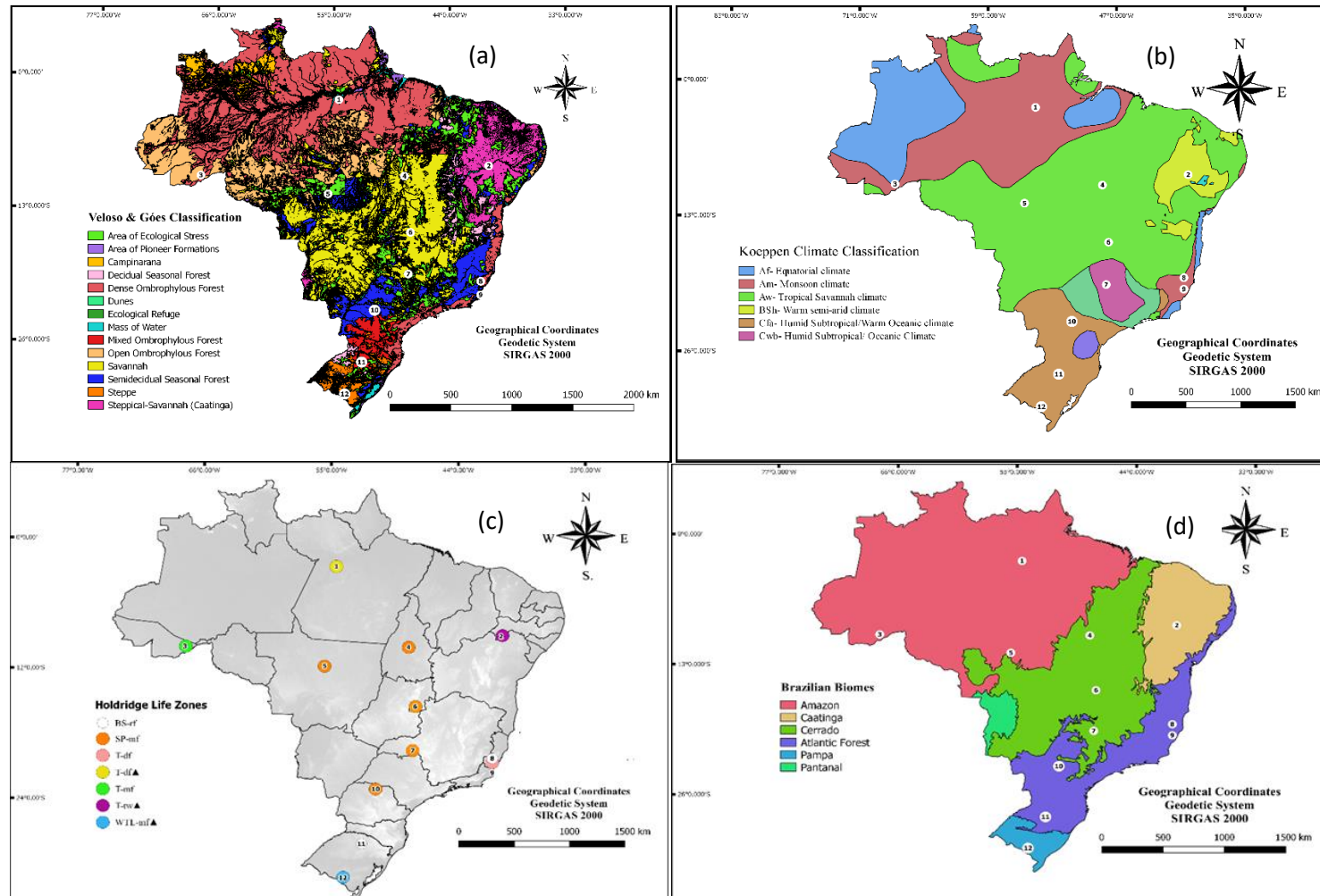
Figure 2 Maps: a) Veloso & Góes Vegetation Classification; b) Köppen-Geiger Climate Classification; c) Holdridge Life Zones; d).Biomes. **Collection Points:** 1- Mojuí dos Campos (Pará); 2- Petrolina (Pernambuco); 3- Rio Branco (Acre); 4- Porto Nacional (Tocantins); 5- Sinop (Mato Grosso); 6-Planaltina (Federal District); 7- Uberaba (Minas Gerais); 8- Domingos Martins (Espirito Santo); 9- Alegre (Espirito Santo); 10- Londrina (Paraná); 11- Passo Fundo (Rio Grande do Sul); 12- Bagé (Rio Grande do Sul).
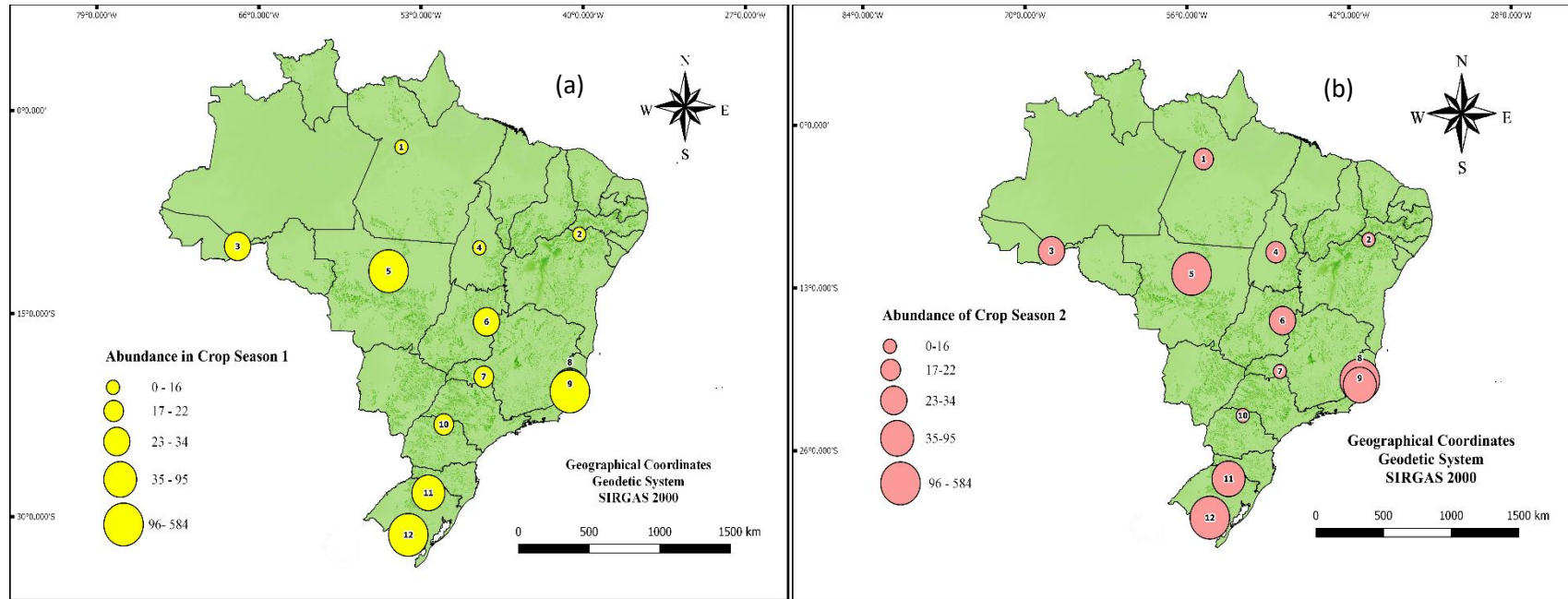
Figure 3 Maps with abundance of *Anicla infecta*: a) Crop Season 1 (2015/2016); b) Crop Season 2 (2016/2017). Collection Points: 1- Mojuí dos Campos (PA); 2- Petrolina (PE); 3- Rio Branco (AC); 4- Porto Nacional (TO); 5- Sinop (MT); 6-Planaltina (DF); 7- Uberaba (MG); 8- Domingos Martins (ES); 9- Alegre (ES); 10- Londrina (PR); 11- Passo Fundo (RS); 12- Bagé (RS).
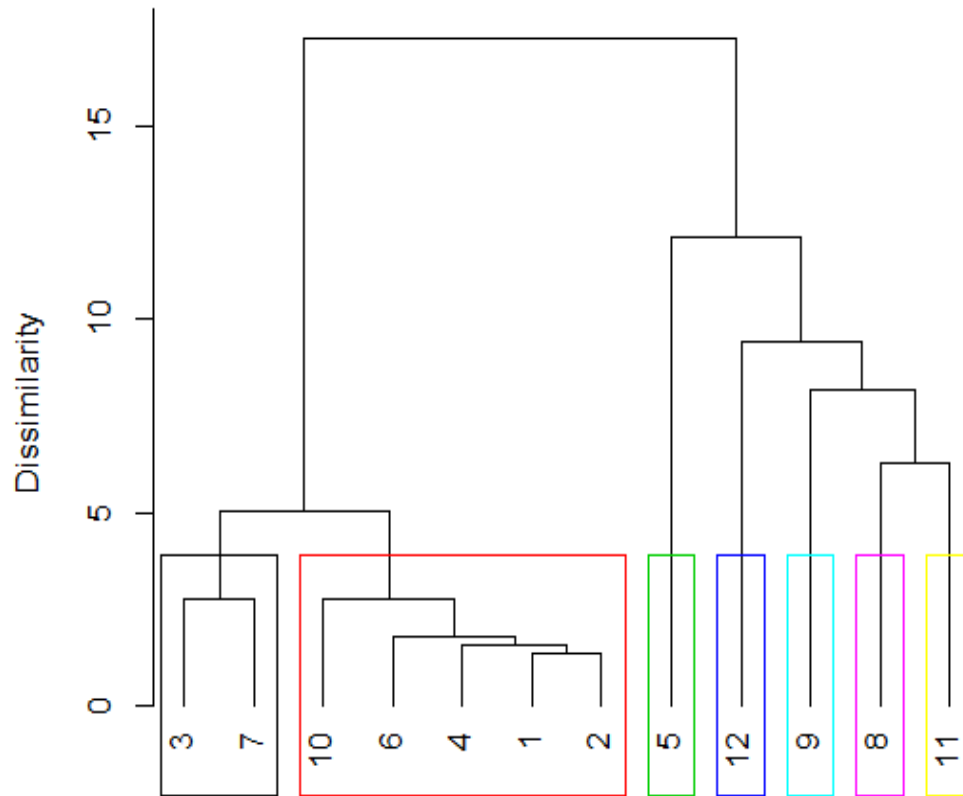
Figure 4 Cluster analysis: *Anicla infecta´s* abundance correlation between 12 Brazilian localities considering 24 months. Collection Points: 1- Mojuí dos Campos (Pará); 2- Petrolina (Pernambuco); 3- Rio Branco (Acre); 4- Porto Nacional (Tocantins); 5- Sinop (Mato Grosso); 6-Planaltina (Federal District); 7- Uberaba (Minas Gerais); 8- Domingos Martins (Espirito Santo); 9- Alegre (Espirito Santo); 10- Londrina (Paraná); 11- Passo Fundo (Rio Grande do Sul); 12- Bagé (Rio Grande do Sul). Cophenetic correlation 0.73
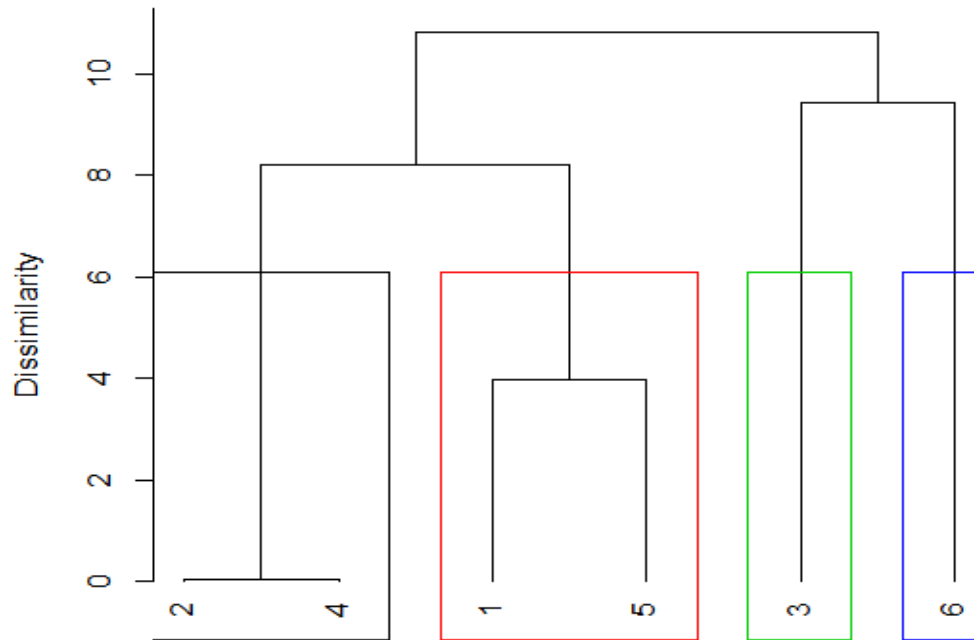
Figure 5 Cluster analysis: *Anicla infecta´s* abundance correlation according to Veloso & Góes Vegetation considering 24 months. Vegetation Types: 1- Steppical-Savannah (Caatinga); 2- Dense Ombrophilous; 3- Dense Steppe; 4- Mixed Ombrophilous; 5- Savannah (Cerrado); 6- Semidecidual Seasonal Forest. Cophenetic correlation 0.90
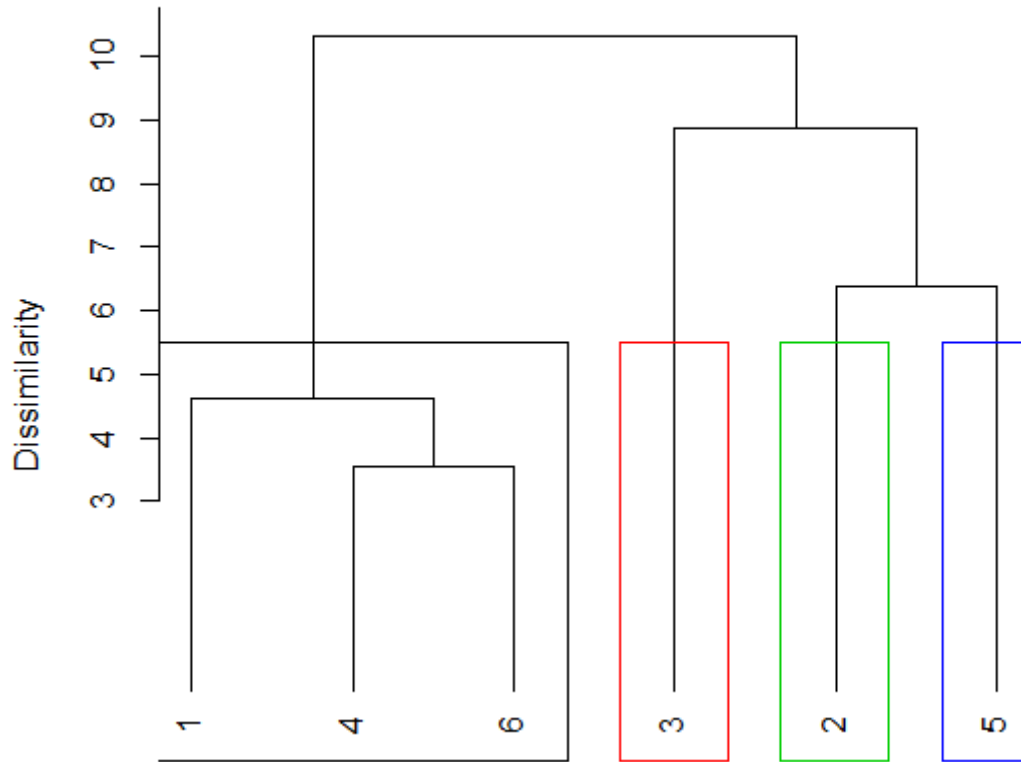
Figure 6 Cluster analysis: *Anicla infecta´s* abundance correlation according to **Köppen-Geiger Climate Classification** including 24 **months.** Climate Categories: 1- Af (Equatorial Climate); 2- Am (Monsoon); 3- Aw (Tropical Savannah); 4- BSh (Caatinga);5- Cfa (Humid Subtropical);6- Cwb (Subtropical Oceanic). Cophenetic correlation 0.81
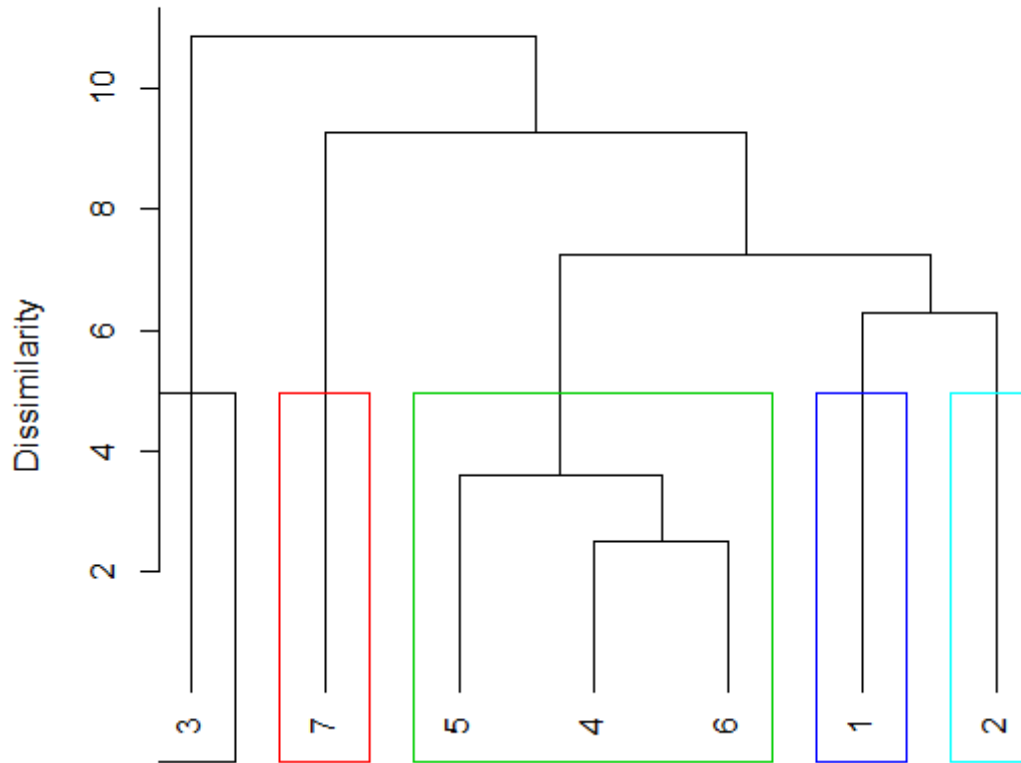
Figure 7 Cluster analysis: *Anicla infecta´s* abundance according to **Holdridge Life Zones** for 24 months. Life Zones: 1-BS-rf (Boreal Subalpine Rain Forest); 2-SP-mf (Subtropical Premontane Rain Forest); 3-T-df (Tropical Dry Forest); 4-T-df Δ (Tropical Dry Forest Transition to Moist Forest); 5-T- mf (Tropical Moist Forest); 6-T- twΔ (Tropical Thorn Woodland Transition to Very Dry Forest); 7-WTL-mfΔ (Warm Temperate Lower-montane Moist Forest Transition to Wet Forest) Cophenetic correlation 0.93
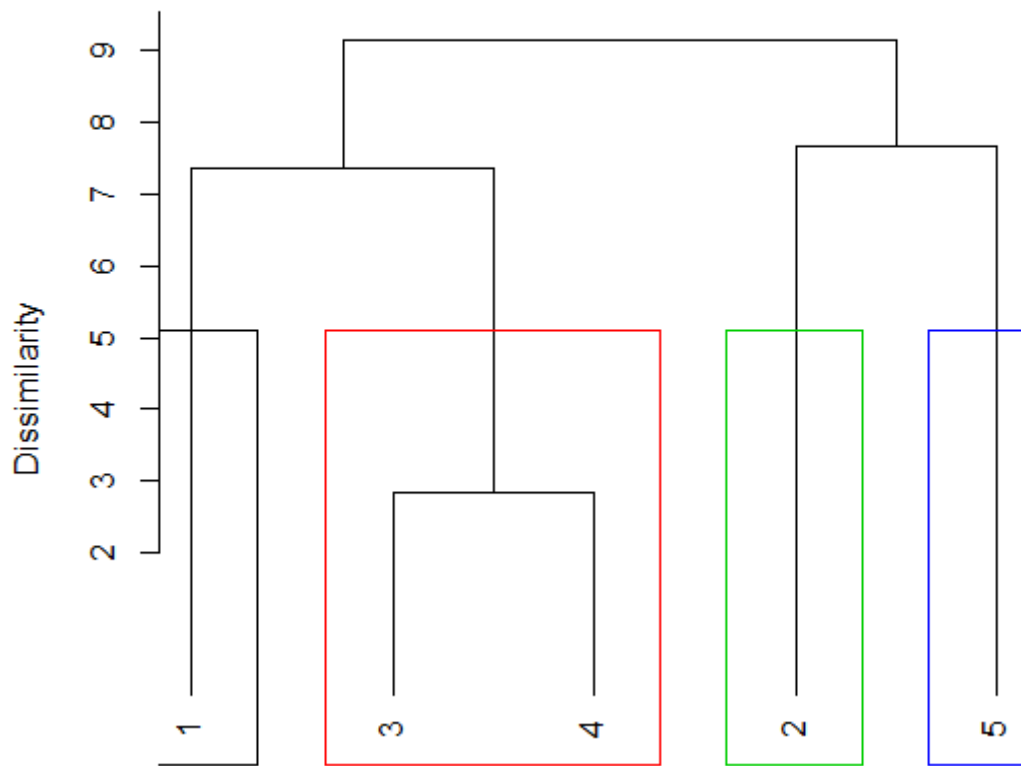
Figure 8 Cluster analysis: *Anicla infecta´s* abundance correlation according **to Brazilian Biomes** during a period of 2 years. Classification. Biomes: 1- Amazon; 2- Atlantic Forest; 3- Caatinga; 4- Cerrado; 5- Pampa. Cophenetic correlation 0.89

ANEXOS

Biology, Ecology and Diversity

The population dynamics of three polyphagous owlet moths (Lepidoptera: Noctuidae) and the influence of meteorological factors and ENSO on them

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ABSTRACT

The owlet moths (Lepidoptera: Noctuidae) *Anicla infecta* (Ochsenheimer 1816), *Elaphria agrotina* (Guenée 1852) and *Spodoptera frugiperda* (J.E. Smith 1797) occur in the entire American continent. These polyphagous moths have a preference for grasses, and have different biological habits. In this study, the populations of these three species were evaluated monthly with light traps in the Brazilian Savannah, ranging a span of four crop seasons (from July, 2013 to June, 2017). The population data were analyzed and correlated with the meteorological variables: maximum temperature, minimum temperature, relative humidity and precipitation. A total of 4719 individuals were collected in the following percentages: *A. infecta* (n = 459; 9.73%), *E. agrotina* (n = 1809; 38.33%) and *S. frugiperda* (n = 2451; (51.94%). The abundance of all species went down from the first crop season (2013/2014) to the third (2015/2016). In the fourth crop season (2016/2017), the populations of *A. infecta* and *E. agrotina* stabilized, but the abundance of *S. frugiperda* experienced further decrease. The numbers of individuals of three species declined when precipitation was much above (crop season 2014/2015) and below (crop season 2015/2016) than expected by the climatological normal. There were significant, but different degrees of correlation, between the meteorological factors and the ONI index (Oceanic Niño Index - indicator for monitoring El Niño-Southern Oscillation or "ENSO") with respect to monthly population variations. The results are discussed in accordance with principles of the Integrated Pest Management (IPM) in mind, given the continental distribution and agricultural importance of the three owlet moth species studied.

Introduction

Insects are very diverse and play fundamental roles in ecosystems. Adult lepidopterans (butterflies and moths) are important pollinators of wild plants and also many food crops (Kondo, 2012). Their larvae, in contrast, have a great negative impact on plants, eating their leaves, flowers, fruits, seeds, branches and even roots (Weisse and Siemann, 2008). Out of their natural habitat lepidopterans can become important pests. The owlet moths, *Anicla infecta* (Ochsenheimer, 1816), *Elaphria agrotina* (Guenée, 1852) and *Spodoptera frugiperda* (J.E. Smith, 1797) are good examples of this. They occur throughout the American continent and recently, *S. frugiperda* has also been detected in the African continent (Goergen et al., 2016), Europe (CABI, 2017) and India (Shylesha et al., 2018). Their caterpillars are polyphagous, with a strong preference for grasses (Teston et al., 2001; Lafontaine, 2004; Casmuz et al., 2010; Specht et al., 2014; Montezano et al., 2018). The caterpillar of *A. infecta* feeds preferentially on the foliar limb of native and cultivated grasses such as oats, ryegrass, grasses, millet and corn (Teston et al., 2001). *Elaphria agrotina* stays in the soil and eats debris/tillageör dead plant structures of crops such as maize, including leaves, cobs, stigmas and dried seeds (Specht et al., 2014). *Spodoptera frugiperda* has a polyphagous caterpillar which can be a pest of many crops, including monocotyledonous and dicotyledonous plants. In cultivated Poaceae, it prefers young leaflets (attacking the maize, millet and sorghum husk), but also attacks reproductive tissues (such as corn ear or panicle of millet and sorghum) (Montezano et al., 2018). When their population numbers are high, they are considered pests due to their negative impact on the production of some crops (Capinera, 2008).

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Lepidopteran pests cause losses not only by impairing plant production, but also by requiring expensive management (Paula-Moraes et al., 2017). The knowledge of the relationships between the population fluctuations of each species with the meteorological variations can contribute with data for the development of forecasting systems, promoting the rationalization of their management (Zalucki and Furlong, 2005). In this way, this work presents and compares the population dynamics of *A. infecta, E. agrotina* and *S. frugiperda* in four crop seasons in Central Brazil, considering the Oceanic Niño Index (ONI) climatic pattern as a possible influence on it.

Materials and methods

Study area

This study was carried out in the area of 'Estação Experimental da Embrapa Cerrados', located in the city of Planaltina, Distrito Federal, Brazil, which is predominantly an agricultural area. It is located in the 'Cerrado' biome (AbŠaber, 2003), also known as the Brazilian Savannah. According to the climate classification of Köppen, it has a Tropical Wet-Dry Climate (Aw), with average temperatures around 17 °C in the coldest and 22 °C in the hottest months. The region is marked by two seasons, defined by the differences in rainfall accumulation. The rainy period starts in September and extends until April. The wettest months are November, December and January. The dry period starts in May and ends in September, resulting in a hot and rainy summer and mild and dry winter (Silva et al., 2017).

The sampled landscape is totally surrounded by native vegetation of Brazilian Savannah, but in the collecting point there are several agriculturally important crops, especially soybean, corn and wheat, which occupy about 25, 15 and 10% of the 400-meter radius from the collecting site. Part of the area is occupied with agricultural buildings (barns and greenhouses) and, to a lesser extent, crops of other species such as bluestem, coffee, cassava, rattleweed, gum, oil palm, panicgrass, passion fruit and sugar cane. Wheat, soybean and corn stand out because the former is restricted to the dry period, while the other two are restricted to the rainy season. It is assumed that other crops do not affect the phenology of *A. infecta, E. agrotina* and *S. frugiperda* because they are perennial plants which are not preferential hosts for these species, and/or are cultivated in small areas. During four crop seasons the crops were repeated to avoid changing the availability of food for the owlet caterpillars.

Meteorological data and Oceanic Niño Index (ONI)

The meteorological data was obtained from the Estação Climatológica Principal da Embrapa Cerrados with meteorological sensors at a distance of 20 m from the light trap. The variables analyzed were maximum (Tmax) and minimum (Tmin) temperature, relative humidity (RH) and precipitation (Precip). The Oceanic Niño Index (ONI) values were obtained in NOAA (2018). The Oceanic Niño Index (ONI) is NOAA's primary indicator for monitoring El Niño and La Niña, which are opposite phases of the climate pattern called the El Niño-Southern Oscillation or "ENSO" for short. NOAA considers El Niño conditions to be present when the ONI is +0.5 or higher, indicating the East-Central Tropical Pacific is significantly warmer than usual. On the other hand, La Niña conditions exist when the ONI is −0.5 or lower, indicating that the region is cooler than usual. Values over 0.5 correspond to El Niño and under −0.5 correspond to La Niña.

Insect collecting

The moths were collected with a Pennsylvania light trap (Frost, 1957) at the following coordinates 15°35′30″ S and 47°42′30″ W,

altitude: 1007 m a.s.l. This trap was equipped with a black fluorescent light model BL T8 15 W (Tovalight) and was lit during five nights at each *novilunium*, to minimize the moonlight effects on trap efficiency. Each night is considered a repetition in the analysis, and the insects collected each night per *novilunium*/month were individualized to calculate the means. This trap was placed three meters from the ground, inside the crop area.

In total, the trap was lit 50 times over a period of four years in *novilunium* to represent all months during that period. The collecting activities started in July when the harvest period starts and ended in June of the following year. Therefore, in the present study we considered four crop seasons, from June of 2013 to July of 2017. Crop season 1 (CS1) – July of 2013 to June of 2014; crop season 2 (CS2) – July of 2014 to June of 2015; crop season 3 (CS3) – July of 2015 to June of 2016 and crop season 4 (CS4) – July of 2016 to June of 2017.

Due to an excess of rainfall and a large number of Coleoptera, Hymenoptera and Isoptera attracted to the trap in November, 2013, the owlet moths were damaged to the point that their identification was not possible. For this reason, the samples collected on that month were not considered. In the months when there were two new moons, July 2015 and September 2016, the collecting process was considered a repetition. Therefore, instead of considering the usual five collections, we considered ten for the same month. The identification of insects during the sorting process was based on the literature (Angulo and Olivares, 1997; Pogue, 2002; Specht et al., 2014). The specimens were preserved in ethanol (96%), and representative vouchers were pinned and deposited in the Entomological Collection of Embrapa Cerrados.

Statistical analysis

Three separate analyses were conducted, one for each species: *A. infecta, E. agrotina* and *S. frugiperda*, for four years with entirely randomized design and five temporal repetitions. The analysis has two qualitative factors: crop season (four crop seasons) and months (twelve).

Normality of variances was tested annually using the Shapiro-Wilk. T-test was used to compare differences in the average abundance among the crop seasons. A Generalized Linear Model (GLM) Poisson Regression was used to determine how the mean expected value of a continuous response variable (abundance) depends on a set of explanatory variables (daily meteorological factors). To complement this, another similar analysis was conducted, comparing the monthly means of the populations of each species with ONI data (Oceanic Niño Index). The Poisson regression model takes into account discrete variables. The analysis using this regression model involved the total number of individuals of *A. infecta, E. agrotina* and *S. frugiperda* collected in each sample (McCullagh and Nelder, 1989). It works with non-normality distributions by modeling the data and identifying problems with discreteness in the outcomes (e.g. the "lump" of zeros) (Vittinhoff et al., 2004).

Data were analyzed and graphed using the R Software ver. 3.3.1, Action Stat Module.

Results

Abundance of species according crop seasons

In general, the results indicate that all populations of the three species decreased in numbers from CS1 to CS4 (Table 1, Fig. 1) with significant between CSs (p < 0.05). There were two exceptions: non-significant variations in the number of individuals were observed for *A. infecta* between CS3 and CS4 (p = 0.77) and for *E. agrotina* between CS2 and CS4 (p = 0.20) and CS3 and CS4 (p = 0.91).

Table 1

Specific abundance of three owlet moth species in four crop seasons: July of 2013 to June of 2017 (CS1 - 2013/2014, CS2 - 2014/2015, CS3 - 2015/2016, CS4 - 2016/2017). T-test comparisons performed using mean number (five nights) of moths captured with light traps in each crop season (60 nights) at Embrapa Cerrados, Federal District, Brazil.

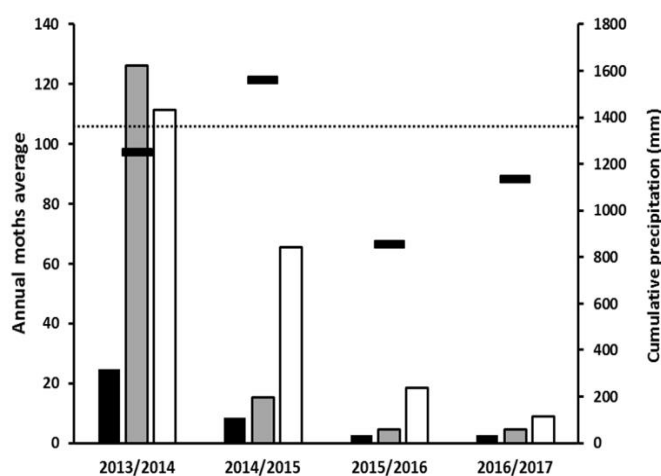| Species	Specific abundance					P value					
	CS1	CS2	CS3	CS4	Total	CS1 × CS2	CS1 × CS3	CS1 × CS4	CS2 × CS3	CS2 × CS4	CS3 × CS4
Anicla infecta	296	102	30	31	459	0.00	0.00	0.00	0.02	0.04	0.77
Elaphria agrotina	1516	183	55	55	1809	0.00	0.00	0.00	0.02	0.20	0.91
Spodoptera frugiperda	1337	786	221	107	2451	0.00	0.00	0.00	0.04	0.00	0.02
Total	3149	1071	306	193	4719	–	–	–	–	–	–

Fig. 1. Annual average abundance of *Anicla infecta* (black columns), *Elaphria agrotina* (grey columns) and *Spodoptera frugiperda* (white columns); cumulative precipitation in cubic millimeters per quadratic meter (black bars) in four Crop Seasons and expected precipitation according to Climatological Normal 1974–2004 (Silva et al., 2014). Moths captured with light traps at Estação Experimental da Embrapa Cerrados, Federal District, Brazil.

Regarding to the variations in populations per species during and among the crop seasons, the following results are notable:

The average number of individuals of *A. infecta* decreased from 24.7 (CS1) to 8.5 in CS2 and to 2.5 in CS3 (Fig. 1). Similarly, and despite the fact that comparisons involving November's CS1 were not possible, significant monthly decreases in numbers of individuals were observed, particularly between CS1 and CS2, CS3 and CS4 (Table 2, Fig. 2a).

The average number of *E. agrotina* individuals decreased from CS1 (126.3), to CS2 (12.3), to CS3 (4.6) and remained stable in CS4 (4.6) (Fig. 1). With respect to the monthly fluctuations between crop seasons showed that July of 2013 (CS1) was the month when there were more individuals collected, with an average total of 106.3 moths per night (Table 2). In most cases, there was a decrease in abundance from one crop season to another, such as in July 2013, when there was a decrease of 96.05% in the average number of individuals (102.1) compared to CS2 and 99.81% (106.1) compared to CS3 and CS4 (Table 2). Significant decreases were also observed in at least half of the months, particularly in the comparisons between CS1 and the other crop seasons (Table 2).

Similarly, for four crop seasons, the total average of individuals of *S. frugiperda* progressively decreased from 111.4 in CS1 to 8.9 in CS4 (Fig. 1). This decrease in population numbers was significant between the harvests of most months, including comparisons with the last harvest (Table 2).

Another important aspect is that all species under study were present (were collected) in practically every month during all four crop seasons. However, the specific monthly abundance of each

species, and the peaks in the population of each species, varied among the crop seasons. This is the case of *A. infecta,* which was more abundant in July, August and September of 2013; April, May and June of 2014. In the case of *E. agrotina*, the greatest numbers of individuals were collected only in July of 2013 and finally, for *S. frugiperda,* the population peak was reached in July of 2013, January, April and November of 2014 (Tables 1 and 2; Fig. 2).

Relationship between meteorological factors and ONI on the specific abundances

According to our results, indicated by the Poisson coefficients and respective p-values, the climatological variables, except for the minimum temperature on *E. agrotina* and precipitation on *S. frugiperda*, influenced each one of the species in a significant and differential way (Table 3).

Our results indicate that the meteorological variables are negatively correlated with the population numbers of *A. infecta* and *E. agrotina*, meaning that lower population numbers were observed when precipitation, temperature and humidity were at their highest (Table 3).

To *S. frugiperda*, precipitation did not affect the populations in a significant way (Table 3). However, higher maximum temperatures, as observed for *A. infecta* and *E. agrotina*, contributed significantly to a decrease in the numbers of individuals of this species in our samples. The minimum temperature and relative humidity, in contrast, were positively associated with estimated values of abundance, meaning that, an increase in the values of

Table 2

Monthly average abundance of *Anicla infecta*, *Elaphria agrotina* and *Spodoptera frugiperda* in four crop seasons (CS1 - 2013/2014, CS2 - 2014/2015, CS3 - 2015/2016, CS4 - 2016/2017). T-Test comparisons performed with mean number (five nights) of moths captured in light traps by month (five repetitions) at "Estação experimental da Embrapa Cerrados", Federal District, Brazil.

Month	Average abundance					Comparisons between crop seasons											
	CS1	CS2	CS3	CS4	Total	CS1 × CS2	P-val	CS1 × CS3	P-val	CS1 × CS4	P-val	CS2 × CS3	P-val	CS2 × CS4	P-val	C3 × C4	P-val
Anicla infecta																	
J	4.5	2.0	1.0	0	7.5	−2.5	0.00	−3.5	0.00	−4.5	0.00	−1.0	0.11	−2.0	0.00	−1.0	0.03
A	3.4	1.8	0.2	0.2	5.6	−1.6	0.06	−3.2	0.00	−3.2	0.00	−1.6	0.01	−1.6	0.01	0.0	1.00
S	3.8	1.5	0.6	0.5	6.4	−2.3	0.08	−3.2	0.01	−3.3	0.01	−0.9	0.11	−1.0	0.09	−0.1	0.80
O	1.7	0.8	0.6	0.8	3.9	−0.9	0.17	−1.1	0.10	−0.9	0.26	−0.2	0.74	0.0	1.00	0.2	0.79
N	–	0.3	0.0	0.2	0.5	–	–	–	–	–	–	−0.3	0.19	−0.1	0.86	0.2	0.37
D	1.4	0.2	0.4	0.6	2.6	−1.2	0.11	−1.0	0.23	−0.8	0.33	0.2	0.63	0.4	0.37	0.2	0.73
J	1.0	0.1	0.8	0.8	2.7	−0.9	0.03	−0.2	0.70	−0.2	0.74	0.7	0.14	0.7	0.23	0.0	1.00
F	0.8	0.3	0.0	0.2	1.3	−0.5	0.11	−0.8	0.01	−0.6	0.08	−0.3	0.08	−0.1	0.70	0.2	0.37
M	0.8	0.3	0.2	0.6	1.9	−0.5	0.19	−0.6	0.11	−0.2	0.70	−0.1	0.62	0.3	0.56	0.4	0.41
A	4.4	0.7	1.8	0.6	7.5	−3.7	0.00	−2.6	0.02	−3.8	0.00	1.1	0.19	−0.1	0.73	−1.2	0.15
M	2.9	0.4	0.2	0.6	4.1	−2.5	0.00	−2.7	0.00	−2.3	0.00	−0.2	0.67	0.2	0.56	0.4	0.35
J	4.9	1.6	0.1	1.2	7.8	−3.3	0.00	−4.8	0.00	−3.7	0.00	−1.5	0.00	−0.4	0.33	1.1	0.00
Elaphria agrotina																	
J	106.3	4.2	0.2	0.2	110.9	−102.10	0.00	−106.1	0.00	−106.1	0.00	−4.0	0.00	−4.0	0.00	0.0	1.00
A	6.1	2.9	0.0	0.2	9.2	−3.19	0.02	−6.1	0.00	−5.9	0.00	−2.9	0.00	−2.7	0.00	0.2	0.37
S	2.3	1.7	0.0	0.0	4.0	−0.57	0.53	−2.3	0.00	−2.3	0.00	−1.7	0.06	−1.7	0.06	0.0	1.00
O	6.2	1.6	0.4	2.0	10.2	−4.60	0.04	−5.8	0.01	−4.2	0.05	−1.2	0.23	0.4	0.75	1.6	0.13
N	–	1.0	0.6	0.4	2.0	–	–	–	–	–	–	−0.4	0.61	−0.6	0.34	−0.2	0.79
D	1.4	2.5	2.2	0.0	6.1	1.17	0.13	0.8	0.40	−1.4	0.01	−0.3	0.74	−2.5	0.00	−2.2	0.05
J	0.3	0.4	0.8	0.4	1.9	0.07	0.84	0.5	0.60	0.1	0.85	0.4	0.65	0.0	1.00	−0.4	0.65
F	0.5	0.0	1.8	0.2	2.5	−0.45	0.14	1.3	0.08	−0.3	0.47	1.8	0.04	0.2	0.37	−1.6	0.05
M	1.9	0.2	0.8	0.2	3.1	−1.68	0.00	−1.1	0.15	−1.7	0.00	0.6	0.40	0.0	0.94	−0.6	0.38
A	13.7	1.3	1.4	5.6	22.0	−12.43	0.01	−12.3	0.01	−8.1	0.16	0.1	0.86	4.3	0.33	4.2	0.34
M	8.0	0.7	0.6	1.6	10.9	−7.30	0.00	−7.4	0.00	−6.4	0.00	−0.1	0.89	0.9	0.10	1.0	0.12
J	3.9	1.0	1.6	0.2	6.7	−2.90	0.00	−2.3	0.02	−3.7	0.00	0.6	0.33	−0.8	0.08	−1.4	0.02
Spodoptera frugiperda																	
J	21.5	4.8	0.4	0.6	27.3	−16.7	0.00	−21.1	0.00	−20.9	0.00	−4.4	0.00	−4.2	0.00	0.2	0.58
A	7.2	0.0	0.8	1.4	9.4	−7.2	0.00	−6.4	0.00	−5.8	0.00	0.8	0.18	1.4	0.02	0.6	0.37
S	4.2	5.1	0.4	0.25	9.9	0.9	0.54	−3.8	0.00	−4.0	0.00	−4.7	0.00	−4.8	0.00	−0.2	0.68
O	5.8	0.0	0.2	2	8.0	−5.8	0.00	−5.6	0.00	−3.8	0.00	0.2	0.37	2.0	0.02	1.8	0.03
N	–	32.9	1.2	4.4	38.5	–	–	–	–	–	–	−31.7	0.00	−28.5	0.01	3.2	0.11
D	12.4	7.7	14.0	4.2	38.3	−4.6	0.17	1.6	0.74	−8.2	0.03	6.3	0.16	−3.5	0.04	−9.8	0.05
J	22.9	9.7	7.4	1.4	41.4	−13.2	0.03	−15.5	0.02	−21.5	0.00	−2.3	0.47	−8.3	0.00	−6.0	0.10
F	8.1	2.5	3.2	0.8	14.6	−5.6	0.01	−4.9	0.04	−7.3	0.00	0.7	0.62	−1.7	0.02	−2.4	0.13
M	13.3	1.7	10.4	1	26.4	−11.6	0.00	−2.9	0.52	−12.3	0.00	8.7	0.05	−0.7	0.20	−9.4	0.04
A	29.2	3.3	2.2	1.4	36.1	−25.9	0.00	−27.0	0.00	−27.8	0.00	−1.1	0.07	−1.9	0.02	−0.8	0.20
M	0.2	2.0	0.6	3.0	5.8	1.8	0.02	0.4	0.35	2.8	0.19	−1.4	0.14	1.0	0.62	2.4	0.28
J	12.2	0.9	2.4	1	16.5	−11.3	0.00	−9.8	0.01	−11.2	0.00	1.5	0.17	0.1	0.82	−1.4	0.19

Table 3

Coefficients of Poisson Multiple Regression Model calculated for the montly variations in the mean number of moths collected, considered as predictor variables for climatic factors and ONI (Oceanic Niño Index). Est - Estimate, SE - Standard Error, P - P-value.

Predictor variables	*Anicla infecta*			*Elaphria agrotina*			*Spodoptera frugiperda*		
	Est	SE	P	Est	SE	P	Est	SE	P
Intercept	0.088	0.054	0.107	1.132	0.034	0.000	1.858	0.021	0.000
Maximum temperature	−0.436	0.067	0.000	−1.112	0.035	0.000	−0.238	0.030	0.000
Minimum temperature	−0.119	0.056	0.010	−0.009	0.031	1.000	0.154	0.030	0.000
Relative humidity	−0.423	0.077	0.000	−0.756	0.042	0.000	0.100	0.036	0.001
Precipitation	−0.235	0.103	0.010	−0.271	0.051	0.000	0.024	0.018	1.000
Intercept	0.201	0.143	0.160	1.521	0.073	0.000	1.796	0.065	0.000
ONI	−0.355	0.175	0.042	−1.027	0.129	0.000	−0.141	0.069	0.040

these parameters was significantly associated with increased abundance of *S. frugiperda* in samples (Table 3).

Beyond the meteorological factors, the numbers of individuals of all species were negatively correlated with the ONI values, the primary indicator for monitoring El Niño and La Niña events (Table 3).

Discussion

The consecutive decrease in the abundance of the three owlet moth species over the four crop seasons (Table 1; Fig. 1) of this study are consistent with the results obtained for other owlet moth species, being *Chrysodeixis includens*, *Spodoptera albula*, *Spodoptera*

cosmioides and *S. frugiperda*, in the same area, in the following crop seasons: 2013/2014, 2014/2015 and 2015/2016 (Piovesan et al., 2017; Santos et al., 2017).

Since this analysis was carried out in a Tropical Savannah (Cerrado) area with two very different seasons (a very long dry season and a very wet season), the temperature (maximum and minimum) fluctuated less than precipitation and relative humidity (Fig. 2). Besides the variations in the observed precipitation values on each crop compared to the expected (Silva et al., 2014), there was a significant drop in precipitation in the fall of 2015/2016, associated with the El Niño. However, in the last crop season (CS4), even without the influence of the El Niño, precipitation and the consequent relative humidity were lower than the annual rainfall
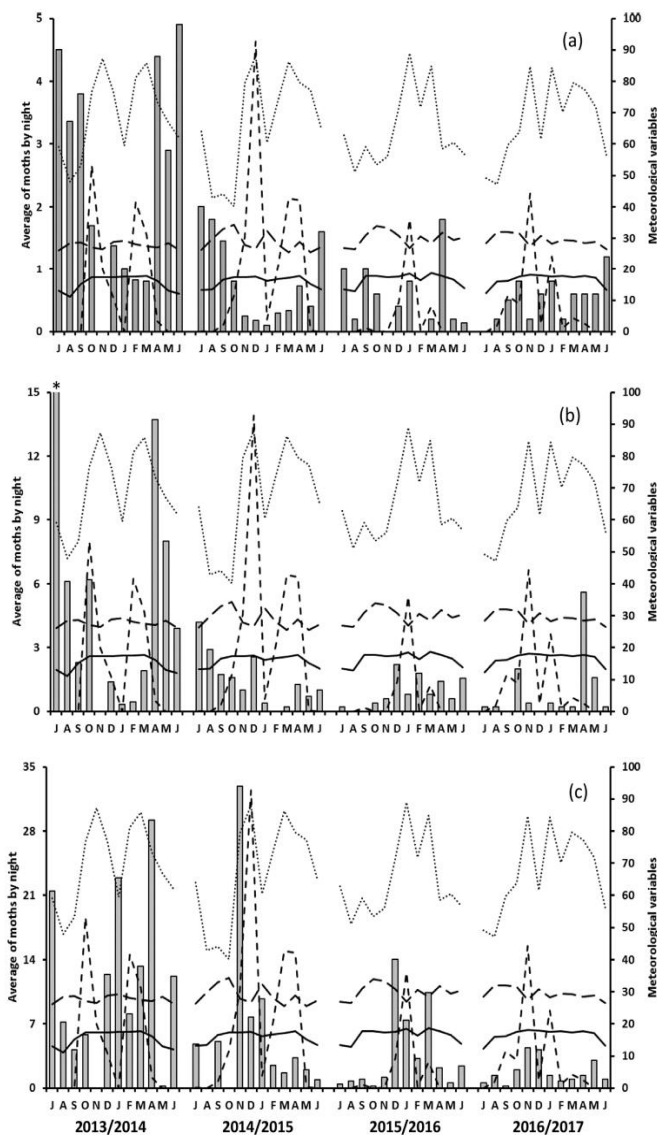

Fig. 2. Average number of moths (a) *Anicla infecta*, (b) *Elaphria agrotina* and (c) *Spodoptera frugiperda* in four crop seasons according to meteorological variables: humidity - dotted line; maximum temperature - long dashed line; minimum temperature - continuous line and precipitation - short dashed line. Left columns have different scales and * [first column of *E. agrotina* (b)] represents 106.3 moths.

volume expected by the climatological normal (Silva et al., 2014, Figs. 1 and 3).

Despite large variations in the volume of precipitation on each crop, according to the Climatological Normal 1974–2004 (Silva et al., 2014), it was not possible to find a connection between the observed decrease in the numbers of individuals of the three species and volume of precipitation (Table 1, Fig. 1). Species' abundances declined significantly (more than 50%) between the 2013/2014 harvest and the 2014/2015 one, when there was an increase of 19.8% (309.4 mm³) in precipitation. The decrease in the number of individuals, at least in the case of *S. frugiperda*, was as expected, since the caterpillars, especially in the early life stages, tend to drown
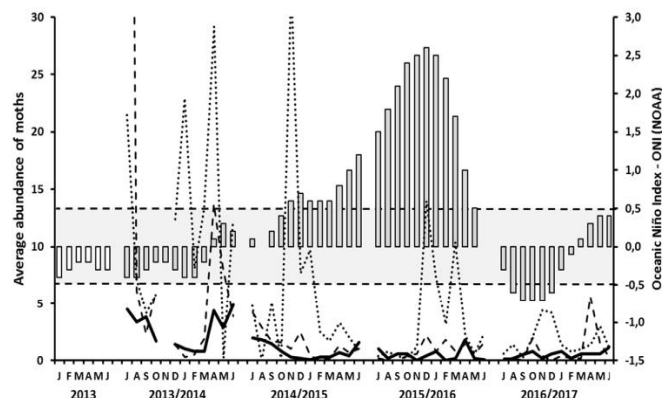
Fig. 3. Average number of *Anicla infecta* (continuous line), *Elaphria agrotina* (dashed line) and *Spodoptera frugiperda* (dotted line) in four crop seasons. Oceanic Niño Index - ONI; the white bars (left) represents six months before the beginning of the collections (gray bars). Values over 0,5 correspond to El Niño and under to −0.5 correspond to La Niña (NOAA, 2018).

inside the corn's cartridge when precipitation is high (its main host plant) (García-Roa et al., 2002). Similarly, the neonate larvae of all the species are, directly or indirectly, highly vulnerable to the impact of raindrops, which can remove them from their host plants (Zalucki et al., 2002). Furthermore, high levels of precipitation, accompanied by high relative humidity, generally induce the occurrence of entomopathogenic epizooties (Ríos-Velasco et al., 2010).

The abundance of the three species continued to drop even more between the 2014/2015 and 2015/2016 crop seasons, when a reduction in precipitation was observed in 54.81% (-705.1 mm3), due to the El Niño phenomenon (Fig. 3). That decrease can be attributed to the extreme water deficit, which among other things, affects the quantity and quality of food available for the insects (Zalucki et al., 2002). Despite this, the abundance decrease in crop season with reduced rainfall differs from the observations reported in the literature where, at least for *S. frugiperda*, the diminution in precipitation would lead to a considerable populational increase, since drier climates favor the larvae of this species (Corte et al., 1985; García-Roa et al., 2002).

In the following crop seasons, between the 2015/2016 and 2016/2017, only the abundance of *S. frugiperda* decreased significantly. It is important to highlight that, although the El Niño event lost its strength, precipitation remained relatively low during the fourth crop season 2016/2017 (1,136.8 mm³) (Figs. 1 and 3). Considering the size of the cultivated area and crop management (same quantity and type of chemical product) over four years and expressive non-intensive agricultural area (3000 ha) around the collecting site, we inferred that the variations in population abundance are linked to other, non-quantifiable elements, such as natural biological control (Pereira et al., 2018).

The fact that the three species were sampled during practically every month of all crop seasons (Table 2, Fig. 2) is conditioned to their multivoltinism, and by the presence, in the study area, of minimal biotic and abiotic conditions for their development and permanence. This also indicates that all species had initial populations (even in the dry season – June to September) that would allow rapid increases in abundance under favorable conditions. However, the monthly abundances of each species within each crop (Table 2, Fig. 2) varied greatly, sometimes with coincident and sometimes antagonistic population peaks, attributed to the behavioral and developmental characteristics of the larvae of each (Kasten et al.,

1978; Teston et al., 2001; Specht et al., 2014). Associated with these variations, the results indicate that the meteorological variables affected the decrease in the numbers of the three species in different ways (Table 3).

The caterpillars of each species have different habits and consume variable food resources (tissues): The caterpillars of *A. infecta* have cryptic coloration (green), rest all day on the leaf limbs and are exposed to daily climatic variations (warmer during the day and cooler at night). Plant tissues commonly consumed (leaves), especially native and cultivated grasses (oats, ryegrass, grasses, millet and corn) tend to be less nutritive (Teston et al., 2001; Lafontaine, 2004). Since they stay close to the leaves, they are relatively more exposed to the attack of natural enemies. *Elaphria agrotina* caterpillars, however, prefer dry plant materials and stay in the soil feeding on debris/tillage or dead plant structures such as maize, including leaves, cobs, stigmas and dried seeds (Specht et al., 2014). Because caterpillars are usually close to the ground, they may or may not feed on nutrient-rich foods (depending on seed availability) and be less exposed to daily variations in temperature and relative humidity and are thus sheltered and protected from natural enemies. At last, *S. frugiperda* caterpillars, although they remain hidden during the day (on the ground or between plant structures), are very mobile from birth and prefer to attack leaves that are starting to develop (attacking the maize, millet and sorghum (Harvey et al., 2008; Casmuz et al., 2010; Favetti et al., 2017). Because they are very mobile, *S. frugiperda* caterpillars are usually sheltered during the day and move out from dusk to early evening to eat, being protected from natural enemies most of the time. This greater mobility still allows their caterpillars (when available) to explore preferred hosts and plant tissues with higher nutritional value, including growing flowers, fruits, seeds or tissues.

Still regarding interspecific variations, the table data shows that the numbers of individuals of *A. infecta* and *E. agrotina* decreased in a similar manner on the three first crops (Table 1) and suffered negative influence of the meteorological parameters that were analyzed (Table 3); but showed differentiated monthly populational variations (Table 2). These divergences between specific monthly abundances were associated with the different degrees of influence of each meteorological parameter (Table 3). We attribute this discrepancy of population variations over time (four crops) and the level of meteorological influence to the different

bioecological aspects of each species (Kasten et al., 1978; Teston et al., 2001; Specht et al., 2014).

It is important to point out in this context is that in the crop season that preceded the first crop of the present study (2012/2013), precipitation was 1229.1 mm^3, very similar to the value of crop season 1 (1250.9 mm^3), before large precipitation oscillations (Fig. 1) motivated especially by El Niño (NOAA, 2018). In this sense, several studies have shown that abrupt climatic variations lead to large population fluctuations of insects, including Lepidoptera (Woiwod, 1997; Cornelissen, 2011; Wilson and Maclean, 2011). In addition to the annual oscillations, one should pay attention to the monthly variations in precipitation (Fig. 2) because it varied considerably in the same crop season from one month to another, and in the same month in the different crop seasons, consequently influencing the other monthly meteorological factors differently. The result of this is that insect populations that have a relatively short life cycle were subjected to great climatic variations either directly or indirectly associated with the availability of host plants.

The significant correlation between meteorological factors and ONI with the specific abundance of the three species (Table 3) indicate that the direct relationship of the oscillation of ONI with cyclical climatic variations (Holmgren et al., 2001) including episodes of drought at the studied site (Figs. 2 and 3), can be used to make predictions and proactive management of pests. To make more precise predictions, however, long-term studies in different places and monitoring both adult and immature forms are necessary (Summerville and Marquis, 2017). Beyond that, the different characteristics of the species and agroecosystems need to be considered, including dispersion capacity (Ferguson et al., 1991), the effects of the agricultural landscape on metapopulations (Mennechez et al., 2003; Colombo and Anteneodo, 2015), gene exchanges (Nagoshi et al., 2017), natural biological control (Pereira et al., 2018), phytosanitary products and cultural practices (Gallo et al., 2002).

The relationship (despite seasonal differences) of the population dynamics of *A. infecta*, *E. agrotina* and *S. frugiperda* with meteorological variables and ENSO indicate the possibility of forecasting related to increases or even population outbreaks, subsidize decision-making to their management. In order to increase the precision of the models associated to the forecasts, it is necessary to monitor these insects for a longer period, including more climatic variations episodes, especially the related to El Niño and La Niña events.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

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