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Spatio-temporal distribution of the leaf crown borer *Eupalamides cyparissias* in coconut (*Cocus nucifera* L.) plantation in a tropical region

Raphael Coelho Pinho[1*], Paulo Roberto da Silva Farias[2], Telma Fatima Vieira Batista[2], Artur Vinicius Ferreira dos Santos[3], Lucas Faro Bastos[4]

[1]Marabá Industrial Campus, Federal Institute of Pará (CMI-IFPA), 68508-970, Marabá, Pará, Brazil
[2]Department of Plant Biology and Plant Health, Institute of Agricultural Sciences, Federal Rural University of the Amazon (UFRA), 66077-530, Belém, Pará, Brazil
[3]Faculty of Geoprocessing, Federal University of Pará (UFPA), 67130-660, Ananindeua, Pará, Brazil
[4] SOCOCO S/A – Agroindústrias da Amazônia, Brazil

***Corresponding author: raphael.pinho@ifpa.edu.br; raphaelcoelhopinho@gmail.com**

Abstract

The leaf crown borer *Eupalamides cyparissias* (Fabricius, 1777) is an agricultural pest that deserves attention in the cultivation of coconut (*Cocos nucifera* L.) and other economically important palm trees (Areacaceae). Several studies address the use of geostatistics to understand the attack of pest insects in agriculture, but there are no studies on the spatial and temporal patterns of *E. cyparissias* in coconut trees. The presence or absence of the borer was verified monthly in all coconut plants of a plot measuring 12.5 hectares, from July 2018 to October 2020. The occurrence of the borer was verified by the appearance of two main symptoms in the coconut trees. Dispersion patterns of *E. cyparissias* were studied using semivariograms to determine the most suitable spatial distribution model for the species. Kriging maps were created. Exponential and spherical semivariogram models showed the best fit to the patterns of spatial dispersion of the borer, showing that the attack on the coconut plantation occurs in an aggregate, and in foci, with a range of 20 to 160 metres. The climatic data had no significant correlation with the infestation rate. These results show that geostatistics are an important tool to define reliable sampling plans for integrated pest management. It is useful to assess the spatial and temporal distribution of *E. cyparissias*.

Keywords: Geostatistics, Kriging, Leaf crown borer, *Cocos nucifera*, spatial distribution, palm trees.
Abbreviations: ha: hectare (measure equivalent to a square with all sides measuring 100 metres).

Introduction

The coconut (Cocos nucifera L.) crop represents important economic activity in Brazil, with a production chain that generates more than 100 different products, both for fresh consumption and industrialized foods, textiles, vehicle upholstery, animal feed, and more. This activity provides direct and indirect jobs for rural farm workers, in the agro-industry, and in product commercialization, favouring the permanence of workers in agricultural regions (Fróes Júnior et al., 2019). Brazil is the world's fourth-largest producer of coconuts, producing 2.46 million tonnes in 2020. The largest global producers are Indonesia, India, and the Philippines (FAO 2020). With a total planted area of 188,801 hectares and a production value of US$222 million, the northeastern Brazil produces the most coconut, accounting for 73.4 percent of the national production, followed by the Brazilian Amazon, at 12.1 percent of the planted area (IBGE 2020; FAO 2022). The leaf crown borer *Eupalamides cyparissias* (Fabricius, 1777) (Lepidoptera: Castniidae), with current nomenclature by Lamas (1995), has the synonyms *Cyparissius daedalus* (Cramer), Castnia daedalus (Cramer), *Eupalamides daedalus* (Cramer) and *Lapaeumides daedalus* (Cramer). It is considered a polyphagous pest native to South America, found from northern South America to the Amazon Basin, including Peru, Colombia, Ecuador, Venezuela, Guyana, and northern Panama (Howard et al., 2001). It is a palm borer that deserves attention due to the damage initially caused to the base and peduncle of the leaves and fruits as well as the stipe near the crown. In some cases, it can reach the meristem of the palm trees and cause their death. The coconut tree is susceptible to attack after the formation of the stipe, at between four to five years, and remains so until it reaches seven metres, whereas the oil palm (*Elaeis guineensis Jacq*.) becomes susceptible after five years (Howard et al,, 2001). The larvae begin infestation by feeding on the tender tissues in the leaf axils, fruit peduncles, and stem, creating galleries that increase in diameter with the development of the larvae. Some larvae can feed on the tissue of the arrows and the meristem, which can lead to the death of the plant. This pest reduces the number and size of inflorescences, fruits, and leaves, which drop prematurely, and increases flower abortion. Its attack can be an attraction for other borer pests such as Ryhnchophorus palmarum L. (Coleoptera: Curculionidae), which is attracted by exudates from the attacked tissues (Ferreira et al. 1997; Howard et al. 2001). Preventive measures such as pest monitoring and pruning and destruction of infested parts, stems, and fruits are necessary as they prevent further damage (Howard et al,, 2001; Vasquez et al., 2008).

In addition to coconut, the borer also attacks oil palm (E. guineensis Jacq.), palm trees of the *genus Maximiliana, Oenocarpus, Pritchardia, Livistona, Mauritia, and Roystonea*, Mauritia carana Wallace, Mauritiella peruviana Becc. Burret, *Astrocaryum murumuru* Mart., Astrocaryum havarense Trail ex Drude, banana (*Musa* spp.), sugarcane (*Saccharum officinarum L*.), and pineapple (*Ananas comosus* L.) (Howard et al., 2001). The palm species *Syagrus romallzoffiana* (Cham.) Glassman, *S*. schizophylla (Mart.) Glassman, *Hyphaene thebaica* (L.) Mart., *Livistona sp*., *L. chinensis* (Jacq.) R. Brown, *Nephrosperma sp*., Phoellix dactylifera L., *P. rupicola* T. Anderson, *Pritchardia pacifica* Seemann and H. Wendl., *Sabal* sp., *S. blackburniana* Glazebrook ex. Schultes, *S. mexicana* Mart., and *Washingtonia filifera* (Linden) H. Wendl are alternative hosts (Delgado and Couturier 2003). The presence of host plants is an important factor in the distribution of insect pests as they provide shelter and food (Zou et al., 2020).

Geostatistics regarding the spatial distribution of insects is essential to understand population dynamics and to develop effective sampling plans that assist in decision making and adoption of more efficient control measures (Ribeiro et al., 2021). This tool has been successfully applied to the study of the spatial distribution of several insect species (Dinardo-Miranda et al., 2007).

Classical statistics assume that sample values are spatially independent (Journel and Huijbregts, 1978). Geostatistics assume the correlation of samples as a function of the distance between them in space. This is used to understand the spatial dependence, spatio-temporal distribution, and colonization patterns of organisms. The dependence is estimated by the interpolation method called kriging. Such estimates are determined by the averages of the weights of neighbouring samples. These weights are determined based on the spatial behaviour of the samples through a variogram model, creating a mathematical function that explains the variation in space (Farias et al., 2018; Ribeiro et al., 2021; Zakeri and Mariethoz, 2021).

This study aims to characterize the spatio-temporal distribution of E. cyparissias in a coconut plantation in the eastern Amazon and report the distribution pattern of this borer.

Results

Spatial and temporal distribution

The coefficients of determination are above 95% in most of the 26 samples, of which only 3 were below this value. All parameters of the exponential and spherical models, with the exception of February 2020, had coefficients of determination above 80%, which indicates a good fit according to Downing (1986).

The exponential model showed the best fit in most of the months evaluated, adjusted in a total of 18 months. The spherical model, in turn, presented adjustment in a total of 8 months, indicating a predominance of the adjustment to the exponential model. The radius of influence ranged from 15 m to 160 m and the lowest value was found in February 2020, when the coefficient of determination was below 80%, according to the criterion of Depickere et al. (2008). Considering only the models with R2 above 80%, the radius ranged from 20 to 160 m. The aggregation area in the coconut plantation ranged from 1256 to 80384 m2. These data suggest that from 8 plants per hectare to 1 plant per 8 hectares should be checked to obtain a reliable estimate of the borer population in July 2018 and July 2019, respectively, according to the aggregation areas and the range of semivariogram models and kriging maps (Table 1, Fig. 2; Fig. 3).

The spatial dependence index is calculated by the ratio between the nugget effect (C0) and the total effect (C0+C1). In the study, there was moderate spatial dependence during most of the evaluated period, with values indicating a strong dependence of 0.19 in September 2020 and a moderate dependence of 0.69 in January 2019. No sample showed a weak degree of dependence, and only the final months of May, June, September and October 2020 showed strong dependence (Table 1).

Association with climatic factors

The climatic data of mean temperature, mean wind speed, mean precipitation, and wind direction had no significant correlation with the infestation rate, with Pearson index values of 0.00004, and Spearman index values -0.13, -0.2183, of 0.08, respectively, indicating that *E. cyparissias* suffers little influence from these climatic factors (Table 3).

Discussion

Spatial and temporal distribution

The borer presents an aggregate pattern of spatial and temporal distribution when attacking coconut plantation. Depickere et al. (2008) confirm this pattern and state that insects are unlikely to have a uniform distribution. Aggregate formation is a common feature, as well as several factors such as behavior and flight habit. More specifically, the borer has a habit of twilight flight, with the aim of mating and laying eggs in coconut trees (Ferreira et al., 1997; Korytkowski and Ruiz 1979).

According to Brandão et al. (2017), who evaluated the spatial distribution of *Opsiphanes invirae* (Lepidoptera: Nymphalidae) in the oil palm crop, these spherical and exponential patterns are the ones that best fit for this pest, with a predominance for the spherical model. These differences in spatial distribution patterns may be associated with the fact that *O. invirae* is a defoliator while *E. cyparissias* is a stem borer, both occurring in coconut and oil palm crops. O. invirae reached ranges that varied from 990 to 3700 m in oil palm, compared to 20 to 160 m for E. cyparissias in coconut.

Despite being a large moth*, E. cyparissias* has a low range value compared to other moths and borers that attack palm trees (Table 1). This low range value can be explained by the few hours of daily flight of *E. cyparissias*, which leads to a lower dispersion and range parameter of the semivariogram in relation to other palm pests (Brandão et al., 2017; Ferreira et al., 1997; Korytkowski and Ruiz 1979; Howard et al., 2001; Pinho et al. 2016).

Focus in Forest

The maps in fig. 2 show an aggregation and distribution trend that starts and expands along the forest edge that surrounds and crosses the J-124 coconut plot. An important factor in the distribution of insect pests is the presence of host plants, as they provide shelter and food and have great influence on the distribution of host insects, which may be

Table 1- Fitted parameters of the semivariogram models from July 2018 to October 2020 in plantation of coconut, state of Pará, Brazil.

Month	Infestation (%) [(a)]	Parameters			Model	R^2 [(b)]	k [(c)]	Spatial dependence
		C_0	C_1	a (m)				
Jul/18	3.6%	0.014	0.0065	20	Exponencial	92%	0.32	Moderate
Sep/18	5.0%	0.018	0.013	28	Exponencial	97%	0.42	Moderate
Oct/18	13.1%	0.034	0.045	45	Exponencial	99%	0.57	Moderate
Nov/18	8.7%	0.037	0.015	130	Spherical	99%	0.29	Moderate
Dec/18	6.3%	0.015	0.026	45	Exponencial	99%	0.63	Moderate
Jan/19	12.7%	0.026	0.059	53	Exponencial	100%	0.69	Moderate
Feb/19	17.4%	0.036	0.069	107	Spherical	100%	0.66	Moderate
Mar/19	13.5%	0.039	0.044	110	Spherical	99%	0.53	Moderate
May/19	16.3%	0.044	0.053	110	Spherical	99%	0.55	Moderate
Jun/19	19.6%	0.058	0.054	110	Spherical	99%	0.48	Moderate
Jul/19	18.1%	0.066	0.042	160	Spherical	99%	0.39	Moderate
Aug/19	16.4%	0.047	0.051	130	Spherical	99%	0.52	Moderate
Sep/19	10.5%	0.064	0.028	70	Exponencial	88%	0.30	Moderate
Oct/19	24.1%	0.045	0.096	50	Exponencial	100%	0.68	Moderate
Nov/19	30.8%	0.06	0.123	70	Exponencial	99%	0.67	Moderate
Dec/19	8.3%	0.03	0.023	35	Exponencial	96%	0.46	Moderate
Jan/20	19.8%	0.0325	0.011	90	Exponencial	97%	0.25	Moderate
Feb/20	7.2%	0.02	0.0185	15	Exponencial	79%	0.48	Moderate
Mar/20	19.7%	0.054	0.056	38	Exponencial	99%	0.51	Moderate
Apr/20	28.3%	0.088	0.09	130	Exponencial	99%	0.51	Moderate
May/20	7.4%	0.03	0.0097	30	Exponencial	99%	0.24	Strong
Jun/20	3.0%	0.0136	0.0034	20	Exponencial	91%	0.20	Strong
Jul/20	33.7%	0.107	0.074	80	Exponencial	99%	0.41	Moderate
Aug/20	21.0%	0.06	0.052	43	Exponencial	100%	0.46	Moderate
Sep/20	5.9%	0.029	0.0067	55	Exponencial	99%	0.19	Strong
Oct/20	5.2%	0.0215	0.0067	34	Spherical	99%	0.24	Strong

[a] Percentage ratio between the number of coconut trees infested with *E. cyparissias* and the total coconut trees. [b] R^2 values next to 100% show a good fit to model. [c] SDI calculated according to the formula $C_0/(C_0 + C_1)$ (Cambardella et al. 1994).

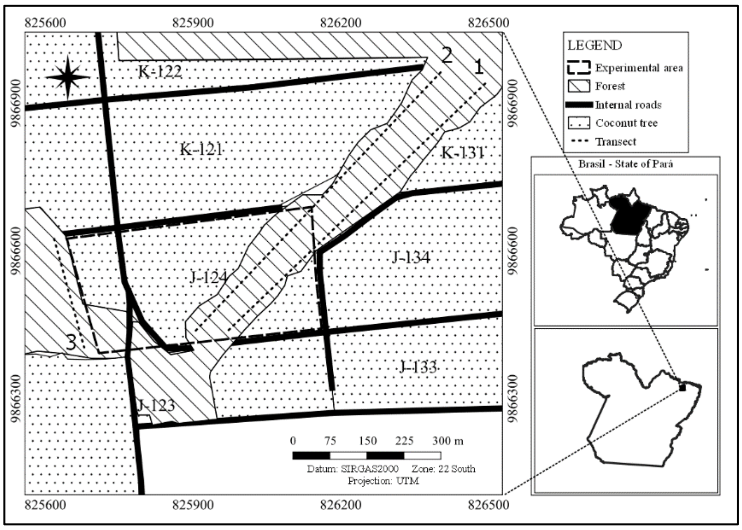

Fig 1. Map of the experimental area J-124 (center), consisting of coconut plantation, forest and internal roads. Dashed lines 1, 2 and 3 are the transects for host plant identification.

Table 2. Plants of the Arecaceae family that host *E. cyparissias* in three transects in the experimental area.

Common name	Scientific name	Occurrences	Number
Mumbaca	*Astrocarium mumbaca* (Mart.)	60	134
Açaízeiro	*Euterpe oleracea* (Mart.)	27	95
Paxiubeira	*Socratea exorrhiza* (Mart.)	15	31
Bacabeira	*Oenocarpus bacaba* (Mart.)	9	15
Ubim	*Geonoma deversa* (Poiteau) Kunth	3	5

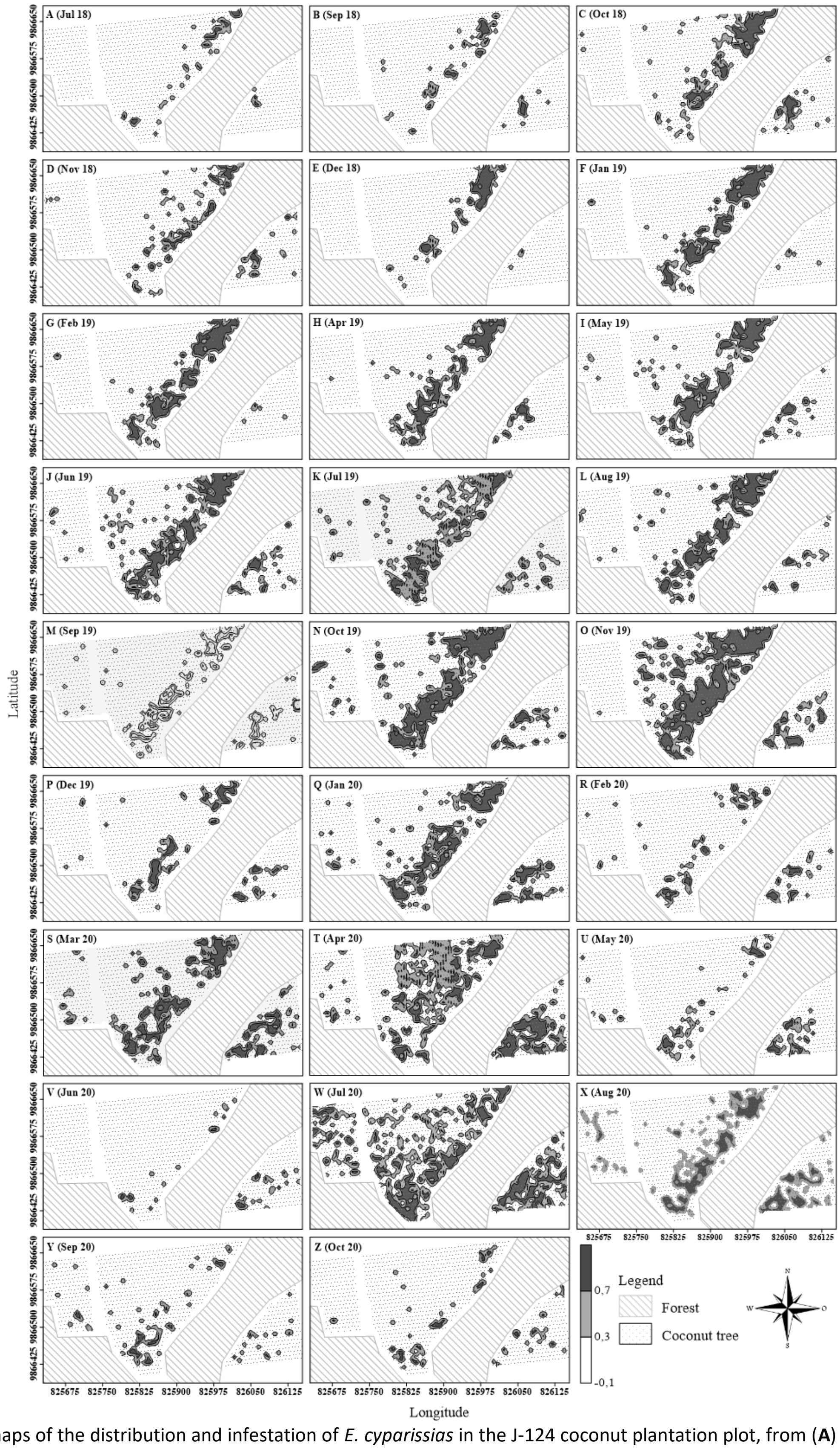

Fig 2. Kriging maps of the distribution and infestation of *E. cyparissias* in the J-124 coconut plantation plot, from (**A**) July 2018 to (**Z**) September 2020. The plot is bordered on the west and southwest by forest, and crossed by riparian forest that divides the plot into two separate areas. Darker spots indicate greater infestation by the borer, that is, greater agglutination of coconut trees with symptoms of the attack.

Table 3. Spearman and Pearson correlations between infestation rate and mean preciptation, mean wind Direction, mean temperature and wind direction from 2018 to 2020. Pearson correlation used for variable with normal distribution and Spearman for at least one variable with non-normal distribution.

Correlated variables with infestation rate**	p-valor	Correlation	Correl. Type
mean temperature**	0.9998*	0.000043	Pearson
mean wind speed***	0.5147*	-0.13	Spearman
mean preciptation***	0.3153**	-0.2183	Spearman
wind direction***	0.6886*	0.08	Spearman

*P values greater than 0.05, correlation does not differ significantly from 0. There is good evidence that the correlation is not significant. **Variable with normal distribution (Shapiro and Wilk test at 5%). ***Variable with no normal distribution (Shapiro and Wilk test at 5%).

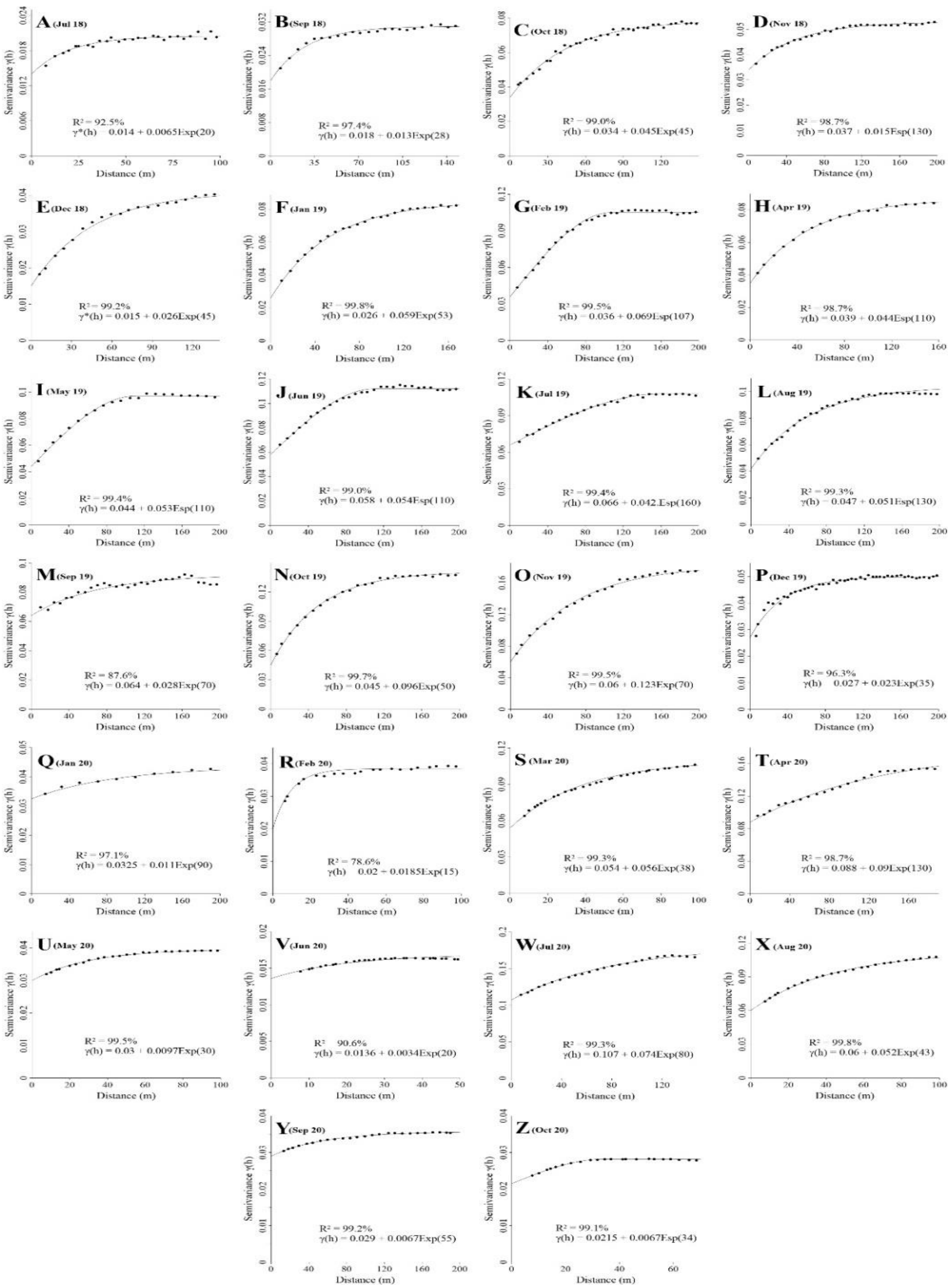

Fig. 3 – Semivariograms of *E. cyparissias* infestation in J-124 plot, from (**A**) July 2018 to (**Z**) October 2020, which show the increase in semivariance "γ*(h)" in relation to the increase in distance "h" between points in space. R^2 values close to 100% indicate a good fit to the model. γ*(h) is the adjusted formula of the semivariogram according to the model, which can be exponential "Exp()" or spherical "Esp()".

linked to this focus of aggregation (Bosco et al., 2020; Rodrigues et al., 2022; Zou et al., 2020). Pinho et al. (2016) observed the relationship of the neighboring forest to the plantation with the emergence of R. palmarum infestations in oil palm, which presents similarity to E. cyparissias and causes drilling in palm trees. Many of the palm trees (Arecaceae) that host the borer are native to the Amazon. In the transept made in the forest areas, the most found Arecaceae species was Astrocarium mumbaca, followed by *Euterpe oleracea, Socratea exorrhiza, Oenocarpus bacaba and Geonoma reverse* (Table 2). *A. mumbaca* is not identified as a host of the borer, while Astrocaryum murumuru (Mart.) and *Astrocaryum javarense* (Trail ex Drud) are identified as hosts. The genera Euterpe and Oenocarpus are host plants, indicating their presence in the experimental area (Howard et al., 2001; Delgado and Couturier, 2003).

The movement of species between habitats is a common phenomenon for several species, and the movement of organisms from natural habitats to agroecosystems is a well-studied phenomenon, but few studies have examined the reverse movement from agroecosystems to natural habitats. The explanation is that organisms are often searching for other sources (food, mating, shelter, microclimate, among others) that are separated in space, in a phenomenon that is called “landscape complementation”, which occurs when landscapes contain two or more non-replaceable and spatially separated resources, important for vertebrates such as moths, parasitoids, and bees. Moths such as E. cyparissias can seek sources other than host plants and leave natural habitats such as forests to coconut plantations (Tscharntke et al., 2012).

Therefore, it would be effective for coconut palm producers to intensify the monitoring of the presence of coconut plants affected by *E. cyparissias* on the margins of riparian forest, as these are more likely to be attacked by this pest insect, as they have a high possibility to emerge from this type of habitat.

Association with climatic factors

The little influence from these climatic factors is partly due to the twilight habit of adults as well as where the pupae and larvae are found (inside the stipe of palm trees and protected from the weather). This differs from other insects that are strongly influenced by climatic factors (Farias et al., 2018; Depickere et al., 2008), such as R. palmarum, which is influenced by rain and does not have a restricted flight schedule (Pinho et al., 2016; Cysne et al., 2013). Liégeois and Tixier et al. (2016) founded a significant correlation between distance and relative humidity, flight preference on clear days and at low wind speeds of Paysandisia archon (Lepdoptera: Castiinidae), however not found a correlation between distance and air temperature, a similar result for E. cyparissias.

Materials and Methods

Exp*erimental site*

The study area is in Santa Izabel do Pará-PA, Brazil, Eastern Amazon in a commercial plantation of green dwarf coconut (*C. nucifera L.*) destined for water extraction at Fazenda Reunidas Sococo. The area is located at coordinates 01°12'21.89"S latitude and 48°04'18.57"W longitude. It is composed of three distinct environments: coconut plantation, vehicle flow roads, and a riparian forest that borders a stream. The study plot is called J-124 and has equilateral spacing (7.5 x 7.5 x 7.5 m). It was implemented in 2012 with 1,450 plants over 12.5 hectares (Fig. 1).

Climatic data and Statistical analysis

The climate is classified as Afi according to Köppen, characterized as rainy tropical, always humid, with no defined dry season, showing an average temperature of the hottest month above 18°C, and exceeding the total of 1,500 millimetres of precipitation per year. In the region, precipitation can reach 3,000 millimetres per year and relative humidity can reach 80 percent. The period of greatest precipitation occurs from January to May, while the period of lowest precipitation occurs from June to December (Andrade et al., 2017; Dubreuil et al., 2017). The values of monthly mean temperature (°C), monthly rainfall (mm), mean wind speed (m/s), and wind direction (°) were correlated to infestation values by the Pearson and Spearman correlation test, using the Rstudio software. Shapiro and Wilk test at 5% was used to test the normality hypothesis. Climatic data was obtained from the conventional weather station in Castanhal, PA (code: A202), under the coordinates 47.95° W longitude and -1.30° S latitude (R Core Team 2022; Best and Roberts 1975; Hollander and Wolfe 1973; INMET 2021).

Measured characteristics

The data used was obtained by monthly monitoring the symptoms of the presence of the borer in the plants from July 2018 to October 2020, in the J-124 plot, accounting for 26 evaluations made available by Sococo S/A. The plants were inspected by highly trained employees who evaluated the presence or absence of symptoms in the plants affected by the attack of the insect pest. For the organization of the database, the binary numerical system was used. When presence was detected, the value "1" was inserted. When presence was not observed, the value "0" was adopted. Identifying the presence of the pest on the farm includes the evaluation of two main symptoms: the occurrence of medium green leaves broken and hanging on the stipe and superficial longitudinal galleries on the stem at 20 centimetres below the leaf crown. The presence of both symptoms is not necessary to attest to the presence of the borer. The method is an adaptation based on Risco (1997) and Korytkowski and e Ruiz (1979b). Three transects were made in the experimental area for sampling and identification of host plants in the forests surrounding the experimental area: two in the riparian forest that crosses the plot, on both sides of the river, with 820 metres each, and another in the forest that is on the west side of the J-124 plot, with 450 metres. The populations of Arecaceae, which comprises the main groups of host plants for the borer, were identified and quantified (Howard et al. 2001; Delgado and Couturier 2003).

Geostatistical analysis and semivariogram calculation

The geostatistical analysis followed the methodology by Farias et al. (2002), which considers the geographic positioning and the values of the samples in each point. The semi-variance of the pairs of samples was calculated and the semivariogram was created, representing the semi-variance as a function of distance, estimated by Eq. 1:

$$\hat{\gamma}^{*}(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(n)}\left[Z(x_i)-Z(x_i+h)\right]^2 \qquad (1)$$

Where: $\gamma^*(h)$ is the estimated semi-variance for a distance h, N(h) is the number of pairs of plants sampled, presence or absence of *E. cyparissias*, and $[Z(x_i)-Z(x_i+h)]^2$ is the difference between the sample values separated by a specific distance h. In this study, each sampled plant represented a point in space with location information (latitude and longitude) as well as presence or absence of the pest in the coconut tree (Eq. 1).

The semivariogram allows for the inference of unsampled values. When there is spatial dependence between the samples, the increase in semi-variance occurs as a result of the increase in the distance of pairs of samples, reaching a sill (C) value, representing the sample variation. The range (a) is the distance from which the semi-variance stabilizes and represents the radius of a circle where the internal samples are correlated. The nugget effect (C0) represents the discontinuity of a semivariogram near the origin when the distances between the sampling units are smaller than the smallest sampling distance or sampling error (Matheron 1963; Vieira et al. 1983; Farias et al. 2018).

For the elaboration of detailed and accurate maps, and for the evaluation of the study, it is necessary to interpolate between the sampled points and to estimate the spatial dependence between the neighbouring samples. The following equation was used:

$$z^*(x_0)=\sum_{i=l}^{N} \lambda_i Z(x_i) \qquad (2)$$

Where: z^* is the estimate, x_0 is the linear combination of the values of the neighbouring measures, N is the number of measured values involved in the estimate, and $Z(x_i)$, λ_i is the weight associated with each measured value (Eq. 2).

Each monthly evaluation underwent adjustment tests to the linear, spherical, exponential, and Gaussian models, using the coefficient of determination (R^2) as a criterion for selecting the model that best fit. Subsequently, the spatial dependence index (SDI) was calculated according to Cambardella et al. (1994), where SDI less than 25 percent indicates strong spatial dependence, SDI between 25 and 75 percent indicates moderate spatial dependence, and SDI greater than 75 percent indicates weak spatial dependence. All adjustments of the semivariograms to the mathematical models and the making of maps interpolated by the kriging method were performed using the software Surfer (Golden Software).

Conclusion

Eupalamides cyparissias presents an aggregated distribution in coconut plantations. The exponential and spherical semivariogram models showed a better fit to the spatial dispersion patterns of the borer. The borer infestation level was not affected by temperature, precipitation, wind speed, and wind direction. The infestation occurred predominantly on the edge of forests and riparian areas, forming aggregates with a range from 20 to 160 metres, making it necessary to intensify sampling and control in these areas.

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