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Original Article

Spatial patterns of the leaf crown borer *Eupalamides cyparissias* (Cramer, 1775) (Lepidoptera: Castiniidae) in coconut (*Cocos nucifera* L.) tropical region

Padrões espaciais da broca da coroa da folha *Eupalamides cyparissias* (Cramer, 1775) (Lepidoptera: Castiniidae) em coco (*Cocos nucifera* L.) região tropical

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Abstract

The leaf crown borer *Eupalamides cyparissias* (Cramer, 1775) is an important pest of coconut (*Cocos nucifera* L.) and other palms (Arecaceae) of economic importance, attacking the base of leaves, inflorescences, and infructescences, increasing fruit abortion. The objective of this study was to evaluate the spatial correlation of the infestation rate of *E. cyparissias* in coconut plantation blocks in the Brazilian Amazon, from January to December 2019, in the city of Santa Izabel, Pará, Brazil. The study area is a farm subdivided into 157 blocks of a commercial plantation of the green dwarf coconut. The Local Moran's Index was used to evaluate the existence of spatial autocorrelation of the *E. cyparissias* infestation rate in the 157 blocks with neighboring blocks. The infestation rate was calculated by the ratio between the number of plants attacked by the borer and the total number of plants in a block. There is a significant correlation of the symptomatology of the attack by *E. cyparissias* in the blocks of the experimental area, which indicates an aggregated pattern of distribution. There is no significant correlation between the attack by the borer and the age of the coconut tree; however there is a significant correlation between the attack by the borer and proximity to forest areas. These results indicate that forest regions are foci of infestation by the borer in coconut plantations.

Keywords: Moran, spatial autocorrelation, leaf crown borer, *Cocos nucifera*, spatial distribution, palm.

Resumo

A broca-da-coroa-foliar *Eupalamides cyparissias* (Cramer, 1775) é um importante praga para as culturas do coqueiro (*Cocos nucifera* Linnaeus) e outras palmeiras (Areacaceae) de importância econômica, atacando a base de folhas, inflorescências e infrutescências acarretando o aumento do abortamento de frutos. O objetivo deste estudo é avaliar a distribuição espacial da taxa de plantas com sintomas de ataque por *E. cyparissias* das quadras de plantio de coqueiro na Amazônia brasileira, de janeiro a dezembro de 2019, no município de Santa Izabel, Pará, Brasil. A área de estudo é uma fazenda subdividida em 157 quadras de plantio comercial de coqueiro anão verde (*C. nucifera*). O Índice de Moran Local foi utilizado para avaliar a existência de autocorrelação espacial da variável sintomatologia do ataque de *E. cyparissias* das 157 quadras com as quadras vizinhas. Há correlação significativa da sintomatologia do ataque por *E. cyparissias* nas quadras da área experimental, o que indica um padrão de distribuição agregado. Não há correlação significativa entre o ataque pela broca e idade do coqueiro, no entanto há correlação significativa entre o ataque pela broca e proximidade a áreas de mata. Esses resultados indicam que regiões de floresta são focos de infestação pela broca em plantios de coqueiro.

Palavras-chave: Moran, autocorrelação espacial, broca-da-coroa foliar, *Cocos nucifera*, distribuição espacial, palmeira.

1. Introduction

The coconut tree probably appeared on the islands of Southeast Asia between the Indian and Pacific oceans. It was later taken to India and East Africa, then to West Africa, arriving in America and the entire tropical region of the globe. The introduction in Brazil first occurred with the Gigante variety in 1553 by the Portuguese, already in the twentieth century the green dwarf was introduced in 1924, the Java variety was introduced in 1939, the yellow dwarf in 1938, and the red dwarf in 1939 (EMBRAPA, 2006).

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In 2021, Brazil was the 5th largest coconut producer in the world with 2.46 million tons in 2020, with Indonesia, India and the Philippines the largest producers (FAO, 2023). With a total harvested area of 186,392 hectares, with a total production value of R$ 1.30 billion, the Brazilian northeast is the largest fruit producer with 75% of production, followed by the southeast region with 13% and the north region with 11% of the production. production. Ceará, Bahia, Alagoas, Sergipe, Pará and Rio Grande do Norte have the largest plantations, with the state of Pará the only one outside the Northeast region (IBGE, 2023). Traditionally in Brazil, the Gigante variety is used for the production of grated coconut, and from 1985 the use of the Anão variety increased, mainly for the production of coconut water. The hybrid coconut palm variety, resulting from the crossing between Gigante and Anão, has dual aptitude, but does not have a significant area, due to the difficulties and costs for the production of hybrid seeds (EMBRAPA, 2006).

During the development of the coconut tree, several diseases and pests appear that cause considerable damage, among them, the borer *Eupalamides daedalus* stands out, an important moth in coconut farming due to the damage initially caused at the base of the peduncle of the leaves and fruits, and in some cases reaching the meristem. of the palm trees causing its death. The pest reduces the number and size of inflorescences, fruits and leaves, which fall prematurely, increasing flower abortion. Its attack can be an attraction for other boring pests such as *Ryhnchophorus palmarum*, the coleoptera is attracted by the exudates of the attacked tissues (Ferreira et al., 1997; Howard et al., 2001). Risco (1996) considers a high population, a coconut plantation with 30.24 larvae per hectare with a critical level of 5% of the plants attacked by the borer. Rai (1973) reported abortion of 85% of flowers in attacked palms.

It is an insect considered polyphagous and native to South America, attacking several species of economic interest. It is found in northern South America and the Amazon Basin, including Peru, Colombia, Ecuador, Venezuela, Guyana and northern Panama (Aldana et al., 2004; EMBRAPA, 2022; Howard et al., 2001, Korytkowski and Ruiz, 1979; Rai, 1973). The adult has crepuscular behavior, very characteristic of the moth, flying in the early morning and late afternoon, at a height between 1 and 4 m (Ferreira et al., 1997). Flight behavior is fundamental for species and sexual dispersal, mating occurs at the end of the flight when the female lands on the tip of a leaflet and lasts from 1 to 3 hours. Depending on the location and climate, the male:female ratio can be 3:1, and the same female can mate with several males (Korytkowski and Ruiz, 1979).

The coconut tree becomes susceptible to attack after the formation of the stipe, between 4 and 5 years, and remains so until it reaches 7 meters. Chemical control with the application of insecticides in the galleries is inefficient due to the great damage already caused by the caterpillar. Preventive measures such as monitoring the pest, changing the harvest cycle, pruning and destroying infested parts are necessary as they prevent greater damage later. Control at the beginning of the infestation has more chances of success, as it minimizes damage, prevents the expansion of the attack , reduces the use of pesticides (Aldana et al., 2004; Howard et al., 2001).

In order to make the control more efficient and precise, it is necessary to know the spatial pattern of distribution of the insect infestation in the field, for that, techniques are used to better understand the spatial dependence between samples through their geographic location and attribute, such as the Moran index. The Moran index (I) is used to understand the spatial distribution between neighboring areas in space, measuring the degree of spatial autocorrelation between variables, and mapping spatial and temporal changes of a phenomenon, indicating as a result a perfect correlation with strong grouping of the phenomenon, a perfect dispersion, or randomness of the phenomenon (Anhê et al., 2021; Lu et al., 2010). Spatial statistics has several applications and can be used for mapping diseases, monitoring environmental problems, ecological studies, and identifying spatial clusters. Clusters represent an aggregate of an event, which can be a disease, mineral concentration, crime, and insect attacks in a given area, and this event is the focus of research in the area of spatial statistics. The types of data used in research are basically referenced points (x, y, z) or adjacent areas (Brasil, 2007; EMBRAPA 2004).

The objective of this study was to evaluate the spatial correlation of the symptomatology of *E. cyparissias* attack in coconut plantation areas in the Brazilian Amazon, from January to December 2019, in the municipality of Santa Izabel, Pará, Brazil.

2. Material and Methods

2.1. Experimental site

The study area is located in the municipality of Santa Izabel do Pará, Pará, Brazil, Eastern Amazon, with a total area of 3567 hectares, subdivided into 157 blocks of commercial plantation of the green dwarf coconut (*C. nucifera*), produced for coconut water, with equilateral spacing (7.5 x 7.5 x 7.5 m), center point 01°12’21.89”S latitude and 48°04’18.57”W longitude (Figure 1).

2.2. Database

Data were obtained through monthly monitoring of symptoms of the borer occurrence in plants in 157 coconut plantation blocks. The plants were inspected by employees who evaluated the occurrence of symptoms on the plants affected by the pest insect attack. The method for identifying the presence of the borer was composed by the evaluation of two main symptoms: medium green leaves broken and hanging from the stipe (out of the common position), and the presence of superficial longitudinal galleries or perforations in the stipe, exactly at 20 cm below the leaf crown; the presence of both symptoms was not necessary to certify the presence of the borer and the method is an adaptation based on Korytkowski and Ruiz (1979), and Risco (1996). The percentage of infestation in each block was given by the ratio between the number of plants with recent symptoms of attack by *E. cyparissias* and the total number of plants in the block. Tukey's test ($p > 0.05$) was applied for the number of plants attacked per month.

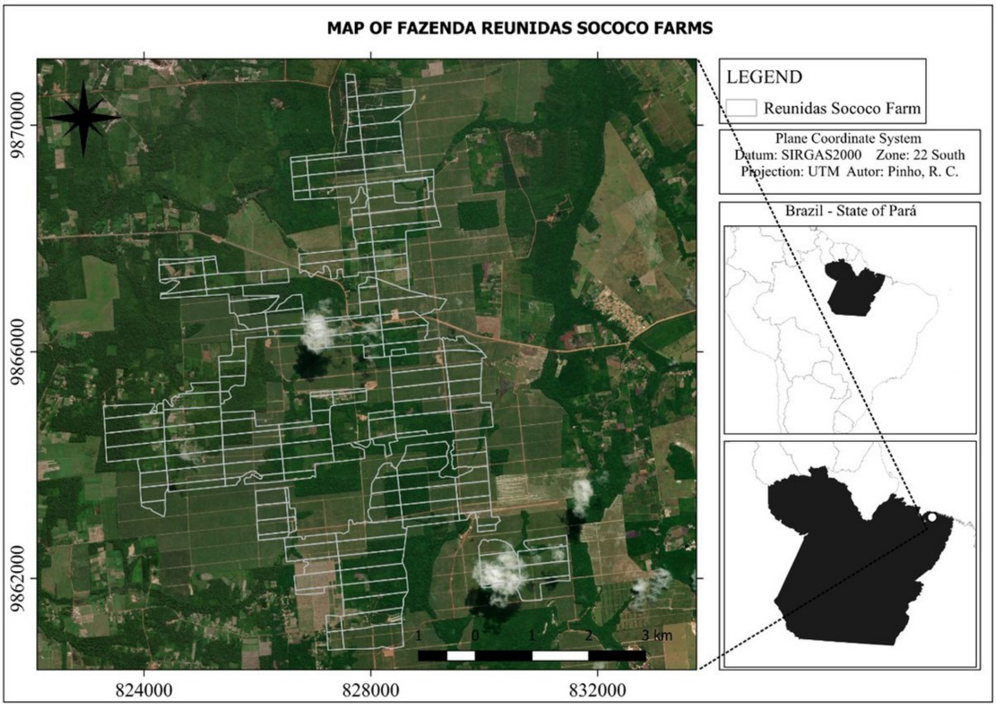

Figure 1. Map of coconut plantation blocks in the experimenxtal area, with satellite image. In dark green are the forest areas, which surround the farm.

2.3. Moran's index

The Local Moran's Index is used to assess the existence of spatial autocorrelation of a variable in a given region with neighboring areas, and to generate area-specific values through spatial clusters (Celebioglu and Dall'Erba, 2010). The Global Moran's Index is calculated by Equation 1:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} z_i z_j w_{ij}}{S_0 \sum_{i=1}^{n} z_i^2} \quad (1)$$

Where n is the number of populations or areas, z_i is the standard deviation of the analyzed plot and z_j is the standard deviation of the neighboring plot, for $i \neq j = 1,....,$ and n observed values of populations i and j centered on the average of the variable x under study; w_{ij} is the element of the weight matrix W, $n \times n$, which expresses the spatial relationship between the n populations, and S_0 is defined by Equation 2:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \quad (2)$$

In this study, the spatial weight matrix based on the proximity of the queen-type contiguity convention was used, as it relates all samples that border (EMBRAPA 2004; Seffrin et al., 2018). The calculation of the Moran scatter diagram is performed to visualize the spatial autocorrelation and the global measure of spatial linear association between its neighbors divided into four quadrants: high-high (AA), high-low (AB), low-high (BA), and low-low (BB) (Figure 2) (Almeida, 2012; Rodrigues et al., 2015).

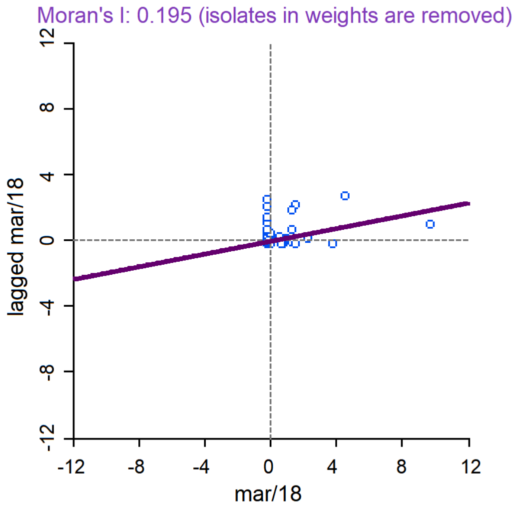

Figure 2. Moran's index scatterplot.

The expected Moran's index is given by E(I)=[-1/(n-1)], where positive values indicate positive correlation, negative values indicate negative correlation, and null values indicate absence of spatial correlation. Values close to 0 indicate lack of correlation and spatial dependence of the studied phenomenon. Values of I equal to 1 indicate perfect correlation, with strong clustering of the phenomenon, while values equal to -1 indicate perfect dispersion, and values equal to 0 indicate randomness of the phenomenon (Anhê et al., 2021; Lu et al., 2010; Cocu et al., 2005).

2.4. Correlation with neighboring areas

The attack symptomatology in each plot was correlated with the perimeter (in meters) that each plot has of proximity to forest areas, using QGIS. The symptomatology of the monthly attack was correlated in order to identify the existence of an association between proximity to forest areas and increased infestation. Additionally, the symptomatology was correlated with the age of each plot to identify the possible association between the two variables (Table 1). The data were submitted to the Shapiro-Wilk's normality test to identify the normality of the variables (Toutenburg et al., 1973; Best and Roberts, 1975; Bishara and Hittner, 2012). Spearman's test values are represented by the letter ρ (rho) and range from -1 to 1, where -1 indicates an opposite relationship, therefore one variable increases with the reduction of the other, while the value +1 indicates a positive relationship, where there is an increase in one

Table 1. Age and measurement of the perimeter of each block adjacent to forest areas in the experimental area (Fazenda Reunidas SOCOCO). The reference year of the plants is 2022.

Block	Age	Adjacent forest (meter)	Block	Age	Adjacent forest	Block	Age	Adjacent forest	Block	Age	Adjacent forest
E-132	10	268 m	G-162	10	261 m	I-131	10	986 m	K-142	10	286 m
E-133	10	260 m	G-163	10	257 m	I-132	2	377 m	K-143	10	1711 m
E-142	10	912 m	G-164	10	646 m	I-133	2	392 m	K-144	10	182 m
E-143	10	839 m	H-101	8	0 m	I-141	10	573 m	K-151	10	604 m
E-144	10	298 m	H-102	8	197 m	I-142	10	763 m	K-152	10	87 m
E-164	10	602 m	H-103	8	104 m	I-143	10	636 m	K-153	10	258 m
E-174	10	79 m	H-104	11	284 m	I-151	10	507 m	K-154	10	254 m
F-131	10	301 m	H-111	11	200 m	I-152	10	1301 m	L-111	10	876 m
F-132	10	440 m	H-112	11	0 m	I-153	10	1192 m	L-121	10	277 m
F-133	10	380 m	H-113	11	0 m	I-154	10	1105 m	L-134	10	149 m
F-134	10	839 m	H-114	11	0 m	I-161	10	0 m	L-141	10	0 m
F-141	10	800 m	H-121	11	548 m	I-162	10	169 m	L-142	10	0 m
F-142	10	1013 m	H-122	11	737 m	I-163	10	0 m	L-143	2	432 m
F-143	10	719 m	H-123	11	169 m	I-164	10	126 m	L-144	10	1400 m
F-144	10	881 m	H-124	11	539 m	J-121	10	517 m	L-151	10	285 m
F-161	10	0 m	H-131	10	524 m	J-122	10	513 m	L-152	10	0 m
F-162	10	402 m	H-132	10	445 m	J-123	10	729 m	L-153	10	963 m
F-163	10	743 m	H-133	10	110 m	J-124	10	959 m	L-154	10	504 m
F-164	10	518 m	H-134	10	263 m	J-132	10	485 m	M-131	10	253 m
F-171	10	438 m	H-141	10	403 m	J-133	10	0 m	M-132	10	266 m
F-172	10	691 m	H-143	10	1292 m	J-134	10	520 m	M-133	10	0 m
F-173	10	273 m	H-144	10	332 m	J-141	2	555 m	M-141	10	483 m
G-104	8	745 m	H-151	10	351 m	J-142	10	696 m	M-142	10	1000 m
G-121	4	0 m	H-152	10	281 m	J-143	10	0 m	M-143	10	0 m
G-122	4	0 m	H-153	2	0 m	J-144	10	862 m	M-144	10	0 m
G-123	4	0 m	H-154	10	0 m	J-151	10	653 m	M-151	10	1233 m
G-124	4	217 m	H-161	10	567 m	J-152	10	0 m	M-152	10	593 m
G-131	10	124 m	H-162	10	570 m	J-153	10	0 m	M-153	10	414 m
G-132	4	105 m	H-164	4	164 m	J-154	10	0 m	M-154	10	299 m
G-133	4	0 m	I-101	11	0 m	J-161	10	561 m	N-141	10	0 m
G-134	4	0 m	I-102	11	0 m	K-112	10	66 m	N-142	10	0 m
G-141	10	1407 m	I-103	11	607 m	K-113	10	792 m	N-143	10	0 m
G-142	10	296 m	I-111	11	0 m	K-114	10	260 m	N-144	10	198 m
G-143	10	259 m	I-112	11	0 m	K-121	10	434 m	N-151	10	478 m
G-144	10	291 m	I-113	10	460 m	K-122	10	141 m	N-152	10	203 m
G-151	10	1041 m	I-114	10	797 m	K-123	10	1105 m	N-153	10	0 m
G-152	10	0 m	I-121	11	555 m	K-124	10	261 m	N-154	10	0 m
G-153	10	0 m	I-122	11	585 m	K-131	10	583 m			
G-154	10	367 m	I-123	10	364 m	K-133	10	711 m			
G-161	10	440 m	I-124	10	590 m	K-141	10	257 m			

variable with an increase in the other. According to Rumsey (2016), ρ values between 0.3 and 0.5 indicate a weak (positive) ascending linear relationship; ρ values between 0.5 and 0.7 indicate a moderate (positive) ascending relationship; and ρ values between 0.7 and 1 indicate a strong (positive) ascending linear relationship. When ρ values are negative, the same scale is used.

3. Results

3.1. Descriptive statistics

When evaluating the number of plants attacked by the borer, in was observed that there is an increase that starts in March 2018 and stabilizes in the 2nd semester of 2019, followed by a decrease from the beginning of 2020. Throughout the analyzed period, the number of plants attacked varied with a periodicity of 4 to 5 months (Figure 3). Many plots had no cases of attacked plants. In the first month, 135 plots, 86% were not attacked, the highest number of plots not attacked during the entire period, while the lowest was 46 plots, 29% without attacks in the last two months, referring to September and November 2020.

Attack values varied greatly in all months studied, with coefficients of variation ranging from 210% in December 2018 to 542% in November 2018, demonstrating that the data set is highly heterogeneous. Anhê et al. (2021) also found high coefficients of variation in a study on the dispersion of fatal yellowing in oil palm, with CV ranging from 142.79 to 436.7%. The curve showed flattening in all months studied, with kurtosis values greater than 1 (Ribeiro Junior, 2011).

The asymmetry of all evaluated months was greater than 1 and data shifted to the left, with a mode lower than the average, therefore the mode for all months is 0 because there was no borer attack in most plots. Tukey's test ($p > 0.05$) was not adequate as the data did not meet the assumptions of homogeneity and homoscedasticity (Figure 3) (Anhê et al., 2021; Ribeiro Junior, 2011).

3.2. Analysis of spatial autocorrelation

Global Moran's index was calculated to analyze the spatial autocorrelation of the borer in the experimental area. The lowest positive value of the index was 0.003 in November 2018, and the only negative value was obtained in February 2019, corresponding to -0.01, close to zero (Table 2). In 2018 and 2019, the number of attacked plants increased, however the Moran' index values did not follow this increase in attacked plants. Index values showed increases in the first half of 2018 and 2019 and declines from the second half of those same years (Figure 4).

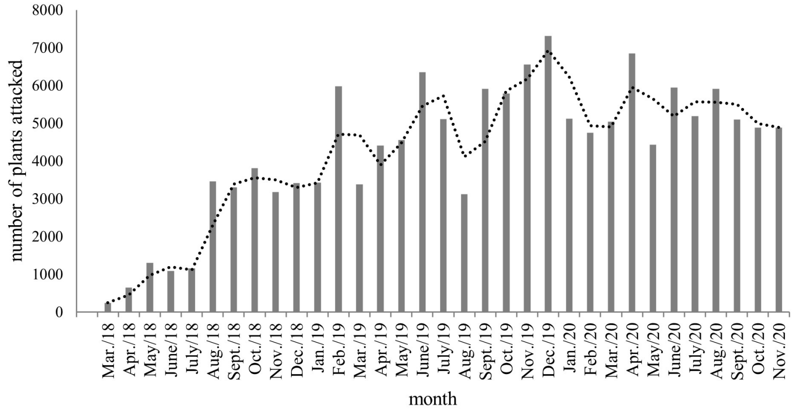

Figure 3. Absolute number of plants with symptoms of attack by *E. cyparissias* in the experimental area per month. Period from March 2018 to November 2020.

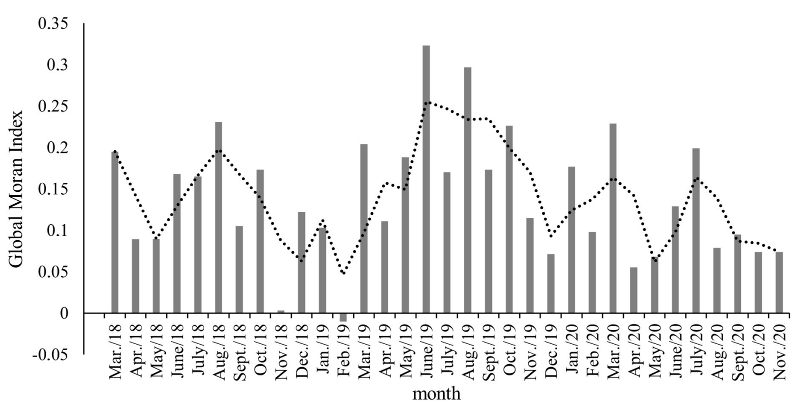

Figure 4. Global Moran's Index of the monthly rate of plants with symptoms of attack by *E. cyparissias* in the experimental area.

Table 2. Parameters of the analysis of the Global Moran's Index for the monthly rate of plants with symptoms of attack by *E. cyparissias* in coconut palms, per block.

Month	Global Moran's Index	p-value	Model	Significance level (%)
March/18	0.195	0.007	Aggregated	1.0
April/18	0.089	0.053	Random	*
May/18	0.09	0.028	Aggregated	5.0
June/18	0.168	0.010	Aggregated	1.0
July/18	0.165	0.011	Aggregated	5.0
August/18	0.231	0.003	Aggregated	1.0
September/18	0.105	0.040	Aggregated	5.0
October/18	0.173	0.006	Aggregated	1.0
November/18	0.003	0.221	Random	*
December/18	0.122	0.025	Aggregated	5.0
January/19	0.103	0.043	Aggregated	5.0
February/19	-0.01	0.441	Random	*
March/19	0.204	0.003	Aggregated	1.0
April/19	0.111	0.041	Aggregated	5.0
May/19	0.188	0.005	Aggregated	1.0
June/19	0.323	0.001	Aggregated	1.0
July/19	0.17	0.01	Aggregated	1.0
August/19	0.297	0.001	Aggregated	1.0
September/19	0.173	0.008	Aggregated	1.0
October/19	0.226	0.002	Aggregated	1.0
November/19	0.115	0.042	Aggregated	5.0
December/19	0.071	0.101	Random	*
January/20	0.177	0.015	Aggregated	5.0
February/20	0.098	0.051	Random	*
March/20	0.229	0.002	Aggregated	1.0
April/20	0.055	0.113	Random	*
May/20	0.068	0.075	Random	*
June/20	0.129	0.021	Aggregated	5.0
July/20	0.199	0.006	Aggregated	1.0
August/20	0.079	0.066	Random	*
September/20	0.095	0.050	Aggregated	5.0
October/20	0.074	0.073	Random	*
November/20	0.074	0.073	Random	*

* Not significant; 5.0 - Significant at 5%; 1.0 - Significant at 1%. (Source: prepared by the author).

In 2018, April and November had a non-significant index, indicating the randomness of the borer attack. In 2019, February and December had a non-significant index value, so the borer attack in these months is random. In 2020, the number of months with random values of the Moran index was 6 months, starting a drop in the index since mid-2019 (Table 3). During this period, the number of plants with borer attack symptoms stabilizes and begins to decrease, the decrease may be associated with the intensification of control of the borer on the farm, decreasing the insect population and breaking the development of the attack, resulting in the large amount of non-significant Moran indices in 2020, therefore the random spatial distribution of the symptoms of the borer attack (Figure 4). Most indices were positive in 2018 and 2019, i.e., in general, in these two years, the borer attack was clustered. The level of statistical significance in the experiment was 1% for months with *p*-value less than 0.01, and 5% for months with *p*-value between 0.01 and 0.05.

In the area, two clusters of the High-High type were identified, with a high incidence of the borer and neighbors with also a high incidence, one in the northwestern region and another in the western region, which remained in 2018 and 2019 and were not constant in 2020 (Figures 5-7).

3.3. Correlation with forest and age

For the correlation between forest and the rate of plants with attack symptoms, only the first month did not have a significant difference from zero ($p > 0.05$), so there was no correlation between the variables, while all the other months differed from zero ($p < 0.05$), reaching 0.54 in August 2018 (Table 4). In 2018, Spearman's correlation values ranged from 0.05 to 0.33 in March and July, respectively. In 2019, the correlation ranged from 0.28 to 0.54 in February and August, respectively. In 2020, the values varied between 0.35 and 0.5 in April and May, respectively. The year 2018 showed the highest correlation values, with the highest rates of symptoms, while the rates decreased in 2020.

Table 3. Descriptive statistics of the percentage of coconut plants with symptoms of attack by *E. cyparissias* from March 2018 to November 2020 in the experimental area.

Month	Total plants attacked	Percentage of blocks attacked			CV	Dispersion	
		Average	Minimum	Maximum		Asymmetry	Kurtosis
March/18	247	0%	0%	4%	438%	7	63
April/18	649	0%	0%	16%	350%	6	43
May/18	1303	0%	0%	14%	508%	10	103
June/18	1092	0%	0%	9%	302%	5	32
July/18	1155	0%	0%	7%	297%	4	20
August/18	3460	1%	0%	24%	249%	5	31
September/18	3308	1%	0%	21%	246%	5	28
October/18	3817	1%	0%	23%	254%	5	31
November/18	3180	2%	0%	15%	542%	12	140
December/18	3423	1%	0%	11%	210%	3	7
January/19	3433	1%	0%	20%	280%	4	19
February/19	5986	2%	0%	34%	283%	5	25
March/19	3380	1%	0%	21%	252%	4	16
April/19	4410	2%	0%	40%	282%	5	34
May/19	4555	1%	0%	16%	231%	3	9
June/19	6356	2%	0%	26%	214%	3	12
July/19	5107	2%	0%	26%	267%	4	14
August/19	3127	1%	0%	17%	265%	4	18
September/19	5919	2%	0%	37%	262%	4	23
October/19	5792	2%	0%	25%	242%	4	15
November/19	6558	2%	0%	37%	236%	4	17
December/19	7319	2%	0%	33%	245%	4	15
January/20	5120	2%	0%	50%	303%	6	40
February/20	4751	2%	0%	23%	225%	4	17
March/20	5044	2%	0%	20%	216%	4	14
April/20	6851	3%	0%	62%	301%	5	30
May/20	4435	1%	0%	21%	236%	4	18
June/20	5943	2%	0%	30%	255%	4	15
July/20	5192	2%	0%	34%	272%	4	17
August/20	5913	2%	0%	37%	253%	4	22
September/20	5096	2%	0%	38%	279%	5	26
October/20	4888	2%	0%	38%	261%	4	24
November/20	4888	2%	0%	38%	261%	4	4

CV: Coeficiente de Variação da estatística descritiva.

Table 4. Spearman's correlation test between the rate of plants with symptoms of the borer attack with the age of the plants in each block and the perimeter of each block that is surrounded by forest.

Month	Spearman's test (ρ) (rate x age)	Spearman's test (ρ) (rate x forest)	Month	Spearman's test (ρ) (rate x age)	Spearman's test (ρ) (rate x age)
March/18	0.00*	0.05*	**August/19**	0.09*	0.54
April/18	-0.02*	0.32	**September/19**	0.14*	0.40
May/18	0.09*	0.20	**October/19**	0.14*	0.48
June/18	0.07*	0.39	**November/19**	0.20*	0.41
July/18	0.14*	0.33	**December/19**	0.07	0.42
August/18	0.11*	0.29	**January/20**	0.13*	0.40
September/18	0.20*	0.29	**February/20**	0.11*	0.41
October/18	0.07*	0.27	**March/20**	0.09*	0.48
November/18	0.02*	0.31	**April/20**	0.04*	0.35
December/18	0.16*	0.26	**May/20**	0.15*	0.50
January/19	0.18	0.34	**June/20**	0.08*	0.44
February/19	0.21	0.28	**July/20**	0.09*	0.48
March/19	0.13	0.31	**August/20**	0.02*	0.47
April/19	0.11*	0.39	**September/20**	0.08*	0.43
May/19	0.19*	0.33	**October/20**	0.08*	0.40
June/19	0.11	0.36	**November/20**	0.08*	0.40
July/19	0.14*	0.36			

*ρ values greater than 0.05 indicate a correlation that does not differ significantly from 0, so there is evidence that the correlation is not significant.

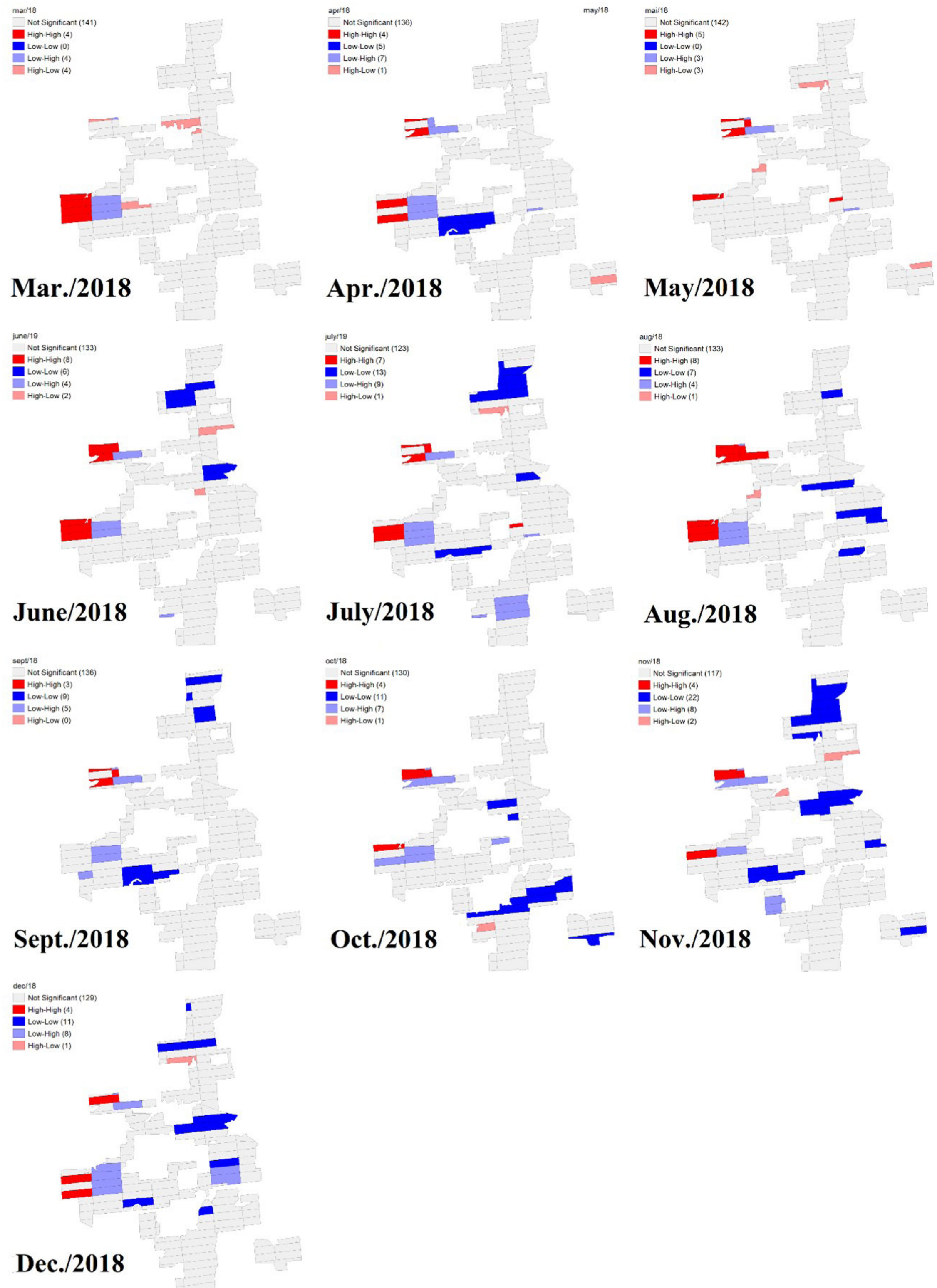

Figure 5. LISA cluster map for spatial correlation of *E. cyparissias* cases in coconut palm (*C. nucifera*) blocks, from March 2018 (Mar./2018) to December 2018 (Dec./2018). Red blocks show a high occurrence of plants with *E. cyparissias* symptoms, and blue blocks show a low occurrence of the borer. The intensity of the color indicates the relationship with neighboring blocks; strong colors indicate positive correlation and weak colors indicate negative autocorrelation.

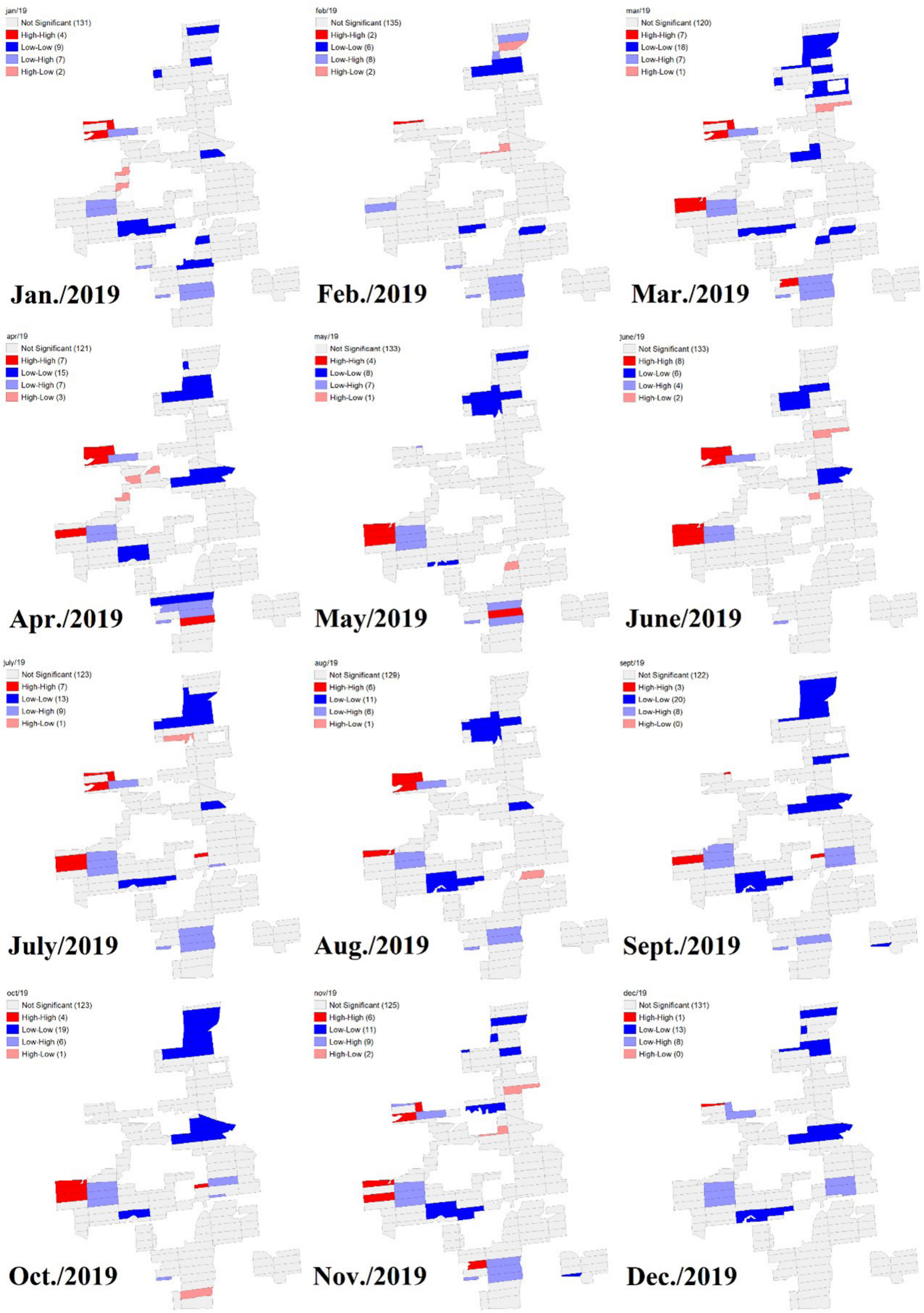

Figure 6. LISA cluster map for spatial correlation of *E. cyparissias* cases in coconut palm (*C. nucifera*) blocks, from January 2019 (Jan./2019) to December 2019 (Sep./2019). Red blocks show a high occurrence of plants with symptoms of *E. cyparissias*, and blocks in blue show a low occurrence of the borer. The intensity of the color indicates the relationship with neighboring blocks; strong colors indicate positive correlation and weak colors indicate negative autocorrelation.

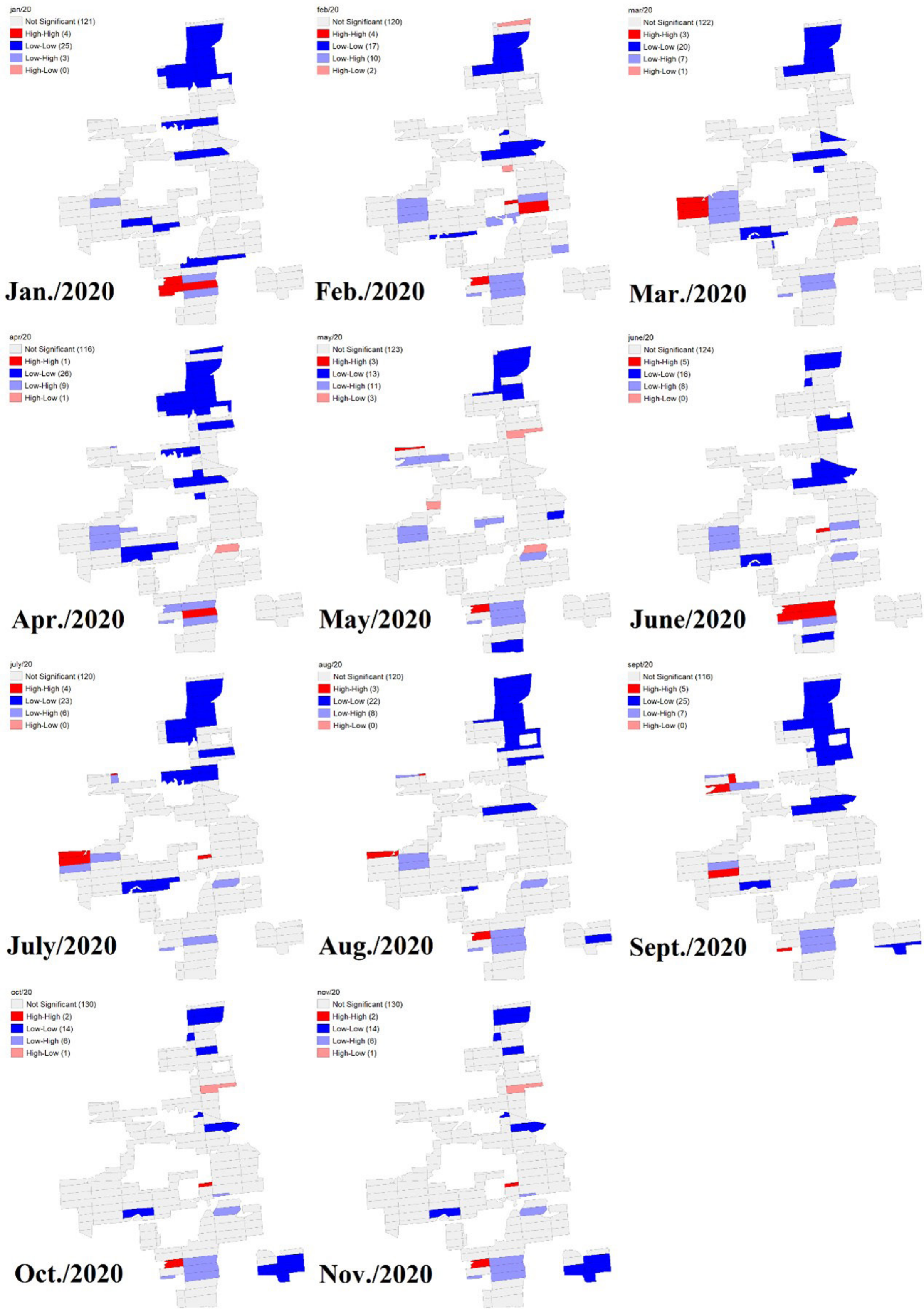

Figure 7. LISA cluster map for spatial correlation of *E. cyparissias* cases in coconut palm (*C. nucifera*) blocks, from January 2020 (Jan./2020) to November 2020 (Nov./2020). Red blocks show a high occurrence of plants with *E. cyparissias* symptoms, and blue blocks show a low occurrence of the borer. The intensity of the color indicates the relationship with neighboring blocks; strong colors indicate positive correlation and weak colors indicate negative autocorrelation.

4. Discussion

The high heterogeneity of the data, positive asymmetry with mode 0 (Table 3), and concentration of attacks in some plots indicate aggregate behavior of the borer and slow dispersion through the field. Anhê et al. (2021) also found high coefficients of variation (CV) in a study on the dispersion of fatal yellowing in oil palm, with CV ranging from 142.79 to 436.7%. The curve showed flattening in all months studied, with kurtosis values greater than 1 (Ribeiro Junior, 2011).

Insects depend on resources that are often located outside the environment where they are found, which causes migration to other areas in search of better conditions to obtain such resources, including cultivated areas. While these insects remain in natural environments, they are normally protected from the application of pesticides, which do not control groups of insects in forests or other areas. Such forest areas thus become a refuge, but nearby cultivated areas become outbreaks of infestation. Tscharntke et al. (2012) explain that organisms are often looking for other sources (food, mating, shelter, microclimate) that are separated in space, in a phenomenon that is called "landscape complementation" and occurs when landscapes contain two or more non-existent replaceable and spatially separated resources. Moths such as *E. cyparissias* may be seeking sources other than host plants, leaving natural habitats for coconut plantations, especially in regions classified as High-High.

Lu et al. (2010) studied the prevalence of soybean mosaic virus (SMV) in counties and municipalities in the state of Iowa/USA and found weak spatial dependence. In the period of highest incidence, the spread of the disease was 2 new infected fields every 2 days. Anhê et al. (2021) evaluated the spatial autocorrelation of fatal yellowing in commercial oil palm plantations in the Eastern Amazon and identified a positive autocorrelation of the incidence of the disease. With the use of the Local Moran's Index, regions of high incidence were identified, making it possible to manage and control the disease more efficiently. As with *E. cyparissias*, fatal yellowing spreads with an aggregated spatial pattern across neighboring blocks. In the study, the possible relationship of the disease to the genetic material of the oil palm in the northeastern region of the experimental area was considered, as well as the possible influence of water bodies on disease development. The borer population presents outbreaks close to forest areas, where host plants are likely to be found, especially from the Arecaceae family, which grow near water courses or reservoirs (Howard et al., 2001; Zou et al., 2020).

Studies carried out by Dionisio et al. (2020) and Pinho et al. (2016), with palm trees, in the oil palm crop, observed that the largest clusters of *R. palmarum* in oil palm plantations start at the edges of the plantation near the forest and grow towards the center, previous studies indicated that these insects invade forests along the edges (Genty et al., 1978). On the other hand, *E. cyparissias* suffered little influence from climatic factors, but the incidence was also higher at the edge of the plantation. In some areas of the experimental area, this phenomenon can be explained by the occurrence of host plants that surround the regions with high incidence clusters (High-High) (Figure 5 and Figure 6), as they provide shelter and food and have great influence on the distribution of the borer (Zou et al., 2020). In Europe, Cocu et al. (2005) applied the Moran's index to study spatial distribution of *Myzus persicae* (Sulzer, 1776), and identified that secondary and primary hosts are located within areas with high insect catch abundance.

Spearman's correlation test was used because attack symptom rates in all months, age of plants in each block, and extension of the perimeter of each block close to forested areas are non-normal variables by the Shapiro-Wilk's normality test (Bishara and Hittner, 2012).

For the behavior of *E. cyparissias*, there was no strong correlation between planting age and attack incidence, indicating that the pest has no preference for plant age of the adult coconut plant, therefore, the analysis was not significant. This behavior was different from that reported by Oliveira et al., (2021) where oil palm in the reproductive stage are more prone to attack by defoliator moths, this palm is known to be little attacked in the younger stage (Table 4). Planting age is probably not a cause of the emergence of High-High clusters (Figure 5-7).

There are strong indications of an association between attack rate and proximity to forest areas (Pinho et al., 2016; Dionisio et al., 2020; Tscharntke et al., 2012; Zou et al., 2020). 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 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. The phenomenon of landscape complementation described by Tscharntke et al. (2012) also explains the positive correlation with proximity to forest areas, as *E. cyparissias* are probably often searching for other sources (food, mating, shelter, microclimate, among others), beyond to host plants that are probably located in the forest neighboring planting, and migrate to coconut plantation, abundant in food, mating, shelter, microclimate.

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