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Spatial and temporal distribution of *Opsiphanes invirae* (Lepidoptera: Nymphalidae) in oil palm, Pará State, Brazil

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ABSTRACT

In this work, we evaluated the spatial and temporal distribution of *Opsiphanes invirae* larvae (Lepidoptera: Nymphalidae) in oil palm plantations in the state of Pará, where 14 samplings were accomplished from April 2008 to August 2014. The experimental area consisted of 3,582 ha splitted into 89 subareas from 50 to 80 ha each. The spatial distribution was determined by sampling the number of larvae in 10% of the plants (sample unit) in each subarea, in which were obtained the variable value (number of larvae / plant) and coordinates (latitude and longitude). The variability and spatial dependence analysis were made through the incorporation of geostatistical procedures based on spatial modeling techniques by semivariograms. The krigagem maps were generated from the *O. invirae* larvae's count data in the field. The *O. invirae* spatial distribution is aggregated with spatial dependence described by the spherical model, forming patches of 990 to 3700 m (range of the model). Initially, the infestation occurs at the planting edges, with subsequent spread to the entire area. *O. invirae* larvae disperse by passing from one plant to another, infesting all the area. The results suggest that the traps are placed at the edges of the planting aiming the collection of adults and, hence, control the population of larvae.

Key words: population dynamics; *Elaeis guineensis*; defoliating worm of palm trees; kriging; semivariogram

Distribuição espaço-temporal de *Opsiphanes invirae* (Lepidoptera: Nymphalidae) em palma de óleo no Pará, Brasil

RESUMO

O objetivo deste trabalho foi avaliar a distribuição espaço-temporal da larva de *Opsiphanes invirae* (Lepidoptera: Nymphalidae) em plantios de palma de óleo no estado do Pará, onde foram realizadas 14 amostragens no período de abril de 2008 a agosto de 2014. A área experimental de 3.582 ha foi dividida em 89 subáreas de 50 a 80 ha cada. A distribuição espacial foi determinada amostrando-se o número de larvas em 10% das plantas (unidade amostral) em cada subárea, no qual se obteve o valor da variável (número de lagartas/planta) e as coordenadas (latitude e longitude). As análises da variabilidade e da dependência espacial foram feitas através de incorporação de procedimentos geoestatísticos baseados em técnicas de modelagem espacial por semivariogramas. Os mapas de krigagem foram gerados a partir dos dados de contagem de lagartas de *O. invirae*, em campo. A distribuição espacial de *O. invirae* é agregada com dependência espacial descrita pelo modelo esférico, formando "reboleiras" de 990 a 3700 m (alcance do modelo). A infestação se dá inicialmente nas bordas do plantio, com posterior disseminação para toda a área. Larvas de *O. invirae* se dispersam passando de uma planta a outra, infestando toda a área. Os resultados sugerem que as armadilhas sejam colocadas nas bordas do plantio, para coleta de adultos e, conseqüentemente, redução da infestação de larvas.

Palavras-chave: dinâmica populacional; *Elaeis guineenses*; krigagem; lagarta-desfolhadora-das-palmeiras; semivariograma

Introduction

The oil palm (*Elaeis guineensis* Jacq.) id originated from the West Coast of Africa. The two largest producers in the world are Malaysia and Indonesia, accounting for 86% of this oilseed production (USDA, 2017). In Brazil, the oil palm adapted well and is currently the highest yielded oilseed crop with yields of 4 to 6 tons of ha⁻¹ year⁻¹ oil (Camillo et al., 2009). The State of Pará is the national leader in the production of oil palm (SAGRI, 2017). However, this production may be affected by phytosanitary problems, constituting a limiting factor (Dionisio et al., 2015). Among the pests that attack the oil palm, there is the larva of *Opsiphanes invirae* Hérber (Lepidoptera: Nymphalidae).

The attack of *O. invirae* is frequent in plantations in the North of Brazil, compromising the productivity of oil palm in the Amazon region. According to Lemos & Boari (2010), only one larva can consume up to 800 cm² of the leaf, which results in a significant defoliation capable of reaching 90% in the affected areas, with repeated defoliation leading to palm death.

The control methods most used to keep infestations under acceptable conditions have been the capture of adults of *Opsiphanes* spp. in traps and the biological control of larvae with the application of *Bacillus thuringiensis*. The traps are constructed from transparent polyethylene plastic bags with the dimensions of 100 cm high by 60 cm wide. The entrance to the trap is kept partially open by an oval-shaped wire loop through which the butterflies enter. The traps are suspended in the plant stipe at a height of about 150 cm from the ground. As an attractive food, 1 liter of sugar cane molasses is used (Loria et al., 2002).

Knowing the space-time dynamics of insects in agricultural ecosystems is important for the development of management strategies and reduction of the use of pesticides. In the same way, it can better support decision-making by the greater amount of information obtained and, as a consequence, control only in areas with infestation (Dal Prá et al., 2011). Therefore, maps of occurrence and distribution of pest insects in agricultural areas contribute to improved sampling methods and more effective control by applying insecticides and/or trapping in the required locations and quantities (Dionisio et al. 2015, Duarte et al., 2015).

There is a great need for studies on the population dynamics and infestation levels of *O. invirae* larvae in the field since these determine where the infestation starts facilitating future decisions. There are several studies on the use of geographic information system (GIS) and geostatistical methods in studies of spatial distribution of insects (Farias et al., 2008; Ifoulis & Savopoulou-Soultani, 2006; Cocco et al., 2010; Rijal et al., 2014), to characterize the spatial dependence of the pest by the elaboration of adjusted semivariograms (Rijal et al., 2016).

From the semivariogram, maps are elaborated to show how space (time/space) of the insect occurs in the area, through the incorporation of geostatistical procedures based on spatial modeling techniques by semivariograms and estimation by kriging. These tools are important for the elaboration of safe methods of sampling and, especially, localized control of the pest (Silva et al., 2015).

These studies prove the efficiency of the use of geostatistics in insect management. However, little is known about the spatial distribution of *O. invirae* in the Amazon region. Thus, the purpose of this study was to evaluate the spatiotemporal distribution of *O. invirae* larvae in oil palm plantations in the state of Pará.

Materials and Methods

Study area

The study was carried out in an area of 3,582 hectares of 20-year-old commercial palm oil plantation, belonging to the company Agropalma S/A, located in the Municipality of Moju (02°35'34"S, 48°44'41"O), Northeast of Pará (Figure 1).

The climate of the region is of the Afi type, according to the classification of Köppen (1948). The highest rainfall rates are from January to May and the lowest from August to November. The soil is of the Yellow Latosol type with clay texture (EMBRAPA, 2006).

The oil palm plants were arranged as an equilateral triangle, with a spacing of 9 m between plants and 7.8 m between rows. The perimeter of the area was demarcated with the aid of a navigation GPS (rhino model 530HCx) and, later, the experimental area was divided into subareas (plots) of sampling. The size of the plots varied from 50 to 80 hectares (1 ha = 143 plants), making 89 plots.

In each plot, 10% of the plants (sample unit) were evaluated, counting the number of *O. invirae* larvae on the 17th leaf of each evaluated plant. Two samplings per year were carried out from April 2008 to August 2014, totaling 14 evaluations. This period was used considering the life cycle of the species ranging from 59 to 77 days (egg phase: 8 to 10 days, larval phase: 36 to 47 days, and pupa phase: 15 to 20 days) (Ferreira, 2006).

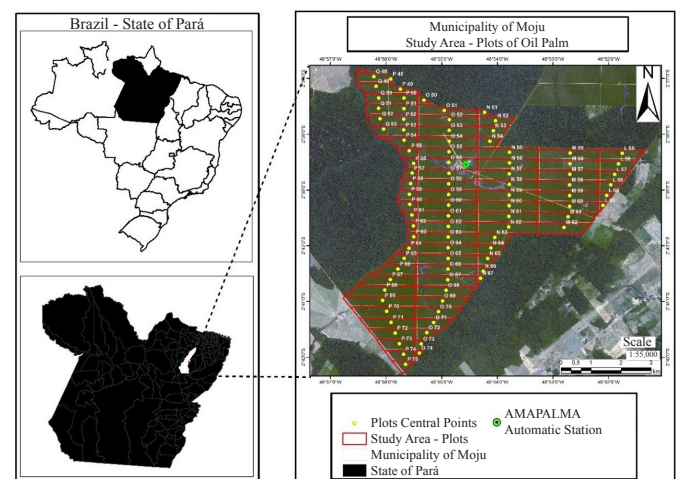


Figure 1. Location of an experiment in the municipality of Moju, with an indication of the plots selected for the study. Image: Sensor SPOT 5, 2010.

Geostatistical analysis

After the data were tabulated, the spatial distribution of *O. invirae* by geostatistics was analyzed using the semivariogram, adjusting the data to one of the four possible models: Gaussian, spherical, power or exponential.

The choice of the model was based on the semivariogram modeling that best fitted the data based on the coefficient of determination (R^2), and this was used in the Kriging process

(contour maps). The semivariogram was estimated by Equation 1, according to Dionisio et al. (2015):

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

where: $N(h)$ is the number of experimental pairs of measured values $Z(x_i)$, $Z(x_i + h)$, separated by a vector h . The graph of $\gamma^*(h)$ versus the corresponding values of h , is a function of distance (h), therefore, dependent on the magnitude and direction of the distance (Farias et al., 2008).

In this study, the semivariogram model fitted to the data was spherical, which is described by Equation 2:

$$\gamma(h) = C_0 + C_1 \left[\frac{3}{2} \left(\frac{h}{a} \right) - \frac{1}{2} \left(\frac{h}{a} \right)^3 \right], 0 < h < a$$

in which, C_0 is the pure nugget effect or minimal semivariance; $C_0 + C_1$ is the maximum level or semivariance; a is the range or radius of aggregation.

Then, the kriging maps were constructed, which use the spatial dependence modeled in the semivariogram and estimate values in any position of the study area without trend and with minimum variance. From the kriging maps (isolines) it is possible to visualize the behavior of the variable under study (Dionisio et al., 2015).

To classify spatial dependence, the methodology described by Cambardella et al. (1994) was used, which considers a strong spatial dependence of the semivariogram that has the value of the pure nugget effect lower than 25% of the plateau, moderate dependence when the value is between 25 and 75%, and of low dependence when this value is greater than 75 %.

For the analysis of the data and preparation of the population distribution maps of *O. invirae* larvae, the software SURFER Version 11.0 was used (GOLDEN SOFTWARE, 2002).

Results and Discussion

Spatial distribution of *O. invirae*

There was a spatial dependence of the density of larvae found per plot. The spherical model was the one that best-fitted semivariograms in all evaluations, indicating an aggregate distribution of *O. invirae* (Table 1). The spherical model is commonly found in work with lepidopteran defoliants such as *Lobesia botrana* larvae (Denis & Schiffermüller, 1775) (Lepidoptera: Tortricidae) (Ifoulis & Savopoulou-Soultani, 2006). These authors concluded that almost 100% of the variable obtained better adaptation to the spherical model, in comparison to the other models tested. A similar result was also found by Carvalho et al. (2015). These authors found that the spherical model was the one that better adjusted the infestation of *Gymnandrosoma aurantiana* larvae (Lima, 1927) (Lepidoptera: Tortricidae) in citrus orchards for all evaluations.

The rays of aggregation of the larvae in the area ranged from 990 to 3700 m. From the radius of aggregation, the area of influence of a plot with an attack of *O. invirae* for the neighbors was estimated, varying from 3.1 to 43 km². A study by Duarte et al. (Lepidoptera: Tortricidae), in peach orchards, found a range from 908 to 6884 m for an area of influence 2.58 to 148.80 km², respectively. Therefore, the value of the radius of aggregation is very important for the development of efficient sampling in lepidopteran control, as well as for its localized control.

In the period from 2008 to 2010, spatial variation and range of spherical models were higher in all assessments than in the period from 2011 to 2014 (Table 1). This result probably reflects the application of biological control with *Bacillus thuringiensis*, from 2011 throughout the area, which may have contributed to the reduction of pest infestation. Alves et al. (2011), found similar results when they studied the population dynamics of the larva of the bush miner in Lavras, Minas Gerais, Brazil. These authors also observed a reduction in spatial variation and reached 2007

Table 1. Parameters of the semivariogram adjusted to the models, the coefficient of determination (R^2) and parameter $k=C_0/(C_0 + C_1)$ for geostatistical analysis of *Opsiphanes invirae* larvae in Agropalma S/A, Moju, PA, Brazil, 2008 to 2014.

Inspection/ Month	Semivariogram parameters			Influence area (km ²) ^a	Model	R ²	K ^b	Space dependence
	C ₀	C ₁	a (m)					
2008								
1 st – April	0.00	55.00	3700	43.0	Spherical	0.97	0.00	Strong
2 nd – November	10.00	190.00	1980	12.3	Spherical	0.98	0.05	Strong
2009								
1 st – May	30000	159000	1620	8.2	Spherical	0.97	0.16	Strong
2 nd – November	25000	43000	2500	19.6	Spherical	0.89	0.37	Moderate
2010								
1 st – March	4000	18000	3200	32.2	Spherical	0.99	0.18	Strong
2 nd – September	0.00	34.00	2050	13.2	Spherical	0.83	0.00	Strong
2011								
1 st – July	0.70	1.05	2990	28.1	Spherical	0.96	0.40	Moderate
2 nd – November	0.02	0.10	1990	12.4	Spherical	0.96	0.16	Strong
2012								
1 st – April	0.00	0.24	990	3.1	Spherical	0.96	0.00	Strong
2 nd – July	0.02	0.07	1400	6.2	Spherical	0.83	0.22	Strong
2013								
1 st – March	0.20	0.48	1370	5.9	Spherical	0.70	0.29	Moderate
2 nd – August	0.33	1.22	1800	10.2	Spherical	0.84	0.21	Strong
2014								
1 st – June	3.00	2.60	1700	9.1	Spherical	0.71	0.54	Moderate
2 nd – August	0.02	0.08	1400	6.2	Spherical	0.93	0.21	Strong

^a Calculated by $\pi \cdot r^2$, where $\pi = 3.14$ and $r = a$

^b Relation between $C_0/(C_0 + C_1)$

assessments for the adjusted spherical model in relation to the previous years of 2005 and 2006, probably due to the application of insecticides in December 2006 and February of 2007.

The values of k obtained in the study ranged from 0.00 to 0.54, presenting strong to moderate spatial dependence (Table 1), evidencing that spatial dependence is of extreme importance when wishing to study this pest and it cannot be disregarded in population dynamics studies of *O. invirae* larvae. These values are within the recommended by Journel & Huijbregts (1978). These authors consider values below 0.80 as indicative of the aggregate distribution of the variable, and values above this index indicate that the phenomenon studied is tending towards randomness.

The semivariograms of the spatial distributions of *O. invirae* are shown in Figure 2. The coefficient of determination (R^2), used in the adjustment, indicates the reliability of the semivariogram model fit. Values close to 1 indicate a good fit of the model (Dionisio et al., 2015), which was observed in this study, in which this parameter presented amplitude of 0.70 to 0.99. Geostatistical analysis showed strong spatial dependence and high values for parameter k . These results can be explained considering that the few sites infested by the larvae were very close, giving a high reliability for geostatistical estimation.

Several studies have used geostatistics to study the spatial distribution of Lepidoptera in plants of economic interest and had similar results to those found in this study. Cocco et al. (2010) evaluated the spatial distribution of the gypsy mite, *Lymantria dispar* (L., 1758) (Lepidoptera: Lymantriidae), using geostatistics and observed that the aggregation radius ranged from 18,530 to 52,200 m of the pest with aggregate distribution in the experimental area.

The kriging maps show the distribution of pest infestation dynamics (Figures 3 and 4). In the maps, it is possible to see the aggregate behavior of this species, forming “reboleilers” of infestation. This observation corroborates the findings of Rijal et al. (2014) for Lepidoptera by analyzing the spatial distribution of *Vitacea polistiformis* (Harris) (Lepidoptera: Sesiidae) and concluded that the defoliator is distributed in an aggregate manner in the field.

In the period of seven years, we can observe that in the first evaluations, the infestations began at the edges of the plots, near open areas. For example, pasture areas around the experiment (Figures 3 and 4). Similar results were obtained by Carvalho et al. (2015), evaluating the infestation of *G. aurantiana* larvae. The authors observed that the main foci of the pest were in

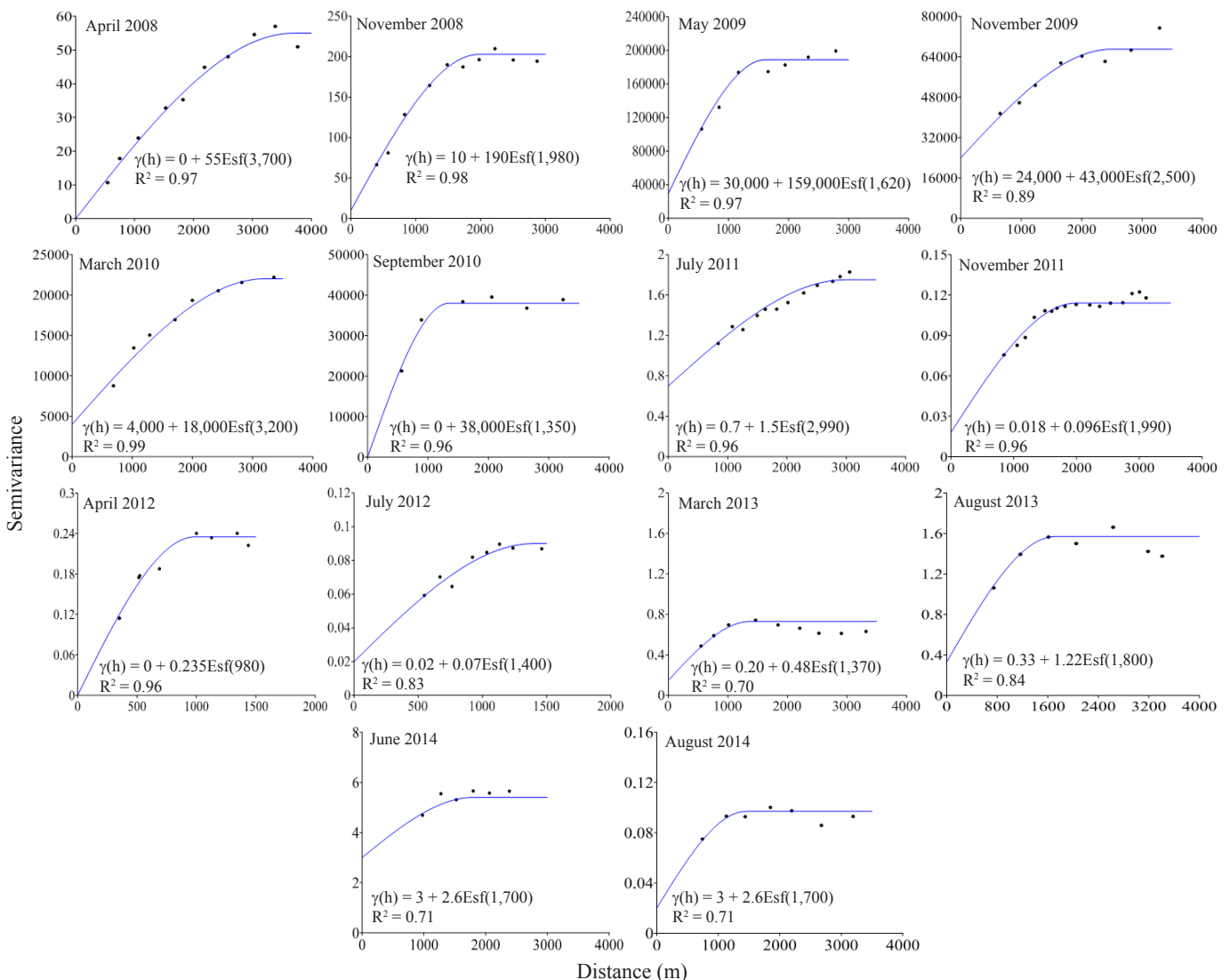


Figure 2. Semivariograms of the plots with *Opsiphanes invirae* larvae adjusted to the models from 2008 to 2010, Moju, PA.

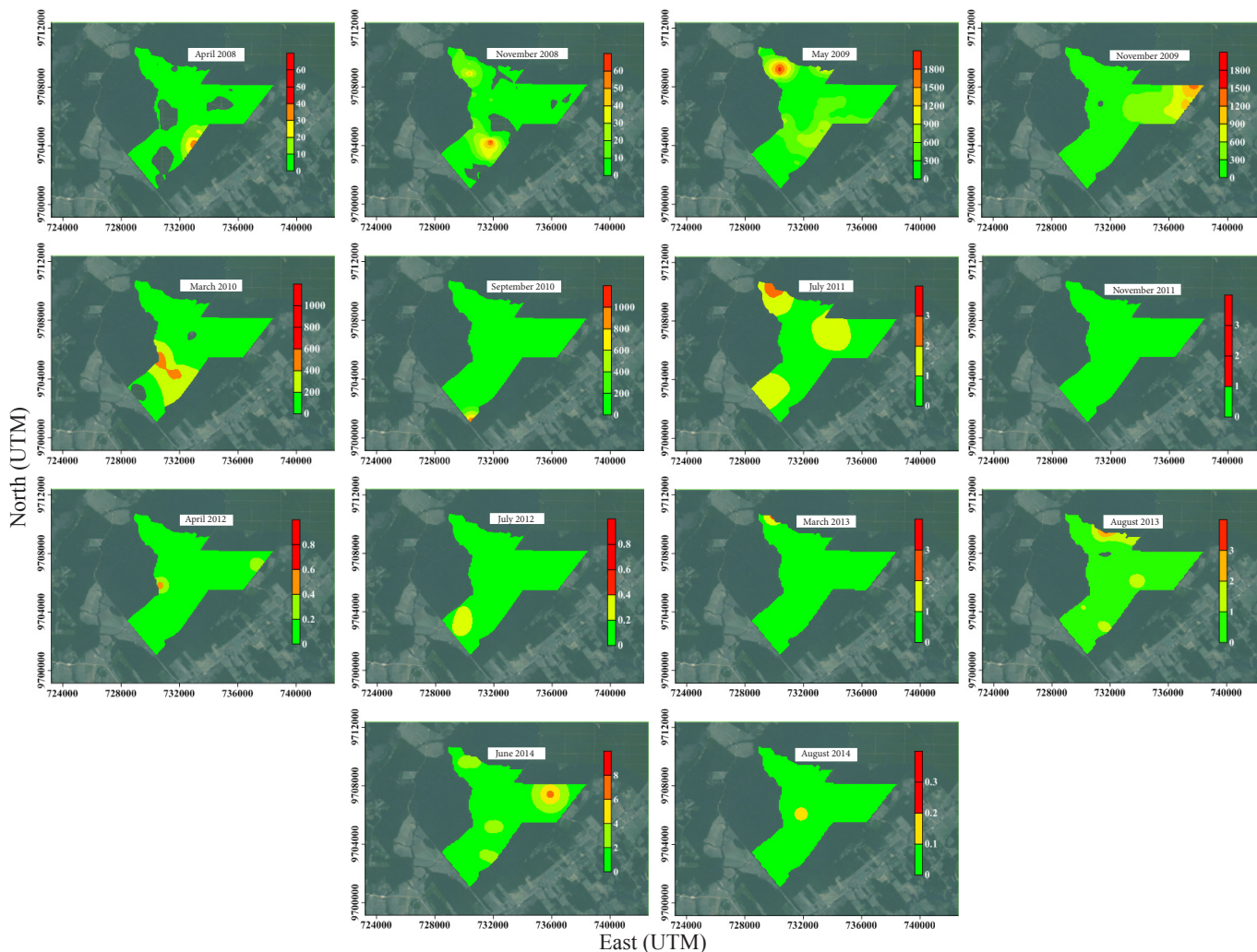


Figure 3. Map of incidence of *Opsiphanes invirae* in the study area from 2008 to 2014, Moju, PA. Note: scale represents the number of larvae.

the plots close to the limits of the experimental area. We can infer that the infestation begins at the border of the plantations, with adults from the plague coming from neighboring areas. Therefore, in this perimeter of planting, the greatest care should be taken regarding pest monitoring to detect the onset of infestation and take measures of control.

According to Cocco et al. (2010), open areas may reduce the presence of alternative hosts for this pest. It also reduces the presence of parasitoids and predators, which are important in maintaining the pest in a longer latency period (Luciano et al., 2002). Therefore, the traps for adult capture and spraying with *B. thuringiensis* on larvae should be intensified at the edges of the planting to control *O. invirae*.

The larvae show a tendency of expansion between the plots. This fact was observed mainly in the evaluations of September, October, and November of 2009. Probably, this is due to the contact between the leaves of the canopy of the palms favoring the dispersal of the larva (Figure 3). Between 2011 and 2014, there was a reduction in the amount of *O. invirae* in the study area (Figure 4). Spraying with *B. thuringiensis* may have contributed to this reduction.

The use of geostatistics allowed the analysis of the spatial distribution of *O. invirae* larvae in oil palm, which could be used in a monitoring program, reducing production costs

with a more efficient control. The results obtained will aid in the integrated management and the monitoring of the pest in future evaluations, as it shows the predominance of the site of infestation, its spatial distribution and the evolution of the infestation in the study area.

Conclusions

Opsiphanes invirae Larvae presents aggregate distribution in oil palm, in the studied locality in the state of Pará;

The pest infestation occurs predominantly in the periphery of the areas, forming reeds from 990 to 3700 m radius;

The dispersal of *O. invirae* larvae occurs with the passage of larvae from one plant to another, resulting in an extensive infestation of the area.

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