SPATIAL PATTERNS OF TERMITE MOUNDS IN GUATEMALA

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■ ABSTRACT: Studying and understanding the behaviour of certain kinds of insects and/or pests in a plantation is critical in any region, since it gives subsidies for possible public and/or private policies if any intervention is needed. In this context, many different studies are available in a wide literature, e.g. about spatial patterns of termite mounds, that cannot be extrapolated for everywhere. Since each region has individual needs, it is reasonable to conduct different studies in specific areas of interest. In this paper we studied spatial patterns of termite mounds in a teak plantation in the northern of Republic of Guatemala, splitting the data set according to termite mounds sizes (small, medium and large) and analysing their individual and cross patterns. For individual patterns we noticed that when only small termite mounds or when all termite mounds were considered an aggregation distribution throughout the studied region was detected, while large termite mounds presented this pattern only in a specific area and medium ones showed a regularity pattern in the whole region. For cross patterns no attraction or inhibition relationships were observed.

■ KEYWORDS: *Nasutitermes nigriceps*; Ripley's K function; spatial point processes; teak tree; *Tectona grandis* L.f.

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1 Introduction

Teak (*Tectona grandis* L.f.) is a tree that belongs to the family Lamaceae, being native to the rainforests in southeast Asia, e.g. India, Java, Laos, Myanmar and Thailand (VERHAEGEN *et al.*, 2010). Its natural range is wide, from parallel 09 ^{o}N up to 25 ^{o}N, including regions from sea level up to 1,000 m, susceptible to annual rainfalls between 500–5,000 mm and absolute temperatures from 2 ^{o}C up to 48 ^{o}C. It is a large tree reaching up to 25 and 35 m high and one meter in diameter at breast height (LIMA *et al.*, 2009) with a straight trunk in its natural environment, with rough, thin and cracked bark and grey or greyish brown branches. Although its bark is not thick, it is a thermal insulation, resulting in a high resistance to fire.

Teak is the main deciduous forest species grown within the Program of Forest Incentives (PINFOR) of the Government of the Republic of Guatemala. The good properties of its wood result in various different applications, such as in furnitures for external use, floors, interior and exterior decoration and shipbuilding, especially for the deck coating on sailboats and yachts (MACEDO *et al.*, 2005; LUKMANDARU and TAKAHASHI, 2008; MIRANDA *et al.*, 2011).

Recently, several studies involving teak wood cultivation and its products are being published in the literature. Figueiredo *et al.* (2005) present an economical study that reports the value of a land when it is reforested with teak, due to the high commercial value of its wood; in the health area, Diallo *et al.* (2008) show that leaves extracts can be used in anemia treatment, increasing hemoglobin, red blood cell count, hematocrit and reticulocyte rate; Almeida *et al.* (2010) report that teak cultivation can be used to increase carbon storage in biomass, resulting in removal of large amounts of CO2 in atmosphere; among others.

Different studies regarding the termite mounds spatial distribution are presented in the literature, e.g., Cunha (2011), Peres Filho *et al.* (2012), Dias *et al.* (2012), Davies *et al.* (2014), among others. However, those studies cannot be extrapolated to all regions, since different regions have distinct properties and require different policies in order to control these insects in the most efficient and sustainable possible way. Hence, the main objective of this paper is to provide subsidies in plantations of *Tectona Grandis* L.f. in Guatemala through spatial analysis, identifying whether there is any spatial pattern near the edges or in the centre of the plantation, using uni and multivariate Ripley's K (and L) functions.

2 Material and methods

2.1 Study area

The data set analysed in this paper regards to a study conducted on 15 July 2013 at GM-99 farm, located in La Libertard, Departamento de Petén, Guatemala. The samples were randomly collected over an area of 46.69 ha, georeferencing each point in the branches of teak trees (Figure 1). The size of the termite mounds were classified according to their diameters: i) small ($<$ 20 cm); ii) medium (20 – 30 cm);

and iii) large (> 30 cm).

Figure 1 - Example of a sampled termite mound.

2.2 Methodology

The spatial point pattern statistical analysis requires a theoretical reference model, which is basis for the development of formal methods that verify the significance of exploratory results. The simplest well-known theoretical model (and widely applied in practice) is named as complete spatial randomness (CSR), that divides the study region **A** into subareas S_i and models spatial point patterns as a random process $\{Z_i(u_i),\, u_i \in S_i,\, i = 1, ..., n\}$. In this study, we consider $Z_i(u_i)$ as the number of events that occur in the subarea S_i. In the CSR model, it was considered that the occurrences in each subarea are uncorrelated and homogeneous, and are associated with the same Poisson probability distribution. In an intuitive view, we can consider that the position of the events is independent and that the events have an equal probability of occurrence in the whole region **A**.

In this process, the initial hypothesis tested is of complete spatial randomness, i.e. that the observations are completely random in the study area,

$$\begin{cases} H_0: & \text{complete spatial randomness} \\ H_1: & \text{nonrandom spatial distribution.} \end{cases}$$

According to Scalon *et al.* (2003), a large amount of statistical methods was proposed to test departure against the null hypothesis of CSR in point patterns.

These methods can be mainly divided in three different groups: i) the first one refers to quadrat count methods, i.e. we select small test regions in order to evaluate the spatial distribution. The observed frequency distribution of the number of points per quadrat is compared, using a χ^2-test, to a theoretical Poisson distribution. The main problem here is that the choice of the region size is arbitrary; ii) in the second group we compare the observed distribution of the nearest neighbour distances with a theoretical Poisson distribution of distances under randomness. Note that this approach presents a considerable loss of information since we summarise complex point patterns onto a single statistic; and iii) the third group relies on spatial patterns descriptors, such as F, G and K functions and is the most used in a wide literature. It requires a completely enumerated point pattern, that is, the information about the location of all individuals under study is required, ensuring that no information is lost.

Since we do have the location of all individuals under study, the first two groups abovementioned are not recommended and thus, in this paper, we are using tests based on the last group, more precisely the Ripley's K function (RIPLEY, 1977). This function was chosen since it is the most indicated when we are interested in understanding the spatial pattern presented in a study area. The K function has as main advantage to assist in the detection of spatial patterns on different scales of distances simultaneously, i.e. it provides a great summary of spatial dependence over a wide range of scales (SCALON *et al.*, 2003). Moreover, it helps in the investigation of spatial independence level between any two groups, e.g. termite mounds of different sizes. F and G functions should be preferred when we are looking for alternative models in case of rejection of the hypothesis of CSR.

Formally, the univariate Ripley's K function estimator is given by

$$\hat{K}(r) = \frac{|S|}{N^2} \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{I_r(d_{i,j} \leq r)}{w_{s_i,s_j}}, \tag{1}$$

where $I_r(\cdot)$ is an indicator function, N corresponds to the number of individuals in region S with area $|S|$, $d_{i,j}$ is the distance between the i^{th} and j^{th} individuals and w_{s_i,s_j} is a correction based on the circunference ratio within region S.

Monte Carlo envelopes are used in order to perform the abovementioned hypothesis test (DIGGLE, 2003). If the observed values are within the confidence envelope, there is an evidence that the individuals' distribution pattern is random, i.e. there is no kind of dependence between events (CAPRETZ *et al.*, 2012); otherwise, there are two alternative hypotheses: attraction or spatial repulsion, i.e. when values are outside the envelopes, which in this condition, for observed values bigger than the upper limit, the pattern is called aggregated; and if they are smaller than the lower limit, the pattern is regular.

Using Montecarlo simulations, envelopes were built. After performing 1,000 simulations of the spatial pattern according to the CSR model and after calculating the estimate of $K(r)$, we build the confidence intervals with the maximum and minimum results (the same approach is used by the majority of authors, such as

SILVA *et al.*, 2008; OLINDA and SCALON, 2010; ARAÚJO *et al.*, 2016; among others). The assumed error is given by $\frac{1}{(m+1)}$, where m is the number of simulations, hence, in this study, the error was given by 0.01%, approximately.

Although, as described, the Rippley's K function is one of the most appropriate to analyse the spatial pattern in individuals with known locations, in practice this function does not present a simple interpretation since it produces a parabola. In order to simplify its visualisation and interpretation, Ripley (1979) proposed a slightly correction in (1), that resulted in a new function called the L function, which produces a linear plot with a similar interpretation. Thus, in order to verify whether a process presents aggregation, the observations just need to be positive. Therefore, we used the L function in this paper, which is defined as

$$\hat{L}(r) = \sqrt{\frac{\hat{K}(r)}{\pi}}.$$

Later, in order to verify a possible relationship between termite mounds with different sizes, we used the bivariate estimator, which is derived from the Ripley's K function, to test the complete spatial randomness and independence (CSRI) (HUGHES *et al.*, 2001). The bivariate Ripley's K function estimator can be defined as

$$\hat{K}_{12}(r) = \frac{|S|}{N_i N_j} \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} \frac{I_r(d_{i,j} \leq r)}{w_{s_i,s_j}},$$

where $I_r(\cdot)$ is an indicator function, N corresponds to the number of individuals in region S with area $|S|$, $d_{i,j}$ is the distance between the i^{th} individual from the first group and j^{th} individual from the second group, and w_{s_i,s_j} is a correction based on the circunference ratio within S.

Analogously to its univariate version, we shall transform the multivariate (bivariate) Ripley's K function in order to simplify its visualisation and interpretation. The resulting function, called the multivariate L function, is given by

$$\hat{L}_{ij}(r) = \sqrt{\frac{\hat{K}_{ij}(r)}{\pi}},$$

and it can be interpreted as follows:

- $\hat{L}_{ij}(r) = 0$: the groups are independents;
- $\hat{L}_{ij}(r) > 0$: positive association (attraction) between groups until r; and
- $\hat{L}_{ij}(r) < 0$: negative association (inhibition) between groups until r.

As in the univariate case, the envelopes were defined using Monte Carlo simulations. After performing 1,000 simulations of the spatial pattern according to the CSRI model, we obtained the estimate of $K_{12}(r)$ and constructed the confidence intervals with the maximum and minimum results.

It is noteworthy that all analyses in this paper were performed in the free statistical software `R` (R CORE TEAM, 2016) using `spatstat` (BADDELEY and TURNER, 2015) and `splancs` (ROWLINGSON and DIGGLE, 2015) packages.

3 Results

We sampled 178 termite mounds, of which 67 were classified as small (diameter smaller than 20 cm), 31 as medium (diameter between 20–30 cm) and 80 as large (diameter greater than 30 cm), and they are displayed in Figure 2 on four different panels, respectively.

3.1 Univariate analysis

Figure 3 displays the returned L functions. Panel (a) provides the L function considering all termite mounds and Panels (b), (c) and (d) plot the L function for small, medium and large termite mounds, respectively. Dashed lines indicate the 99% confidence intervals obtained through Monte Carlo simulations for CSR, while the continuous line indicates the fitted L function to the data. We can see that the spatial pattern from all the data set, does not satisfy the CSR hypothesis in distances until r=385 m, since the function stays outside the upper bound of the envelope, i.e. the termite mounds are not randomly distributed in the study area, but present an aggregation spatial pattern in this scale. For distances greater than r=420 m, the termite mounds present a regularity pattern.

Moreover, Figure 3(b) shows that small termite mounds (diameter smaller than 20 cm) present an aggregation spatial pattern and after r=375 m the individuals' distribution pattern is random. Medium (diameter between 20–30 cm) and large (diameter greater than 30 cm) termite mounds, displayed in panels (c) and (d) respectively, have a similar behaviour than when all termite mounds are considered. There is an aggregation spatial pattern until r=325 m and regularity for distances greater than r=390 m in these sizes.

3.2 Bivariate analysis

Figure 4 displays the confidence envelopes for the bivariate L function in order to perform the CRSI analyses between termite mounds of different sizes: Panels (a), (b) and (c) display the analysis between small versus medium, small versus large and medium versus large termite mounds, respectively. As in the univariate case, dashed lines indicate the 99% confidence intervals obtained through Monte Carlo simulations, while the continuous line indicates the fitted multivariate L function to the data. The analyses between small versus medium and small versus large termite mounds presented an attraction relationship with scale up to 100 m and 90 m, respectively. For scales greater than these values, the CSRI hypothesis was

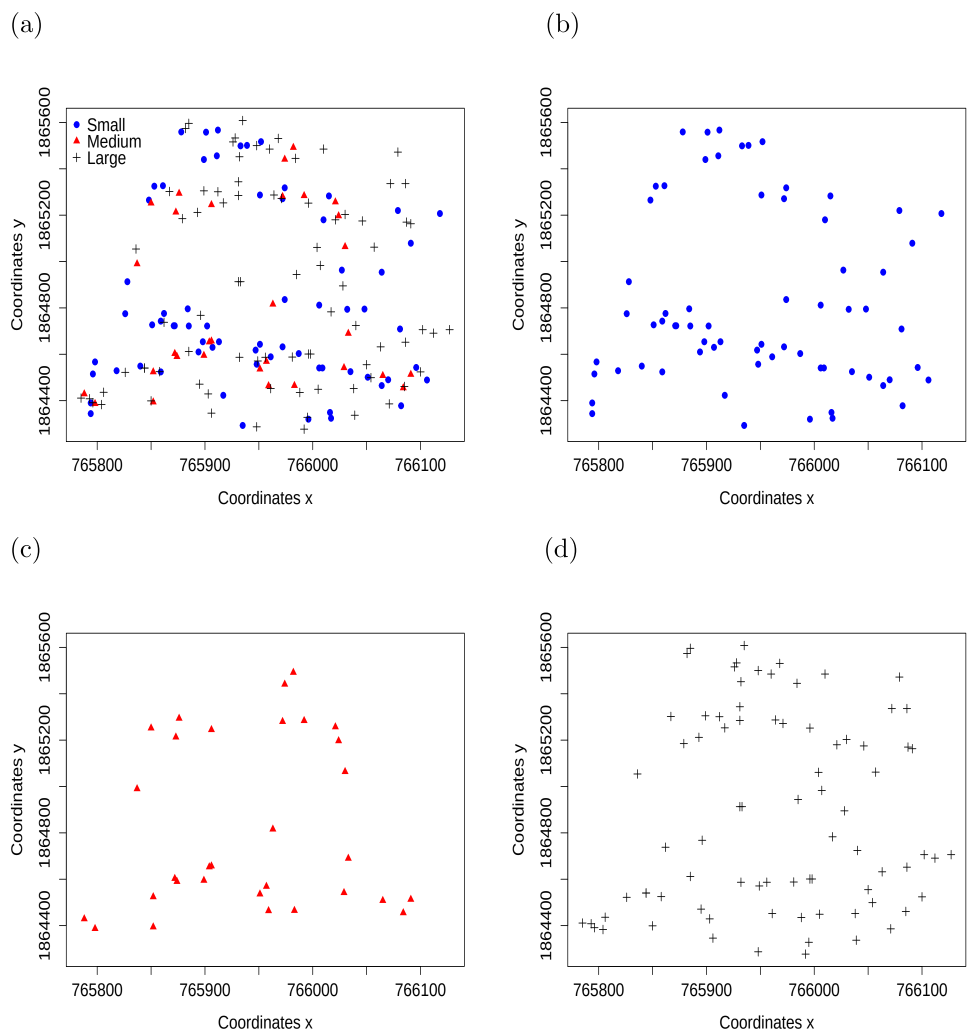

Figure 2 - Termite mounds spatial distribution map: (a) all; (b) diameter smaller than 20 cm; (c) diameter between 20-30 cm; and (d) diameter greater than 30 cm.

not violated. Further, medium and large termite mounds presented an attraction relationship in scales up to 320 m and, for greater values than 400 m it can be seen an inhibition relationship.

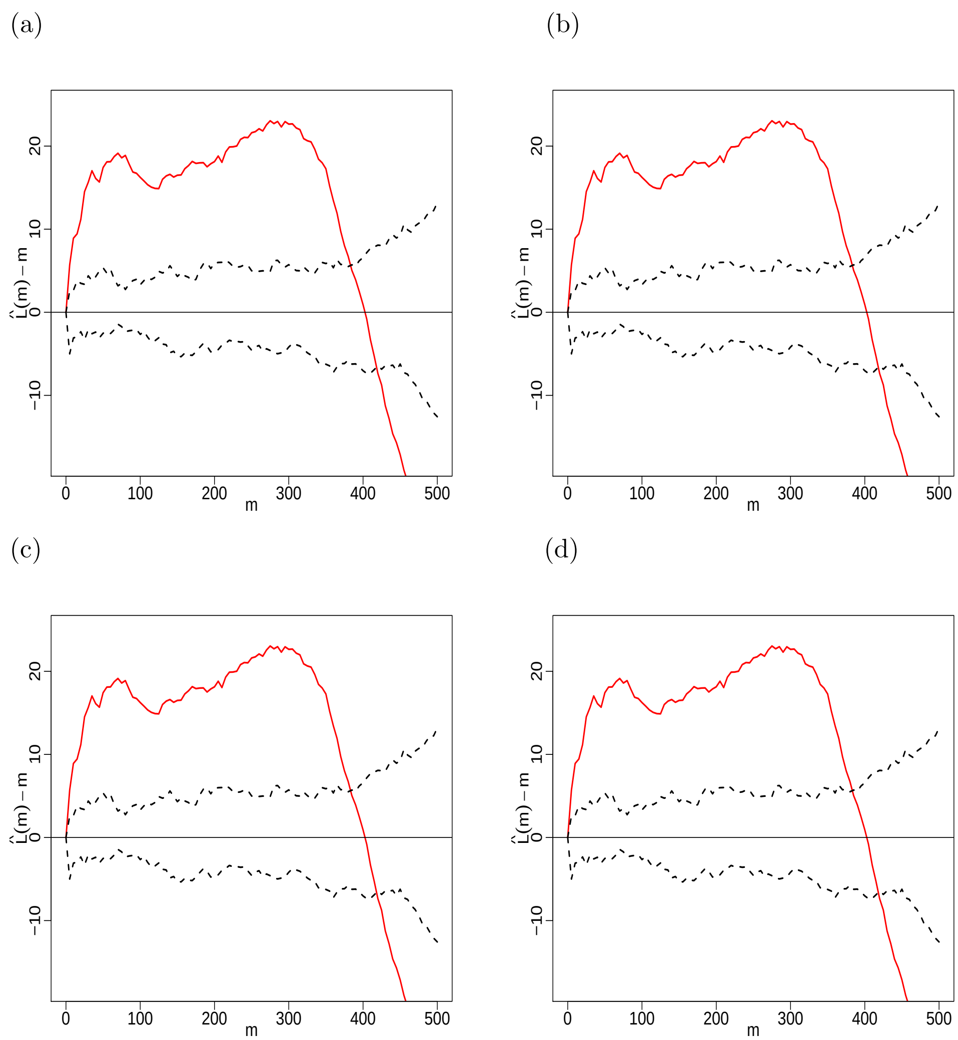

Figure 3 - Spatial dependence analysis of the termite mounds: (a) all; (b) diameter smaller than 20 cm; (c) diameter between 20–30 cm; and (d) diameter greater than 30 cm.

4 Discussion

4.1 Univariate analysis

The spatial pattern analysis of teak infected trees showed a significant aggregation distribution for the termite mounds. The same pattern was reported by Dias *et al.* (2012) in pasture lands, where the individuals were concentrated in

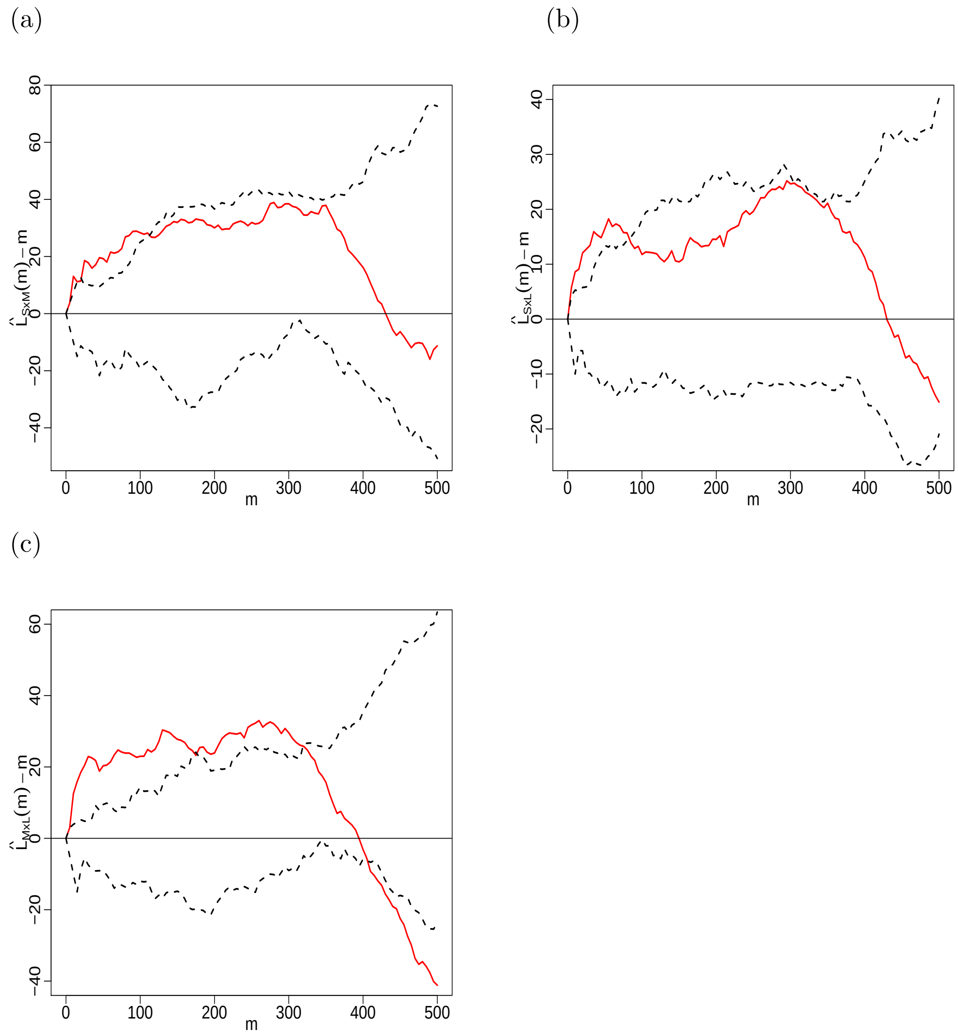

Figure 4 - Analysis of the spatial interaction between the different sizes of termite mounts: (a) small versus medium, (b) small versus large, (c) medium versus large.

areas with greater availability of organic matter and moisture.

According to Grohmann *et al.* (2010), the regularity was already described in different termite species and it is interpreted as a result of an intraspecific and interspecific competition (POMEROY, 2005). The termite mounds regularity aims to minimise negative interactions, such as competition between individuals that share the same area and resources (FORTIN and DALE, 2005). Further and

Hutchinson (1957) states that every species interact with others, affecting somehow its fundamental niche, restricting it to a subset.

Hence, the termite mounds spatial distribution map on this study, may indicate that there are no spots throughout the region in study presenting better conditions for the establishment of termite mounds, or the absence of intra-specific competition of space and food resources (BEGON and HARPER, 1996). Finally, the low density of termite mounds throughout the region in study might be another factor to contribute with this pattern.

4.2 Bivariate analysis

According to the modified bivariate Ripley's function, small termite mounds, with diameter smaller than 20 cm, occur closer to bigger termite mounts (medium and large, with diameters between 20–30 cm and greater than 30 cm, respectively) more than expected to be considered as a nonrandom pattern. The same behaviour is observed when medium and large termite mounds are compared. Grohmann *et al.* (2010) highlight that if we consider two termite mounds founded on the same period, in which one has better growing conditions, the fastest growing colony can suppress the growth of the other colony, or that the smaller termite mounds will be a branch of the larger one, i.e. polydomous colonies.

Conclusions

When all termite mounds or just the small ones (diameter smaller than 20 cm) are considered, we can see an aggregation distribution throughout the studied region. Large termite mounds (diameter greater than 30 cm) also presented this pattern but only in a certain distance (45–80 m), while medium termite mounds present a regularity pattern in the whole region. Regarding the bivariate analysis, the CSRI hypothesis was not rejected and then we can conclude that there is no attraction or inhibition relationship between termite mounds of different sizes in the study area.

RIGUETTO, A. J.; FRADE, D. D. R.; NAKAMURA, L. G.; RAMIRES, T. G.; BAUTISTA, E. A. L.; RIBEIRO JUNIOR, P. J. Distribuição espacial de cupinzeiros na Guatemala, *Rev. Bras. Biom.,* Lavras, v.35, n.4, p.701-713, 2017.

▪ *RESUMO: O estudo e compreensão do comportamento de certos insetos praga em uma plantação atividades importantes para determinada região, uma vez que a informação gerada fornece subsídios para a possível criação de políticas públicas e/ou privadas se quaisquer intervenções forem necessárias. Neste contexto, diferentes estudos estão disponíveis em uma vasta literatura, como, por exemplo, o estudo da distribuição espacial da colônia de cupins, cujos resultados, infelizmente, não podem ser extrapolados para qualquer região no mundo. Uma vez que cada região possui déficits singulares, é razoável conduzir diferentes estudos para áreas específicas de interesse. Neste artigo a distribuição espacial de cupinzeiros em uma plantação de teca na região norte da República da Guatemala é estudada, dividindo-se o conjunto de dados de acordo com o tamanho dos cupinzeiros (pequeno, médio e grande) e analisando o comportamento de cada um desses grupos, bem como suas interações. O padrão observado para cupinzeiros de pequeno porte, bem como o padrão observado quando todos os cupinzeiros são analisados sem distinção de tamanho, indica agregação em toda região de estudo. No que tange à distribuição de cupinzeiros de médio e grande porte, nota-se que apresentam uma distribuição regular e distribuição agregada apenas em uma parte da região, respectivamente. No estudo da interação entre os cupinzeiros, não foram observadas nem atração nem inibição.*

▪ *PALAVRAS-CHAVE: Função K de Ripley; Nasutitermes nigriceps; Processos pontuais; Teca; Tectona grandis L.f.*

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