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Spatial Distribution of *Acromyrmex balzani* (Emery) (Hymenoptera: Formicidae: Attini) Nests Using Two Sampling Methods

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Abstract

The spatial distribution (SD) of organisms is a key parameter in studies of population ecology. Among the methods to describe the SD of sessile organisms, sampling by way of plots and transects are widely used. The measurement of the distance between individuals ("nearest neighbor") is a simple method that has not been employed in population studies with ants. This study aimed to evaluate the SD of ant mounds of *Acromyrmex balzani* (Emery, 1890), using both plot sampling and nearest neighbor methods in order to evaluate which method is more appropriate for determining SD of this species. In January 2013 we established 359 plots of 10 m² on a fragment of grassland in Sergipe, Brazil. In the same study area 25 colonies were randomly selected and the distance of the closest neighbor colony was determined. In total, 153 ant mounds were sampled (plots) and the density was estimated in 975 × colonies ha^{-1}. Colonies were clumped in the environment either by plot sampling ($\chi 2 = 453.93$; *p* < 0.05) as well as by the method of nearest neighbor (Ax = 0.67, t = -1.72, p < 0.05). The aggregation of *A. balzani* colonies found in this study may be due to habitat heterogeneity or relate to the strategy of colony foundation. We conclude that the use of the nearest neighbor method was as accurate as the plot sampling method, providing the same results with much lower sampling effort.

Introduction

The spatial distribution of organisms in an environment is a key parameter in studies of population ecology (Krebs, 1989; Begon et al., 1996). It allows the inference of ecological aspects of great importance such as the dispersal pattern of individuals, possible existence of competition or other agonistic interactions, the density of individuals in the study area and species dominance at the community level (Brower et al., 1997). These inferences, in turn, enable the development of pest management programs (Ferguson et al., 2003), to cope with invasive species (Zhu et al., 2007) and to plan conservation strategies in the case of rare and endangered species (Beissinger & Westphal, 1998).

Although it is a good tool in population studies, spatial distribution is dependent of several variables that determine the suitability of sites for the establishment of individuals in the environment, such as sun exposure, soil or air humidity, altitude, availability of food and shelter, and sites for nesting and breeding (Soares & Schoereder, 2001; Van Gils & Vanderwoude, 2012).

In general, the distribution (dispersal) of organisms in the environment can be differentiated in three spatial arrangements: (1) random, (2) aggregate or contagious, when the organisms tend to be distributed in groups, and (3) regular or uniform, when the individuals are uniformly distributed in a population (Taylor, 1984; Krebs, 1989; Begon et al., 1996). In nature, organisms are rarely distributed in an arrangement as uniform as plants in agroecosystems; instead, they are usually aggregative (Gao, 2013). For ants, clumped distributions may reflect the spatial heterogeneity of the habitat in relation to resource availability (Belchior et al., 2012; Van Gils & Vanderwoude, 2012), reflect the outcome of the reproductive strategy (Rissing et al., 1986; Nicholas & Vilela, 1996; Debout et al., 2007) or are related to the social behavior of some species (Soares & Schoereder, 2001; Schatz & Lachaud, 2008). A completely random distribution (in which the position of an organism is completely independent of any other position in the same population) may reflect an environment with homogeneous provision of resources, where intraspecific competition is negligible (Soares & Schoereder, 2001). On the other hand, uniform distribution may also indicate the

existence of strong intraspecific competition between individuals in the population, such as when animals defend sites for mating or foraging (Bernstein & Gobbel, 1979; Schatz & Lachaud, 2008).

Two main methodological approaches are used to describe the spatial distribution of organisms (Brower et al., 1997). One involves sampling through plots (frequently referred to as plot sampling or quadrat sampling) where the sampling is done by marking plots in different locations in the community and counting the number of organisms (ant nests) in each plot, followed by data comparisons using indices and probability models (i.e. Poisson distribution and Morisita's index) (Soares & Schoereder, 2001; Schatz & Lachaud, 2008; Silva Junior et al., 2013). Another method involves sampling the distance between individuals (usually plants and sessile organisms) or between the individual and a random point previously established, known as "nearest neighbor" method (Brower et al., 1997; Gao, 2013). Distance methods can help us to determine whether ant mounds are growing or having foraging territories in discernible (and often ecologically important) patterns or are randomly dispersed. Many intra-specific relationships among ant mounds are difficult to observe without using distance based sampling techniques. Moreover, the effectiveness of plot sampling depends on plot size and shape and this method fails in giving the relative positions of individuals within plots (Gao, 2013). However, due to the influence of several environmental factors involved, more than one index should be estimated before concluding about the spatial arrangement of a particular species (Brower et al., 1997; Mollet et al., 1984).

Leaf-cutting ants of the genera *Atta* and *Acromyrmex* are considered important modifiers in their environments, promoting the turnover and aeration of soil in areas adjacent to the mounds, incorporating organic matter to the system (Moutinho et al., 2003; Sousa-Souto et al., 2008), acting in carbon and nutrient cycling (Stenberg et al., 2009; Sousa-Souto et al., 2012a) and directly affecting the plant community structure (Garrettson et al., 1998; Leal & Oliveira, 1998; Corrêia et al., 2010). However, species of these two genera are also considered major pests in Brazilian agroecosystems by causing considerable damage due to intense and constant attacks on plants at all stages of development (Della Lucia 2011; Nickele et al., 2013). For this reason, the majority of studies examining the spatial distribution of leaf-cutting ant mounds were made in reforestation areas, with the goal of developing pest management plans to control these ants (Caldeira et al., 2005; Cantareli et al., 2006; Nickele et al., 2009).

This study evaluates the spatial distribution of mounds of *Acromyrmex balzani* using the methods of plot sampling and nearest neighbor distance. If different sampling methods produce similarly robust results, the simplest method would thus be more appropriate for determining the spatial distribution of this ant species in the future.

Material and Methods

Study area

The study was performed on a fragment of grassland, located in the municipality of São Cristovão, Sergipe, Brazil (11 ° 00'54 "S, 37 ° 12'21" W). The dominant vegetation consists of grasses and herbs, mainly *Paspalum notatum* Flügge (Poaceae), *Cynodon dactylon* L. (Poaceae) and *Richardia brasiliensis* Gomes (Rubiaceae) (Poderoso et al., 2009). The average annual temperature is 29 ºC with average annual rainfall of about 2000 mm. The soil type is Spodozol, mainly sandy clay, deep, with low fertility, high porosity (draining rainfall), high acidity and salinity (Sousa-Souto et al., 2012b). The leaf-cutting ant *A. balzani* is commonly found and is clearly the most abundant leaf-cutting ant species in the study area. Nests of *A. balzani* are small (0.2 to 1m² of area) compared with other leaf-cutting ant species but with population densities that may reach beyond 100 nests per hectare (Poderoso et al., 2009; Sousa-Souto et al., 2012b; Silva Junior et al., 2013). Each nest has a single entrance (Fig. 1 A-B) with a depth varying from 12 to 150 cm. This ant species relies mainly on leaves from monocotyledons (Fowler et al., 1986) which are deposited within the nest chamber (Poderoso et al., 2009). The waste material is delivered outside the colony, forming small piles of refuse (Mendes et al., 1992; Sousa-Souto et al., 2012b).

Fig. 1 – *Acromyrmex balzani* (Emeri) in the study area. A – Workers in the nest entrance. B – Detail of a nest entrance formed by two tubes of straw and other vegetable waste. C - General view of the area with nest mounds (blank spots).

Ant sampling

In a fragment of approximately 0.5 ha, during January 2013 (dry season), we established 360 plots of 2 x 5 m (10 m²), with a total sampled area of 3,600 m² (72% of the total area of fragment). In each plot, the number of colonies of *A. balzani* was obtained and the data were subjected to analyses of dispersion in order to determinate the type of spatial distribution. We used three index of dispersion: The Poisson probability model of distribution, Morisita's index of dispersion and the nearest neighbor method (Brower et al., 1997). For Poisson model, the observed frequency is compared with the expected frequency, calculated by the formula: $P(x) = (\mu^x e^{-\mu})/x!$, where: $P(x)$ = probability of finding x ant nests within plot; μ = average number of nests; a positive real number (1, 2, 3...) and e = is the base of the natural logarithm (= 2.71828...). The distribution pattern obtained can be compared by Chi-square statistic (Brower et al., 1997).

In addition to the adjustment of the Poisson distribution, data were submitted to the Morisita's index of dispersion: $Id = n(\sum X^2 - N)/(N(N-1))$ where *n* is the number of plots, $\sum X^2$ is the squares of the number of ant mounds per plot, summed over all plots and N is the total number of mounds counted on all *n* plots (Brower et al., 1997).

For the nearest neighbor method, random points (ant mounds) were located in the 5,000 m² stand and the distance from each sampling point to the nearest ant nest was measured (n = 25 mounds). Only one measurement was made from each random nest, and all distances for all mounds were summed and divided to yield one average distance. We then determined whether mounds were distributed randomly, regularly, or were clumped using an aggregation index $A1 = (D/\mu)^2$ (Clark & Evans, 1954), where D is the mean distance between these pairs of ant mounds; that is the mean nearest neighbor distance. The statistical significance of A1 is determined by $\mu = 1/(^2\sqrt{(n/A)})$, where SE = $0.26136/\sqrt{(n^2/A)}$ and the critical value of *t* is that for infinite (∞) degrees of freedom.

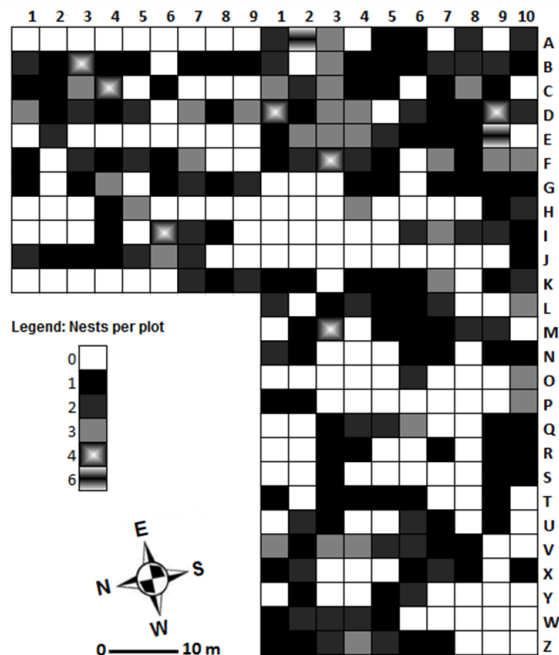Polydomy for *A. balzani* has been described (Caldato,

Fig. 2 – Schematic representation of the 359 plots distributed in the study area (3,600 m² of a total of 5,000 m²) and the frequency of *A. balzani* colonies per plot.

2010), meaning, two or more ant mounds in the same plot could be subnests associated with a single colony. However, for the purpose of this study, any ant mound was considered a sampling unit, considering that the physical presence of an ant mound can affect the plant community as well as the establishment of another colony, regardless of being a subnest or the main colony.

Results

We sampled 351 mounds of *A. balzani* in the 360 plots, with values ranging from 0 to 6 mounds per plot (Figs. 1C and 2). The nest density of 0.04 nests/m² and an average number of 0.98 ant mounds/plot found in this study is high (975 × colonies ha⁻¹), since the densities for this species can vary from 80-210 colonies × ha⁻¹ in similar environments of

Table 1 – The observed data from figure 01 and the probabilities expected from the Poisson Distribution with a mean (μ) of 0.98 ant mounds per plot.

Number of ant mounds in plot (X)	Observed frequency $f(X)$	Observed Probability $p(X)$	Poisson Probability $P(X)$
0	154	0.43	0.38
1	110	0.31	0.37
2	54	0.15	0.18
3	33	0.09	0.06
4	6	0.02	0.01
5	0	0.0	0.0
6	2	<0.01	0.0

the study region (Poderoso et al., 2009; Sousa-Souto et al., 2012b). For another leaf-cutting ant species (*Ac. landolti*) nest density can reach values of 2,000 colonies per hectare (Fowler et al., 1986).

The values obtained in the plot sampling method ($\chi2$ = 37.22; p < 0.05 and Iδ = 1.35) indicate that the colonies are clumped in the environment (Table 1). The same results were obtained using the nearest neighbor method (*t* = -1.72; p < 0.01). The mean distance between the pairs of ant mounds was 4.05 m and most of them (70%) were in a range of 2 to 6 m (Fig 3).

Discussion

The present study evaluated the spatial distribution of *A. balzani* through sampling plots and nearest neighbor methods. Both methods indicated the ant mounds were aggregately distributed, corroborating our hypothesis that different sampling methods give similar results for nest spatial distribution. These results contrast with previous studies of leaf-cutting ant species in *Eucalyptus* spp. forests, where the distribution of nests was random (Caldeira et al., 2005; Nickele et al., 2009). However, the aggregate spatial arrangement of ant nests has also been observed in pasture (Silva Junior et al., 2013) as well as in environments with native vegetation (Rissing et al., 1986; Soares & Schoereder 2001). Other ant species also show an aggregate distribution pattern, such as *Solenopsis invicta* (Buren) (Almeida et al., 2007), *Mycetophylax simplex* (Emery) (Albuquerque et al., 2005) and several litter ant species (Soares & Schoereder, 2001).

For social insects, aggregate distribution of nests may occur in response to physical (habitat heterogeneity) and biological factors (low rate of dispersion, nest budding or chance of survival increased when the organisms are grouped) (Nicholas & Vilela, 1996; Elisei et al., 2012; Leal et al., 2012). Termites, for example, have aggregated distribution when favorable soil conditions to the nest establishment are distributed in patches (Dias et al., 2012) or when foraging sites are sparsely distributed (Filho et al., 2012). The uniform pattern of distribution is common in some ant species and occurs when there is high nest density (Nicholas & Vilela, 1996). Such a distribution may be due to high intraspecific competition for resources, involving territory defense by colonies (Bernstein & Gobbel, 1979; Soares & Schoereder, 2001).

The usual limiting resources for ants are food and nesting sites (Fowler et al., 1983; Leal et al., 2012). It is possible, however, that these resources are not limited for leaf-cutting ants in pasture and cultivated fields or Eucalyptus forests, so that intra and interspecific competition might not be strong because these habitats have a constant abundance of food resources. The high density of aggregately distributed ant mounds found in this study indicate that *A. balzani* do not show aggressive defense behavior for their foraging sites.

In fact, it is common to find workers of different colonies in the same foraging site without any incidents of aggressive behavior (personal obs.). Besides, the occurrence of subnests around the main nest (polydomy) was found for *A. balzani* (Caldato, 2010). One could say that polydomy can mask the real dispersion pattern of this ant species, because a proportion of ant mounds could be subnests from a same main colony, leading to a clumped pattern in the landscape. Since the confirmation of polydomy is only possible through experiments of aggression (Caldato, 2010), and considering that the impact of an ant mound on herbivory is similar, regardless of the origin of the mound (subnests or the main nest), we can assume that the aggregate pattern of ant colonies is prevalent, even with a high rate of polydomy.
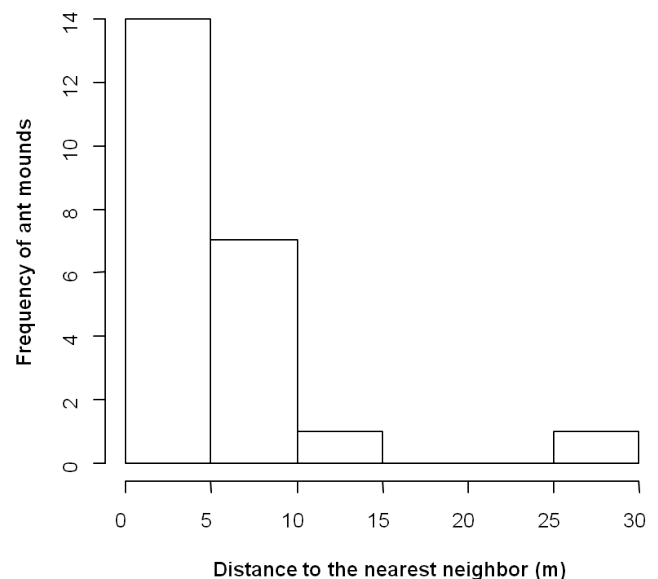

Fig 3. – Frequency of ant mounds of *A. balzani* according to the distance between pairs of mounds.

The high density of ant mounds found in the present study can be explained by the preference of these ants for open and human perturbed areas. Previous studies have found that other leaf-cutting ant species such as *Acromyrmex lobicornis* (Emery), *Ac. landolti* Forel and *Atta laevigata* (F. Smith) are abundant in areas with greater sun exposure, mostly open places (grasslands and pastures) or sites with trees or shrubs with reduced canopy cover (Bucher & Montenegro, 1974; Clark & Evans, 1954; Nickele et al., 2009; Silva Junior et al., 2013).

It is possible that interspecific competition also act in determining the aggregate pattern of colonies of leaf-cutting ants. Colonies of species with large numbers of workers and aggressive behavior, such as *Atta sexdens* or *At. laevigata* may be present in foraging areas coexisting with *Acromyrmex* spp., confining the latter to restricted sites within the fragment or forcing these colonies to emigrate (Fowler, 1977;

1983). In his study about distribution of leaf-cutting ants in Paraguay, Fowler (1983) proposed that the most important factor determining the local abundance of leaf-cutting ant species was interspecific competition. In other words, in sites where *Acromyrmex* species were locally abundant, *Atta* species were rare or absent, and vice versa. Indeed, in our study area we found two colonies of *At. opaciceps* with an average area of 5 m² which were located on plots which also hadcolonies of *Ac. balzani.* It is possible that competition is minimized by differentiation of the time of foraging (*Ac. balzani* is diurnal whereas *At. opaciceps* is nocturnal) and the type of resources collected (leaves of grasses *versus* shrubs and trees). In a previous study, Wetterer (1991) investigated the overlap of foraging areas between colonies of *At. cephalotes* and *Ac. octospinosus*, noting that there was only a single case of simultaneous exploitation of of the same resource (flowers). Several other differences in foraging strategies (e.g., type of substrate harvested, foraging time, size range of foragers) were also concluded to contribute to the sustained coexistence of these species (Wetterer, 1991). Future studies focusing on the interaction of these two genera will help clarify whether the dispersion of colonies is determined by the presence of interspecific competitors.

The use of plots is a well-established method for studying the dispersion pattern of colonies in leaf-cutting ants. This method is appropriate in reforestation areas (*Pinus* and *Eucalyptus* spp.), where planting areas are divided into quadrats according to the age of trees.

However, the use of the nearest neighbor method, as seen in this study, proved to be just as effective as plot sampling for determining distribution patterns of colonies in environments under native vegetation and fragments with irregular shape, making it a preferred method since we can provide the same results with lower sampling effort, compared with plot sampling method.

Acknowledgments

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