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Kerteszia Theobald (Diptera: Culicidae) mosquitoes and bromeliads: A landscape ecology approach regarding two species in the Atlantic rainforest

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ABSTRACT

On the ecological scale of an organism, a homogeneous geographical landscape can represent a mosaic of heterogeneous landscapes. The bionomy of *Kerteszia* mosquitoes can contribute to foundation landscape ecology by virtue of in the role of the configuration and composition of the habitat played in the distribution of mosquito species. Thus, this study aimed: to compare the abundance of *Kerteszia* in dense tropical rainforest, restinga and rural area, to assess the bioecological characteristics of the main bromeliads hosting *Kerteszia*, and to associate the bioecological arrangement of the bromeliads with *Kerteszia* distribution. Field collections were conducted in a monthly schedule from December of 2010 to November 2011. The vegetation of landscapes was characterized on the basis of a digital cartographic database, the manual of the Brazilian vegetation, environmental atlas information, satellite images and visits to the sites. Multivariate generalized linear models were employed using the R-project statistical program. The results were: *Anopheles cruzii* was the most frequent species in dense tropical rainforest (67.42%), with a positive association (deviance = 25.8; P = 0.002). *Anopheles bellator* was more abundant in the Restinga area (78.97%), with a positive association (deviance = 10.4, P = 0.018). There was a positive aggregation of Restinga with *An. bellator* (RR = 2.42) but a lower level with *An. cruzii* (RR = 0.31). Thus we can conclude that landscape characteristics influence the distribution of *Kerteszia* mosquitoes. *An. bellator* has a higher prevalence in Restinga areas, whereas *An. cruzii* was the most prevalent in the dense tropical rainforest.

1. Introduction

The definition of a scale of observation is critical for landscape analysis and its interaction with the organisms that inhabit it (Wiens, 1989; Turner, 2005). What appears to be uniform on a macro scale can actually be a heterogeneous environment composed of a mosaic of habitats, formed of isolated and dissociated fragments when observed on a micro scale. Scales of observation may adopt the anthropic point of view by means of the use of geographical and ecological scales when dealing with species and communities.

Landscape characteristics determine variations in spatial distribution of mosquito species, and thus of the vector-borne diseases associated to them, such as human malaria associated with them (Ostfeld et al., 2005). Moreover the spatial distribution of a mosquito vector species is associated with the spatial distribution of its larval habitats within the landscape (Pfaehler et al., 2006; Cailly et al., 2011).

On the ecological scale of mosquito vector species, a homogeneous geographical landscape can represent a mosaic of heterogeneous landscapes. Spatial interactions among landscapes and larval habitats can explain the patterns of spatial distribution of mosquito species and the dynamics of vector borne diseases (Cohen et al., 2010).

In this context, to understand the interactions between landscapes, mosquito species distribution and the risk of malaria transmission it is important to consider the composition and configuration of the heterogeneous landscapes within the tropical Atlantic rainforest, Restinga and the connectivity between these two ecosystems of bromeliads occurrence. The studied areas are relevant from a historical, ecological and epidemiological point of view, given the strong human pressure on the occupation of these

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areas, which in the past served as a gateway to European colonization, and in recent years houses environmental protection areas, which has come under human occupation and of pressure from real estate holding (Sampaio, 2005).

The tree canopy of tropical forests is recognized as one of the most diverse ecological systems, (Oliveira, 2004). Several species of animals, vertebrates and invertebrates, use the water present in the tanks of epiphytic bromeliads for foraging, reproduction and as a refuge from predators (Rocha et al., 1997). The interactions between ecological niches of vertebrates and the spatial distribution of mosquitoes, which coexist in the tree canopy of tropical forests, can contribute to the transmission of enzootic diseases that can also cause diseases in humans.

Mosquitoes of the subgenus *Kerteszia* of the genus *Anopheles* Meigen are distributed throughout northern South America, extending as far as Atlantic Coast in Southeastern of Brazil (Marrelli et al., 2007). This group of mosquitoes is mainly associated with the vegetation of the Bromeliaceae Juss as its development niche. In Brazil, several species of subgenus *Kerteszia* are potential vectors of the parasites that cause human malaria outside the Amazon region, forming a system known as bromeliad-malaria (Oliveira-Ferreira et al., 2010). Furthermore, considering the distribution of bromeliad plants in tropical rainforest landscapes, the configuration and composition of plants modulates and determines the maintenance and the dispersal of the *Kerteszia* species because most species depend on bromeliad phytotelmata for the development of their immature stages. The only exception is *An. bambusicolus* Komp that uses the internodes of bamboo as larval habitat.

Anopheles cruzii Dyar and Knab, *Anopheles bellator* Dyar and Knab and *Anopheles homunculus* Komp are competent to transmit *Plasmodium* Marchiafava and Celli parasites that can occasionally infect humans in the areas of the coastal Atlantic Forest (Smith, 1952; Deane, 1986; Forattini et al., 1986). *An. homunculus* and *An. bellator* are auxiliary vectors playing a secondary role in the dynamics of malaria transmission because they are usually less abundant than *An. cruzii*, considered to be the main vector.

Veloso et al. (1956) has indicated three major habitats of *Kerteszia*, the dense rainforests of the plains, mountainous dense rainforest and Restinga. In view of the fact that *An. cruzii* and *An. bellator* are indifferent to the geographical conditions mentioned above, Veloso et al. (1956) have suggested that there must be an ecological explanation in terms of microclimate (exposure to sunlight) and the volume of water between bromeliad leaves. The hypothesis presented in this study is that in addition to the factors cited by Veloso et al. (1956), the characteristics of the landscape structure may be considered as species dispersing facilitators or as ecological barriers to the distribution and dispersion of *Kerteszia* species. Recently, Eycott et al. (2012) have hypothesized that a matrix structurally similar to the ideal habitat of a species tends to increase its dispersion when compared to matrices approximating to a non-ideal habitat. According to the authors, for a wide range of species, habitat networks based on an array of elements of similar structure may increase the local flow of individuals, which could lead to the increased dispersion and persistence of a given population. Considering the patch-corridor-matrix model (Forman, 1995) and taking the landscape units as a framework for the population dynamics of *Kerteszia* mosquitoes, we analyzed ecological factors of the Bromeliaceae family with connections related to the dispersion of these insects in the Southeastern Atlantic forest of São Paulo State.

2. Materials and methods

The vegetation present in the study area was characterized based on the following data bases: the digital cartographic data base of the "Instituto Geográfico e Cartográfico" (IGC, http://www.igc.sp.gov.br), São Paulo State, the technical manual of the Brazilian vegetation of the "Instituto Brasileiro de Geografia e Estatística" (IBGE, 2012), the Atlas with environmental information on Biota/Fapesp (SinBiota, http://www.sinbiota.biota.org.br) and high resolution satellite images that were complemented with information obtained during field collections. The vegetation present in the study area was composed of dense tropical rainforest (submontane), Restinga (with medium-sized trees of up to 12 m height), and mangrove areas that have been intensively modified as the result of a long history of human occupation and land use that started in 1500 with the beginning of European colonization.

According to the classification proposed by Köppen (Trewartha and Horn, 1980), the climate is of the Cfa type, subtropical and super-humid, with a moderately dry winter and a hot humid summer season. The average annual temperature is 19.9 °C, with constant rainfall throughout the year. The average annual rainfall is 1,801.1 mm, July being the driest month and February the wettest (INMET http://www.inmet.gov.br). For environmental analysis, it adopted the average temperature of 15 days before the collects, because of the biological development conditions of these mosquitoes, and the sum of 30 days before the collects this time for accumulated precipitation by intrinsic issues of the formation of larval habitat.

To address the abundance of species in the tropical rainforest, Restinga and rural area, we conducted monthly collections of adults, adopting the experimental design of Latin square. So, the traps were alternated between sampling sites.

Three types of trap were employed to capture mosquitoes in order to maximize the sampling effort. The CDC-LT (BioQuip Rancho Dominguez, CA) developed by Sudia and Chamberlain (1962), CDC without light but with Lurex3™ and CO^2, and Mosquito Magnet® Independence with CO^2 and Lurex3™ (Woodstream Corporation Lititz, PA) were installed 0.8 m above the ground from 3.00 p.m. to 9.00 p.m. on alternate days in the landscapes. The field collections were carried out monthly, from December 2010 to November 2011, each month represents a sample. Mosquitoes were collected on three consecutive days per month, representing a sampling effort of 216 h in a whole year.

In municipality of Cananéia, southeast São Paulo State were selected an area of dense rainforest (UTM N7245247 m/E211114m; Zone 23 South; Datum SIRGAS 2000), at 30 m altitude and one kilometer away an area in Restinga vegetation (UTM N7244204m/E211952m; Zone 23 South; datum SIRGAS 2000), at 12 m altitude.

In a rural area of the muncipality of the Pariquera-Açu (UTM N7275538m/E207786m; zone 23 south; Datum SIRGAS 2000) at 20 m altitude was installed the same traps. This area is 30 km away from the other two sites and served as the landscape control for comparison, although in the context of landscape ecology each landscape is a single unit (Bissonette, 1997; Metzger et al., 2007). This is a landscape of cultivated land, interspersed with residual forests. It is thus a disturbed area, with residual fragments of tropical rainforest without functional connectivity.

Specimens were identified, whenever possible, to species level, using the morphological identification keys.

Fig. 1 shows the three landscapes where mosquito collections were carried out on two main geographic scales, one on the scale of 1:25,000 m showing local vegetation cover and land use, and the other on satellite orthophoto (www.igc.com.br) on a scale of 1: 2500 m showing the regional landscape.

All the statistical analyses were undertaken using the R-project program (available at http://www.r-project.org), employing specific packages for Windows version 3.0 (R Project for Statistical Computing, Vienna, Austria): mvabund (Warton, 2008). Comparisons between the landscapes were carried out by qui-square