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Mosquito populations dynamics associated with climate variations

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ABSTRACT

Mosquitoes are responsible for the transmission of numerous serious pathogens. Members of the *Aedes* and *Culex* genera, which include many important vectors of mosquito-borne diseases, are highly invasive and adapted to man-made environments. They are spread around the world involuntarily by humans and are highly adapted to urbanized environments, where they are exposed to climate-related abundance drivers. We investigated Culicidae fauna in two urban parks in the city of São Paulo to analyze the correlations between climatic variables and the population dynamics of mosquitoes in these urban areas. Mosquitoes were collected monthly over one year, and sampling sufficiency was evaluated after morphological identification of the specimens. The average monthly temperature and accumulated rainfall for the collection month and previous month were used to explain climate-related abundance drivers for the six most abundant species (*Aedes aegypti, Aedes albopictus, Aedes fluviatilis, Aedes scapularis, Culex nigripalpus* and *Culex quinquefasciatus)* and then analyzed using generalized linear statistical models and the Akaike Information Criteria corrected for small samples (AICc). The strength of evidence in favor of each model was evaluated using Akaike weights, and the explanatory model power was measured by McFadden's Pseudo-R^2. Associations between climate and mosquito abundance were found in both parks, indicating that predictive models based on climate variables can provide important information on mosquito population dynamics. We also found that this association is species-dependent. Urbanization processes increase the abundance of a few mosquito species that are well adapted to man-made environments and some of which are important vectors of pathogens. Predictive models for abundance based on climate variables may help elucidate the population dynamics of urban mosquitoes and their impact on the risk of disease transmission, allowing better predictive scenarios to be developed and supporting the implementation of vector mosquito control strategies.

1. Introduction

Mosquitoes are responsible for the transmission of numerous serious pathogens to humans and animals. The three most important genera of mosquitoes are *Anopheles*, which transmits malaria; *Culex*, which is responsible for the transmission of filariasis and several arboviruses, such as West Nile virus; and *Aedes*, which transmits dengue, Zika, chikungunya and yellow fever viruses, among many others (World Health Organization, 2016, 2015, 2012a, 2012b). These diseases cause millions of deaths every year and endanger approximately 3 billion people in endemic areas around the world. *Aedes* and *Culex* mosquitoes are highly invasive and well-adapted to man-made environments and are spread around the world involuntarily by humans (World Health Organization, 2016, 2015, 2012b). Mosquitoes' ability to live in urban environments depends mainly on two factors: (a) the availability of breeding sites for the females to lay eggs and (b) the availability of hosts for blood feeding. However, changes in the environment, such as a reduction in the availability of food supplies and variations in climate, can affect and regulate mosquito populations. Two major mechanisms affect population dynamics: (a) exogenous (i.e., climate-related) abundance drivers, such as rainfall and temperature, and (b) endogenous (i.e., density-dependent) drivers, such as population size (Begon et al., 2006; Chaves et al., 2012; Legros et al., 2009; Ratikainen et al., 2007).

Rainfall and temperature, among other climatic variables, play a major role in the population dynamics of urban mosquitoes. Man-made environmental changes can expand specific mosquito species' habitats, increasing their abundance and decreasing total species richness, which will inevitably have an impact on vector ecology and the epidemiology of infectious diseases. For exam-

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ple, there is a strong correlation between climatic conditions, such as temperature and rainfall, and increases in the incidence of diseases transmitted by *Aedes aegypti* (Descloux et al., 2012; Kamgang et al., 2013). Unplanned urbanization may lead to an increase in suitable breeding sites and consequently greater proliferation of mosquitoes known to vector human disease such as *Culex quinquefasciatus, Culex nigripalpus, Culex tarsalis, Ae. aegypti, Aedes albopictus* and *Aedes fluviatilis* (Descloux et al., 2012; Do et al., 2014; Lambrechts et al., 2011; Norris, 2004; Sang et al., 2015).

Urbanization is characterized not only by an increase in built-up areas because of migration, but also by the natural growth of a city and consequent conversion of rural areas into urban areas. The architectural design of major cities relies on the creation of urban parks to mitigate the impact of such urban growth. Over time, as natural vegetation is gradually replaced by urbanized areas, these parks become "green islands" harboring various mosquito species as well as reptile, bird and mammal species that can maintain an enzootic transmission cycle. Contrary to what might be expected, there is a decrease in mosquito richness in these parks and selection of a few species that are well-adapted to the urban environment as a result of both human-made environmental modifications and climatic variations (Nielsen et al., 2013; Samson et al., 2015). The use of simple predictive models to elucidate associations between climatic variables and population dynamics of epidemiologically important mosquito species may be of great help in anticipating disease outbreaks and assessing transmission risks.

In light of the strong association between climatic variables and mosquito abundance (and consequent increase in disease transmission), it is clear that a better understanding of exogenous influences on the population dynamics of mosquitoes is essential. We therefore sought to analyze correlations between exogenous climatic variables and mosquito population dynamics in urban areas. To this end, we tested whether variations in rainfall and temperature over one year can be a significant exogenous driver for urban mosquito population dynamics in two city parks.

2. Materials and methods

2.1. Collection areas

Collections were performed between August 2012 and July 2013 in two municipal parks in São Paulo, SP, Brazil: Piqueri Park (23° 31′ 39.98″ S, 46° 34′ 24.88″ W) and Previdência Park (23°34′50"S 46°43′36"W). After a preliminary survey of Culicidae fauna in the 59 municipal parks in the city of São Paulo (Medeiros-Sousa et al., 2013), Piqueri and Previdência parks were chosen for this study because of their highly urbanized surroundings and their locations on opposite sides of the city.

Piqueri Park and Previdência Park were created in 1978 and 1979, respectively. Piqueri Park, on the east side of São Paulo, extends over 97,200 m^2, and the vegetation consists of eucalyptus groves, mixed undergrowth, gardens, lawns and bamboo. The vertebrate fauna comprises 90 species, including fishes, mammals, small amphibious lizards and 79 bird species.

Previdência Park is located in the extreme west of São Paulo and covers an area of 91,500 m^2 with mixed flora consisting mainly of remnants of the Atlantic Forest and reforested areas and gardens. The vertebrate fauna comprises 75 species, including reptiles, mammals and 57 bird species.

2.2. Collection techniques

Collections were made monthly between August 2012 and July 2013 (twelve collections). Specimens were collected using four different techniques: (i) larval dippers or suction tubes (for immature stages); (ii) a hand-held vacuum aspirator powered by a 12 V battery in a standardized 20-min collection effort (for adult mosquitoes) (Natal and Marucci, 1984); (iii) CDC light traps with 200 g of dry ice placed 1 m above the ground (two traps) and in the canopy 5 m above the ground (two traps) for three hours; and (iv) Shannon traps, from which specimens were collected two hours after twilight fell by two individuals wearing personal protective equipment (Bustamante and Pires, 1951).

2.3. Species identification and analysis

All the material collected was transported to the Entomology Laboratory at the School of Public Health, University of São Paulo, and morphologically identified by means of taxonomic keys (Consoli and Lourenço-de-Oliveira, 1994; Forattini, 2002) and comparison with standard specimens in the collection at the School of Public Health, University of São Paulo. The abbreviations for genus and subgenus used here follow the standardization proposed by Reinert (2001).

To confirm sample sufficiency, the EstimateS program was used to plot sample-based species accumulation curves and estimate total richness by the jackknife 1 method (Burnham and Overton, 1979) with 1000 randomizations without replacement and a 95% confidence interval (Colwell et al., 2004). To evaluate climate-related drivers of mosquito abundance, average monthly temperature and monthly cumulative rainfall for the city of São Paulo recorded throughout the study period by the Brazilian National Institute of Meteorology were used (INMET –Instituto Nacional de Metereologia, 2015).

Because of limitations in the collection techniques (e.g., the fact that CDC and Shannon traps are not attractive to males and tend to attract mosquitoes that are active at twilight) and the consequent low sampling power, only adult mosquitoes could be used in the analysis of mosquitoes that are active at twilight (*Ae. fluviatilis, Ae. scapularis, Cx. nigripalpus* and *Cx. quinquefasciatus*) and immature forms in the analysis of day-biting mosquitoes (*Ae. aegypti* and *Ae. albopictus*). Four climatic explanatory variables were used to assess the relationship between exogenous factors and mosquito abundance: (a) monthly average temperature for the collection month; (b) monthly average temperature for the previous month; (c) cumulative rainfall for the collection month; and (d) cumulative rainfall for the previous month. The response variable was the variation in abundance of the six most abundant species: *Ae. aegypti, Ae. albopictus, Ae. fluviatilis, Ae. scapularis, Cx. nigripalpus* and *Cx. quinquefasciatus.*

Since the response variables are expressed as count data and there was strong evidence of overdispersion (variance higher than expected), an overall model with negative binomial errors (log link function) was fitted to the observed mosquito counts with temperature and rainfall as explanatory variables. A theoretical approach based on the Akaike Information Criteria corrected for small samples (AICc) was used to select the most plausible statistical models. To avoid over parameterization, models with no more than four parameters were used: (a) intercept; (b) dispersion parameter (θ); and (c) and (d) two explanatory variable slopes. The best models were considered to be those associated with the smallest AICc, and a value-of-evidence threshold of $\Delta AICc \leq 2$ was adopted to select the most plausible models. The strength of evidence in favor of the model was evaluated using Akaike weights, and the explanatory model power was measured by McFadden's Pseudo-R^2 (Burnham and Anderson, 2002; McFadden, 1973). The collinearity between the explanatory variables was checked by the Variance Inflation Factor (VIF); values close to 1 were taken to indicate no relationship between predictors, and values greater than 10 to indicate high collinearity (O'Brien, 2007).