Bulletin of Entomological Research (2010) **100**, 153–158 doi:10.1017/S0007485309006919

First published online 5 May 2009

Distribution of mosquitoes in relation to urban landscape characteristics

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Abstract

The current global increase in prevalence of vector borne diseases, as well as an expansion of tropical infections to more temperate zones, justifies further studies on vector populations. Urban areas may favour viral transmission to humans through close contacts between the vectors and the vertebrate hosts, and also affecting mosquito populations by offering larval habitat, refuges and adequate microclimates to survive the winter. This work analyses the spatial distribution of potential vector mosquitoes in relation to landscape characteristics in an urban environment in a temperate climate region. Mosquitoes were trapped monthly from October 2005 to March 2006 in 25 sites within Córdoba city and suburbs with miniature light traps + CO_2. Nine species were collected, and the most abundant were *Culex quinquefasciatus* (37.1%), *C. apicinus* (26.6%) and *Aedes aegypti* (13.9%). Species that may be involved in SLEv transmission were recorded throughout the sampling. *C. quinquefasciatus* was detected in 92% of the sites; however, only two sites showed consistently larger collections. The site of highest *C. quinquefasciatus* abundance was located within an area of high Saint Louis Encefalitis virus prevalence and risk of infection, further supporting this species involvement as a vector. Significant correlations were detected between land cover characteristics and abundance of *C. apicinus*, *C. interfor* and *C. maxi* that were consistent with previous knowledge about their larval habitat and domestic preferences, which may be useful for targeting vector control operations.

Keywords: Diptera, mosquito, landscape, geographic information systems

(Accepted 7 March 2009)

Introduction

Mosquitoes are insects of major public health concern, mainly for their role as vectors of pathogens to humans and animals (WHO, 2002; Snow *et al*., 2005). The geographic distribution of several vector-borne viral diseases, such as West Nile virus and Rift Valley fever are currently expanding (Gubler, 2002; Morales *et al*., 2006), and a rise in morbidity and mortality is noticeable (Rezza *et al*., 2007). In Argentina in 2005, an outbreak of viral meningo-encephalitis, mainly by the mosquito-borne Saint Louis Encephalitis virus (SLEv; Flaviviridae), was recorded in Córdoba province (Diaz *et al*., 2006). West Nile virus (WNv), first reported in North America in 1999, was detected in horses (Morales *et al*., 2006) and humans (ProMED-Mail, 2006) early in 2006. Thus, further studies on the ecology and biology of vector populations are justified.

Urban ecosystems may affect mosquito populations by offering larval habitat, refuges and adequate microclimates to survive the winter. Deforestation and new urbanizations promote larval habitats in artificial containers (Jacob *et al*.,

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2003; Leisnham *et al*., 2004). Shaded and vegetated neighbourhoods, with plenty of sites less exposed to sunlight and with taller and closer vegetation, were found the most favourable microhabitats for *A. aegypti* larvae in Buenos Aires (Argentina) (Vezzani *et al*., 2005). The abundance of two malaria vectors, *Anopheles funestus* and *A. gambiae* s.s., in Western Kenya Highlands was related to housing characteristics and land cover; adult abundance was higher in areas with low tree canopy coverage (Zhou *et al*., 2007, and references therein).

Urban landscape characteristics may also influence the epidemiology of mosquito-borne diseases by affecting host availability and accessibility. Highly diverse host communities have been related to lower infection risk of vector-borne diseases, probably by reducing human exposure to the pathogens through a 'dilution effect' (Ezenwa *et al*., 2006). Urbanization alters the composition of avian communities, favouring those species that can take advantage of anthropogenic habitats (Marzluff *et al*., 2001). Associations between land cover variables and prevalence of WNv have been detected in Chicago and Detroit, with a higher prevalence in suburbs dominated by 1940–1960 housing, with moderate vegetation cover, that may allow combinations of mosquito species and birds needed to sustain transmission (Ruiz *et al*., 2007).

Remote sensing and geographic information systems (GIS) provide resources to analyze data involving a spatial component, such as the relation between vector populations, land cover and land use (for example Nicholson & Mather, 1996; Gleiser *et al*., 2002; Masuoka *et al*., 2003; Hay *et al*., 2006; Gleiser & Gorla, 2007). The present work studied the spatial distribution of multiple mosquito species within an urban environment in a temperate region. In particular, it explored the correlates of abundance of potential vectors and landscape characteristics.

Material and methods

Study area and mosquito sampling

The study area was the city of Córdoba, homonym province, located in the centre of Argentina (64°11′W–31°24′S) at 360–480 m above sea level (http://www.cordoba.gov.ar/). It has a population of approximately 1,290,000 inhabitants (INDEC, 2001). The climate is temperate, mesothermal, with an average summer temperature of 24°C and average winter temperature of 11°C. Rainfalls prevail during October to December and March, with an average annual rainfall ranging between 750 and 800 mm (Jarsún *et al*., 2003).

Adult mosquitoes were collected with CDC miniature light traps baited with dry ice as a source of CO_2 (Service, 1993) from spring (October 2005) to fall (March 2006). The time frames cover the warm and rainy season, when peaks of mosquito abundance are more likely to occur in the area. Traps were operated from dusk to dawn among 24 sites. In November, only eight sites were sampled. However, those sites were spread throughout the city, and mosquitoes were almost absent from traps, suggesting their populations were very low at the time. On another seven isolated occasions, technical problems (such as trap malfunctions, inaccessibility to a site) precluded sampling; thus, in all there were a total of 121 trap nights. Sampling sites were selected to represent different levels of urbanization and land cover, from highly constructed (0% unbuilt lots), to suburban and open areas (55% unbuilt lots), and were located at varying distances from waterways (ranging from 15 to 3200 m). Mosquitoes were determined to species level in the laboratory based on morphological characters (Darsie, 1985; Almirón, 1992).

Spatial analyses

Latitude and longitude coordinates of the sites were recorded with a global positioning system (GPS) (Garmin Surveyor Global Positioning System) for GIS processing using Idrisi Andes (Eastman, 2006). Vector layers were generated for site location, and for presence and abundance of each species.

In order to assess macro-scale factors that the spatial distribution of mosquitoes may be related to, the following landscape characteristics were estimated for a circular buffer area (radius 400 m) around each sampling site:

1. The normalized differences vegetation index (NDVI) was used as an overall indication or 'proxy' of vegetated surfaces, and was calculated as a ratio between measured reflectivity in the red and NIR portions of the electromagnetic spectrum estimated from Landsat images of Cordoba City from January 2006. The NDVI is a spectral index that relates to plant biomass (Tucker & Sellers, 1986) and is computed directly without any bias or assumptions regarding plant physiognomy, land cover class, soil type or climatic conditions.
2. The presence and proximity to waterways (river, creek, lagoons and water channels) because they may provide larval breeding habitat in pools on margins. Also, drain ditches flow to the creeks and river, and their flood pools may also provide suitable larval habitat.
3. The number of unbuilt lots, unbuilt and built lot surfaces were obtained from the City Hall for each neighbourhood where sampling sites were set (http://www.cba.gov.ar/). The following proxy variables (indicators of construction density) were estimated for each sampling site: (i) % of unbuilt lots: percentage of lots that are not built in a neighbourhood (complements percentage of built lots); (ii) % of unbuilt surface: for each neighbourhood, the percentage of the total surface (m^2) covered by unbuilt lots, and (iii) % of built surface: percentage surface covered by housing and other building constructions.
4. The percentage surface covered by and proximity to informal settlements. Informal settlements consist of small, irregular, precarious dwellings, frequently assembled from pieces of plywood, wood and corrugated metal, lacking the most basic services, including sanitation systems. Sewer ditches are usually seen along the unpaved streets. Due to sanitation conditions and availability of open containers, they were expected to provide breeding sites for mosquitoes. Maps on the distribution of informal settlements were obtained from the City Hall.

Statistical analyses

Spearman's rank correlation (R) was used to evaluate the relation between the average and coefficient of variation of female abundance at each site with each of the landscape variables described above. A linear correlation (R^2) examined the relation between total mosquito abundance and the number of species collected. A *P*-value $\leqslant 0.05$ was considered statistically significant.

Table 1. Mosquito specimens collected at 25 sampling sites and percentage of sites where each species was detected in Córdoba city, homonym province, from October 2005 to April 2006.

Mosquito species	Specimens collected	Sites detected (%)
Aedes aegypti	125 (13.9)	68
Culex apicinus	240 (26.6)	88
Culex chidesteri	1 (0.1)	4
Culex dolosus	24 (2.7)	44
Culex interfor	59 (6.5)	60
Culex maxi	87 (9.7)	60
Culex quinquefasciatus	334 (37.1)	92
Ochlerotatus albifasciatus	28 (3.1)	52
Ochlerotatus scapularis	3 (0.3)	12

The number in parenthesis is the percentage of the total sample.

Results

A total of 1167 specimens belonging to nine species within *Aedes*, *Culex* and *Ochlerotatus* genus were collected, and 87% of them were female. Table 1 shows the species collected in the study area and the percentage of sites positive for each species (115 specimens could only be identified as *Culex spp*. because of missing appendices and/or scales, and were not included in the table or further data analysis). *Culex quinquefasciatus* Say and *C. apicinus* Philippi were by far the most widely distributed and abundant species, followed by *A. aegypti*. *Ochlerotatus albifasciatus* (Macquart) represented only 3% of the total number of mosquitoes collected, but was present at 52% of the sites.

To assess the relation between landscape characteristics and mosquito abundance, the average and coefficient of variation of female abundance at each site were correlated to each of the landscape variables. Significant correlations are presented in table 2.

The spatial distribution of mosquito abundance was biased, showing a higher percentage of mosquitoes collected at a site to the east of the city (fig. 1a). Species diversity (represented by the number of species collected) showed a less clustered distribution, but was also higher on the eastern sites (fig. 1b). Although a significant relationship was detected between mosquito abundance (ln (n + 1)) and species diversity ($R^2 = 0.72$, $P \leqslant 0.5$), some sites representing a low proportion of specimens collected (ranging from 2 to 3% each) yielded six or more different species.

Discussion

The presence of mosquito species of sanitary importance was recorded throughout the study (table 1). *C. quinquefasciatus*, the most abundant and widespread species, is a suspected urban vector of SLEv (Mitchell *et al*., 1980; Diaz *et al*., 2006). In fact, in the present study, the site of highest *C. quinquefasciatus* abundance was located within an area of high SLEV prevalence and risk of infection (Spinsanti *et al*., 2007). *C. interfor* was another spatially widespread species collected that might be involved in the cycle of SLEv. This virus has been isolated from *C. interfor* specimens sampled at the residence of an SLE confirmed patient in Córdoba (Diaz *et al*., 2006). It would be worthwhile to assess the potential involvement of *C. apicinus* in the SLE cycle because this domestic species, cited as ornitophilic in Córdoba (Almirón & Brewer, 1995), was collected since the spring-time (October), when the SLE virus may be amplifying.

Although *C. quinquefasciatus* was the most frequent species, only a few sites were more productive in terms of the number of specimens collected. The site of highest abundance was located close to the river and ponds rich in organic matter, in proximity to informal settlements and garbage dumps, which may provide a wide availability of larval habitats. Immature stages of this species have been collected in diverse habitats, including cisterns, tires, flower-pots, pools in drains and ponds (Almirón & Brewer, 1996; Stein *et al*., 2002; Pires & Gleiser, 2007). *C. quinquefasciatus* has been reported to share larval habitats with *A. aegypti*; however, their spatial distributions were not correlated ($R^2 = 0.16$, $P = 0.45$), which may be a consequence of *C. quinquefasciatus* taking advantage of a wider range of larval habitats (Almirón & Brewer, 1996; Pires & Gleiser, 2007). Although no significant correlations were detected between *C. quinquefasciatus* and the landscape variables evaluated, a negative tendency between abundance and percentage of unbuilt surface was observed, probably reflecting the adaptability of this species to the urban environment. Local characteristics at a lower scale than considered may be more relevant to explain spatial variations in *C. quinquefasciatus* abundance. On the other hand, *C. interfor* abundance was negatively correlated with NDVI and positively correlated with the percentage of built surface, suggesting a preference for densely constructed areas.

The NDVI was an important variable in several predictive models of *A. aegypti* larval index developed for a dengue endemic area in north-western Argentina (Estallo *et al*., 2008). Considering that this mosquito species has a short dispersal rate, usually clustering 1 to 30 m from houses

Table 2. Correlations between mosquito abundance at 25 sampling sites and landscape variables in Córdoba city, homonym province.

	Culex apicinus	*Culex interfor*		*Culex maxi*		*Culex quinquefasciatus*	
	Coeff. Var.	Average	Coeff. var.	Average	Coeff. var.	Average	Coeff. var.
NDVI avg.		−0.70 (< 0.01)	−0.59 (< 0.01)				
NDVI sdev.				0.42 (0.04)			
NDV coeff. var.		0.57 (< 0.01)	0.69 (< 0.01)				
%unbuilt lots		−0.49 (0.01)		0.46 (0.02)			
%unbuilt surface		−0.40 (0.05)				−0.37 (0.07)	
%built surface		0.64 (< 0.01)					
Distance to water	−0.42 (0.04)				0.37 (0.07)		−0.38 (0.06)

Values in table are Spearman's R. *P*-values are included in parenthesis. Only correlations with $P < 0.08$ are shown.
avg., average; sdev., standard deviation; coeff. var., coefficient of variation.

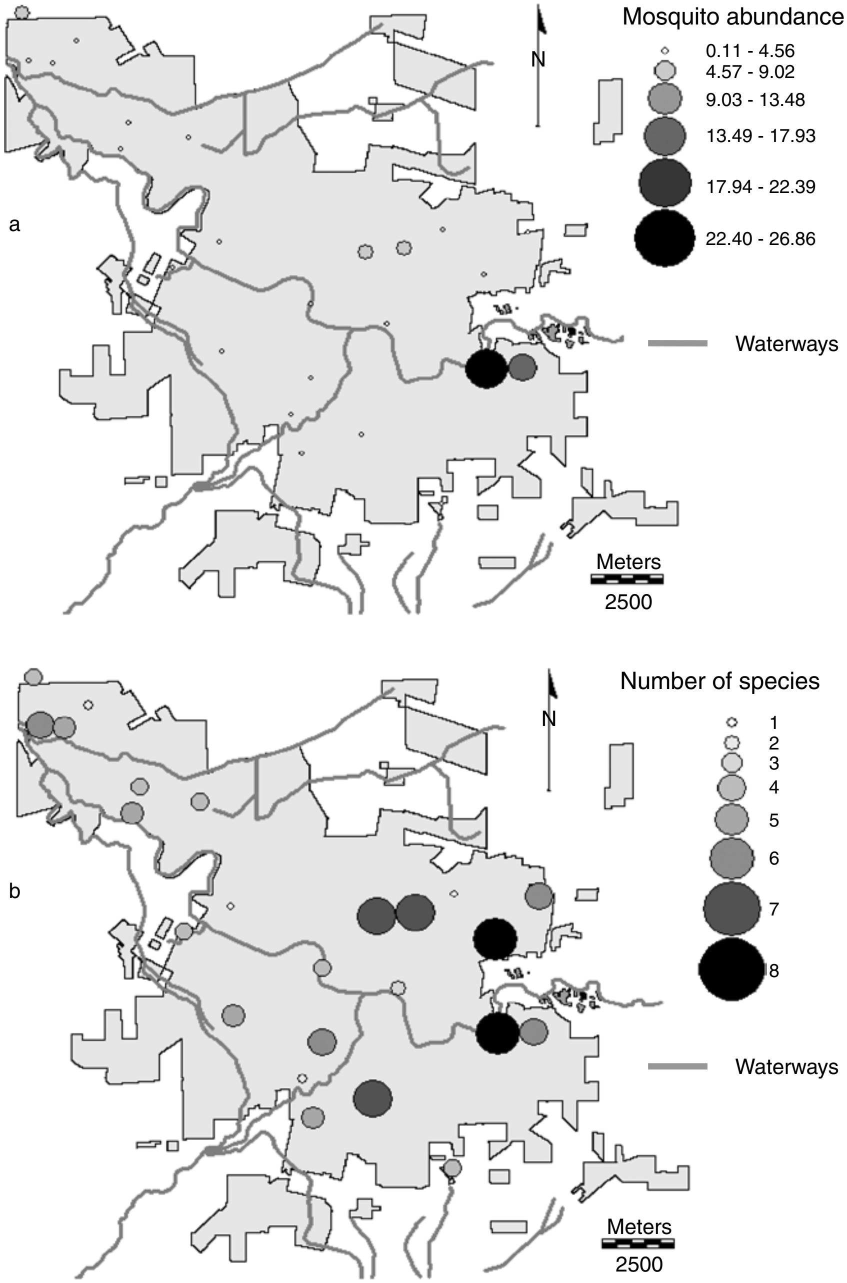

Fig. 1. Distribution of sampling sites in Córdoba city. (a) Mosquito abundance, expressed as percentage of mosquitoes collected at each site; (b) species diversity, estimated as number of species collected at each site.

(Getis *et al*., 2003; Lourenço-de-Oliveira *et al*., 2004) and dispersing up to 320 m from a release point (Liew & Curtis, 2004), a similar relation between landscape and mosquito abundance was expected for Córdoba. However, no significant correlations were found, suggesting that, at least during the rainy season, availability of water-holding containers was widespread. It would be interesting to assess whether this pattern changes seasonally.

Culex apicinus and *C. maxi* showed opposing patterns regarding their relationship with waterways. *C. maxi* abundance tended to be less variable near waterways, and collections were higher as the percentage of unbuilt lots increased, probably reflecting availability of breeding sites. Immature of this species have been collected in the city in stream margins and pools in margins of rivulets, rivers and road drains (Almirón & Brewer, 1996) and temporary pools in association with *O. albifasciatus* (Pires & Gleiser, 2007). A significant correlation between abundance and variability of the NDVI suggests a preference for heterogeneous urban habitats such as suburbs, where constructed lots alternate with open spaces, as opposed to areas where the construction density is high.

The identification of areas with consistently high numbers of mosquitoes, which may also have higher risk of disease transmission (Ribeiro *et al*., 1996), is relevant to target mosquito surveillance and selective control measures. The detection of significant correlations between some species and landscape characteristics, that were consistent with previous knowledge about their ecology and larval habitat preferences, encourages more detailed studies, both spatially and temporally, and the incorporation of geographic information systems as an aid in the evaluation, planning and decision making for vector control operations.

Acknowledgements

We are grateful to W. Almirón and G. Rossi for their assessment in taxonomic determination of *Culex* specimens. We would like to acknowledge an anonymous reviewer for constructive comments on the manuscript that helped improve it. This work has been partly funded by CONICET, SECYT-UNC and FONCYT. We acknowledge CONAE (National Spatial Commission, Argentina) for the provision of satellite imagery under 'PlagaSat' project.

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