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Effect of temperature on the flight activity of culicids in Buenos Aires City, Argentina

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Daily temperature could determine mosquito activity and competence for transmitting arboviruses. This work aims to determine the seasonal occurrence of mosquito species and to characterize their flight activity in relation to the mean daily temperature in Buenos Aires, Argentina (March 1998 to April 2001). The proportion of capture events for each culicid species throughout all seasons and thermal ranges, obtained by classifying daily mean temperatures corresponding to every capture event, was compared using a test for multiple independent proportions. Twenty-three species from six genera were captured and two groups could be identified: group 1, species captured in all thermal ranges and group 2, species not captured below 11°C. Flight activity of the different species would be affected by daily and seasonal mean temperature. Species of group 1, which are present throughout the year, seem to be triggered above a certain threshold of temperature, regardless of the season. Group 2 species would display a seasonal activity pattern.

Keywords: Culicidae; temperature; seasonality; flight activity; Buenos Aires

Introduction

Mosquitoes are attracted to hosts by a variety of factors including exhaled carbon dioxide, odour, body warmth, thermal convection currents and visual stimuli (Clements 1963; Torres Estrada and Rodríguez 2003). Attractants have been used in various methods for capturing adult mosquitoes, such as light traps.

The light traps are designed to intercept flying adult mosquitoes by means of light and carbon dioxide as visual attractant and bait, respectively (Service 1976). This method is used to estimate the presence and abundance of culicid females, which depend on the environmental conditions (e.g. latitude and meteorological and topographic variables) and on the particular biological features of each species (dispersal capacity from breeding sites, adaptation to climatic conditions and biting activity).

Mosquitoes, like most insects, are highly sensitive to temperature, and the species from temperate climates frequently show great seasonal variations in their abundance (Samways 1995). This phenomenon has been documented in many countries of South America. In Buenos Aires Province, Argentina, seasonal changes in abundance have been reported for the following species: *Ochlerotatus*

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(Ochlerotatus) albifasciatus (Macquart), *O. (Ochlerotatus) crinifer* (Theobald), *Culex (Culex) dolosus* (Lynch Arribálzaga), *Mansonia (Mansonia) indubitans* Dyar and Shannon, *M. (Mansonia) titillans* (Walker), *Psorophora (Janthinosoma) ferox* (Humboldt) and *Runchomyia (Runchomyia) paranensis* (Brethes) (Ronderos et al. 1992; Campos et al. 1995; García et al. 1995; Maciá et al. 1995, 1996). In the location of Punta Lara, Maciá (1997) found adults of *C. dolosus* all year round, adults of *C. maxi* during all months except June and July, and *M. indubitans* and *M. titillans* from October to April. In Serra do Mar, located in the subtropical region of Brazil, individuals of *O. scapularis* occurred throughout the year with highest abundance from December to March, when mean temperatures ranged between 22.5 and 26.2°C (Guimarães et al. 2000).

Daily temperature has been considered a determining factor for mosquito activity. Gjullin et al. (1961) and Corbet and Danks (1973) reported no activity below 5°C for mosquitoes inhabiting the tundra. Brust (1980) observed that the dispersal activity of different species of genus *Aedes* (currently *Ochlerotatus*; Reinert, 2000) took place when the mean night temperature exceeded 15°C. In Córdoba, Argentina, *O. albifasciatus* was found to modify its daily activity pattern at daily minimum temperatures below 6°C (Ludueña Almeida and Gorla 1995). In *C. tarsalis*, flight and feeding are triggered above 13°C and 15°C, respectively (Bailey et al. 1965).

Temperature is known to affect the competence of mosquitoes for transmitting arboviruses. Dohm et al. (2002) proposed that this factor should be considered when modelling the risk of West Nile virus transmission by *C. pipiens* in the field.

Buenos Aires City (34°35′ S, 58°29′ W; 25 m above seal level) has a temperate climate with marked seasonality but no variability in the amplitude of monthly mean temperatures over the years.

The objective of the present work was to determine the seasonal occurrence of mosquito species and to characterize their biting activity in relation to mean daily temperature.

Taking into account the geographic distribution of family Culicidae, species distributed to the south of Buenos Aires City would show activity within a wider temperature range than those having their southern limit at the latitude of the city. In turn, the latter would restrict their activity to summer periods, when temperatures are higher. On this basis, the different species are expected to exhibit activity only within the environmental temperature range to which they are adapted.

Material and methods

Study area

Buenos Aires City shows marked seasonality; mean temperatures in autumn and spring are around 17°C, with cool mornings and nights. In winter, it is moderately cold during the day and very cold at night, with a daily mean temperature between 11.0°C in July and 12.3°C in August. Summer, in contrast, is characterized by strong sun radiation and hot weather conditions, with a mean daily temperature above 23°C and a relative humidity ranging from 60 to 90% (Servicio Meteorológico Nacional).

The study was conducted in two types of green spaces: an ecological reserve and city parks (Figure 1). The Costanera Sur Ecological Reserve, located on the bank of the Río de la Plata, shows a great variety of environments and highly diversified

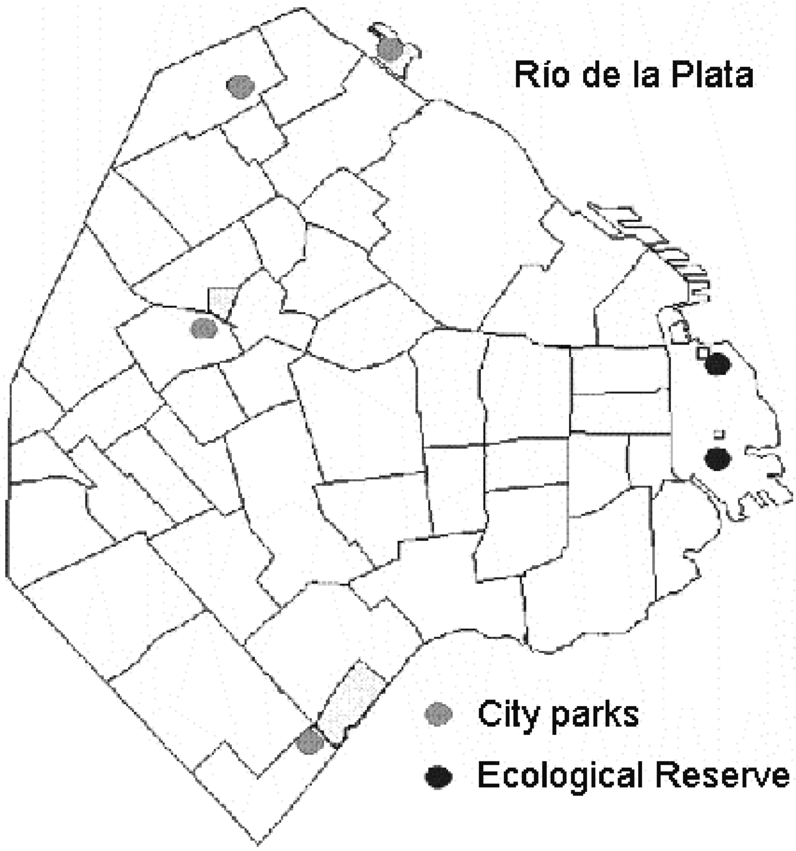

Figure 1. Collection sites of mosquitoes using CDC light traps. Buenos Aires City, April 1998 to March 2001.

fauna and flora, and as a consequence it provides abundant breeding sites and blood sources for culicids. The city parks, which are widespread over the city, are mainly covered by herbaceous and gramineous vegetation with a few trees and show a low diversity of animal species.

Methodology

A total of 496 CDC light traps (274 in the reserve and 222 in the city parks) operated for 330 nights between April 1998 and March 2001. Traps were uniformly distributed through the study period; they were placed in sites protected from the wind and baited with dry ice as the CO_2 source. Mosquito capture started shortly after the onset of dusk and lasted approximately 8 h.

Mosquitoes were identified to species using dichotomous keys (Darsie and Mitchel 1985; Rossi et al. 2002).

All mosquito species captured were ranked in decreasing order of accumulated abundance. Data were transformed using $\log_{10}(n + 1)$ before analysis. Species were considered very abundant (if $\log_{10}(n + 1) \geq 3$), abundant if they increased in

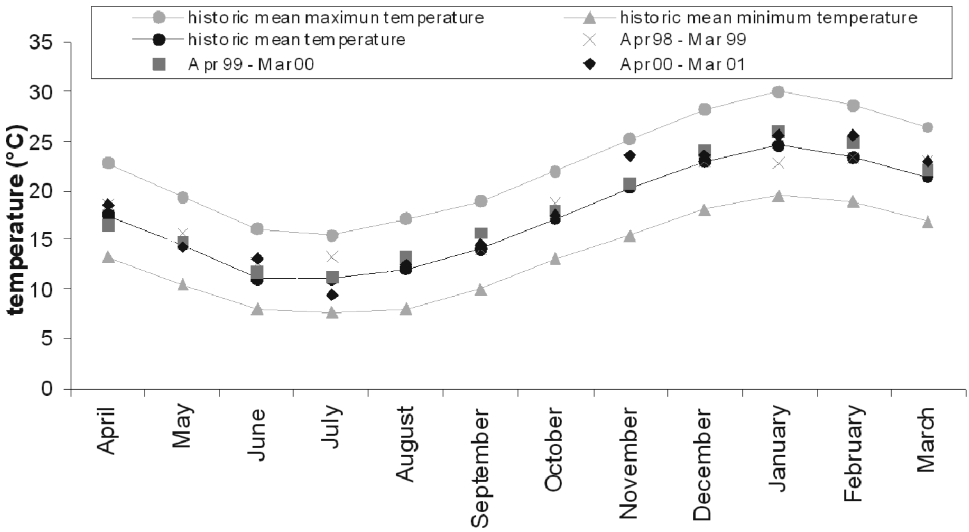

Figure 2. Mean monthly temperatures per year for the period April 1998 to March 2001, and minimum, maximum and mean temperatures for the period 1861–2003. Buenos Aires City.

abundance during a period of the year (if $2 < \log_{10}(n + 1) < 3$), less abundant (if $1 < \log_{10}(n + 1) < 2$) and scarce (if $\log_{10}(n + 1) < 1$).

Moreover, species were classified based on their frequency of capture as very frequent (> 30%), frequent (20.1–30%), less frequent (10.1–20%), infrequent (3.1–10%) and rare (< 3%). Species present in 10 samples or fewer were not included in the analysis.

Mean monthly temperatures during the study were within the range of monthly temperatures for the period 1961–1990 (Figure 2). Daily temperature and rainfall data were provided by the local meteorological service (Servicio Meteorológico Nacional). Daily mean temperatures corresponding to every capture event were classified into the following four thermal ranges: cold (4–10.9°C), cool (11–18.9°C), warm (19–25.9°C) and hot (26–32.9°C)

Capture events were analysed by season and thermal range. The proportion of capture events was calculated for each species as the number of capture events in each season divided by the total number of capture events in the same season. Likewise, the proportion of capture events was calculated for each species as the number of capture events in each thermal range divided by the total number of capture events in the same thermal range. The test for multiple independent proportions (Fleiss 1981) was used to compare the proportion of capture events of each species among seasons and thermal ranges.

Results

The daily mean temperature for the study period ranged between 4 and 30.8°C, but captures were recorded between 6.8 and 29.2°C.

Table 1 shows the abundance and frequency of capture for each mosquito species. A total of 23 species belonging to six genera were captured during the study period, and 15 of these were present on more than 10 occasions. The species *C. eduardoi*,

Table 1. Classification of species according to abundance and frequency of capture during 330 dates of capture in Buenos Aires City, April 1998 to March 2001.

Species	Number of capture events	Abundance		Frequency of capture	
		$\text{Log}_{10}(n + 1)$*	Category	% of capture events†	Category
C. eduardoi	161	4.250	very abundant	48.8	very frequent
C. chidesteri	118	3.394		35.8	
M. indubitans	71	3.589		21.5	frequent
M. titillans	57	3.254		17.3	
C. dolosus	91	3.114		27.6	
C. maxi	45	2.829	abundant	13.6	less frequent
C. pipiens	90	2.735		27.3	
C. bidens	46	2.550		13.9	
C. brethesi	62	2.528		18.8	
O. albifasciatus	72	2.515		21.8	
O. crinifer	44	2.514		13.3	
P. albigenu	14	2.457		4.2	
C. renatoi	37	2.401		11.2	
O. scapularis	17	1.667	less abundant	5.2	infrequent
Ae. aegypti	13	1.550		3.9	
P. cyanescens	7	1.439		2.1	
P. ferox	6	1.204		1.8	
C. coronator	10	0.954	scarce	3.0	rare
Ur. nataliae	5	0.845		1.5	
An. albitarsis	6	0.699		1.8	
Ur. pulcherrima	1	0.301		0.3	
Ur. lowi	1	0.301		0.3	
Ur. geometrica	1	0.301		0.3	

*Log_{10} (total abundance + 1). †(Number of capture events / total nights trap) × 100.
Ae., *Aedes*; *An.*, *Anopheles*; *C.*, *Culex*; *M.*, *Mansonia*; *P.*, *Psorophora*; *O.*, *Ochlerotatus*; *Ur.*, *Uranotaenia*.

C. chidesteri and *C. pipiens* were found throughout the study period, with the former species occurring in both types of environments and the remaining two species in the reserve only. Mosquito species differed significantly in the proportion of captures among seasons, except for *C. eduardoi*, *C. chidesteri*, *C. dolosus* and *C. brethesi* (Figure 3). The species *C. maxi*, *C. pipiens*, *C. renatoi* and *O. albifasciatus* only showed significant differences during autumn ($p < 0.001$, $p < 0.001$, $p < 0.05$ and $p < 0.001$, respectively). The species *C. bidens* was more frequently captured in autumn ($p < 0.001$), followed by summer ($p < 0.01$), spring ($p < 0.05$) and winter. *Ochlerotatus crinifer* was significantly less frequently caught in winter ($p < 0.01$), whereas *M. indubitans*, *M. titillans* and *Aedes aegypti* were not detected in this season. *Aedes aegypti* was mainly caught in autumn ($p < 0.001$), and *M. indubitans* was more frequently captured in autumn than in spring ($p < 0.05$) and showed no significant difference in the frequency of captures between autumn and summer. *Psorophora albigenu* and *O. scapularis* were only found in summer and autumn, with no significant differences in abundance between these seasons.

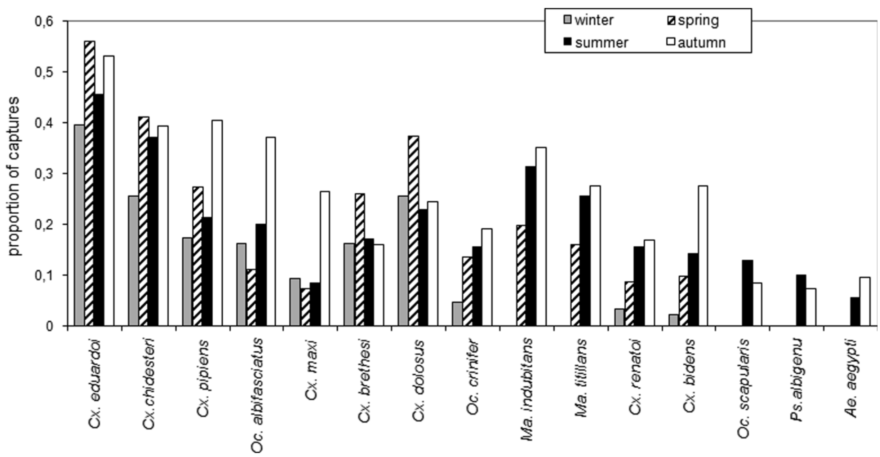

Figure 3. Proportion of captures by season and species. Buenos Aires City, April 1998 to March 2001.

The abundance of *C. renatoi*, *C. bidens* and *O. crinifer* increased linearly from winter to autumn ($p < 0.005$, $p < 0.005$ and $p < 0.01$, respectively) and that of *M. indubitans* from spring to autumn ($p < 0.05$).

Figure 4 shows the median quartiles of capture events according to the mean temperature of the day on which they occurred, as well as the maximum and minumum temperature at which each species was captured. Most of the days during the study period were within the ranges of mean daily temperatures corresponding to the ranges "cool" and "warm".

Two groups of species could be identified in relation to their capture in the different temperature ranges: group 1 comprised species captured at all thermal ranges and group 2 species were not captured below 11°C (thermal range cold) (Table 2). Taking

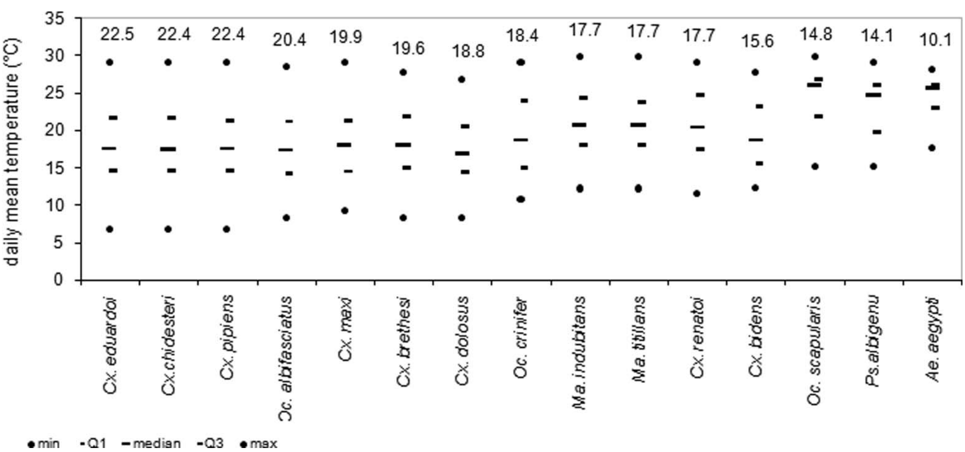

Figure 4. Median, quartiles and thermal amplitude of capture events according to the mean temperature of the day at which they were recorded. Species are ranked from higher to lower thermal amplitudes (indicated in brackets).

Table 2. Comparison of proportions of capture events among thermal ranges using the test for multiple independent proportions (Fleiss 1981).

	Species	Cold				Cool				Warm	
		Cool	Warm	Hot		Warm		Hot		Hot	
GROUP 1	*C. dolosus*	NS	NS	NS		NS		NS		NS	
	C. brethesi	NS	NS	NS		NS		NS		NS	
	C. pipiens	NS	NS	NS		NS		NS		NS	
	C. maxi	NS	NS	NS		NS		NS		NS	
	O. albifasciatus	NS	NS	NS		NS		NS		NS	
	C. chidesteri	$p < 0.05$			>CD	NS		NS		NS	
	C. eduardoi	$p < 0.01$			>CD	NS		NS		NS	
	O. crinifer	NS	NS	$p < 0.025$	<HT	NS		$p < 0.025$	<HT	$p < 0.025$	<HT
GROUP 2	*C. bidens*	–	–	–		NS		NS		NS	
	M. indubitans	–	–	–		$p < 0.005$	<WR	$p < 0.01$	<HT	NS	
	M. titillans	–	–	–		$p < 0.005$	<WR	$p < 0.05$	<HT	NS	
	C. renatoi	–	–	–		NS		$p < 0.025$	<HT	$p < 0.025$	<HT
	P. albigenu	–	–	–		NS		$p < 0.001$	<HT	$p < 0.001$	<HT
	O. scapularis	–	–	–		NS		$p < 0.001$	<HT	$p < 0.001$	<HT
	Ae. aegypti	–	–	–		NS		$p < 0.001$	<HT	$p < 0.001$	<HT

CD, cold; CL, cool; WR, warm; HT, hot.
Ae., *Aedes*; *C.*, *Culex*; *M.*, *Mansonia*; *P.*, *Psorophora*; *O.*, *Ochlerotatus*;

into account the entire study period, species of group 1 were captured at thermal amplitudes above 18°C (between 18.4 and 22.5°C) and the minimum temperature was equal to or lower than 10.8°C (Figure 4). This group was represented by species captured in all seasons, with *C. eduardoi* and *C. chidesteri* being the only species present in more than 35% of the captures (Table 1). Both species, however, showed a significant decrease in the frequency of captures when daily temperature amplitudes varied between 4 and 10.9°C, with similar proportions of captures within this range (Table 2).

Species of group 2 were captured during days with smaller thermal amplitudes (between 10.7 and 17.7°C) and a minimum temperature above 11.5°C (Figure 4). *Aedes aegypti*, *O. crinifer* and *C. renatoi* were most frequently caught at the thermal range "hot" (26–32.9°C). *Mansonia titillans* was captured at higher thermal amplitudes, corresponding to thermal ranges "warm" and "hot" (Table 2).

Among the species mainly captured from summer to autumn and not captured in winter, *M. indubitans* was significantly more frequent in thermal ranges "warm" ($p < 0.005$) and "hot" ($p < 0.01$) than in "cool", and *P. albigenu* ($p < 0.001$) and *O. scapularis* were more frequently found in the thermal range "hot" ($p < 0.001$) .

Discussion

The fact that the temperature pattern obtained during the study period is comparable to the historical record of Buenos Aires City allows us to characterize the activity response of the mosquito species present in this city.

Species differed in frequency and abundance. Very abundant species captured frequently could be considered as resident species, whereas those that were less frequent and increased in abundance in particular periods of the year (abundant) could be considered as seasonal species. A third group, in which species were less abundant, less frequent or infrequent, could be considered as incidental species.

A frequency lower than 10%, as observed in some of the collected species, can be explained in four ways: (1) species in which the dispersal from high to low anthropogenic environments (dwellings and reserve, respectively) is triggered above a certain level of population abundance (e.g. *Ae. aegypti*); (2) species in which the dispersal from non-anthropogenic environments is triggered above a certain level of population abundance; these species were not usually found despite the presence of environments suitable for breeding in the city (*P. cyanescens*, *P. ferox* and *O. scapularis*); (3) species rarely observed in the city because environments are unsuitable for their reproduction (*Anopheles albitarsis*); (4) inappropriate sampling method and/or site of trap installation (*Uranotaenia* spp., *Ae. aegypti*).

In a study performed in the surroundings of the northern bank of the Río de la Plata in Buenos Aires City, Manso Soto and Martinez (1948) mentioned five species of genus *Anopheles* and in the present study, *An. albitarsis* was the only representative of this genus. This could be caused by the urban development and landscape changes in the city, which have modified the habitat of some species (disappearance of breeding sites and shelters) leading to a decrease in their abundances. This fact reduces the risk of malaria in the region.

The species *C. eduardoi*, *C. chidesteri*, *C. dolosus* and *C. brethesi* are likely to be well adapted to the environmental conditions of Buenos Aires City on the basis that they showed activity throughout the study period. *C. eduardoi* and *C. chidesteri* were present in high abundances at a temperature amplitude above 22°C, and consequently, these species would be considered to be active in a wide temperature range. *C. dolosus* and *C. brethesi* showed higher activity within the range "cold", but they were restricted to a narrow temperature amplitude, suggesting that these species are less affected by low temperatures.

C. dolosus and *C. eduardoi* are closely related species. They have been considered as belonging to the same species (Almirón and Brewer 1995) or as separate species based on external morphological characteristics (Darsie and Mitchel 1985; Rossi et al. 2002; Valente Senise and Mureb Sallum 2008). The different activity patterns of these species in Buenos Aires City should be taken into account in further studies.

The temperatures in Buenos Aires City apparently do not restrict the activity of *O. albifasciatus* because it was caught in a wide thermal range. In Argentina, females of this species have been found at latitudes to the south of Buenos Aires City, such as Sarmiento, Chubut (45°36′ S, 69°00′ W, unpublished data) and Tierra del Fuego (54° S, 68° W, Bachmann and Bejarano 1960), with mean temperatures lower than those in the city. This fact supports the hypothesis that the activity of species with a distribution range extending to the south of Buenos Aires City occurs within wider temperature ranges. The increase in population abundance observed in autumn may be explained by environmental factors other than temperature, such as a longer permanence of temporary water bodies, which constitute the principal breeding sites for this species (Fischer et al. 2002).

The latitude of Buenos Aires City is at the southernmost distribution limit of *Ae. aegypti*, *M. indubitans* and *M. titillans* (Forattini 1965a,b). We could determine the minimum but not the maximum temperature triggering activity in these species which exhibit an increased activity within the range "warm". Hence, it is reasonable to presume that the activity of these species is reduced at low temperatures.

In green spaces, adults of *Ae. aegypti* appear in the season when the species reaches the maximum geographical distribution in the city (Carbajo et al. 2004). This may result in an increased number of dispersive individuals, so enhancing the probability of capture in green spaces.

Ae. aegypti and species of genus *Mansonia*, which are endemic to Buenos Aires City, can withstand adverse environmental conditions by means of resistant eggs and overwintering larval stages, respectively (Torreta et al. 2006).

Our results suggest that the hematophagous and flight activities of the different species in Buenos Aires City would be affected by daily temperature and seasonal mean temperature. The activity of the species of group 1, which are present throughout the year, seems to be triggered above a certain threshold of temperature, regardless of the season. Instead, the species of group 2 would display a seasonal activity pattern; adults captured would be the result of occasional emergence or dispersal from breeding sites, and their biting and dispersal would occur under suitable environmental and meteorological conditions.

These results would be useful for evaluating the risk of transmission of some pathogens in Buenos Aires City.

West Nile virus is a flavivirus recently found in the American continent (Canada, USA and Caiman Islands) coming from Africa, Asia and Europe. It was probably carried by migratory birds during the 1990s. This virus was isolated in the USA from *P. ferox* and *C. pipiens* (CDC 2000). Although the first of these mosquito species is infrequent in Buenos Aires, the second one is abundant throughout the year.

Mitchell et al. (1985) isolated the West Equine Encephalitis (WEE) virus from *An. albitarsis*, *Mansonia* spp, *O. scapularis* and *Psorophora* spp. during an interepizootic period (1977–1980) in Chaco, Corrientes and Santa Fe. During other epizootia with human cases (1982–1983) in Santa Fe, WEE virus was found in *O. albifasciatus*, *An. albitarsis* and *Mansonia* spp. (Mitchell et al. 1987). The abundance of *O. albifasciatus* during outbreaks of WEE in Argentina, its great distribution in the country, its preference for feeding on mammals (particularly equines and bovines) as well as its experimental vectorial competence incriminate these culicids as vectors of this virus in South America (Avilés et al. 1992).

Further epidemiological studies on Buenos Aires culicids should be made. Some mosquitoes are well known as vectors in this region but the epidemiological information about others is still scarce.

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