Environmental Factors Related to the Abundance and Activity of *Ochlerotatus albifasciatus* (Diptera: Culicidae) in an Agricultural Landscape of Steppe Arid Climate

M. J. GARZÓN,[1,2,3] O. JENSEN,[4] AND N. SCHWEIGMANN[1,2]

J. Med. Entomol. 51(4): 733–741 (2014); DOI: http://dx.doi.org/10.1603/ME14016

ABSTRACT *Ochlerotatus albifasciatus* (Macquart) is a flood water mosquito whose highest density has been found associated both with natural landscapes (prairies or grazing fields) in temperate and subtropical regions and with rainfall events. In the current study, we aimed to find out how the marked differences between environmental factors of agricultural landscape patches in a steppe arid region affect the relative abundance of this species. In wetland patches, the high activity of adults was closely associated with the flood irrigation system, suggesting that the agricultural activity contributes to the proliferation of this mosquito. The steppe patches would constitute an adverse environment reflected by the abrupt decrease in abundance. Multiple linear regression showed that some explanatory variables, such as wetland patches and moment of the day (midday), did not contribute significantly to the relative abundance variation. In contrast, temperature, wind, and cloud cover seemed to regulate the biting activity of females. Temperature affected the activity of mosquitoes in the steppe but seemed to have no effect in wetland patches, where the activity of mosquitoes was permanent and more stable against changes in temperature. In the steppe, which presents low levels of humidity, scarce vegetation, and greater wind exposure, the activity seemed to be unstable against small thermal variations. The variability of the relative abundance of *Oc. albifasciatus* in an agricultural landscape was widely explained by temperature in combination with the microenvironment type, wind speed, and cloud cover and indirectly by human activity.

KEY WORDS activity, anthropic, flooding, steppe, wetland

From the ecological point of view, landscapes consist of patches inside a matrix with particular characteristics (Forman and Gordon 1981). The modern agricultural landscape is characterized by intensive land use. This usually creates a mosaic of markedly contrasting habitats or patches (Tscharntke et al. 2002) that modifies the natural ecological features at spatial and temporal level (Benton et al. 2003). In many cases, the agricultural activity has encouraged the proliferation of some species such as some mosquitoes (Chandler and Highton 1975). Therefore, the population dynamics of insects can be modified by human activity (Hooks and Johnson 2003) through the modification of the natural landscape.

Studies about *Ochlerotatus albifasciatus* (Diptera: Culicidae) in temperate regions have shown that adult abundance is closely associated with precipitations (Gleiser and Gorla 1997) and that density distribution is dependent on the type and characteristics of the natural habitat (Gleiser et al. 2002). In arid steppe regions, such as Patagonia, there are no studies about adult abundance and activity, but immature instars of *Oc. albifasciatus* have been detected in water bodies and ditches related to the irrigation system (Burroni et al. 2007) in agricultural areas, during the spring–summer season when precipitations are scarce (Elissalde et al. 1998).

This species requires main attention, as it has shown vectorial capacity for western equine encephalitis (Avilés et al. 1992). Its large population explosions negatively affect livestock production (Raña et al. 1971) and cause inconvenience in both humans and domestic animals (Prosen et al. 1960, Forattini 1965). In particular in our study site, the bite of this species during the warmer months may negatively affect the everyday life of residents.

Although *Oc. albifasciatus* is considered a diurnal species (Prosen et al. 1960, Forattini 1965), its daily activity varies depending on the time of the year and the thermal conditions (Hack et al. 1978, Ludueña et al. 1995). The records in temperate and subtropical regions suggest that temperature affects the hematophagic behavior of this species.

[1] Grupo de Estudio de Mosquitos, Departamento de Ecología, Genética y Evolución, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires. Ciudad Autónoma de Buenos Aires, Argentina.

[2] Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET), Av. Rivadavia 1917 (C103AAJ), Ciudad Autónoma de Buenos Aires, República Argentina.

[3] Corresponding author, e-mail: maxigarzon@yahoo.com.ar.

[4] Departamento de Investigación en Salud, Secretaria de Salud, Chacra 18 (9020), Sarmiento, Chubut, República Argentina.

Different studies have shown that the activity and abundance of mosquito species vary according to the relationship with temperature, humidity, wind, precipitation, vegetation, and human activity, among other environmental factors (Okogun et al. 2003, Yang et al. 2008, Pinto et al. 2009, Gray et al. 2011). In other groups such as Ceratopogonidae, temperature, relative humidity, solar radiation, and time of day appear to affect the biting activity (Carrieri et al. 2011), whereas in Plecoptera, the temperature and wind speed seem to be key to flight activity (Briers et al. 2003).

Abundance and activity studies associated with agricultural landscapes with heterogeneous patches (microenvironments) could be useful to understand the spatio-temporal dynamics of insects in natural environments.

Thus, the aim of the current study was to compare the relative abundance of *Oc. albifasciatus* among microenvironments of an agricultural landscape (patches) with different characteristics (favorable and unfavorable), at different times of the day. We compared the environmental variables of the patches associated with the activity and abundance of this species and finally we constructed a regression model to relate the environmental variables with *Oc. albifasciatus* activity.

Materials and Methods

Study Area. The study was carried out in the agricultural area of Sarmiento (45° 35′ S, 69° 05′ W), Chubut province, Argentina. The area comprises a grazing area of ≈42,000 ha, 12,000 of which are irrigated: less than a quarter receives controlled irrigation for forage, fruit and vegetable production, whereas the rest receives eventual irrigation because it is used for direct grazing (Ñancucheo et al. 2008).

The predominant areas or patches are clearly delimited by characteristic vegetation: wetlands, represented by natural hydrophilic herbaceous, and cultivated areas by implanted species and steppes, represented by xerophytic vegetation with dominance of shrub and subshrub species (Elissalde et al. 1998). The Patagonian region has a steppe arid climate (Peel et al. 2007), with a marked annual temperature range where the absolute summer maximum and mean temperatures reach 39.3°C and 11.1°C, respectively, and the absolute winter minimum and mean temperatures reach −33°C and 4.1°C, respectively (Elissalde et al. 1998, Ñancucheo et al. 2008). The average annual rainfall is 147.2 mm (series 1931–1960), cold season being the one with greatest precipitation records (Elissalde et al. 1998) and the warm months not exceeding 15 mm. The mean monthly relative humidity is ≈75–80% in winter (June and July) and 40% in summer (Ñancucheo et al. 2008). The region is characterized by being very windy. Wind is characterized by gusts with periods of calm, which, depending on the weather conditions, may have greater or lesser intensity and frequency. The gusts of wind usually present mean speeds ranging between 8 and 30 km/h, highest values being recorded in the warmer months and predominantly from the West quadrant (Ñancucheo et al. 2008).

The Senguer River, which flows through Sarmiento Valley, has an irrigation system that is distributed through a network of canals of ≈60 km from a waterwheel to the whole livestock-grazing area.

Environmental Variables. To assess the period of activity of adults of *Oc. albifasciatus* in the study area, we considered the air temperature records obtained by an HOBO sensor data logger (Onset, Cape Cod, MA) placed in the shade of a willow (*Salix* sp.) between March 2010 and February 2011. We also considered the records obtained at the Instituto Nacional de Tecnología Agropecuaria (INTA) of Sarmiento during 2009–2011.

Temperature (°C) and relative humidity (RH) were recorded at ground level with a portable thermo-hygrometer sensor LZ 122D (Litz instruments, Argentina). The maximum wind speed (km/h) was recorded one meter above the ground by using a field anemometer SmartSensor (Intell Instruments Plus, China). Finally, cloud cover was recorded as the percentage of time during which the sun was covered by clouds during the time of capture.

A preliminary evaluation was conducted to characterize the gusts and periods of calm of wind. During this evaluation, the wind speed was recorded every two seconds and for 3–5 min, and the relationship between the maximum speed of the gust and the proportion of the time and duration of calm was then analyzed. "Calm" was considered when the wind was below the threshold (10.08 km/h) where mosquitoes stop orienting themselves toward their prey or other stimuli (Grimstad and De Foliart 1975, Bidlingmayer et al. 1995).

Sampling Method. Over 3 yr (2009–2011), the weekly presence of adults was evaluated by means of detection of females with biting activity, and this was associated with flood irrigation periods. To choose the times of day with greatest and least activity, preliminary captures were carried out every 2 h, from sunrise to sunset (0630–2100 hours) during the 2 d previous to the definitive study. Then, we chose the most contrasting times of day for activity based on observed patterns.

For the study of relative abundance of *Oc. albifasciatus* in relation to the microenvironment and the time of day, mosquito females were captured during the summer of 2011 in seven farms over an area of 400 ha in the rural area of Sarmiento Valley (Fig. 1). These sites were chosen for presenting the three microenvironments or patches analyzed (wetland [W], cultivated area [C], and steppe [S]) only a few meters (100–200 m) from one another. We assumed that individuals may disperse equivalently within and among the three microenvironments. Biting activity was measured by the method of capture per man hour with the help of an electric aspirator. Comparing the levels of activity in different places and at the same time allowed assessing differences in relative abundance. The pattern of daily behavior of biting activity

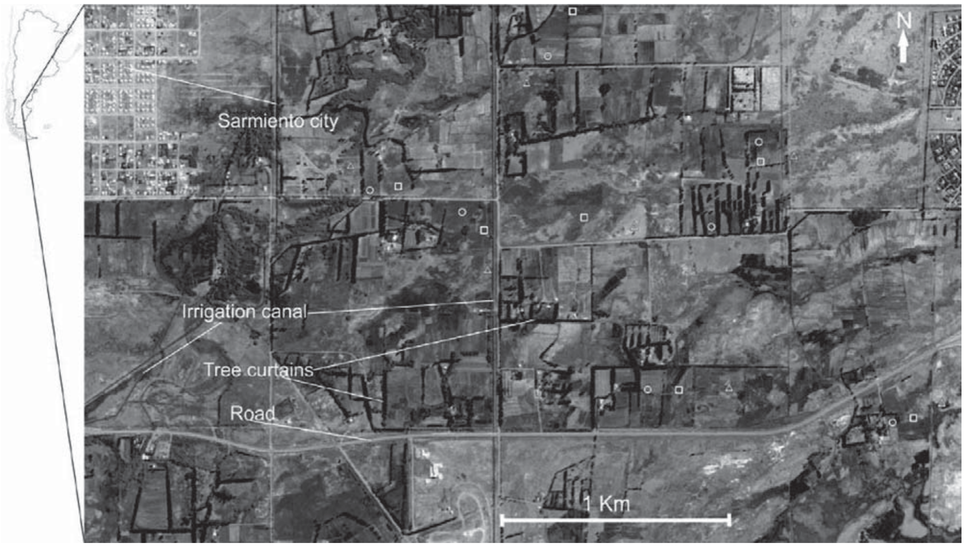

Fig. 1. Agricultural landscape of Sarmiento valley (Chubut, Argentina) where sampling was conducted. Map shows the patches: Wetland (square), Cultivated area (circle), and Steppe (triangle) and some landscape features.

was calculated as the difference between the numbers of females captured at two different times for the same site.

The behavior of mosquitoes in the gusts of wind was recorded during all capture sessions.

Statistical Analysis. The differences in relative abundance between sites and the pattern of behavior were analyzed by pairs with parametric statistics (paired *t*-test) and nonparametric statistics (Wilcoxon test) as appropriate (Zar 1996), and with a significance level of 0.05. The same procedure was used for the associated environmental variables.

We used multiple linear regressions (Chatterjee et al. 2000): 1) to estimate the relationship between the physical variables recorded during the capture sessions and *Oc. albifasciatus* activity, 2) to determine the variables that most influenced the variability of relative abundance, and 3) to obtain a model to predict *Oc. albifasciatus* abundance in Sarmiento Valley.

The model proposed was as follows:

$$y_i = \beta_0 + \beta_1{*}x_{1i} + \ . \ . \ . \ + \beta_7{*}x_{7i} + \gamma_1{*}x_{5i}x_{1i} + \ . \ . \ . \ + \gamma_4{*}x_{5i}x_{4i} + \ . \ . \ . \ + \gamma_m{*}x_{ji}x_k + \varepsilon_i$$

Where y_i is the response variable Log (N+1) (N = relative abundance), β_0 is the intercept to the origin and β_i (i = 1–7) the coefficients of partial regression. The explanatory variables were—x_1: temperature (°C), x_2: relative humidity (%), x_3: clouds (%), x_4: maximum wind speed (km/h), x_5: steppe (dummy 1), x_6: natural wetland (dummy 2), and x_7: midday (dummy 3). Because the indicator or dummy variables interact with the quantitative ones (Chatterjee et al. 2000), interaction terms (γ_m) (m = 1–12) were added, leaving x_j as the indicator or dummy variables (j = 5–7), and x_k as the quantitative ones (k = 1–4). The response variable was normalized (Log (N+1)), and the model was run with a statistical software (Multiple linear regression, Infostat 2008). After running the model, we removed a total of 12 outliers (response variables + explanatory variables; $N_{initial}$ = 90) and those terms whose coefficients were not significant ($P > 0.05$).

Finally, the relative abundance of mosquitoes was estimated under conditions hypothetically favorable and unfavorable in both microenvironments (steppe and natural wetlands) included in the regression. The ranges of minimum and maximum activity of *Oc. albifasciatus* were considered as indicators of conditions of environmental favorability. The variables of greater significance obtained by the multiple linear regressions were taken into account.

Results

Annual Activity Period. Biting activity of *Oc. albifasciatus* (shaded area in Fig. 2) was detected from the beginning of November (3–4 wk after the beginning of the irrigation period) until the end of April (2–3 wk before the end of the irrigation period). During this period, the monthly mean minimum air temperatures recorded both at INTA and by the HOBO sensor were higher than 4.86°C (dotted line, Fig. 2). At all times, the HOBO temperature sensor recorded slightly higher temperature values than INTA (only shown for the months before and after the presence of mosquitoes).

Selection of Activity Time. The preliminary evaluation allowed observing a bimodal pattern of activity in the natural wetlands (W) and cultivated areas (C) and no variations throughout the day in the steppe (S; Fig. 3). Based on these results and day length in the region during the summer, we selected and defined midday (m; 1330–1500 hours) and afternoon (a; 1700–

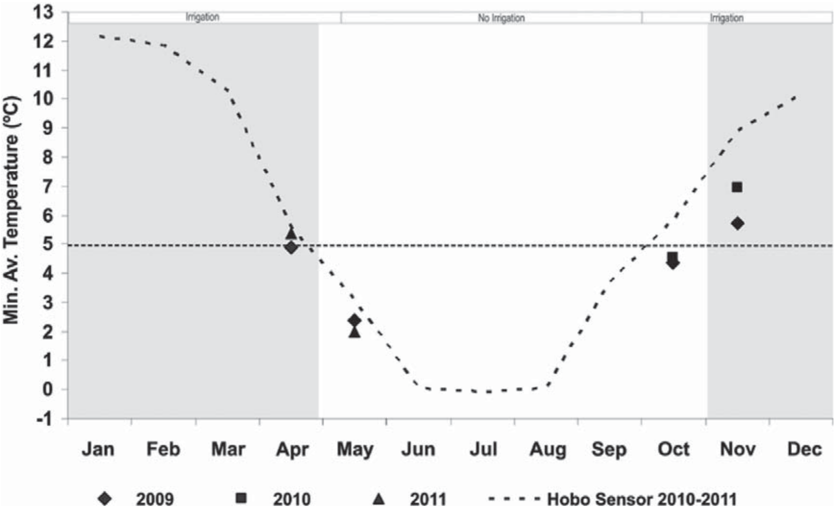

Fig. 2. The activity period of *Oc. albifasciatus* during the year (shaded area). Minimum monthly average temperature (air) determined by a HOBO temperature sensor (dotted line) from March 2010 to February 2011. Monthly minimum average temperature (air) for the months before and after the beginning and end of the activity: April–May and October–November 2009 (diamond), October–November 2010 (square), and April–May for 2011 (triangle); we did not have access to the thermal records at the beginning of activity 2010 and the end of activity 2011. The periods of irrigation in Sarmiento Valley are indicated at the top of the chart.

1830 hours) for studies of comparison of abundance among microenvironments.

Relative Abundance in Relation to the Microenvironments and the Time of Day. The relative abundance of mosquitoes in the natural wetlands and cultivated areas was similar to each other (paired *t*-test, midday C–W: $P = 0.2699$; afternoon C–W: $P = 0.1547$), while that in the steppe was significantly lower than that of the natural wetlands and cultivated areas, even more than one order of magnitude (Fig. 4; paired *t*-test, midday: C–S [$T = 4.25$; df = 14; $P = 0.0008$], W–S [$T = 3.51$; df = 14; $P = 0.0035$]; paired *t*-test, afternoon: C–S [$T = 4.61$; df = 14; $P = 0.0004$], W–S[$T = 4.88$; df = 14; $P = 0.0002$]).

With respect to the time of day, the activity in the wetlands and cultivated area was significantly higher toward the afternoon than during midday (Wilcoxon test, W [Sum(+) = 3; df = 14; $P < 0.0001$]; C

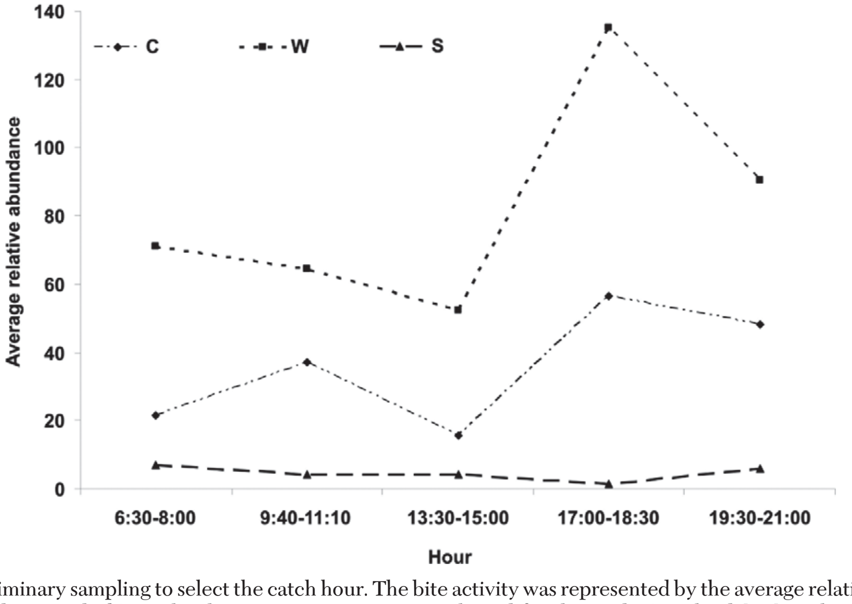

Fig. 3. Preliminary sampling to select the catch hour. The bite activity was represented by the average relative abundance (catches from dawn to dusk), in the three microenvironments selected for the study (Wetland [W], Cultivated area [C], and Steppe [S]).

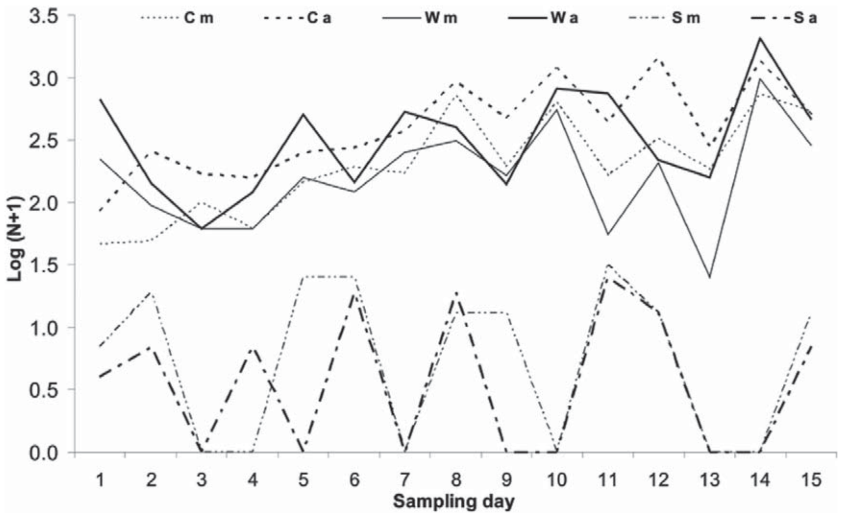

Fig. 4. Relative abundance of *Oc. albifasciatus* (log (N + 1)) estimated by the catch per man-hour during midday (m) and afternoon (a) in the three microenvironments of the valley (Wetland [W], Cultivated area [C], and Steppe [S]). The capture events (15) were performed in the period from 27 January to 12 February in Sarmiento Valley, Chubut, Argentina.

[Sum(+) = 1; df = 14; $P < 0.0001$]), while that in the steppe showed no differences (paired *t*-test, $P = 0.056$; Fig. 4). When taking into account only cloudy days, there were no differences at different times of the day in the natural wetland or cultivated area (paired *t*-test, W+C [$T = -2.77$; df = 4; $P = 0.05$]).

Direct observations indicate that *Oc. albifasciatus* is always active in the period of calm between gusts.

Temperature. The temperatures recorded at ground level ranged between 15.7 and 32.8°C for the natural wetland, between 15.5 and 28.9°C for the cultivated area, and between 19.2 and 37.6°C for the steppe. The temperatures in the steppe were above those of the natural wetland and cultivated area (paired *t*-test, midday S–C [$T = -3.07$; df = 14; $P = 0.009$], S–W [$T = -2.75$; df = 14; $P = 0.016$]; paired *t*-test, afternoon S–C [$T = -3.85$; df = 14; $P = 0.002$], and S–W [$T = -6.14$; df = 14; $P < 0.0001$]), whereas no differences were found between the temperatures of the natural wetlands and cultivated areas (paired *t*-test, midday C–W [$P = 0.393$]; paired *t*-test, afternoon C–W [$P = 0.181$]; Table 1). Regardless of the place, the temperature during midday was significantly higher than that in the afternoon (paired *t*-test, C [$T = 2.90$; df = 14; $P = 0.012$], W [$T = 2.29$; df = 14; $P = 0.022$], and S [$T = 2.46$; df = 14; $P = 0.028$]).

Table 1. Mean ± SE for each of the environmental variables recorded during the sampling of *Oc. albifasciatus* adults

Microenvironments/time	Temp (°C)	Relative humidity (%)	Max wind speed (km/h)
Cultivated area/midday	25.13 ± 1.34	48 ± 2.85	4.37 ± 4.71
Cultivated area/afternoon	22.95 ± 0.76	49 ± 2.39	5.21 ± 4.70
Wetland/midday	24.23 ± 1.18	49.13 ± 2.38	7.21 ± 5.64
Wetland/afternoon	21.53 ± 0.9	48.33 ± 2.16	7.59 ± 5.90
Steppe/midday	27.63 ± 1.38	32.33 ± 1.94	7.88 ± 6.93
Steppe/afternoon	25.88 ± 1.13	31.87 ± 1.34	9.70 ± 7.84

Relative Humidity. The relative humidity of the air at ground level ranged between 37 and 68% for the natural wetlands, between 31 and 70% for the cultivated areas, and between 24 and 48% for the steppe. The values of relative humidity between natural wetlands and cultivated areas showed no differences (paired *t*-test, midday C–W [$P = 0.678$]; afternoon C–W [$P = 0.836$)]; Fig. 5), but were significantly higher than those of the steppe (paired *t*-test, midday, C–S [T = 5.51; df = 14; $P = 0.0001$] and W–S [T = 6.34; df = 14; $P < 0.0001$]; paired *t*-test, afternoon, C–S [T = 5.64; df = 14; $P = 0.0001$] and S–W [T = −7.58; df = 14; $P < 0.0001$]). Regardless of the sampling site, we detected no significant differences in the relative humidity between midday and afternoon (paired *t*-test, W [$P = 0.718$], C [$P = 0.064$], and S [$P = 0.833$]; Table 1).

Wind. *Gusts and Periods of Calm.* The maximum duration of calm was observed in a single event of about 3 min (10 km/h). When records of maximum speeds were 20 and 22 km/h, we observed 12 and 5 events of calm respectively, in both cases with a median of 6 s, and representing 28 and 15% of the total recording time, respectively. Preliminary results suggest that there would be an inverse relationship between the maximum wind speed and the duration and frequency of the periods of calm. This relation seems to occur approximately at speeds lower than 24 km/h, but not at higher speeds (Fig. 5).

Maximum Wind Speed. During the time of capture, the wind speed reached maximum values of 20 km/h in the natural wetlands, 14 km/h in the cultivated areas, and 24 km/h in the steppe. During the afternoon, the wind values recorded in the steppe were significantly higher than those recorded in the cultivated areas (paired *t*-test, afternoon S–C [$T = 2.82$; df = 14; $P = 0.014$]) and same as natural wetlands

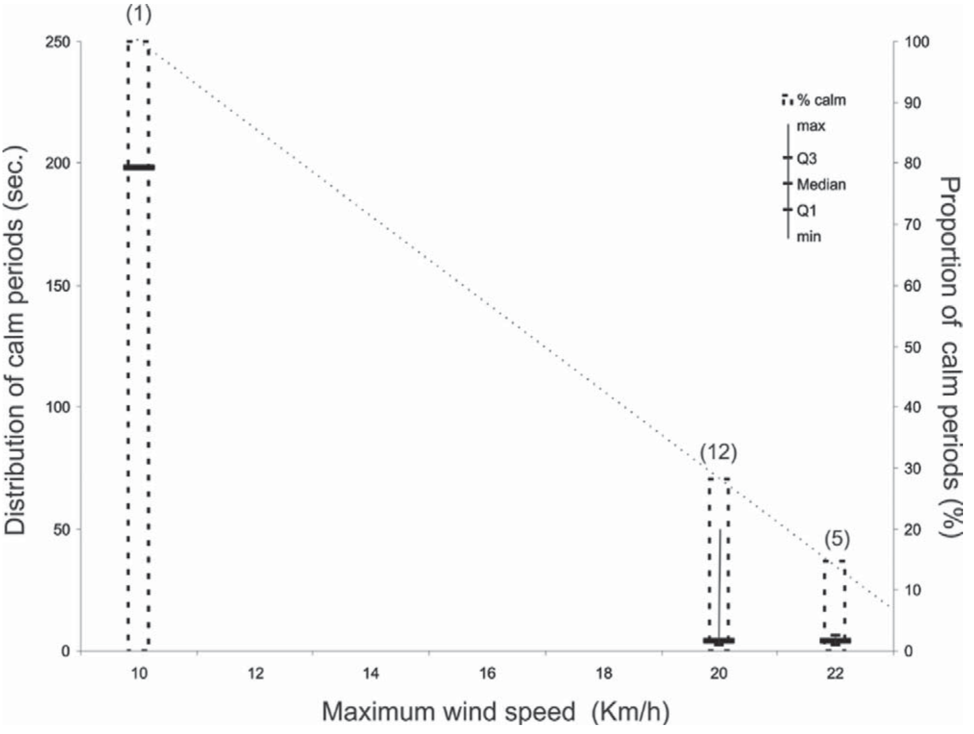

Fig. 5. Frequency, proportion, and distribution of the calm periods in relation to the maximum wind speed (gust). The records were made during three sessions of 3–5 min per day in Sarmiento Valley, Chubut, Argentina (24–26 January).

(paired *t*-test, afternoon W–S [$P = 0.077$]), whereas during midday, the wind values recorded in the steppe were significantly higher only than those recorded in the cultivated areas (paired *t*-test, midday C–S [$T = -2.37$; df = 14; $P = 0.033$]).

Wind speeds in the natural wetlands were significantly higher than those in the cultivated area (paired *t*-test, midday W–C [$T = 2.27$; df = 14; $P = 0.039$]; Wilcoxon test, afternoon W–C [Suma(+) = 10.50; df = 14; $P < 0.0001$]; Table 1). The values during midday were similar to those in the afternoon, regardless of the sampling site, showing no significant differences (paired *t*-test, C [$P = 0.435$], W [$P = 0.714$], and S [$P = 0.207$]; Table 1).

Multiple Linear Regressions. The model of multiple linear regression proposed allowed explaining 86% of the variability in the abundance of mosquitoes captured during the sampling ($r^2 = 0.86$). The final function obtained was

$$y_i = b_0 + b_3 x_{3i} + b_4 x_{4i} + c_1 x_{5i} x_{1i},$$

where b_0 is the intercept to the origin, b_i the partial regression coefficients for x_3: cloud cover (%) and x_4: wind speed (km/h), and c_1 the interaction coefficient between x_1: temperature (°C) and x_5: steppe (type of microenvironment as dummy variable). The coefficient values estimated, estimates of variances for parameters, the residual mean-square error, *P* values, and Mallows coefficients are summarized in Table 2.

The interaction between the physical variable (temperature) and the type of environment was the factor that most contributed to the adjustment of the proposed model. This was the most influential (SS: 39.88) in the variability of the abundance, and its coefficient indicated an inverse relationship with mosquito activity.

The maximum wind speed explained the variability in an order of magnitude lower (SS: 3.66) and was negatively related to the number of mosquitoes (−0.04). Finally, cloud cover, with SS of 1.57, had a positive influence (0.0032) on the activity of mosquitoes. In the steppe, the thermal factor was taken into account for the activity, whereas in the wetland, the term which included the temperature was not significant and, therefore, the variation in the abundance depended directly on cloud cover and, inversely, on maximum wind speed. The dummy variables midday and wetland were neither significant individually nor in the interaction with other quantitative variables.

Table 2. Multiple linear regression of relative abundance (activity estimator) of *Oc. albifasciatus* depending on environmental factors and microenvironment

Variables	SS	MS	Coefficient	*P* value	Cp Mallows
Constant			2.48	<0.0001	
Cloud cover	1.57	1.57	0.0032	0.0004	16.63
Max Wind speed	3.66	3.66	−0.04	<0.0001	34.66
Steppe × Temp	39.88	39.88	−0.06	<0.0001	348.21
Error	8.43	0.11			

$r^2 = 0.86$; $n = 78$; $P < 0.05$. SS: Sum Squares; MS: Mean Square.

Relative humidity was excluded from the final model to avoid colinearity with temperature.

Relative abundance under hypothetically favorable (and unfavorable) conditions in the steppe and natural wetlands showed that the activity of *Oc. albifasciatus* seems to be favored (vs not favored) by conditions of low temperature (vs high temperature), cloudy (vs clear), and calm (vs windy). These hypothetical circumstances would be fulfilled within the range of records obtained during the sampling. In the case of the steppe, within the range recorded, 19.2°C would be a favorable thermal condition, while 37.6°C would be unfavorable. In the wetland, there would be no significant effect of temperature. Both for the steppe and the wetland, the increase in the percentage of cloud cover (from 0 to 100%) would encourage the activity of *Oc. albifasciatus* (not shown).

Maximum wind speed in the steppe was a favorable condition when it was null (0 km/h) and unfavorable when it was 24 km/h. In the wetland, the favorability/unfavorability ranged from 0 km/h to 20 km/h, respectively. The number of mosquitoes estimated from the theoretical model for the steppe was 47/0 (lower/upper limit) under favorable and unfavorable conditions respectively, whereas that for the wetlands was 630/48. The abundance estimated in the more favorable conditions of the steppe was similar to that estimated for the less favorable conditions of the wetlands. Although the actual captures were within the estimated limits, records for the steppe were closer to the lower limit whereas those for the wetlands were at the upper limit.

Discussion

In Sarmiento Valley, *Oc. albifasciatus* adult activity begins approximately 1 mo after the start of the irrigation season in the farms and culminates about 2 wk before the end of the season (Fig. 1), suggesting that the anthropic activity (agriculture) would substantially contribute to the reproductive success of this species. The temporary delay of adult activity from the start of the irrigation season could be because of the development time in the thermal context (Fontanarrosa et al. 2000), while the early ending of adult activity respect to the end of the irrigation period could be because the temperatures were close to the thermal limit (5°C; Ludueña et al. 1995).

The networks of irrigation canals are more relevant in the production of breeding puddles than natural flooding by river overflows or rainfall, as is the case in temperate regions (Gleiser and Gorla 1997, Fontanarrosa et al. 2000, Gleiser et al. 2000, Fischer et al. 2002). In Sarmiento, the farm owners decide the flooding in their fields both spatially and temporally and the land therefore constitutes an asynchronous system of floods, which permanently offers new sites for oviposition and breeding. This system maintains high levels of abundance of *Oc. albifasciatus* in the entire valley during the spring–summer season.

Similarly to that observed in rice fields (Bambaradeniya and Amerasinghe 2003), the field agro-system of Sarmiento seems to be another example where human activity sustains not only a population of mosquitoes but also the biodiversity of other species. In this agricultural landscape, the marked differences between the environmental qualities of the wetlands (and cultivated areas) and the steppe patches are reflected in the relationships between relative abundance and some environmental factors such as temperature, relative humidity, and maximum wind speed (Fig. 4 and Table 1). These differences occur because wetlands (and cultivated areas) are moisture patches owing to the flooding irrigation for pastures, forage, or both, or the controlled irrigation for various crops (Ñancucheo et al. 2008). However, the scarce rains of the region (Paruelo et al. 1998) and the absence of irrigation that characterizes the steppe patch make this environment unfavorable for *Oc. albifasciatus.*

The highest biting activity of *Oc. albifasciatus* and the presence of breeding sites suggest greater reproductive success in wetlands and cultivated areas than in the steppe. However, this species seems to be able to disperse toward the steppe, although with a sharp decrease, at least until 200 m, with a decrease in the relative abundance of two orders of magnitude respect to the wetlands and cultivated areas (Fig. 4). In natural landscapes such as grasslands of temperate regions, which are homogeneous and favorable environments, sharp decreases in relative abundance (like that observed in Sarmiento Valley) have been recorded at distances >500 m (Gleiser and Gorla 1997). This means that in an agricultural landscape with heterogeneous patches as Sarmiento, the range of natural dispersion of this species is restricted owing to an abrupt change from a favorable environment (wetlands) to an unfavorable environment (steppe). The effect of fragmented habitat, with unsuitable and suitable patches, may have a profound influence on dispersion (Hunter 2002) as that observed in *Oc. albifasciatus* and other insects (Roland et al. 2000, Schtickzelle et al. 2006).

In reference to the activity pattern, the behavior of this population was similar to that observed in temperate populations (Ludueña et al. 1995). The lower captures during midday with respect to those in the afternoon (Fig. 4) in clear days and similar abundance during overcast days sustain the fact that the activity of females would be regulated by the exogenous inhibitory effect of environmental temperature.

In terms of environmental variables recorded at the time of capture, the temperature, which showed a negative relationship, turned out to be the variable that best explained the patterns of abundance among patch type and among different times of the day. The highest temperatures were observed in the steppe (although this environment is more exposed to the strong Patagonian winds) and at midday. Relative humidity, which showed a direct relationship, would explain only the pattern of abundance observed among patch types.

The captures showed an inverse relationship with maximum wind speed. This could be because the periods of calm are less frequent between gusts of wind of higher speed (Fig. 5) and therefore there is less time for biting activity. This was supported by unpublished data during which the females were active at intervals of calm and ceased their biting activity just before these gusts occurred so as to remain protected among the vegetation. The maximum wind speed showed a decreasing pattern from the steppe, through the natural wetlands to the cultivated areas. The tree curtains around the farms would be the ones marking these differences with respect to the areas of open countryside (Ñancucheo et al. 1998).

The regression model showed that the interaction among the temperature and the environment contributes significantly to the activity of mosquitoes. Although temperature affects the steppe patches adversely, it seems to have no effect on the wetland patches. In the latter, the favorable characteristics generated a permanent and more stable activity of mosquitoes against changes in temperature. In the steppe, however, which presents low levels of humidity, scarce vegetation, and greater wind exposure, the activity was unstable against small thermal variations.

In the three patch types of this agricultural landscape, the increase in maximum wind speed seemed to cause a negative effect on the flight activity of *Oc. albifasciatus,* reflected in lower captures. However, this effect was not direct, as the maximum wind speed during the gusts of wind was inversely related to the times of calm (Fig. 5), which are the periods of time during which mosquitoes show flying and biting activity. Therefore, the insignificant or absent periods of calm between gusts when speed exceed 24 km/h rather than the magnitude of the wind speed are the ones preventing this behavior. On every capture session, *Oc. albifasciatus* was active only in times of calm, among which the level of captures was similar. This could be explained by the refuge behavior among the vegetation to avoid being passively transported by the wind, as it has been studied for some culicid species both in the field (Snow 1982) and the laboratory (Hoffmann and Miller 2003) and for other orders of insects (Briers et al. 2003).

The positive relationship between cloud cover and *Oc. albifasciatus* activity further evidences the negative effect of solar radiation on insects. Except for observations made in temperate regions (Hack et al. 1978), no relationship has been found so far between wind or cloud cover and the activity of this species.

In this work, the combination of environmental factors (temperature, wind speed, and cloud cover) and types of landscape patches (steppe, natural wetland, and cultivated area) allowed explaining the spatio-temporal distribution of *Oc. albifasciatus.*

The proliferation of this species, favored by agricultural activity, could be mitigated by applying alternative irrigation systems that minimize the flooding of soils for prolonged periods.

References Cited

Avilés, G., M. S. Sabattini, and C. J. Mitchell. 1992. Transmission of western equine encephalomyielitis virus by argentine *Aedes albifasciatus* (Diptera: Culicidae). J. Med. Entomol. 29: 850–853.

Bambaradeniya, C.N.B., and F. P. Amerasinghe. 2003. Biodiversity associated with the rice field agroecosystem in Asian countries: a brief review. Working paper 63. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Benton, T. G., J. A. Vickery, and J. D. Wilson. 2003. Farmland biodiversity: is habitat heterogeneity the key?. Trends Ecol. Evol. 18: 182–188.

Bidlingmayer, W. L., J. F. Day, and D. G. Evans. 1995. Effect of wind velocity on suction trap catches of some Florida mosquitoes. J. Am. Mosq. Control Assoc. 11: 295–301.

Briers, R. A., H. M. Carris, and J.H.R. Gee. 2003. Flight activity of adult stoneflies in relation to weather. Ecol. Entomol. 28: 31–40.

Burroni, N., V. Loetti, G. Freire, O. Jensen, and N. Schweigmann. 2007. New record and larval habitats of *Culex eduardoi* (Diptera: Culicidae) in an irrigated area of Patagonia, Chubut Province, Argentina. Mem. Inst. Oswaldo Cruz, Río de Janeiro 102: 237–240.

Carrieri, M., E. Montemurro, S. V. Valentino, and R. Bellini. 2011. Influence of environmental and meteorological factors on the biting activity of *Leptoconops noei* and *Leptoconops irritans* (Diptera: Ceratopogonidae) in Italy. J. Am. Mosq. Control Assoc. 27: 30–38.

Chandler, J. A., and R. B. Highton. 1975. The succession of mosquito species (Diptera, Culicidae) in rice fields in the Kisumu area of Kenya, and their possible control. Bull. Entomol. Res. 65: 295–302.

Chatterjee, S., A. S. Hadi and B. Price. 2000. Regression analysis by example, 3rd. ed. Wiley, Inc., Brentwood, CA.

Elissalde, N.O., P. E. Rial, M. E. Llanos, J. M. Escobar and M. Mühleman. 1998. Sistema de Información Geográfica para el Sector Agropecuario del Valle de Sarmiento. Prodesar, proyecto argentino alemán, Chubut, Argentina.

Fischer, S., M. C. Marinone, and N. Schweigmann. 2002. *Ochlerotatus albifasciatus* in rain pools of buenos aires: seasonal dynamics and relation to environmental variables. Mem Inst. Oswaldo Cruz, Rio de Janeiro 97: 767–773.

Fontanarrosa, M. S., M. C. Marinone, S., Fischer, P. W. Orellano, and N. Schweigmann. 2000. Effects of flooding and temperature on *Aedes albifasciatus* development time and larval density in two rain pools at Buenos Aires Universty City. Mem. Inst. Oswaldo Cruz, Rio de Janeiro 95: 787–793.

Forattini, O. P. 1965. Entomologia Médica, 2. *Culicini: Culex, Aedes e Psorophora,* Univ. São Paulo, São Paulo.

Forman R.T.T. and M. Gordon. 1981. Patches and structural components for a landscape ecology. BioScience 31 733–740.

Gleiser, R., and D. Gorla. 1997. Abundancia de *Aedes (Ochlerotatus) albifasciatus* (Diptera: Culicidae) en el sur de la laguna de Mar Chiquita. Ecol. Austral. 7: 20–27.

Gleiser, R. M., D. E. Gorla, and G. Schelotto. 2000. Population Dynamics of *Aedes albifasciatus* (Diptera: Culicidae) South of Mar Chiquita Lake, Central Argentina. J. Med. Entomol. 37: 21–26.

Gleiser, R. M., G. Schelotto, and D. E. Gorla. 2002. Spatial pattern of abundance of mosquito, *Ochlerotatus albifasciatus,* in relation to habitat characteristics. Med. Vet. Entomol. 16: 364–371.

Gray, K. M., N. D. Burkett-Cadena, M. D. Eubanks, and T. R. Unnasch. 2011. Crepuscular flight activity of *Culex erraticus* (Diptera: Culicidae). J. Med. Entomol. 48: 167–172.

Grimstad, P. R., and G. R. De Foliart. 1975. Mosquito nectar feeding in Wisconsin in relation to twilight and microclimate. J. Med. Entomol. 11: 691–698.

Hack, W. H., G. J. Torales, N. E. Bar, and B. Oscherov. 1978. Observaciones etológicas sobre culícidos de Corrientes. Rev. Soc. Entomol. Argent. 37:137–151.

Hoffmann, E. J., and J. R. Miller. 2003. Reassessment of the role and utility of wind in suppression of mosquito (diptera: culicidae) host finding: stimulus dilution supported over flight limitation. J. Med. Entomol. 40: 607–614.

Hooks, C.R.R., and M. W. Johnson. 2003. Impact of agricultural diversification on the insect community of cruciferous crops. Crop Prot. 22: 223–238.

Hunter, M. D. 2002. Landscape structure, habitat fragmentation, and the ecology of insects. Agric. For. Entomol. 4: 159–166.

InfoStat. 2008. Manual del usuario, versión 2008. Editorial Brujas, Córdoba, Argentina.

(INTA) Instituto Nacional de Tecnología Agropecuaria de Sarmiento. 2009–2011. Sistema de Información de la Patagonia Sur (S.I.P.A.S.). Agrometeorología. (http://www.inta.gob.arregionpassipassipasindex.htm).

Ludueña Almeida, F. F., and D. E. Gorla. 1995. Daily pattern of flight activity of *Aedes albifasciatus* in central Argentina. Mem. Inst. Oswaldo Cruz, Rio de Janeiro 90: 639–644.

Ñancucheo, A., C. Mundet, G. Iñirrita and M. Winogrand. 2008. Desarrollo agropecuario en el valle de Sarmiento-Chubut. Concurso Argentino Rural.

Okogun, G.R.A., B.E.B. Nwoke, A. N. Okere, J. C. Anosike, and A. C. Esekhegbe. 2003. Epidemiological implications of preferences of breeding sites of mosquito species in Midwestern Nigeria. Ann. Agric. Environ. Med. 10: 217–222.

Paruelo, J. M., A. Beltrán, E. Jobbágy, O. E. Sala, and R. A. Golluscio. 1998. The climate of Patagonia: general patterns and controls on biotic processes. Ecol. Austral. 8: 85–101.

Peel, M. C., B. L. Finlayson, and T. A. McMahon. 2007. Updated world map of the Koppen-Geiger climate classification. Hydrol. Earth Syst. Sci. Discuss 4: 439–473.

Pinto, C. S., U.E.C. Confalonieri, and B. M. Mascarenhas. 2009. Ecology of *Haemagogus sp.* and *Sabethes sp.* (Diptera: Culicidae) in relation to the microclimates of the Caxiuanã National Forest, Pará, Brazil. Mem. Inst. Oswaldo Cruz, Rio de Janeiro 104: 592–598.

Prosen, A. F., A. Martínez, and R. V. Carcavallo. 1960. La familia Culicidae (Díptera) de la rivera fluvial de la provincia de Buenos Aires. An. Inst. Med. Reg. 6 :59–124.

Raña, J. C., O. R. Quaino and D. H. Paterno. 1971. Informe sobre daños provocados por mosquitos en la zona del Departamento San Cristóbal, limítrofe con Córdoba y Santiago del Estero. Informe Técnico INTA EERA-Rafaela, Santa Fe, Argentina.

Roland, J., N. Keyghobadi, and S. Fownes. 2000. Alpine parnassius butterfly dispersal: effects of landscape and population size. Ecology 81: 1642–1653.

Schtickzelle, N., G. Menennchez, and M. Baguette. 2006. Dispersal depression with habitat fragmentation in the bog fritillary butterfly. Ecology 87: 1057–1065. mcSnow, W. F. 1982. Further observations on the vertical distribution of flying mosquitoes (Diptera: Culicidae) in West African savanna. Bull. Entomol. Res. 72: 695–708.

Tscharntke, T., I. Steffan-Dewenter, A. Kruess, and C. Thies. 2002. Characteristics of insect populations on habitat fragments: A mini review. Ecol. Res. 17: 229–239.

Yang, G. J., B. W. Brook, P. I. Whelan, S. Cleland, and C.J.A. Bradshaw. 2008. Endogenous and exogenous factors controlling temporal abundance patterns of tropical mosquitoes. Ecol. Appl. 18: 2028–2040.

Zar, J. H. 1996. Biostatistical analysis. Prentice-Hall, NJ.

Received 22 January 2014; accepted 28 February 2014.