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Satellite observation to assess dengue risk due to *Aedes aegypti* and *Aedes albopictus* in a subtropical city of Argentina

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Abstract

Earth observation environmental features measured through remote sensing and models of vector mosquitoes species *Aedes aegypti* and *Ae. albopictus* provide an advancement with regards to dengue risk in urban environments of subtropical areas of Argentina. The authors aim to estimate the effect of landscape coverage and spectral indices (Normalized Difference Vegetation Index [NDVI], Normalized Difference Water Index [NDWI] and Normalized Difference Built-up Index [NDBI]) on the larvae abundance of *Ae. aegypti* and *Ae. albopictus* in Eldorado, Misiones, Argentina using remote satellite sensors. Larvae of these species were collected monthly (June 2016 to April 2018), in four environments: tire repair shops, cemeteries, dwellings and an urban natural park. The proportion of landscape coverage (water, urban areas, bare soil, low vegetation and high vegetation) was determined from the supervised classification of Sentinel-2 images and spectral indices, calculated. The authors developed spatial models of both vector species by generalized linear mixed models. The model's results showed that *Ae. aegypti* larvae abundance was better modelled by NDVI minimum values, NDBI maximum values and the interaction between them. For *Ae. albopictus* proportion of bare soil, low vegetation and the interaction between both variables explained better the abundance.

KEYWORDS
Aedes aegypti, *Aedes albopictus*, dengue, Eldorado city, landscape, public health, urban ecology, urban environment

INTRODUCTION

Interconnection mainly due to human population migrations, tourism, growth of the transport of food and products, environmental changes related to urbanization, deforestation and climate change, among others are the main causes of *Aedes* mosquitoes and the associated diseases global dispersion and distribution (Juliano & Lounibos, 2005; Rúa-Uribe et al., 2012). Although there are other mosquito species of public health concern like *Anopheles* (Meigen) vector of malaria (Dantur Juri et al., 2005; Ramírez et al., 2016), globally vectors *Aedes* (*Stegomyia*) *aegypti* Linnaeus and *Aedes* (*Stegomyia*) *albopictus* (Skuse) represent one of the greatest concerns as vectors of among. This situation places these *Aedes* mosquitoes on the wall of public health global concern. That is, *Aedes aegypti* and *Ae. albopictus* species are present in urban, suburban and rural settlements due to their ability to inhabit both natural (e.g., tree holes) and artificial (e.g., manholes, water storage containers, flower pots and used tires) larval habitats (Hawley, 1988; Vezzani & Carbajo, 2008). In particular, the distribution of *Ae. aegypti* includes tropical, subtropical and temperate regions of the world. These species are considered anthropophilic mosquitoes associated with urban areas, whereas *Ae. albopictus* is distributed in the tropics worldwide, but also in temperate regions in the northern hemisphere, being associated with the peri-domicile of suburban and rural environments (De Lima-Camara et al., 2006; Robert et al., 2020).

In Asia, *Ae. albopictus* is the main vector of dengue, chikungunya and Zika (Paupy et al., 2009). By contrast, in America, it is not considered the main vector of these arboviruses; however, sporadically, it has been found naturally infected with dengue in countries such as the United States (North America), Colombia and Brazil (South America) (Lourenço-de-Oliveira et al., 2003; Rúa-Uribe et al., 2012). Indeed, in South America (Merle et al., 2018) and in Argentina (Vezzani & Carbajo, 2008), the main vector of dengue, chikungunya and Zika is *Ae. aegypti* vector. However, in Argentina, dengue is the only arbovirus that has presented an epidemic behaviour over the years. During the year 2020, the most important dengue epidemic was registered in the country, with 59,383 confirmed cases and 26 registered deaths, Misiones province being the fifth province with the highest cumulative incidence of confirmed cases of dengue (MNS, 2020). In Misiones, sporadic seasonal outbreaks have been observed since 2009. However, at the beginning of 2016, there was an unusual increase in suspected cases in this province, which in May 2016 was identified as the epicentre of the epidemic with the greatest impact in Argentina for that decade (MSN, 2016).

Actually, in Argentina, *Ae. aegypti* is present in 19 provinces including Buenos Aires, Catamarca, Chaco, Córdoba, Corrientes, Entre Ríos, Formosa, Jujuy, La Pampa, La Rioja, Mendoza, Misiones, Neuquén, Salta, San Juan, San Luis, Santa Fe, Santiago del Estero and Tucumán (Grech et al., 2012; Páez et al., 2016; Rossi, 2015; Rubio et al., 2020). The first record of *Ae. albopictus* in Argentina dates from 1998 when it was found in the cities of San Antonio and Eldorado in Misiones province (Rossi et al., 1999; Schweigmann et al., 2004). For 20 years, it had only been detected in three other cities in Misiones (Puerto Iguazú, Comandante Andresito and Colonia Aurora) (Lizuain et al., 2019; Vezzani & Carbajo, 2008) and recently has been found in Corrientes province, 200 km south from its previous records (Goenaga et al., 2020).

Environmental features, such as landscape coverage, strongly affect the presence, abundance and distribution of *Ae. aegypti* and *Ae. albopictus* development (Mudele et al., 2021; Mudele & Gamba, 2019), affecting each species of mosquito differently because they have certain habitat requirements, which can vary greatly even between related species (Johnson et al., 2008; Steiger, 2012). Changes in environmental conditions as a result of urbanization have been related (directly or indirectly) to the availability of larval habitats, and the modification in the abundance, richness, development and survival of adult mosquitoes (Baldacchino et al., 2017; Bennett et al., 2021). Satellite remote sensors have been used to indicate and identify favourable mosquitoes larval habitats (Hassan et al., 2013). Some studies have linked mosquito populations to remotely detected land cover features, as Vanwambeke et al. (2007) who found a high probability of finding larvae of *Ae. albopictus* in the peri-urban. Its presence has also been related to mixed areas of urbanization and vegetation (Manica et al., 2016). Nevertheless, for *Ae. aegypti* mosquitoes, urbanization has been highlighted in several studies as a main environmental feature that affects abundance and distribution of the vector (Benitez et al., 2019; Sallam et al., 2017). As one of the frequently described environmental characteristics used in *Aedes* mosquitoes studies, vegetation is the most applied for spatial scale analysis (Heinisch et al., 2019). In fact, there are numerous remote sensing earth observation applied algorithms for spatial and temporal mosquitoes studies, like Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI), among others (Benitez et al., 2019; Estallo et al., 2018; Mudele et al., 2021; Mudele & Gamba, 2019; Pope et al., 1994) as well as applied in mosquito-borne diseases (Vergara-Cid, 2013). For Argentina, although the knowledge about the biology of *Ae. aegypti* is well documented (Benitez et al., 2019; Carbajo et al., 2006; Estallo et al., 2018), there is a lack of information on *Ae. albopictus* (Alonso, 2021; Alonso et al., 2022; Faraone et al., 2021; Lizuain et al., 2019; Schweigmann et al., 2004). The management and control of both *Aedes* species is a main subject to prevent the related diseases associated with their presence if viral circulation occurred. Therefore, the aim of the present study was to estimate the effect of landscape coverage and spectral indices on the larvae abundance of *Ae. aegypti* and *Ae. albopictus* in Eldorado, Misiones, Argentina, using remote satellite sensors.

MATERIALS AND METHODS

Study site

Eldorado city (Figure 1) is located in the north-west of Misiones province, within the Neotropical region (26° 24′ S, 54° 38′ W). The phytogeographical region is Paraná province. The area is characterized by the presence of three arboreal strata, with lianas, epiphytes and hemiepiphytes and an undergrowth of ferns and herbaceous and shrubby phanerophytes, including bamboos (Oyarzabal et al., 2018). The climate is subtropical, hot and humid, without a marked dry season. The mean annual temperature is 22°C, with a maximum temperature of 38.5°C (January) and a minimum of 5.4°C (July); the mean annual rainfall is 2020 mm (Silva et al., 2008).

Eldorado is the third largest city in the province with a population of 90,484 inhabitants (INDEC, 2020) and a surface of 215 km^2 where 14% corresponds to rural areas, 30.6% to natural forests and 55.4% to other uses (Molinatti et al., 2010). The city expands on both sides along the National Route N° 12. The main economic activities of the region are forestry (sawmills, pulp and paper industry) and agriculture, oriented towards industrial crops production of yerba mate, tea, tobacco and citrus.

Entomological sampling

Larvae of *Aedes aegypti* and *Ae. albopictus* were collected monthly from June 2016 to April 2018, in four outdoor environments: tire repair shops, cemeteries, dwellings and an urban natural park (Parque Schwelm) (Figure 2), seeking to cover the most favourable environments for the breeding of mosquitoes, based on the samples previously collected by this study's work group. Sampling sites with larval presence of both species were georeferenced using the Global Position System (GPS-Garmin eTREX 10). The number of monthly samples was N = 60, distributed as follows: 20 from natural larval habitats; 20 from artificial larval habitats of cemeteries, 10 from tire repair

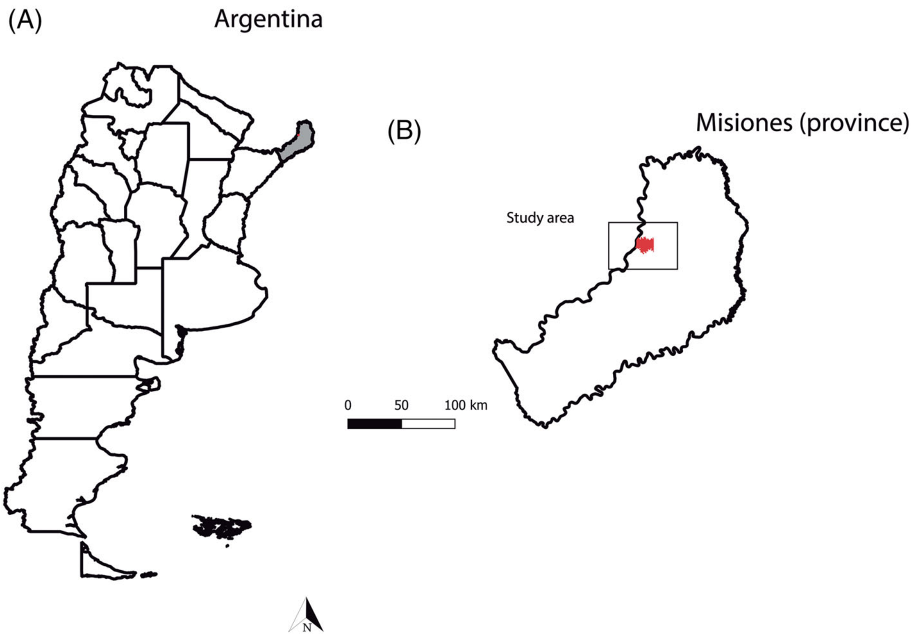

FIGURE 1 (A and B) Geographic location of the study area in Misiones, Argentina

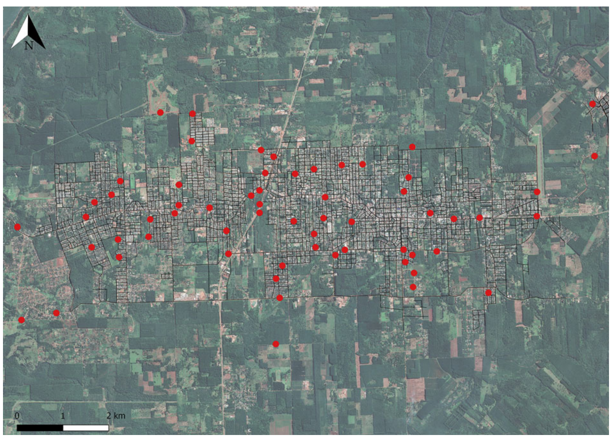

FIGURE 2 Sampling sites spatial distribution in Eldorado, Misiones, Argentina

shops; and 10 from dwellings. The dwellings were visited according to the provisions of the Environmental Sanitation Direction of the Municipality of Eldorado, where each month different neighbourhoods were visited. The larvae were transferred to the laboratory of the Institute of Regional Medicine (UNNE) for conservation and determination. In the laboratory, larvae of instar I, II and III were reared to obtain the fourth instar larvae for morphological identification of the specimens using dichotomous keys (Consoli & Lourenço-De-Oliveira, 1994; Darsie, 1985).

Remote sensing data

In order to estimate the different landscape coverage in the city, five Sentinel-2 satellite images were downloaded from the Land Viewer website and processed (https://eos.com/landviewer/). The satellite images correspond to the succession of seasons from the 3 years of sampling and were selected according to the availability of images on the website and the absence of clouds over the area of interest. The spatial resolution of the Sentinel-2 satellite depends on the spectral band. The bands used were B5 (705 nm), B6 (740 nm), B7 (783 nm), B8A (865 nm), B11 (1610 nm) and B12 (2190 nm) with 20 m spatial resolution, and bands B2 (490 nm), B3 (560 nm), B4 (665 nm) and B8 (842 nm) with 10 m spatial resolution (https://sentinels.copernicus.eu/).

The landscape coverage was characterized by obtaining a thematic map by supervised classification (Minimum Distance to Mean) of the images. Subsequently, five types of coverage were defined: water (rivers, lakes, artificial bodies of water), bare soil (soil without any vegetation cover, unpaved streets), urban areas (buildings, paved streets and roads), low vegetation (herbs and grasses) and high vegetation (trees and shrubs). To check the accuracy of the classification obtained, the confusion matrix method was used and the value of the Kappa's coefficient calculated (values close to 1 indicate greater accuracy of the classification method). In addition, a total of 100 control points (called areas of verification) were defined by landscape coverage following the criteria recommended by Chuvieco Salinero (2008), and following the visualization of the historical record of Google Earth images (https://earth.google.com/web) (Qian et al., 2015). On each satellite image, Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Difference Built-up Index (NDBI) were calculated. The NDVI reflects the contrast of vegetation reflectivity between the spectral regions of red (B4) and near infrared (B8) reflectance (Equation 1). This index can be associated with the vegetation cover, in terms of abundance and vigour, since it is strongly related to the photosynthetic activity of the vegetation, allowing to identify the presence of vegetation on the surface and characterize its spatial distribution. The values vary from −1 to +1, where high values correspond to areas with vigorous vegetation, negative values are associated with covers such as water and values close to zero correspond to bare soil (Chuvieco Salinero, 2008). On the other hand, the NDWI is an index that takes into account the water content present in the mesophyll of the leaves and indirectly measures precipitation and soil humidity (Estallo et al., 2012). It varies between −1 and +1, depending on the water content of the leaves, but also on the type of vegetation and cover. It is based on the contrast between the reflectances of short-wave infrared (B11) and near infrared wavelengths (B8A) (Equation 2) (Gao, 1996). The NDBI is an index that highlights urban areas, where there is typically a higher reflectance in the short-wave infrared region (B11), compared with the near infrared region (B8) (Zha et al., 2003) (Equation 3). Positive NDBI values indicate built-up areas and those close to 0 indicate vegetation, whereas negative values represent bodies of water (Ranagalage et al., 2017).

$$\mathrm{NDVI} = (\mathrm{B8} - \mathrm{B4})/(\mathrm{B8} + \mathrm{B4}) \quad (1)$$

$$\mathrm{NDWI} = (\mathrm{B8A} - \mathrm{B11})/(\mathrm{B8A} + \mathrm{B11}) \quad (2)$$

$$\mathrm{NDBI} = (\mathrm{B11} - \mathrm{B8})/(\mathrm{B11} + \mathrm{B8}) \quad (3)$$

On the thematic maps and on each spectral index image, a 100 m, circular influence area was generated around each sampling site, from which the proportion of each kind of coverage was extracted and the mean, minimum and maximum values of NDVI, NDWI and NDBI. The overlapping of the areas was avoided and it was also considered that these vector mosquitoes species flight ranges rarely exceed 100 m (Osmany, et al., 2010; Velez et al., 1998). QGIS 3.4.15 software (https://www.qgis.org/) was used for the pre-processing and processing of the images.

TABLE 1 Explanatory variables used to explain the variation in the abundances of *Ae. aegypti* and *Ae. albopictus* in Eldorado, Misiones

Variable	Description
highV	Proportion of high vegetation cover extracted from a 100 m buffer around each sampling site
lowV	Proportion of low vegetation cover extracted from a 100 m buffer around each sampling site
soil	Proportion of bare soil cover extracted from a 100 m buffer around each sampling site
urban	Proportion of urban areas cover extracted from a 100 m buffer around each sampling site
ndvi	Mean value of NDVI extracted from a 100 m buffer around each sampling site
ndvimin	Minimum value of NDVI extracted from a 100 m buffer around each sampling site
ndvimax	Maximum value of NDVI extracted from a 100 m buffer around each sampling site
ndwi	Mean value of NDWI extracted from a 100 m buffer around each sampling site
ndwimin	Minimum value of NDWI extracted from a 100 m buffer around each sampling site
ndwimax	Maximum value of NDWI extracted from a 100 m buffer around each sampling site
ndbi	Mean value of NDBI extracted from a 100 m buffer around each sampling site
ndbimin	Minimum value of NDBI extracted from a 100 m buffer around each sampling site
ndbimax	Maximum value of NDBI extracted from a 100 m buffer around each sampling site

Data analysis

To analyse the possible effects of landscape coverage and spectral indices on the abundance of larvae, generalized linear mixed models (GLMM) were constructed for each species separately. To control over-dispersion, negative binomial distribution was used with a logarithmic link function (Zuur et al., 2009). In the analyses, the response variable used was the number of larvae collected from each site per month. The sites were incorporated as a random intercept to include spatial correlation. The explanatory variables used are shown in Table 1. Water coverage was not incorporated into the models because it was not found in any influence area.

First, data exploration was implemented following the protocol described by Zuur et al. (2010). The explanatory variables were standardized to balance their weight and also to avoid introducing errors in the model produced by the different measurement units of each variable. Then, a Spearman's rank test was performed to analyse the correlation of the explanatory variables.

The models were built using a manual step-by-step forward procedure. The authors began by evaluating the significance of each response variable from univariate GLMM. The variables that were significant for each species were in turn used as starting points in the different branches of the modelling. Subsequent variables were added one by one as long as they did not have a correlation coefficient >0.7 with some variables already included. Interactions between them were also tested. In each step, the significance of each addition was evaluated with a significant reduction (2 points) in the Akaike information criterion corrected for low sample sizes (AICc) (Zuur et al., 2009). The GLMMs were classified according to the AICc and the model with the lowest value was selected as the best model. The multicollinearity between variables was evaluated in the final models using the variance inflation factor, considering a threshold value equal to 5. Finally, the ggResidpanel package was used to verify the normality of the residual distribution and evaluate the residual plot.

The free software R, version 4.0.3 (https://www.r-project.org/) and the packages lme4 (*glmer.nb* function), MuMin (*model.sel* function) and car (*vif* function) were used to perform the statistical analyses.

RESULTS

A total of 23,658 larvae of the species under study were collected during the entire sampling period. Of that total, *Ae. aegypti* presented

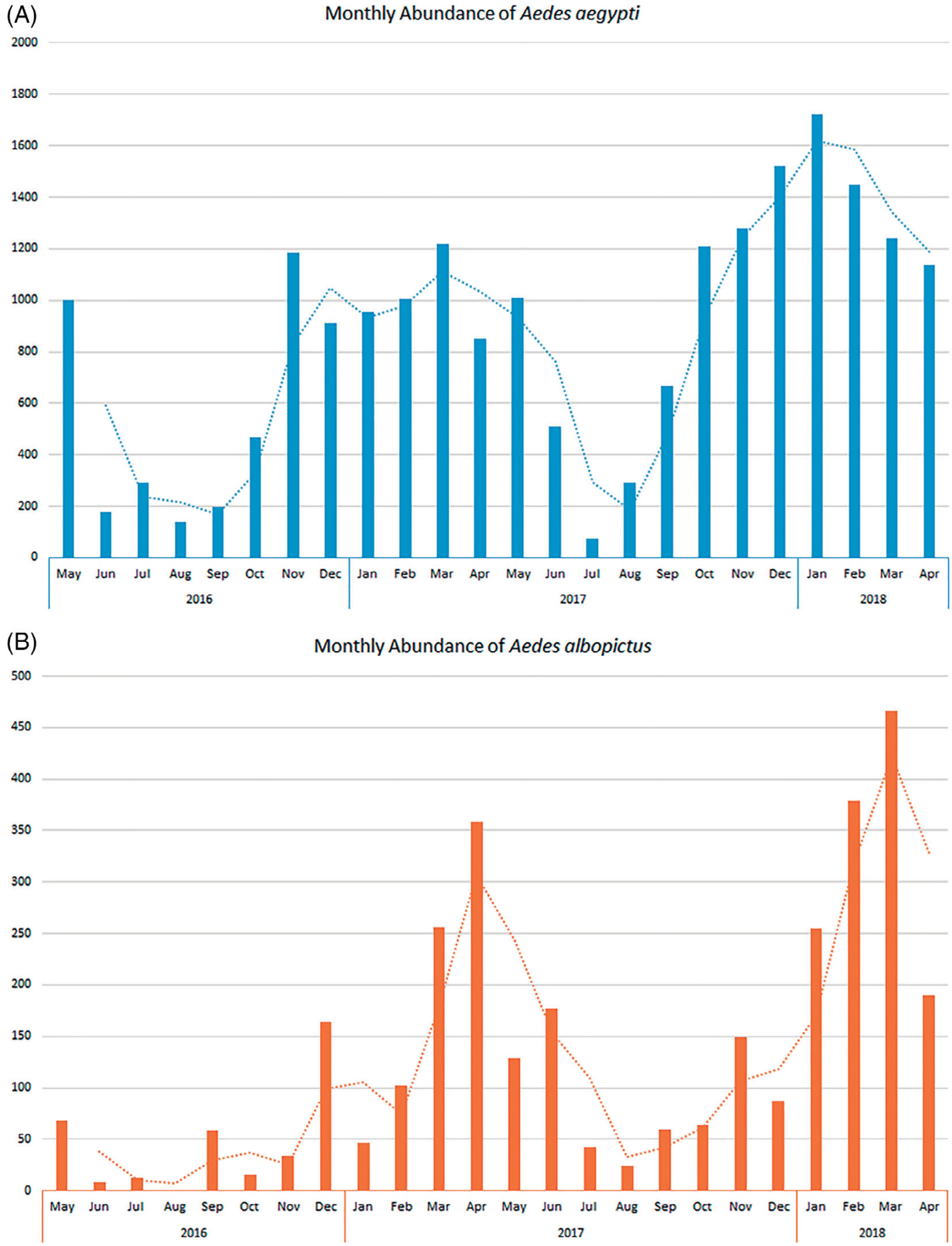

FIGURE 3 Monthly abundance of (A) *Ae. aegypti* and (B) *Ae. albopictus* in the city of Eldorado in the sampling period

a relative abundance of 86.70% ($n = 20{,}511$), whereas *Ae. albopictus* presented a relative abundance of 13.30% ($n = 3147$). The presence of both species was recorded throughout the sampling period. For both species, the lowest mean abundance was in winter and spring, and the highest values were in autumn and summer (Figure 3). Regarding the sites, the highest total larval abundance of *Ae. aegypti* was found in dwellings (relative abundance of 43.75%), followed by habitats found in cemeteries (32.04%), tire repair shops (23.95%) and the smallest number in the natural park (0.26%). For *Ae. albopictus*, its highest larval abundance corresponds to habitats found in cemeteries (49.09%), followed by dwellings (42.21%), tire repair shops (5.6%) and natural parks (3.01%).

Regarding the supervised classification of Sentinel-2 images, the overall accuracy of the classifications ranged from 91% to 99.6%, with Kappa indices from 0.8875 to 0.995. The average of the classifications allowed the authors to identify in Eldorado the high vegetation as the predominant in the image with a proportion of 0.6389, followed by low vegetation (landcover proportion of 0.1586), bare soil (landcover proportion of 0.1225), urban areas (landcover proportion of 0.0445)

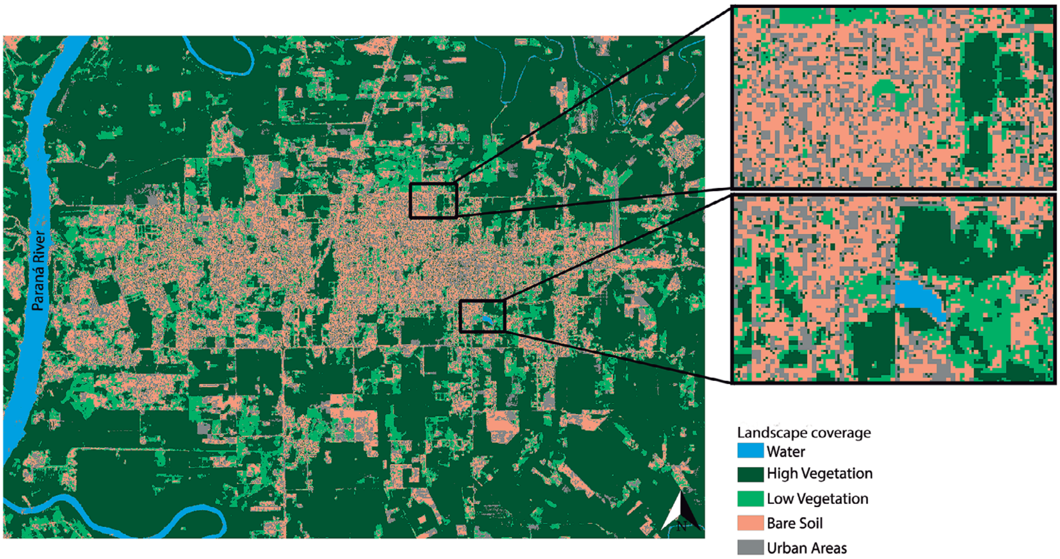

FIGURE 4 Eldorado thematic map for November 12, 2016

TABLE 2 Generalized linear mixed models (GLMM) selected for *Ae. aegypti* and *Ae. albopictus*

Specie	Model	Variable	AICc
Ae. aegypti	Ma3	highV+ndvimin	7683.7
	Ms11	soil*ndvimin	7643.2
	Mv16	ndvimin*ndbimax	**7633.7**
	Mb5	ndbi*ndvimin	7648.1
	Mm16	ndbimax*ndvimin	**7633.7**
Ae. albopictus	Ms11	soil*lowV	**3440.9**

Note: The number in bold is the one with the lowest value, that is, the best model.

and water with the lower coverage percentage (land cover proportion of 0.0355) represented mainly by the Paraná River (Figure 4).

Based on the exploratory analysis of the variables and considering those with statistical significance in the univariate GLMMs, five model branches were constructed for *Ae. aegypti* and one branch for *Ae. albopictus*. For the first species, the univariate GLMMs of: high vegetation, bare soil, NDVI minimum values, NDBI mean values and NDBI maximum values were started, and after considering the correlations between the independent variables, 66 models were made that evaluated the addition of more variables and interactions. By contrast, for *Ae. albopictus* GLMMs were modelled from the variable: bare soil, making 14 models (see Table S1–S7 in Supporting Information). In Table 2, the selected models within each branch are displayed from the comparison of the goodness of fit indicators (AICc) for the species under study.

The GLMM results showed that the larvae abundance of *Ae. aegypti* was better modelled by NDVI minimum values, as well as NDBI maximum values and the interaction between both variables. The coefficients of the fixed effects showed that larvae abundance of *Ae. aegypti* was higher at lower NDVI minimum values and NDBI maximum values, and higher at higher values of the interaction between both indices (Table 3). By contrast, the abundance of *Ae. albopictus* was better explained by bare soil, low vegetation and the interaction between both variables. The coefficients of the fixed effects showed that larval abundance of *Ae. albopictus* presented a positive association with the variables bare soil and the interaction of soil*lowV, and a negative association with the variable low vegetation (Table 4). The other GLMM with the same AICc (soil*ndbimax) was not selected for presenting a vif > 5 in the interaction between the variables.

TABLE 3 Coefficients of the final generalized linear mixed models (GLMM) selected for *Ae. aegypti*

Variable	Estimate	Std. error	Z value	Pr(>|z|)
Intercept	5.18544	0.01475	351.6	<2e-16**
ndvimin	−14.48629	0.01481	−977.8	<2e-16**
ndbimax	−6.94077	0.01481	−468.6	<2e-16**
ndvimin*ndbimax	17.40568	0.01482	1174.7	<2e-16**

Note: Two asterisks mean $p < 0.01$.

TABLE 4 Coefficients of the final generalized linear mixed models (GLMM) selected for *Ae. albopictus*

Variable	Estimate	Std. error	Z value	Pr(>|z|)
Intercept	0.2294	0.5501	0.417	0.6766
soil	0.3630	1.1394	0.319	0.7500
lowV	−2.9152	1.3444	−2.168	0.0301*
soil*lowV	10.5393	4.4811	2.352	0.0187*

Note: An asterisk means $p < 0.05$.

DISCUSSION

The present study allowed us to identify the effect of landscape covers and spectral indices on the larvae abundance of *Ae. aegypti* and

Ae. albopictus in a subtropical city of Misiones, Argentina, through Sentinel-2 images applied.

The global distribution of the frequent sympatric species, *Ae. aegypti* and *Ae. albopictus*, have changed in recent decades due to differences in their abilities to compete with each other (Bennett et al., 2021). Generally, *Ae. aegypti* is highly adapted to domestic environment, and therefore abundance is positively correlated with increasing urbanization (Higa, 2011). In this study, a negative association was found between the larvae abundance of *Ae. aegypti* and NDVI minimum values and NDBI maximum values. In accordance with Bennett et al. (2021) who found for both species in Panamá a negative association with lower NDVI values.

Urban areas provide this mosquito species to oviposition sites and artificial larval habitats where the immature stages then develop (Flaibani et al., 2020). Previous studies in the United States, Costa Rica, Puerto Rico, Brazil and Argentina have related the abundance of the species with urban areas, buildings and high housing density (Benitez et al., 2019; Carbajo et al., 2006; Fuller et al., 2010; Heinisch et al., 2019; Little et al., 2011; Montagner et al., 2018; Vezzani & Carbajo, 2008). In turn, Chaves et al., (2021) in Costa Rica found a negative association between vegetation index (measured through the Enhanced Vegetation Index-EVI-) and the abundance of *Ae. aegypti*, whereas Samson et al. (2015) found that urban areas identified by urban index were found to be important in predicting the distribution of the species and that the results of their models show a high probability for *Ae. aegypti* in and around urban areas. In accordance with the present study's findings about the negative association of *Ae. aegypti* with NDBI maximum values, a spatial study conducted in Buenos Aires city, Argentina found that the proliferation of mosquitoes *Ae. aegypti* was highest in medium urbanization levels (not densely built on the suburban areas) (Carbajo et al., 2006). Due to the different population densities of both cities, the authors expect that the maximum NDBI values in Eldorado (90,484 inhabitants) will be related to the mean values of NDBI in Buenos Aires (12,801,364 inhabitants). In cities with a high degree of urbanization and high population density, the peripheral area is the most conducive to the reproductive activity of the vector since highly urbanized areas of the city offer few spaces with vegetation (for food and shelter), few larval habitats and reduce the connectivity between patches of habitat that are more favourable (Benitez et al., 2019; Carbajo et al., 2006).

Our study found a positive association between the larvae abundance of *Ae. aegypti* and the interaction between both indices in accordance with previous studies for Costa Rica (Troyo et al., 2009) and temperate Argentina area (Benitez et al., 2019) where moderately built-up residential areas with moderate tree cover likely contain a relatively high number of positive habitats for this species, therefore heterogeneity in urban areas can be linked to the distribution of this species.

On the other hand, previous studies associated the distribution of *Ae. albopictus* with vegetation in rural, suburban and urban areas and its abundance is negatively affected by urbanization. This difference in distribution along the urban–rural gradient is associated with behaviour related to blood feeding, host preference and preference for vegetation, offering ideal conditions for resting and egg laying (Heinisch et al., 2019; Higa, 2011; Manica et al., 2016). The authors observed a negative association between the larvae abundance of the species and low vegetation coverage, and a positive association between the interaction between soil and low vegetation. In this work, the land cover class soil has been related to the sampling sites with sandy streets (unpaved road) (see Figure S1 in Supporting Information). The present study's results are in accordance with Myer et al. (2020), who found an important relationship between the abundance of *Ae. albopictus* and grass cover (negative) and the interaction between impervious and grass cover (positive).

In agreement with Rey et al. (2006), Honorio et al. (2009) and Cianci et al. (2015) low vegetation coverage that includes grasses was negatively associated with the larvae abundance of *Ae. albopictus*, indicating that open areas are less attractive for this mosquito species. In Porto Alegre, Brazil, *Ae. albopictus* was dominant in urban areas with vegetation, relating its adaptation to transition zones between urban and non-urban/natural habitats (Montagner et al., 2018). According to Forattini (2002), the adaptation of the species to transition zones results from being able to use larval habitats and sources of blood food from both environments. Likewise, in Florida, United States, Rey et al. (2006 who found a positive relationship between the abundance of immature *Ae. albopictus* and land covers: ground vegetation, unpaved road and bare ground. Likewise, there are studies that found a greater vulnerability of *Ae. albopictus* to drought conditions, it may be for this reason that it is found less in more open places (without vegetation cover) where the probability of moisture loss is greater (Juliano et al., 2002).

This is the first work carried out in the country to relate the abundance of *Ae. albopictus* with products derived from remote sensors, and the results obtained provide important knowledge about the biology of this species in Argentina. The Pan American Health Organization (PAHO, 2016) has recommended the immediate responsibility to contain and control *Ae. albopictus* in areas of recent infestation, to prevent further spread. For this, knowledge is required on numerous aspects of the ecology of the species, areas of distribution, periods of greater activity, among others that generate baselines to understand the dynamics of pathogen transmission and therefore implement effective programmes of control. Earth observation environmental features measured through remote sensing and models of *Ae. aegypti* and *Ae. albopictus* mosquito species provide an advancement with regards to dengue risk in urban environments of subtropical areas of Argentina, as were developed here. In conclusion, in Argentina, it is necessary that all control and/or prevention programmes for dengue and other arboviruses begin taking into account the presence of *Ae. albopictus*, updating the current surveillance protocols for *Aedes* mosquitoes due to the different environmental requirements of both species, as well as deepening the ecological and spatial and temporal distribution studies.

AUTHOR CONTRIBUTIONS

Mía Elisa Martína was involved in formal analysis, writing—original draft, writing—review and editing. Ana Carolina Alonso was involved in investigation, methodology, writing—original draft, writing—review and editing. Janinna Faraone was involved in investigation, methodology, writing—original draft, writing—review and editing. Marina Stein was involved in conceptualization, funding acquisition, methodology, investigation, resources, supervision, writing—original draft, writing—review and editing. Elizabet Lilia Estallo was involved in formal analysis, methodology, writing—original draft, writing—review and editing.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

TABLE S1. GLMM developed for *Ae. aegypti* starting with the variable highV

TABLE S2. GLMM developed for *Ae. aegypti* starting with the variable soil

TABLE S3. GLMM developed for *Ae. aegypti* starting with the variable ndvimin

TABLE S4. GLMM developed for *Ae. aegypti* starting with the variable ndbi

TABLE S5. GLMM developed for *Ae. aegypti* starting with the variable ndbimax

TABLE S6. GLMM selected for *Ae. aegypti*

TABLE S7. GLMM developed for *Ae. albopictus* starting with the variable soil

FIGURE S1. Photos taken at sampling sites when mosquito larvae were collected

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