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Aedes (*Stegomyia*) *aegypti* in ditches from an arid region of Argentina

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ABSTRACT

Aedes aegypti is the primary vector of dengue worldwide and is able to transmit several other arboviruses of public health importance. Despite extensive research on its ecology throughout the world, limited attention has been given to arid regions. The province of San Juan is an arid region of Argentina with unique climatic characteristics commonly known as the "monte ecoregion". It has scarce precipitation and, therefore, has a network of irrigation canals that supply water to the region. The canal system is outdated, poorly maintained and, accumulating small bodies of water of anthropic origin. Urban ditches were checked from January to December 2019, and during January to June, 771 immature specimens of *A. aegypti* were found. In this work, we report the presence of *A. aegypti* in ditches, describing for the first-time new breeding sites that, despite their extreme physical and chemical properties, were used as successful larval habitats. The remarkable adaptability of *A. aegypti* in this breeding sites raises concerns about the possible detection and spread of dengue cases in the province. The alarming expansion of dengue cases in the region further highlights the urgent need to take control measures against this insect.

1. Introduction

Aedes (*Stegomyia*) *aegypti* (Linnaeus) (Diptera: Culicidae) is the primary mosquito vector of several arboviruses of global health importance, including four serotypes of dengue virus, Zika, chikungunya, urban yellow fever, and several types of encephalitis (Becker et al., 2020). In the Americas, records of arboviral diseases are gradually increasing year by year, with the most significant expansion being in cases of dengue fever. During 2022, the number of recorded cases of this disease doubled compared to 2021, while the number of deaths tripled during the same period. Furthermore, until epidemiological week 13, 2024, in the Americas 260% more suspected cases of dengue were reported compared to the same period in 2023 and 448% compared to the average of the last 5 years, with 3 or 4 dengue viral serotypes circulation in almost all the region, also with an increase in cases of other arboviruses such as Zika and chikungunya (Ministerio de Salud de la República Argentina, 2024).

This mosquito is considered the culicid most closely associated with human populations due to its synanthropic and anthropophilic nature (Barata et al., 2001). The subspecies *A. aegypti aegypti*, the domestic form of this insect, is native to Africa and prefers human blood for food (Scott and Takken, 2012). It breeds in man-made containers and has spread globally through human-generated movement and trade (Kamal et al., 2018; Kotsakiozi et al., 2018). Historically, this species colonized tropical and subtropical regions between 35°N and 35°S (Pan American Sanitary Bureau, 1994). Actually, the dispersal and colonization of new areas by this mosquito can be facilitated by large-scale global warming events such as El Niño or other factors such as passive migration from human activity on a local scale (Díaz-Nieto et al., 2016).

Aedes aegypti is well established in northern and central Argentina, where the dominant climates are temperate and subtropical and where it can breed in outdoor containers filled with rainwater (Carbajo et al., 2019). It has successfully established itself in warm climates, but in recent years, native populations have migrated to colder climates,

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extending their distribution to the south of the country (Díaz-Nieto et al., 2016; Fischer et al., 2017; Vezzani et al., 2022; Dennis and Damiani, 2023).

Rubio et al. (2020) reported the presence of this mosquito in locations with extreme environmental conditions. In Tandil, the Argentine city with the lowest mean annual temperature (14.17 °C), and in San Antonio del Oeste, a vast and extremely arid region, they found immature stages in a tire repair shop and public toilets. *A. aegypti* eggs were collected in Neuquén province, a region with a cold, semi-arid climate (Grech et al., 2012). However, the ecology of *A. aegypti* in arid climates has not been extensively documented.

The province of San Juan, located in the central west of Argentina, falls within the "Monte" ecoregion. This ecoregion is exclusive to Argentina and is characterized by its arid conditions, with very scarce rainfall and notable thermal amplitude between day and night. It has a continental-desert climate with areas covered by forests and xerophytic groves (Poblete and Minetti, 1999). This region has very different climatic conditions than northern Argentina (Morello, 2012), where *A. aegypti* has been described since 1986 (Fischer et al., 2019). Despite the desert climate of this province, the irrigation system provided by artificial canals, known as "acequias" or "ditches," supplies water to a variety of fruits and vegetables produced in the fertile valleys, as well as to street trees, transforming rural and urban areas into a kind of oasis (Schliserman et al., 2014). The ditches in the urban areas of the province are included as a mandatory part of the urbanization process in all types of real estate developments (Nacif et al., 2011). Due to the lack of maintenance or dry weather, the irrigation system by ditches has been partially unavailable or useless for at least the last 10 years, and currently, only 54 km out of 184 km has been reactivated. In addition to the water from the urban irrigation system, water from another origin, such as from washing machines, sinks, and laundries, is frequently dumped in the ditches (Cabrera, com. pers.). Consequently, this urban irrigation system could generate excellent conditions for the development of the immature stages of Culicidae species (Illa, 2021).

The immature stages of *A. aegypti* develop in all kinds of freshwater bodies, domestic or peridomestic, originating from rain or artificial irrigation, such as vases, drums, cans, old tires, and gutters (Rueda, 2008). The success of these vectors in urban areas is facilitated by factors such as inadequate urban infrastructure and basic sanitation, deficient garbage collection, irregular water distribution, and a lack of awareness and community participation in environmental health actions (Carvalho and Moreira, 2017). Recent findings indicate that this insect can adapt to areas with unfavorable water quality or even share breeding sites with other species, such as *Aedes albopictus* (Skuse) and *Culex quinquefasciatus* Say (Manrique-Saide, et al., 2012; Paploski et al., 2016).

Aedes aegypti introduction in San Juan Province is very recent, and adults of this mosquito were detected for the first time in 2015 in San Agustín, Valle Fértil (Carrizo Páez et al., 2016), located 248 km northeast of San Juan city. This town has very particular characteristics, unique in the area, characterized by an average annual rainfall of 400 mm (Poblete and Minetti, 1999). In 2020, San Juan recorded indigenous cases of dengue for the first time (Ministerio de Salud de la República Argentina, 2020). Currently, this mosquito has been detected in 4 departments (Díaz-Nieto et al., 2020) and is constantly expanding around the province (Illa, 2021); however, to date, the types of hatcheries used by *A. aegypti* in this region have not been reported. In general, adults are detected, despite the difficulty in finding breeding sites containing rainwater, due to conditions of low rainfall, low environmental humidity, and high sunlight exposure. The objective of this study was to determine whether irrigation ditches serve as breeding sites for *A. aegypti* in this region. In this work, we report new *A. aegypti* breeding sites in arid areas of Argentina, highlighting the role of urban ditches in the maintenance of *A. aegypti* populations.

2. Methods

Ethics approval

This work was carried out under a scientific license provided by the direction of conservation and protected areas of San Juan (Exp. 1300-0152-2021) for sampling in protected areas, in some private places where specific permits from the owners were needed, and in some free-access lands where permits were not needed. None of the endangered or protected species were included in this study.

2.1. Study site

San Juan Province is included in the Monte ecoregion (Morello, 2012). The climate is continental, arid and dry, with a wide thermal amplitude (maximum 35 °C and minimum 0 °C) and an annual mean temperature of 19 °C. A mean relative humidity of 43% and scarce precipitation (110 mm annual) are concentrated in the summer season (December through March) (Poblete and Minetti, 1999; Cuesta et al., 2020). The native vegetation is characterized by xerophytic shrubs dominated by Zygophyllaceae, such as the genera *Larrea* and *Bulnesia*, associated with Fabaceae of the genus *Prosopis* (Márquez et al., 2014). This ecosystem has been transformed due to irrigation systems conforming to oases within the desert matrix (Núñez-Campero et al., 2022). The study was carried out in the oasis of Tulum (31°32′15″S, 68°32′11″W; at 640 m.a.s.l.) where Great San Juan City is located, and the urban nucleus concentrates more than 60% of the total population of the province. This oasis is composed of 13 departments.

2.2. Study design

In order to evaluate ditches as a potential breeding site for *A. aegypti,* we selected eight sampling places, corresponding to four points of the irrigation system in each department analyzed (Fig. 1).

Ditches (Fig. 2) have cuboid or subtrapezoidal sections, approximately 60 cm deep by 60 cm high, and are waterproofed with cement. However, to irrigate the street trees, the bottom of the ditch has a nonwaterproofed sector every 1 m between trees (Nacif et al., 2011). The water in the sampled ditches was stagnant, with a depth of approximately 30 cm, and a high content of organic matter.

Each ditch was checked twelve times from January to December 2019, sampling from all eight points between 8 a.m. and 1 p.m., alternating the order of visits each time. The ditches were characterized according to sunlight exposure; presence of organic material, such as leaves, wood, or flowers, in the accumulated water; water odor; and water turbidity. Five *in situ* physical and chemical parameters (temperature, pH, conductivity, salinity and total dissolved solids) of breeding sites were measured by a multiparameter monitor (Multi-Parameter meter Eutech PCTestr® 35). Immature specimens were captured at each site, introducing a 300 mL dipper five times, every 3 m, up to a final volume of 1.5 L of water.

The immature stages were transferred to the laboratory in covered plastic containers, and pupae were placed in cages until adulthood (temperature ranging from 25 °C to 27 °C). Four-instar larvae and adults were identified under a stereoscopic microscope and identified according to morphological-based taxonomic keys (Darsie, 1985). The voucher specimens were deposited in the entomological collection of the Institute and Museum of Natural Sciences, National University of San Juan, Argentina (Collection 464, Center 801-UNSJ).

2.3. Weather data

To determine the relationship between the presence of *A. aegypti* and climatic variables such as the mean temperature, precipitation and accumulated days of rain, data from CLIMATE-DATA (climate-data.org) were recorded and compared. Three periods were analyzed: 1) prior to

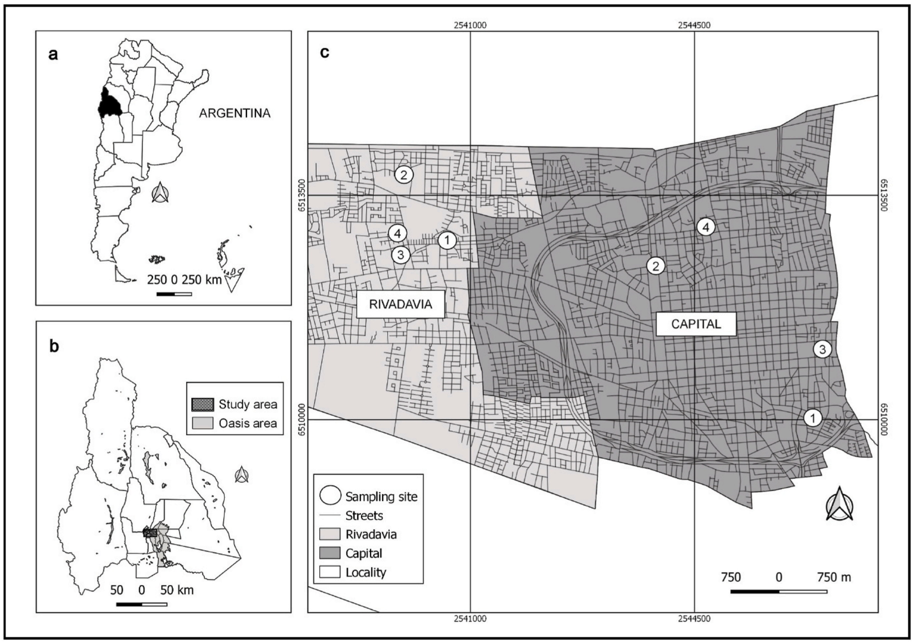

Fig. 1. Study area and detail of the location of the sampling points: **a** Location of San Juan in Argentina; **b** San Juan province, map shows the locations of the oasis and study area; **c** Study area shows the location of the eight sampling points.

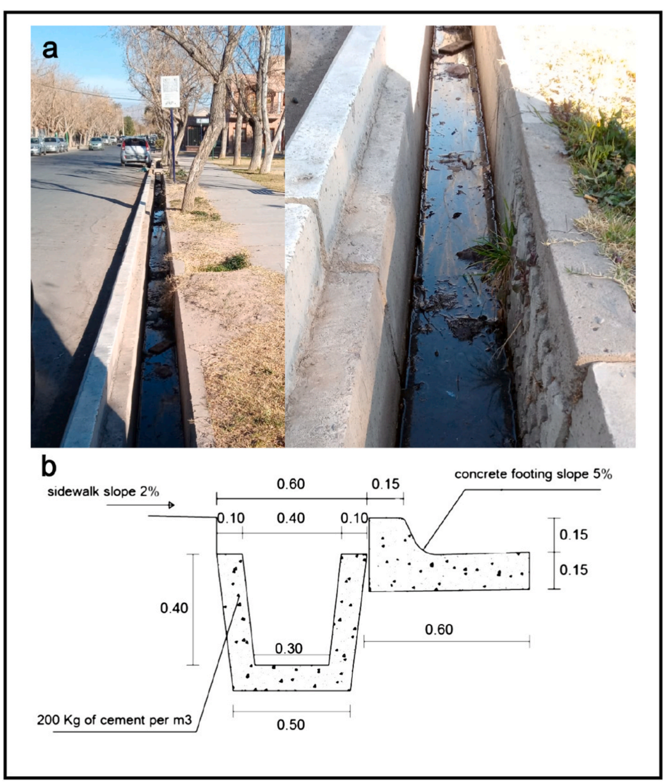

Fig. 2. Irrigation systems: **a** Photograph of an urban ditch; **b** Sketch of its structure.

A. aegypti detection in San Juan (2010–2014); 2) after the first registration in the Valle Fértil department, prior to this study (2015–2018); and 3) during the sampling period (January to December 2019).

2.4. Statistical analysis

The comparison of the frequency of the specimens collected between the ditch groups of the Capital and the Rivadavia departments was evaluated using the chi-square test. To associate the characteristics of the ditches with the presence of *A. aegypti*, a bivariate logistic regression model was applied (Ananth and Preisser, 1999). Differences between the water parameters found between ditches with and without *A. aegypti* were evaluated. For this, 10 datasets of ditches with *A. aegypti* (from Capital) and 10 without *A. aegypti* (from Rivadavia) were analyzed. The values of the pairs compared, with and without *A. aegypti*, were recorded on the same day. The Mann-Whitney test was used for nonparametric data, and the unpaired *t*-test was used for parametric data. The Kruskal-Wallis test was used to compare differences between the climatic data of the three selected periods. Multiple linear regressions were performed to analyze the relationship between the abundance of individuals per species and the climatic variables mentioned above. Statistical analyses were performed using GraphPad Prism version 4.01 for Windows (GraphPad Software, La Jolla California USA, www.graphpad.com). The bivariate logistic regression model was run with the SPSS Statistics program. For all statistical analyses, the significance level was 0.05.

3. Results

A total of 14,007 mosquito specimens were captured in all sampled ditches, 771 of which were identified as *A. aegypti*, 4 as *Culex apicinus* and 13,236 as members of the *Culex pipiens* complex (Fig. 3a). Immature stages of *A. aegypti* and *Culex* spp. were captured in ditches of the Capital department, while in the Rivadavia department, only *Culex* spp. were collected (Fig. 3b).

Differences in the variation in the abundance between *Culex pipiens* complex species and *A. aegypti* were observed during the four seasons. *Culex pipiens complex* species was found inhabiting the ditches during three of the four sampled seasons. The highest record was detected during the summer, with some significant differences between months (January vs February $p = 0.049$; January vs July $p = 0.009$; January vs August $p = 0.009$; January vs September $p = 0.009$; January vs October $p = 0.009$; January vs November $p = 0.009$; January vs December $p =$

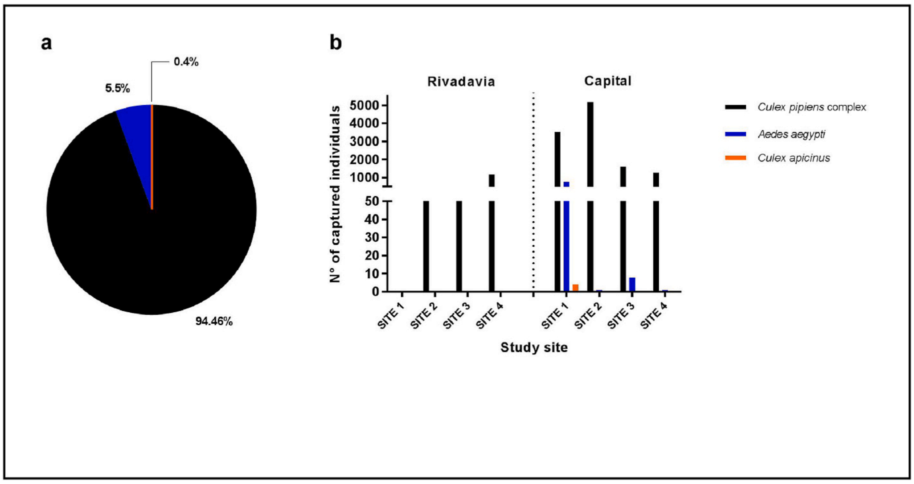

Fig. 3. Mosquitoes captured in ditches: **a** Relative abundance of specimens captured; **b** Number of captured individuals by species and collection site.

0.009). *A. aegypti* was present in the summer and autumn seasons, registering its highest peak also during the summer, although no significant differences were observed (Fig. 4).

Significant differences were observed when the physical and chemical parameters were analyzed between ditches with and without the presence of *A. aegypti* (Table 1).

During the sampling period, accumulated water was found in 47 opportunities (48.9%) on 96 inspected ditches (S1 Table). The bivariate model results show that there was no preference of *A. aegypti* for any of the variables analyzed (odor $p = 0.866$; turbidity; $p = 0.866$; sun exposure $p = 0.730$, organic matter $p = 0.357$).

The weather variables analyzed around the three periods (2010–2014; 2015–2018 and January to December 2019) suggest a similar pattern (Fig. 5a). Significant differences were observed only between the rainfall obtained in the period 2010–2014 (prior to *A. aegypti* detection in San Juan) vs 2019 (during the sampling period) ($p = 0.04$) (Fig. 5b).

The correlation analysis between the abundance of individuals per species and the climatic variables was only significant for *Culex pipiens* complex species depending on the days with rainfall ($F(1.5) = 25.00733$, $p = 0.004$) (Fig. 6).

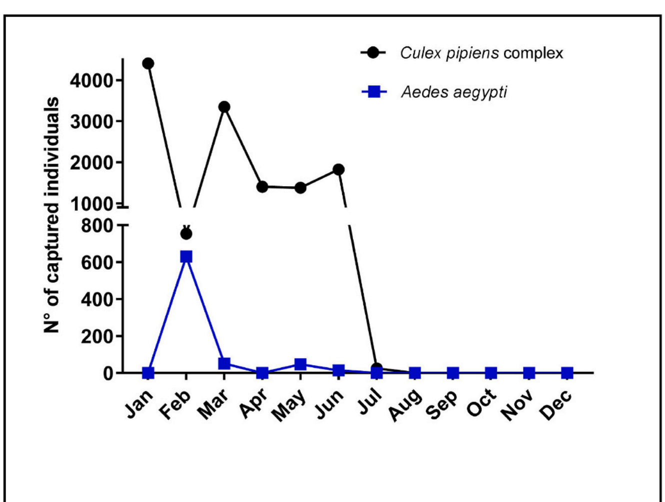

Fig. 4. Monthly variation in *Culex pipiens* complex and *Aedes aegypti* during the sampling months.

Table 1
Physical and chemical parameters measured in ditches.

	Ditch without *A. aegypti* (N = 10)		Ditch with *A. aegypti* (N = 10)		
Parameters	Average	SD	Average	SD	*p* Value
Temperature	23.75	4.24	25	1.89	0.86
Total of dissolved solid (ppm)	556.3	202.06	552	251.64	0.52
Salinity (ppm)	542.1	179.25	380	108.86	0.02[a]
pH	8.09	0.52	7.7	0.65	0.01[a]
Conductivity (μS)	1055.1	215.11	772	214.69	0.02[a]

N= Number of samples used for each parameter.
[a] Indicate significant differences ($p < 0.05$).

4. Discussion

In this work, we describe new breeding sites of *A. aegypti* in an arid region of Argentina characterized by extremely low precipitation. These breeding sites, which are shared with immature stages of *Culex* spp., are located in an old and disused artificial irrigation system. They currently function as urban and domestic waste drains, causing the accumulation of water from artificial irrigation, mixed with domestic waste, with a high organic content. Despite the water conditions, L4 larvae of *A. aegypti* have been collected in these environments and successfully matured into adulthood in the laboratory. The detection of populations of this mosquito in this type of habitat strongly suggests that this breeding site is used as an aquatic habitat for its development.

It is widely known that *A. aegypti* larvae and pupae develop preferably in environments with clean water deposited in breeding sites, both natural (such as tree holes, leaf axils or rock ponds) and artificial (such as discarded tires, storage tanks and all types of packaging), in urban and peri-urban environments (Dom et al., 2016; Madzlan et al., 2016). However, it has been described that they can tolerate appreciable variations in pH, so that they have been found in brackish waters, and they can also tolerate environments with abundant decomposing organic matter (de Brito-Arduino et al., 2010).

In this mosquito hatcheries, the physical and chemical parameters of water such as conductivity, total dissolved solids, salinity, and pH, were analyzed. In particular, our results showed a high conductivity recorded in the breeding sites of *A. aegypti*, with the average conductivity recorded in ditches without this mosquito being 1055.1 μS cm-1, while in the presence of this species, it was 772 μS cm-1. This pattern was observed in water tank studies from Girardot, Colombia, and forest sites from La Lope, Africa, where conductivity was lower in *A. aegypti* larval habitats

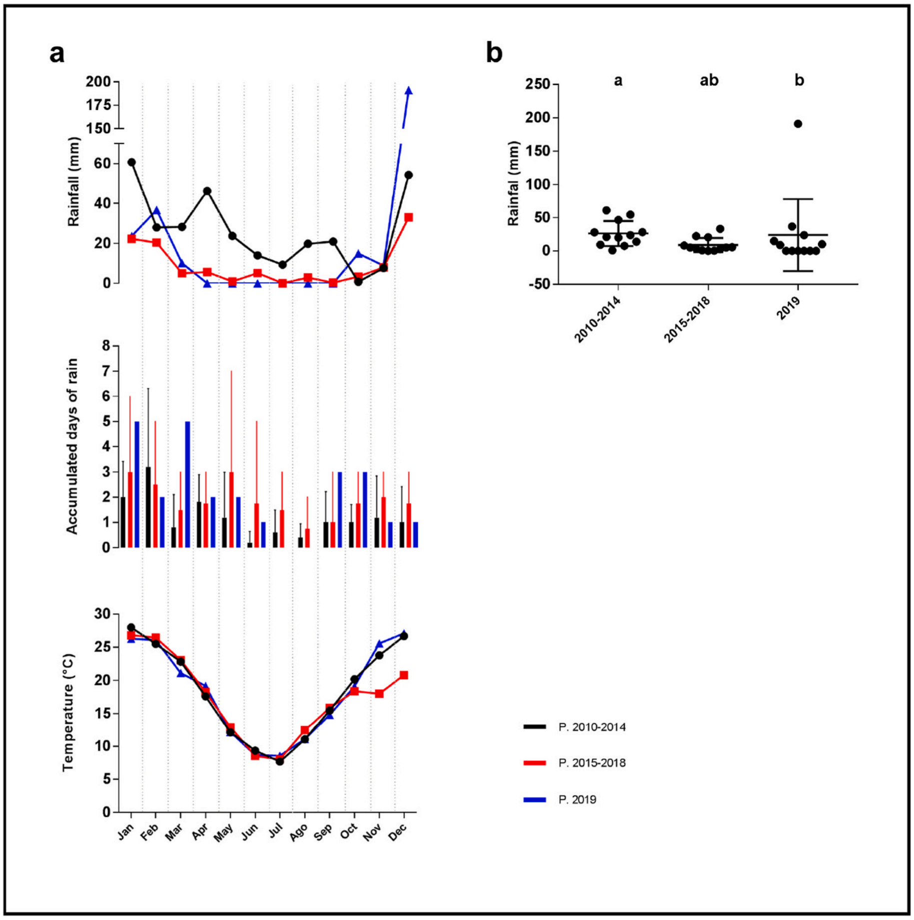

Fig. 5. Climatic data comparison: **a** Climate data recorded during the periods 2010–2014, 20,015–2018 and 2019; **b** Monthly rainfall comparison between the different periods analyzed. Means with different letters are significantly different ($p < 0.05$).

(50–180 μS cm-1 vs 107–184 μS cm-1 and 96.2 μS/cm vs 134.9 μS/cm, respectively) (García-Sánchez et al., 2017; Xia et al., 2021). However, Xia et al. (2021) reported higher conductivity at natural breeding sites with *A. aegypti* present compared to larval sites without this mosquito in Rabai, Kenya (1119.1 μS/cm vs. 468.8 μS/cm).

In the San Juan irrigation ditches where *A. aegypti* developed, the average value of total dissolved solids (TDS) was 552 ppm, confirming that this species can withstand high TDS limits. This parameter had been associated with breeding sites of mosquito species such as *Culex ingrami* and *Anopheles wilsoni* (Adebote et al., 2008) but not with the presence of *A. aegypti* until 2021, when Xia et al. (2021) reported the highest levels of TDS (797.5 ppm) in *A. aegypti* larval sites measured in Rabai Forest, Kenya.

Regarding salinity, in the irrigation ditches of San Juan with the presence of *A. aegypti*, an average of 380 ppm (0.038%) was detected. This parameter would not be a barrier in this type of hatchery since it has been reported that many larvae of mosquito species are tolerant to salinity. In particular, *A. aegypti* larvae have been detected in boats in use or abandoned or stored in marinas (de Brito-Arduino et al., 2010). Under laboratory conditions, this mosquito was able to lay eggs in saline solutions of up to 17% sodium chloride, and its larvae were capable of developing in salt concentrations of up to 14% (de Brito-Arduino et al., 2015). According to its osmoregulation strategy, this species is considered a euryhaline osmoconformist (tolerant to exposure to salinity due to its ability to acclimatize) (Bradley, 1987).

Ditches with *A. aegypti* had a slightly alkaline pH, as has been widely reported in some studies that have shown that this mosquito prefers sites with neutral or slightly alkaline water (Stein et al., 2011; Dom et al., 2016). Although the ionic composition and pH of the environment are important physical factors that restrict the distribution of aquatic organisms (Sutcliffe and Hildrew, 1989), there are no records of pH levels limiting the habitats of mosquito larvae in nature (García-Sánchez et al., 2017). Some physical and chemical properties of water can affect the development of mosquito larvae (Clements, 1992). However, according to our results and as described previously, *A. aegypti* can adapt to suboptimal environmental conditions that are different from the ideal range (Xia et al., 2021) and could occupy breeding sites with unfavorable water quality, such as urban sewers (Paploski et al., 2016).

Environmental parameters such as temperature and the amount of water accumulated by precipitation are also considered highly relevant factors in the establishment and development of mosquito populations. In many species, temperatures below 14 °C and above 30 °C can reduce the rate of larval development (Clements, 1992; Domínguez et al., 2000). The average water temperature of the ditches recorded with *A. aegypti* was 25 °C, previously reported as the optimal temperature for the development of this species (Grech et al., 2015; García-Sánchez et al., 2017). However, in this region, there is a large thermal amplitude between day and night, which could also affect the temperature of small bodies of water as well as the organisms that develop in them.

Precipitation is an abiotic factor that significantly influences the presence of breeding sites and the emergence of *A. aegypti* adults due to its role in promoting water accumulation in discarded containers (Basso et al., 2012). In environments with low rainfall, this mosquito species exploits different types of domestic containers for water collection and egg laying, thereby expanding its distribution area (Ortiz et al., 2015). This behavior has been observed globally (Basso et al., 2016) and could serve as an alternative water source in the absence of rainfall (Fischer et al., 2017). In the province of San Juan, where rainfall is infrequent

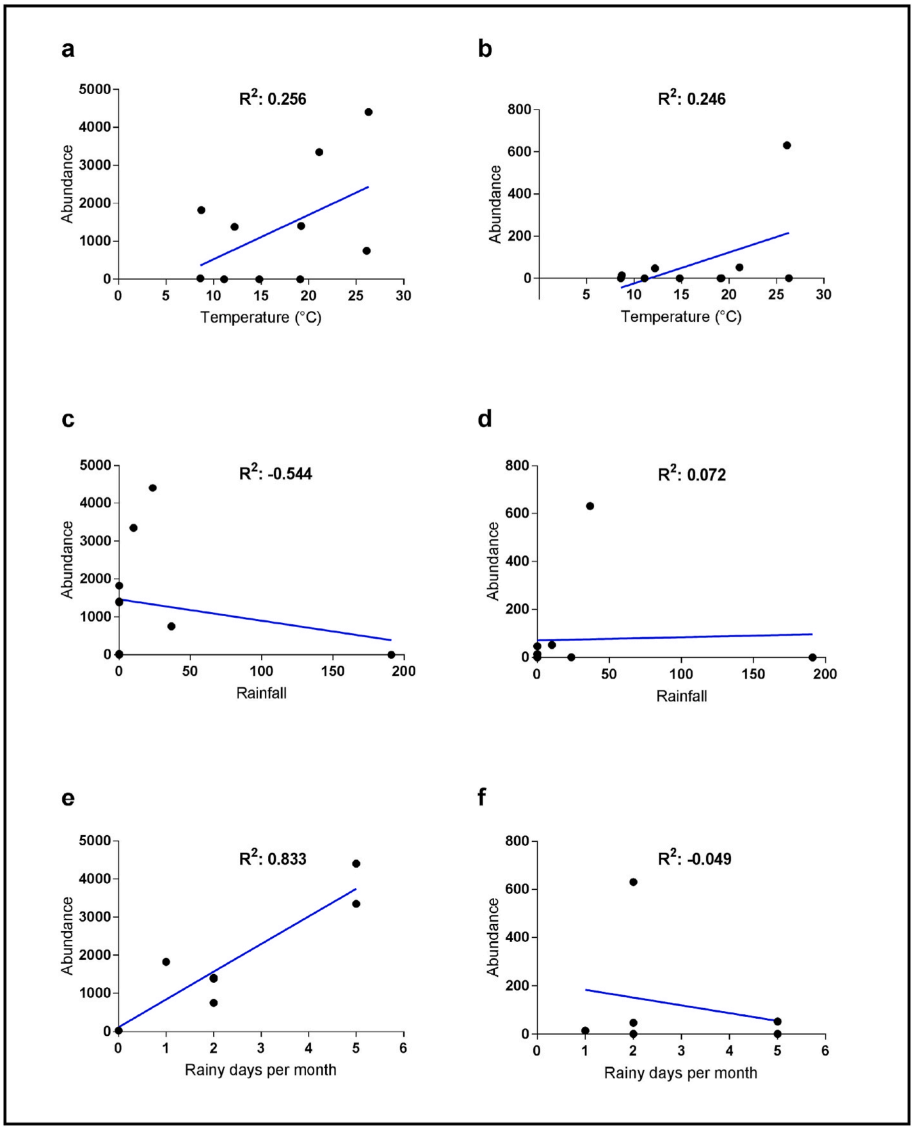

Fig. 6. Correlations between the abundances per month and species depending on the different climatic factors analyzed: **a, c** and **e** correspond to *Culex pipiens* complex species; **b, d** and **f** correspond to *Aedes aegypti*.

and sporadic, primarily occurring during periods of high summer temperatures (Poblete and Minetti, 1999), conditions do not favor water accumulation in containers left outdoors for extended periods due to high evaporation rate. Consequently, anthropogenic water accumulation, independent of rainfall in ditches, could potentially facilitate the development of suitable breeding sites for *A. aegypti*.

The seasonal pattern of maximum abundance of *A. aegypti* larvae was observed in February, which is consistent with the findings from La Pampa (Breser et al., 2013) and from Buenos Aires City, where the maximum abundance was detected in February–March (Vezzani et al., 2004). This contrasts with the patterns observed in other Argentine provinces, such as Corrientes and Salta, where the *A. aegypti* reproduction occurs throughout the year probably due to constant high temperatures (Borda et al., 1999; Micieli and Campos, 2003). Previous research carried out in the country has suggested a minimum temperature for oviposition would be around 15 °C (Benitez et al., 2021), proposing that there would be a reduction in mosquito activity in mid-May due to the drop in temperature (Grech et al., 2015). However, in this study, immature activity was detected in the ditches until early June, when the average monthly temperature was 8.7 °C. During winter and spring, *A. aegypti* larvae were not detected in the ditches, which is related to the low presence of water in the sampled ditches, which fluctuates depending on the management of the irrigation system. Domínguez et al. (2000) suggested that the main factors regulating the presence of *A. aegypti* could be water availability and climatic conditions.

In this work, we found the presence of *A. aegypti* larvae sharing reproduction sites with *Culex pipiens* complex species, as has been previously documented in Brazil by Paploski et al. (2016) and in other regions around the world (Chumsri et al., 2020; Mbanzulu et al., 2022). This would indicate that these two species could share the same habitat choice requirements in this arid region. Possibly for this reason, the bivariate model does not show differences in the selection of the different ditches based on the characteristics of both species.

The analysis of climatic variables in the three selected periods suggests a similar pattern. Differences were observed only in the days with precipitation, between the periods without records of *A. aegypti* and the second period in which this mosquito was detected. Although it is known that rainfall increases the availability of breeding sites (Basso et al., 2016), in arid areas, the presence of small containers filled with water, such as jars, bottles or vases, would not increase due to high evaporation. However, rainfall could favor the fluctuation of the water level in the ditches that previously contained some wastewater or artificial irrigation, allowing the proliferation of *A. aegypti* in these breeding sites.

It has been determined that *A. aegypti* uses different types of artificial containers. Some authors report that females of *Aedes* species prefer smaller water containers by oviposition (Dom et al., 2016; Sunahara et al., 2002), although they can also breed in larger containers such as water tanks (Basso et al., 2012; García-Sánchez, et al., 2017), sewers (Paploski et al., 2016) and septic tanks (Burke et al., 2010). On the other hand, it has been described that irrigation systems entail a proliferation of *Anopheles* species due to irrigation defects, poor drainage, or unfortunate practices in system management (Organización Panamericana de la Salud, 1977). Oguoma and Ikpeze (2008) reported captures of several mosquito species in rural irrigation systems, puddles, and bed pools in millet and guinea-corn fields from an agro-ecological zone of north-central Nigeria. In Africa and in the Caribbean region, the *A. aegypti* forest population breeds in natural containers such as tree holes and rocks (Xia et al., 2021). Grech and Ludueña-Almeida (2016) report different breeding sites in Argentina, with shallow containers with a wide mouth, generally made of plastic, glass, metal, ceramic, or rubber, such as vases, cans, jars, buckets, and worn tires, being the most frequent. According to Grech and Ludueña-Almeida (2016), *A. aegypti* does not breed in cement containers, and the maximum volume of the breeding sites does not exceed 500 mL of water. However, in the desert and semiarid areas of Rajasthan, India, it was observed that cement tanks, used by the inhabitants to store water, were the main breeding habitat for *A. aegypti* (Sharma et al., 2008). Here, we showed that irrigation ditches, an extensive cement structure with a subtrapezoidal shape (up to 100 m long and 60 cm deep with the presence of *A. aegypti*), are a new breeding site for this species in Argentina. In addition to ditches in the province of San Juan, different artificial containers with immature stages of *A. aegypti,* such as flowerpots, vases, animal waterers, bottles, rain gutters, disused toilets, inspection boxes, plastic water tanks, scrap metal, discarded vehicle tires, rubber tanks and canvas pools, were detected (Vector Control Program, pers. comm.). Some of them are similar to those found in Argentina by Grech and Ludueña-Almeida (2016) and by Maciel-de-Freitas et al. (2007) in Brazil. However, it should be noted that, in the case of San Juan, all these containers were filled with water from artificial irrigation of anthropic origin.

5. Conclusion

Our results demonstrate that in the Monte ecoregion of Argentina, *A. aegypti* can adapt to new breeding sites with physical and chemical parameters that exceed the thresholds previously recorded for this species. This mosquito develops successfully in environments subject to great climatic variation between day and night, high irradiance, low rainfall, and extremely low environmental humidity. It can lay its eggs near bodies of waters with high organic content, high conductivity, and high concentration of total dissolved solids, where the immature stages successfully complete their development. In this work, 8 points were surveyed within an extensive disused irrigation system that included only 2 departments of the 19 in total that the province of San Juan has, and a large number of immature *A. aegypti* and *Culex* spp. were found at the selected points. Considering the great extension of this irrigation system throughout the province, as well as its efficient use as a breeding site for *A. aegypti*, it can be estimated that this type of environment could contribute favorably to the maintenance, reproduction, and dispersion of the populations of this mosquito in the region, where during the last summer, there were dengue autochthonous cases. To prevent future outbreaks of this disease in this arid region of Argentina, it will be necessary to activate the irrigation system, preventing the ditches from becoming breeding sites for *A. aegypti* and other mosquito species of health importance.

CRediT authorship contribution statement

Emeli Illa: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Fernando Murúa:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Fernando H. Aballay:** Writing – review & editing, Methodology, Formal analysis. **Florencia Cano:** Writing – review & editing, Validation, Methodology. **Liliana Salvá:** Writing – review & editing, Resources, Conceptualization. **Corina Berón:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Leonardo M. Díaz-Nieto:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Leonardo Martin Diaz Nieto reports financial support was provided by National Scientific and Technical Research Council. Emeli Illa reports equipment, drugs, or supplies was provided by National University of San Juan. Fernando Aballay reports financial support was provided by National Scientific and Technical Research Council. Florencia Cano reports financial support was provided by Ministerio de Salud de San Juan. Liliana Salva reports financial support was provided by Ministerio de Salud de San Juan. Corina Beron reports financial support was provided by National Scientific and Technical Research Council. Leonardo Martin Diaz Nieto reports a relationship with National Scientific and Technical Research Council that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

Adebote, D.A., Oniye, S.J., Muhammed, Y.A., 2008. Studies on mosquitoes breeding in rock pools on inselbergs around Zaria, northern Nigeria. J. Vector Borne Dis. 45, 21–28.

Ananth, C.V., Preisser, J.S., 1999. Bivariate logistic regression: modelling the association of small for gestational age births in twin gestations. Stat. Med. 18, 2011–2023. https://doi.org/10.1002/(sici)1097-0258(19990815)18:15<2011::aid-sim169>3.0.co;2-8.

Barata, E.A., da Costa, A.I.P., Chiaravalloti Neto, F., Glasser, C.M., Barata, J.M.S., Natal, D., 2001. *Aedes aegypti* (L.) population in an endemic area of dengue in the south east Brazil. Rev. Saude Publica 35, 237–242. https://doi.org/10.1590/S0034-89102001000300004.

Basso, C., García da Rosa, E., Lairihoy, R., González, C., Norbis, W., Roche, I., Caffera, R. M., da Rosa, R., 2016. Epidemiologically relevant container types, indices of abundance and risk conditions for *Aedes aegypti* in Salto (Uruguay), a city under threat of dengue disease. J. Infect. Dis. Pharmacother. 1 https://doi.org/10.4172/2472-4998.1000103 art. 1000103 OMICS International.

Basso, C., Caffera, R.M., Da Rosa, E.G., Lairihoy, R., González, C., Norbis, W., Roche, I., 2012. Mosquito-producing containers, spatia distribution, and relationship between *Aedes aegypti* population indices on the southern boundary of its distribution in South America (Salto, Uruguay). Am. J. Trop. Med. Hyg. 87, 1083–1088. https://doi.org/10.4269/ajtmh.2012.12-0328.

Becker, N., Petrić, D., Zgomba, M., Boase, C., Madon, M.B., Dahl, C., Kaiser, A., 2020. Mosquitoes: Identification, Ecology and Control. Springer Nature.

Benitez, E.M., Estallo, E.L., Grech, M.G., Frías-Céspedes, M., Almirón, W.R., Robert, M. A., Ludueña-Almeida, F.F., 2021. Understanding the role of temporal variation of environmental variables in predicting *Aedes aegypti* oviposition activity in a temperate region of Argentina. Acta Trop. 216, 105744 https://doi.org/10.1016/j.actatropica.2020.105744.

Borda, C.E., Rea, M.F.J., Rosa, J.R., Mosqueda, L.A., Sario, H., 1999. Vector de la fiebre amarilla urbana y el dengue en la ciudad de Corrientes, Argentina. Comunicaciones Científicas y Tecnológicas de la Universidad Nacional del Nordeste, Argentina 3, 1. http://www.unne.edu.ar/cyt/cyt2000.htm.

Bradley, T.J., 1987. Physiology of osmoregulation in mosquitoes. Annu. Rev. Entomol. 32, 439–462.

Breser, V.J., Diez, F., Rossi, G.C., V Micieli, M., 2013. Determinación del período estacional de oviposición de *Aedes aegypti* (Diptera: Culicidae) en la ciudad de Santa Rosa, La Pampa, Argentina. Rev. Soc. Entomol. Argent. 72, 111–114.

Burke, R.L., Barrera, R., Lewis, M., Kluchinsky, T., Claborn, D., 2010. Septic tanks as larval habitats for the mosquitoes *Aedes aegypti* and *Culex quinquefasciatus* in Playa-Playita, Puerto Rico. Med. Vet. Entomol. 24, 117–123. https://doi.org/10.1111/j.1365-2915.2010.00864.x.

Carbajo, A.E., Cardo, M.V., Vezzani, D., 2019. Past, present and future of *Aedes aegypti* in its South American southern distribution fringe: what do temperature and population tell us? Acta Trop. 190, 149–156. https://doi.org/10.1016/j.actatropica.2018.11.017.

Carrizo Páez, R.E., Carrizo Páez, M.A., Murúa, A.F., 2016. Primer registro de *Aedes aegypti* (Diptera: Culicidae) en San Juan, Argentina. Revista de la Sociedad Entomológica Argentina SciELO Argentina 75, 93–95.

Carvalho, F.D., Moreira, L.A., 2017. Why is *Aedes aegypti* linnaeus so successful as a species? Neotropical entomology Springer 46, 243–255. https://doi.org/10.1007/s13744-017-0520-4.

Chumsri, A., Jaroensutasinee, M., Jaroensutasinee, K., 2020. Spatial and temporal variations on the coexistence of *Aedes* and *Culex* larvae in Southern Thailand. Journal of Animal Behaviour and Biometeorology 8, 250–256. https://doi.org/10.31893/jabb.20033.

Clements, A.N., 1992. The Biology of Mosquitoes. Volume 1: Development, Nutrition and Reproduction. Chapman and Hall.

Cuesta, G., Martín, P., Guillen, L., Lemole, G., 2020. San Juan county horticulture profile. Horticultura Argentina 39, 35–57.

Darsie Jr., R.F., 1985. Mosquitoes of Argentina. I. Keys for identification of adult females and fourth stage larvae in English and Spanish (Diptera, Culicidae). Mosq. Systemat. 17, 153–362.

de Brito Arduino, M., Mucci, L.F., Serpa, L.L.N., De Moura Rodrigues, M., 2015. Effect of salinity on the behavior of *Aedes aegypti* populations from the coast and plateau of southeastern Brazil. J. Vector Borne Dis. 52, 79.

de Brito-Arduino, M., Marques, A.M., Serpa, L.L.N., 2010. Registro de larvas e pupas de *Aedes aegypti* e *Aedes albopictus* em recipientes com água salina em condições naturais. BEPA - Boletim Epidemiológico Paulista 83, 22–28.

Dennis, G.R., Damiani, M.L., 2023. *Aedes aegypti* (Diptera: Culicidae) in Bahía Blanca city: incipient colonization in the entrance to Argentinian Patagonia? Medicina 83, 342–343.

Díaz-Nieto, L.M., Murúa, A.F., Cano, F.A., Laurito, M., Almirón, W.R., Salvá, L., 2020. New records of Culicidae (Diptera) in agricultural oases of san juan province, Argentina. Check List. 16, 1085–1093. https://doi.org/10.15560/16.4.1085.

Díaz-Nieto, L.M., Chiappero, M.B., Díaz de Astarloa, C., Maciá, A., Gardenal, C.N., Berón, C.M., 2016. Genetic evidence of expansion by passive transport of *Aedes (Stegomyia) aegypti* in eastern Argentina. PLoS Neglected Trop. Dis. 10, e0004839 https://doi.org/10.1371/journal.pntd.0004839.

Dom, N.C., Madzlan, M.F., Nur, S., Hasnan, A., Misran, N., 2016. Water quality characteristics of dengue vectors breeding containers. International Journal of Mosquito Research 3, 25–29.

Domínguez, M., Ludueña Almeida, F., Almiron, W., 2000. Dinámica poblacional de *Aedes aegypti* (Diptera: Culicidae) en Córdoba Capital. Rev. Soc. Entomol. Argent. 59, 41–50.

Fischer, S., De Majo, M.S., Di Battista, C.M., Montini, P., Loetti, V., E Campos, R., 2019. Adaptation to temperate climates: evidence of photoperiod-induced embryonic dormancy in *Aedes aegypti* in South America. J. Insect Physiol. 117, 103887 https://doi.org/10.1016/j.jinsphys.2019.05.005.

Fischer, S., De Majo, M.S., Quiroga, L., Paez, M., Schweigmann, N., 2017. Long-term spatio-temporal dynamics of the mosquito *Aedes aegypti* in temperate Argentina. Bull. Entomol. Res. 107, 225–233. https://doi.org/10.1017/S0007485316000869.

Garcia-Sánchez, D.C., Pinilla, G.A., Quintero, J., 2017. Ecological characterization of *Aedes aegypti* larval habitats (Diptera: Culicidae) in artificial water containers in Girardot, Colombia. J. Vector Ecol. 42, 289–297. https://doi.org/10.1111/jvec.12269.

Grech, M., Ludueña-Almeida, F., 2016. Mosquitos que se crían en microambientes artificiales. In: Berón, C.M., Díaz-Nieto, L.M., Schweigmann, N., Salomón, O.D., Gleiser, R.M. (Eds.), Investigaciones sobre mosquitos de Argentina. Universidad nacional de Mar del Plata, Mar del Plata, pp. 142–155.

Grech, M.G., Sartor, P.D., Almirón, W.R., Ludueña-Almeida, F.F., 2015. Effect of temperature on life history traits during immature development of *Aedes aegypti* and *Culex quinquefasciatus* (Diptera: Culicidae) from Córdoba city, Argentina. Acta Trop. 146, 1–6. https://doi.org/10.1016/j.actatropica.2015.02.010.

Grech, M., Visintin, A., Laurito, M., Estallo, E., Lorenzo, P., Roccia, I., Korin, M., Goya, F., Ludueña-Almeida, F., Almirón, W., 2012. New records of mosquito species (Diptera: Culicidae) from Neuquén and La Rioja provinces, Argentina. Rev. Saude Publica 46, 387–389.

Illa, E., 2021. Estudio sobre Culicidae (Diptera) en acequias de San Juan. Universidad Nacional de San Juan. Thesis.

Kamal, M., Kenawy, M.A., Rady, M.H., Khaled, A.S., Samy, A.M., 2018. Mapping the global potential distributions of two arboviral vectors *Aedes aegypti* and *Ae. albopictus* under changing climate. PLoS One 13, e0210122. https://doi.org/10.1371/journal.pone.0210122.

Kotsakiozi, P., Evans, B.R., Gloria-Soria, A., Kamgang, B., Mayanja, M., Lutwama, J., Le Goff, G., Ayala, D., Paupy, C., Badolo, A., Pinto, J., Sousa, C.A., Troco, A.D., Powell, J.R., 2018. Population structure of a vector of human diseases: *Aedes aegypti* in its ancestral range, Africa. Ecol. Evol. 8, 7835–7848. https://doi.org/10.1002/ece3.4278.

Maciel-de-Freitas, R., Marques, W.A., Peres, R.C., Cunha, S.P., De Oliveira, R.L., 2007. Variation in *Aedes aegypti* (Diptera: Culicidae) container productivity in a slum and a suburban district of Rio de Janeiro during dry and wet seasons. Mem. Inst. Oswaldo Cruz 102, 489–496. https://doi.org/10.1590/s0074-02762007005000056.

Madzlan, F., Dom, N.C., Tiong, C.S., Zakaria, N., 2016. Breeding characteristics of *Aedes* mosquitoes in dengue risk area. Procedia-Social and Behavioral Sciences 234, 164–172.

Manrique-Saide, P., Uc, V., Prado, C., Carmona, C., Vadillo, J., Chan, R., Dzib-Florez, S., Che-Mendoza, A., Barrera-Perez, M., Sanchez, E.C., Arredondo-Jimenez, J.I., 2012. Storm sewers as larval habitats for *Aedes aegypti* and *Culex* spp. in a neighborhood of Merida, Mexico. J. Am. Mosq. Control Assoc. 28, 255–257. https://doi.org/10.2987/12-6244R.1.

Márquez, J., Ripoll, Y., Dalmazzo, A., Arizza, M., Jordán, M., 2014. Árboles nativos de la Provincia de San Juan. Universidad Nacional de San Juan, p. 78.

Mbanzulu, K.M., Mboera, L.E., Wumba, R., Engbu, D., Bojabwa, M.M., Zanga, J., Mitashi, P.M., Misinzo, G., Kimera, S.I., 2022. Physicochemical characteristics of *Aedes* mosquito breeding habitats in suburban and urban areas of Kinshasa, Democratic Republic of the Congo. Frontiers in Tropical Diseases 2, 789273. https://doi.org/10.3389/fitd.2021.789273.

Micieli, M.V., Campos, R.E., 2003. Oviposition Activity and Seasonal Pattern of a Population of *Aedes (Stegomyia) Aegypti* (L.) (Diptera: Culicidae) in Subtropical Argentina, 98. Memórias do Instituto Oswaldo Cruz, pp. 659–663.

Ministerio de Salud de la República Argentina, 2020. Boletín Epidemiológico Nacional N° 499. Retrieved from. https://bancos.salud.gob.ar/recurso/boletin-integrado-de-vigilancia-n499-se23-2020.

Ministerio de Salud de la República Argentina, 2024. Boletín Epidemiológico Nacional N° 699. Retrieved from. https://www.argentina.gob.ar/sites/default/files/2024/04/ben-699-se14.pdf.

Morello, J., 2012. Ecorregíón del Monte de Sierras y Bolsones. In: Morello, J., Matteucci, S.D., Rodriguez, A.F., Silva, M.E. (Eds.), Ecorregiones Y Complejos Ecosistémicos Argentinos. Orientación Gráfica Editora, pp. 265–291.

Nacif, N.E., Espinosa, M. del P., Martinet, M.G., 2011. Una ciudad oasis de zona sísmica. Revista Iberoamericana de Urbanismo RIURB 6, 73–80.

Núñez-Campero, S.R., González, C., Rull, J., Ovruski, S.M., 2022. Maximum Entropy (MaxEnt) as extreme distribution indicator of two Neotropical fruit fly parasitoids in irrigated drylands of Argentina. Bull. Entomol. Res. 112, 1–10. https://doi.org/10.1017/S0007485322000013.

Oguoma, V., Ikpeze, O., 2008. Species composition and abundance of mosquitoes of a tropical irrigation ecosystem. Animal Research International 5, 866–871. https://doi.org/10.4314/ari.v5i2.48748.

Organización Panamericana de la Salud, 1977. Prevención de la proliferación de mosquitos en terrenos de riego. Manual Agrícola Nº 319. Estados Unidos. Departamento de Agricultura de los Estados Unidos.

Ortiz, P.L., Rivero, A., Linares, Y., Pérez, A., Vázquez, J.R., 2015. Spatial models for prediction and early warning of *Aedes aegypti* proliferation from data on climate change and variability in Cuba. MEDICC Review 17 (6), 20–28. https://doi.org/10.37757/MR2015.V17.N2.

Pan American Sanitary Bureau, 1994. Dengue and Dengue Hemorrhagic Fever in the Americas: Guidelines for Prevention and Control (No. 548). Pan American Health Organization.

Paploski, I.A.D., Rodrigues, M.S., Mugabe, V.A., Kikuti, M., Tavares, A.S., Reis, M.G., Kitron, U., Ribeiro, G.S., 2016. Storm drains as larval development and adult resting sites for *Aedes aegypti* and *Aedes albopictus* in Salvador, Brazil. Parasites Vectors 9, 419. https://doi.org/10.1186/s13071-016-1705-0.

Poblete, A.G., Minetti, J.L., 1999. Configuración espacial del clima de San Juan. In: de Geología, Instituto (Ed.), Síntesis del Cuaternario de la Provincia de San Juan. San Juan: Universidad Nacional de San Juan, pp. 1–14.

Rubio, A., Cardo, M.V., Vezzani, D., Carbajo, A.E., 2020. *Aedes aegypti* spreading in South America: new coldest and southernmost records. Memórias do Inst. Oswaldo Cruz 115, e190496.

Rueda, L.M., 2008. Global diversity of mosquitoes (Insecta: Diptera: Culicidae) in freshwater. Hydrobiologia 595, 477–487. https://doi.org/10.1007/978-1-4020-8259-7_48.

Schliserman, P., Aluja, M., Rull, J., Ovruski, S.M., 2014. Habitat degradation and introduction of exotic plants favor persistence of invasive species and population growth of native polyphagous fruit fly pests in a Northwestern Argentinean mosaic. Biol. Invasions 16, 2599–2613. https://doi.org/10.1007/s10530-014-0690-5.

Scott, T.W., Takken, W., 2012. Feeding strategies of anthropophilic mosquitoes result in increased risk of pathogen transmission. Trends Parasitol. 28, 114–121. https://doi.org/10.1016/j.pt.2012.01.001.

Sharma, K., Angel, B., Singh, H., Purohit, A., Joshi, V., 2008. Entomological studies for surveillance and prevention of dengue in arid and semi-arid districts of Rajasthan, India. J. Vector Borne Dis. 45, 124–132.

Stein, M., Ludueña-Almeida, F., Willener, J.A., Ricardo Almirón, W., 2011. Classification of immature mosquito species according to characteristics of the larval habitat in the subtropical province of Chaco, Argentina. Mem. Inst. Oswaldo Cruz 106, 400–407. https://doi.org/10.1590/s0074-02762011000400004.

Sunahara, T., Ishizaka, K., Mogi, M., 2002. Habitat size: a factor determining the opportunity for encounters between mosquito larvae and aquatic predators. J. Vector Ecol.: Journal of the Society for Vector Ecology 27, 8–20.

Sutcliffe, D.W., Hildrew, A.G., 1989. Invertebrate communities in acid streams. In: Morris, R., Taylor, E.W., Brown, D.J.A., Brow, J.A. (Eds.), Acid Toxicity and Aquatic Animals. Society for Experimental Biology, Seminar Series. Cambridge University, Cambridge, pp. 13–29.

Vezzani, D., Cetraroand, H., Sánchez Chopa, F., 2022. Surveillance of the dengue vector at its distribution limit. A collaborative experience between the scientific, municipal and citizen ambits. Medicina 82, 505–512.

Vezzani, D., Velázquez, S.M., Schweigmann, N., 2004. Seasonal pattern of abundance of *Aedes aegypti* (Diptera: Culicidae) in Buenos Aires city, Argentina. Memórias do Inst. Oswaldo Cruz 99, 351–356.

Xia, S., Dweck, H.K.M., Lutomiah, J., Sang, R., McBride, C.S., Rose, N.H., Ayala, D., Powell, J.R., 2021. Larval sites of the mosquito *Aedes aegypti formosus* in forest and domestic habitats in Africa and the potential association with oviposition evolution. Ecol. Evol. 11, 16327–16343. https://doi.org/10.1002/ece3.8332.