Vector Mosquito Surveillance Using Centers For Disease Control and Prevention Autocidal Gravid Ovitraps In San Antonio, Texas

Joel A. Obregón  
*Texas A&M University-San Antonio, jolalxndr@gmail.com*

Michelle A. Ximenez  
*Texas A&M University-San Antonio, michelle.mendoza127@gmail.com*

Estefany E. Villalobos  
*Texas A&M University-San Antonio*

Megan R. Wise De Valdez  
*Texas A&M University-San Antonio, Megan.WiseDeValdez@tamusa.edu*

Follow this and additional works at: [https://digitalcommons.tamusa.edu/bio_faculty](https://digitalcommons.tamusa.edu/bio_faculty)

Part of the Biology Commons

Repository Citation  
Obregón, Joel A.; Ximenez, Michelle A.; Villalobos, Estefany E.; and Wise De Valdez, Megan R., "Vector Mosquito Surveillance Using Centers For Disease Control and Prevention Autocidal Gravid Ovitraps In San Antonio, Texas" (2019). *Biology Faculty Publications*. 25.  
[https://digitalcommons.tamusa.edu/bio_faculty/25](https://digitalcommons.tamusa.edu/bio_faculty/25)

This Article is brought to you for free and open access by the College of Arts and Sciences at Digital Commons @ Texas A&M University- San Antonio. It has been accepted for inclusion in Biology Faculty Publications by an authorized administrator of Digital Commons @ Texas A&M University- San Antonio. For more information, please contact [deirdre.mcdonald@tamusa.edu](mailto:deirdre.mcdonald@tamusa.edu).
VECTORS MOSQUITO SURVEILLANCE USING CENTERS FOR DISEASE CONTROL AND PREVENTION AUTOCIDAL GRAVID OVITRAPS IN SAN ANTONIO, TEXAS

JOEL A. OBREGÓN, MICHELLE A. XIMENEZ, ESTEFANY E. VILLALOBOS AND MEGAN R. WISE DE VALDEZ1

Program of Biology, Department of Science and Mathematics, Texas A&M University–San Antonio, One University Way, San Antonio, Texas 78224

ABSTRACT. Mosquito surveillance in large urban areas of the southern USA that border Mexico has become increasingly important due to recent transmission of Zika virus and chikungunya virus in the Americas as well as the continued threat of dengue and West Nile viruses. The vectors of these viruses, *Aedes aegypti*, *Ae. albopictus*, and *Culex quinquefasciatus*, co-occur in residential areas, requiring vector control entities to deploy several different trap types, often expensive and labor-intensive, to surveil these ecologically different species. We evaluated the use of a single trap type, the US Centers for Disease Control and Prevention autocidal gravid ovitraps (AGO), to monitor all 3 vector species across residential neighborhoods in San Antonio, TX, over 12 wk (epiweeks 24–35). Mosquito abundance was highest early in our surveillance period (epiweek 25) and was driven largely by *Cx. quinquefasciatus*. The AGOs collected significantly more *Cx. quinquefasciatus* than both *Aedes* species, with more *Ae. aegypti* collected than *Ae. albopictus*. The average number of *Ae. aegypti* captured per trap was consistent across most neighborhoods except for 2 areas where one had significantly the highest and the other with the lowest mosquitoes collected per trap. The average number of *Ae. albopictus* captured per trap varied with no clear pattern, and *Cx. quinquefasciatus* were trapped most often near forested hill country neighborhoods. These results indicate that AGOs are appropriate for detecting and tracking the relative abundance of *Ae. aegypti*, *Ae. albopictus*, and *Cx. quinquefasciatus* across a large and diverse urban landscape over time and therefore may be an inexpensive and streamlined option for vector surveillance programs in large cities.

KEY WORDS Aedes aegypti, *Aedes albopictus*, Culex quinquefasciatus, geographic distribution, urban

INTRODUCTION

Mosquito surveillance in large urban areas of the southern USA that border Mexico has become increasingly important due to recent transmission of Zika virus (ZIKV) and chikungunya virus (CHIKV) in the Americas as well as the continued threat of dengue virus (DENV) and West Nile virus (WNV). As reported to ArboNET (CDC 2018), the national arboviral disease surveillance system, local transmission of ZIKV, CHIKV, and DENV has occurred in Florida and Texas, and WNV is consistently present across the USA. The vectors of these viruses, *Aedes aegypti* (L.) (ZIKV, DENV), *Ae. albopictus* (Skuse) (CHIKV), and *Culex quinquefasciatus* Say (WNV) co-occur in residential areas in the southern USA, and with the recent establishment of *Ae. aegypti* in California and Arizona, local transmission of some of these viruses may expand to the US Southwest (Fredericks and Fernandez-Sesma 2014). It is, therefore, important to monitor the distribution of these vectors, especially in areas where humans are most likely to be exposed to mosquitoes (Wen et al. 2014).

Surveillance of *Ae. aegypti* and *Ae. albopictus* in urban areas of the USA has been problematic due to their preference for cryptic artificial containers near private dwellings. Larval surveys are a standard technique, but not only are larval indices unreliable indicators of adult densities (Tun-Lin et al. 1996, Sivagan name and Gunasekaran 2012), but conducting larval assays is invasive and requires a large number of households for accurate estimates (Richie et al. 2014), and obtaining permission from homeowners is difficult. Ovitraps, while less intrusive, cheaper, and easier to operate, are still problematic because *Ae. aegypti* and *Ae. albopictus* exhibit skip-ovipositioning, and clutch size can vary with nutritional/age status of the female (Rozeboom et al. 1973, Hawley 1988, Clements 1999, Facchinelli et al. 2007). An effective method of adult *Ae. aegypti* and *Ae. albopictus* monitoring is the BG-sentinel® trap (BG trap; Kröckel et al. 2006, Farajollahi et al. 2009, Barrera et al. 2013). However, BG traps require a power source, and the cost per trap and labor required can be prohibitive for intensive temporal monitoring in urban and suburban areas of a large city. Likewise, the CDC gravid trap and the CDC light trap that are used regularly by vector control entities for the surveillance of adult *Cx. quinquefasciatus* require a power source and are labor-intensive. Because *Cx. quinquefasciatus* are less anthropophilic than *Ae. aegypti* (Tempelis et al. 1970), density estimates can be obtained by placing traps in forested areas, drainage ditches, and storm sewers and not necessarily next to human dwellings, saving time. However, urban landscapes are heterogeneous, which affects *Culex* distribution (Chaves et al. 2011), and sampling only on public lands may lead to inaccurate population estimates. Therefore, in

1 To whom correspondence should be addressed.
large urban areas it is beneficial to evaluate a trap that
can be placed in residential areas and is more cost-
effective in monitoring both Aedes and Culex
species.

Autocidal gravid ovitraps (AGOs) as designed by the
US Centers for Disease Control and Prevention
(CDC) in Puerto Rico (Mackay et al. 2013) are a
potential solution to the cost and labor of other
trapping methods. Although used primarily as a
method for controlling Ae. aegypti and limiting the
spread of DENV and CHIKV (Barrera et al. 2014a,
2014b, 2016), they have also been used as sentinel
AGOs to monitor Ae. aegypti populations (Barrera et
al. 2014b, Cornel et al. 2016, Cilek et al. 2017).
Barrera et al. (2014a) established that AGOs and BG
traps were similar in the number of female Ae. aegypti
captured and therefore used only AGOs in their
subsequent studies (Barrera et al. 2014b, 2016,
2018). Cornel et al. (2016) conducted a small-scale
(16 km<sup>2</sup>) suburban trial in Clovis, CA, where they
evaluated BG traps and AGOs to monitor the
presence and abundance of Ae. aegypti. They found
that although BG traps were more sensitive in the
measure of abundance in novel areas, the AGOs
performed equally well in areas where Ae. aegypti
populations were already known to be present. Only
one study has evaluated the AGOs in collecting
species other than Ae. aegypti. Cilek et al. (2017)
conducted an 8-wk study in 5 Jacksonville, FL,
backyards that were known to have a history of large
mosquito populations. They compared the effective-
ness of 3 different traps (BG-GAT, CDC gravid trap,
and AGO) and found that the AGOs collected
significantly more Cx. quinquefasciatus than Ae.
aegypti or Ae. albopictus and significantly more Ae.
aegypti than Ae. albopictus.

San Antonio, TX, located in Bexar County,
approximately 100 miles from the border of Mexico,
is the 7th largest city in the USA and the 2nd largest in
Texas. It is home to established populations of 3
important mosquito vectors: Ae. aegypti, Ae. albopictus,
and Cx. quinquefasciatus (Wise de Valdez 2017).
Unlike other large cities in Texas with extensive
county control districts (e.g., Harris, Tarrant, and
Dallas counties), formal mosquito control and surveil-
lance in San Antonio is underfunded and decentral-
ized, with multiple entities, including military, county,
and city, conducting uncoordinated monitoring. Here
we report on the first widescale use of AGOs as a
systematic way of monitoring these 3 important
arbovirus vectors. In addition, this is the first study
to deploy the AGOs across diverse neighborhoods in
an urban area with greater than 1.5 million residents
and an area of greater than 700 km<sup>2</sup>.

**MATERIALS AND METHODS**

**Surveillance area and sampling sites**
San Antonio, TX, has a population of more than
1.5 million (United States Census Bureau 2019a) and
was ranked the fastest growing urban area in the USA
in 2016–2017 (United States Census Bureau 2019b).
San Antonio receives an average of 73 cm of rainfall a
year, and May is consistently the wettest month,
followed often by September and October. Winters
are mild with an average high of 17.7°C and low of
4.4°C (Weather Underground 2018). Summers are
hot with an average high of 32.7°C (Weather
Underground 2018). San Antonio is located in a
diverse ecological zone spanning primarily Black-
land Prairie but influenced by at least 3 other
ecoregions: Post Oak/Clay Pan, Edwards Plateau,
and Northern Rio Grande Plain (Griffith et al. 2007).
San Antonio is also one of the most economically
segregated cities in the USA (Florida and Mellander
2015).

With the ecological and socioeconomic diversity
in San Antonio, it was important to represent these
differences in our surveillance area. Rather than
going door-to-door across such a large city, we
reached out to local media to run a story on our need
for homeowner participation in a study to survey the
mosquito that transmits ZIKV. With the outbreak of
Zika earlier in the year, the news station was eager to
report on local research efforts. We provided the
news station with a link to an online form. After the
single-evening broadcast, we had more than 400
people register their address for inclusion in the
study. We plotted these addresses using Google Maps
(Google LLC, Mountain View, CA) and looked for
natural clusters of homes to create surveillance
zones. In selecting our clusters, we wanted a well-
distributed geographic representation of the city as
well as clusters representing urban, suburban, and
semirural neighborhoods because a previous study
indicated that species distribution in San Antonio
varied by these factors (Wise de Valdez 2017).
We established 10 zones and randomly selected 12
homes within each cluster that would be easiest to
access (total trap locations = 120; Fig. 1). The zones
we created were the following: Central urban
downtown (Zone 1), Urban (Zones 2, 4), Suburban
central (Zone 7), Suburban West and Northwest
(Zones 5, 6, 8), Suburban East (Zone 10), Semirural
Far North-Hill Country (Zone 9), and Semirural Far
South-Agricultural (Zone 3). The average size of
each zone was 17.3 km<sup>2</sup> with a range of 9.5–31.0
km<sup>2</sup>. When added together, the surveillance areas
covered approximately one-quarter of the area of San
Antonio. Because our primary goal was to assess the
efficacy of AGOs in monitoring mosquito popula-
tions, we did not further categorize the neighbor-
hoods.

**Trap placement and maintenance**
On episeek 23 (June 5–11, 2016) one AGO was
placed in the front yard of each residence included in
the study. We chose not to place traps in back yards
due to difficulty in gaining weekly access. Traps
were placed near the residential structure where they
received at least partial shade during the day. Traps remained in place for 13 wk (epiweek 23–35, June 5–September 3, 2016). On the day of trap deployment, we added 10 liters of water and 30 g of coastal hay (Barrera et al. 2014a) to serve as an attractant to ovipositing female mosquitoes. We also lined the opening with sticky paper (provided by the CDC), which passively captures and kills the female mosquitoes. After 5 wk, we noticed that we were capturing fewer *Ae. aegypti* and more *Cx. quinquefasciatus* than we expected. Therefore, on epiweek 28, in 6 of the 12 traps in each zone, we replaced the 30 g of hay with 7 g of hay, in hopes of improving our ability to capture *Ae. aegypti* (Mackay et al. 2013). Water, sticky traps, and hay (7 g or 30 g) were replaced in all AGOs 8 wk after deployment (epiweek 31). By the end of the trial we had lost 5 traps due to theft or homeowner removal.

**Data collection**

We visited all traps once a week for mosquito identification and removal. Sticky papers were removed from the AGOs, and the immobilized female mosquitoes were visually identified on-site to one of 3 species; *Ae. aegypti*, *Ae. albopictus*, or *Cx. quinquefasciatus*. Identification on-site was a necessity because removal of the mosquitoes from the sticky paper rendered them too damaged for later microscopic examination. Each species was identified using morphological characteristics visible to the naked eye that distinguished them from other species found in San Antonio. *Aedes aegypti* was identified using the lyre-shaped pattern on the scutum, *Ae. albopictus* was identified using the singular white stripe down the scutum, and *Cx. quinquefasciatus* was identified using the dorsal and lateral banding pattern on the abdominal terga as well as by the lack of banding on the last set of legs (Darsie and Ward 2005, Burkett-Cadena 2013). It may be argued that identification of *Culex* species without the use of a microscope is problematic. While we acknowledge that on-site identification of all *Culex* species would likely be impossible, we were interested only in identifying *Cx. quinquefasciatus*. In San Antonio only 6 other *Culex* species are likely to be captured in any appreciable number (*Cx. coronator* Dyar and Knab, *Cx. erraticus* (Dyar and Knab), *Cx. nigripalpis* Theobald, *Cx. interrogator* (Dyar and Knab), *Cx. restuans* Theobald, and *Cx. tarsalis* Coq.; Wise de Valdez 2017), and none of them have the same dorsal banding pattern on the abdominal segments as *Cx. quinquefasciatus*. If we were unable to confirm the
morphological characteristics of *Ae. aegypti*, *Ae. albopictus*, and *Cx. quinquefasciatus*, we categorized the species as “other.” After mosquito identification and removal, the sticky papers were returned to the AGOs.

We collected weekly cumulative precipitation data from epiweeks 22–35 using 3 airport weather stations, San Antonio International Airport, Lackland Airforce Base, and Stinson Municipal Airport (Weather Underground 2018; Fig. 1), and averaged them to obtain precipitation patterns in our study region (Fig. 2). We also reported the average weekly temperature in San Antonio (Weather Underground 2018; Fig. 2).

Simple $t$-tests assuming unequal variances were used to compare total counts between species (SAS®, SAS Inc., Cary, NC). In order to evaluate differences in mosquito abundance for each species among geographically distinct zones, we square-root transformed mosquito count data (Williams et al. 2007) and used a mixed model with repeated measures (SAS). Fixed variables in this model were zone, week, and hay treatment. Random variables were trap within zone, and the repeated measure was trap within zone weekly. After determining that hay treatment (30 g vs. 7g) did not have a significant effect on mosquito capture for any of the 3 species ($P > 0.05$), we removed it from the model.

**RESULTS**

Over the course of 12 wk (epiweek 24–35) we trapped more than 35,000 female mosquitoes (Table 1). We caught significantly more *Cx. quinquefasciatus* than both *Aedes* species ($P < 0.0001$), with more *Ae. aegypti* collected than *Ae. albopictus* ($P < 0.0001$; Table 1). During our sampling timeframe, total mosquito abundance, as measured by average number of mosquito/trap/wk, was highest on epiweek 25 (June 19–25; $\bar{x} = 68.99$ mosquitoes/trap/wk, $N = 115$), followed by epiweeks 26 ($\bar{x} = 44.37$ mosquitoes/trap/wk, $N = 116$) and 27 ($\bar{x} = 31.37$ mosquitoes/trap/wk, $N = 114$; Fig. 2). The average number of mosquitoes/trap/wk dropped and remained low after epiweek 30 ($\bar{x} < 22.60$ mosquitoes/trap/wk, $N = 115$; Fig. 2). The temporal pattern of mosquito abundance during our surveillance period was largely driven by *Cx. quinquefasciatus* with the average number caught/trap/wk ranging from $\bar{x} = 3.68$ at the end of our sampling period (epiweek 35) to $\bar{x} = 48.38$ at its peak (epiweek 25; Fig. 2). The average number of *Ae. aegypti* and *Ae. albopictus* caught/trap/wk was lower than *Cx. quinquefasciatus* and did not show as much fluctuation. The average number of *Ae. aegypti* caught/trap/week ranged from $\bar{x} = 2.15$ on epiweek 30 to $\bar{x} = 7.05$ at its peak (epiweek 25; Fig. 2). The average number of *Ae. albopictus* caught/trap/wk
| Species                  | Total collected | Mean/trap (± SE) | Variance | Range |
|-------------------------|-----------------|------------------|----------|-------|
| *Aedes aegypti*         | 6,030           | 4.40 (0.11)      | 17.98    | 0–33  |
| *Aedes albopictus*      | 2,588           | 1.89 (0.06)      | 5.27     | 0–21  |
| *Culex quinquefasciatus*| 20,113          | 14.69 (0.61)     | 523.80   | 0–303 |
| Other                   | 6,530           | 4.77 (0.23)      | 70.45    | 0–121 |

The mixed model with repeated measures analysis run for each species showed a “zone effect” ($P < 0.0001$). The pairwise comparisons among zones showed no differences in the relative abundance of *Ae. aegypti* among 8 of 10 geographically distinct zones in San Antonio ($P > 0.05$, Fig. 3a). However, zone 4 showed a significantly higher number of *Ae. aegypti* ($\bar{x} = 5.77$ mosquitoes/trapping event; pairwise comparison $P$ values ranged from $P < 0.0001$ to $P = 0.018$) than all but zone 3 ($\bar{x} = 5.0$ mosquitoes/trapping event; $P = 0.089$; Fig. 3a). Zone 7 showed a significantly lower number of *Ae. aegypti* than all other zones ($2.87$ mosquitoes/trapping event; pairwise comparison $P$ values ranged from $P < 0.0001$ to $P = 0.011$; Fig. 3a). The distribution of *Ae. albopictus* among zones varied more than that of *Ae. aegypti* (Fig. 3b). Zone 5 had significantly lower *Ae. albopictus* than any other zone ($\bar{x} = 0.88$ mosquitoes/trapping event; pairwise comparison $P$ values ranged from $P < 0.0001$ to $P = 0.002$; Fig. 3b). Zones 8 and 10 had significantly higher numbers of *Ae. albopictus* than 6 of the other zones with $\bar{x} = 2.62$ and $\bar{x} = 2.81$, respectively ($P$ values ranged from $P < 0.0001$ to $P = 0.03$; Fig. 3b). No differences were seen in the abundance of *Cx. quinquefasciatus* among 6 of 10 geographically distinct zones in San Antonio ($P > 0.05$; Fig. 3c). Zone 9 had significantly more *Cx. quinquefasciatus* than any other zone ($\bar{x} = 33.13$ mosquitoes/trapping event; in all pairwise comparisons $P < 0.0001$), followed by zone 8 ($\bar{x} = 19.04$ mosquitoes/trapping event; pairwise comparison $P$ values ranged from $P < 0.0001$ to $P = 0.03$). Zones 2, 3, 4, 5, 6, and 10 had the lowest average of *Cx. quinquefasciatus* captured per trapping event, with a range of $\bar{x} = 6.80$ in zone 2 to $\bar{x} = 14.15$ in zone 7 (Fig. 3c).

**DISCUSSION**

Our study is the first to report on the widespread use of AGOs as a systematic way of monitoring 3 important arbovirus vectors, *Ae. aegypti*, *Ae. albopictus*, and *Cx. quinquefasciatus*, in the southern USA. We found that AGOs captured significantly more *Cx. quinquefasciatus* females than either *Ae. aegypti* or *Ae. albopictus*, which was similar to findings in a small-scale study by Cilek et al. (2017). In addition, we were able to assess the rise and fall of *Cx. quinquefasciatus* populations over the 12 wk (Fig. 2). It is difficult to conclude from this study whether San Antonio residential areas have a larger population of *Cx. quinquefasciatus* than *Aedes* species because we do not have long-term data using multiple trap types in San Antonio. In fact, Wise de Valdez (2017), who used BG and CDC mini-light traps, indicated that *Ae. aegypti*, not *Cx. quinquefasciatus*, was the most prevalent. Thus, for *Ae. aegypti* and *Cx. quinquefasciatus*, it is important to note that trap type matters in assessing abundance relative to other species. We are more confident, however, in our understanding of the relative abundance of *Ae. albopictus* in San Antonio. In both 2015 (BG traps/CDC light traps) and 2016 (AGOs), *Ae. albopictus* was collected significantly less than both *Cx. quinquefasciatus* and *Ae. aegypti*.

We found that temporal pattern of mosquito abundance during our study period peaked between epiweeks 25–27 and that the average number of females collected per trap dropped by epiweek 30 and stayed low. These results are similar to those by Wise de Valdez (2017), who reported peaks on epiweeks 22 and 25–26 and a maintained drop-off by week 30. Our data, in combination with other studies (Barrera et al. 2014a, Cornel et al. 2015, Cilek et al. 2017), as well as the conformity of our results to those by Wise de Valdez (2017) a year prior in the same area, suggest that AGOs are appropriate for use in tracking the temporal distribution of mosquitoes in a large urban area.

Regarding the geographic distribution of abundance, *Ae. aegypti* was evenly distributed across the city. Only 2 zones were significantly different from other zones. Zone 7, a central suburban neighborhood, had significantly fewer *Ae. aegypti* than any other zone, and zone 4, an urban neighborhood, had significantly more *Ae. aegypti* than all but 1 zone. Although zone 7 (low densities) is surrounded by the city of San Antonio, it is technically located in an independent municipality that has its own government, services, ordinances, and homeowner codes. It is possible that this scenario is an example of independent municipalities impacting vector densities because of their own vector-control policies as described by LaDeau et al. (2015) and Tedesco et al. (2010). We were unable to confirm specific policies implemented in this municipality. Zone 4 (high densities) is one of the oldest areas of San Antonio, with several historic districts and landmarks (City of San Antonio 2018). It is also primarily urban characterized by a high density of houses relative to...
Mean number of female mosquitoes collected per trapping event (± standard error bars) in each zone over 12 wk: (a) *Aedes aegypti*, (b) *Aedes albopictus*, and (c) *Culex quinquefasciatus*. Although the statistical analyses were performed using square-root transformed data of each species, the graphs were generated using nontransformed data to provide more meaningful numbers. Within each species analysis, bars sharing the same letter were not significantly different ($P > 0.05$).
to other zones (Wise de Valdez, unpublished data), and residents are primarily low income (US Census Bureau, 2010). It is possible that this area may experience greater numbers of Ae. aegypti because of its socioeconomic status (LaDeau 2013), housing density (Carbajo et al. 2006), and house age (Walker et al. 2011). The distribution of Ae. albopictus is less clear; there did not appear to be a geographic pattern of distribution, and all areas were significantly different from one another. This may be an artifact of low capture rates using the AGO. Finally, because significantly more Cx. quinquefasciatus was found in a semirural area of the far North-Hill Country (zone 9) and the zone bordering it (zone 8), it appears that relative abundance in San Antonio may be linked to proximity to undeveloped forested areas of San Antonio. We hypothesize that because of the proximity to undeveloped forested areas that Cx. quinquefasciatus has greater refuge sites and water sources than other neighborhoods in San Antonio. Because the aim of this study was to evaluate the use of the AGO in monitoring relative mosquito abundance temporally and spatially, we did not evaluate the effect of human and environmental factors on the populations of these 3 species of mosquitoes.

In conclusion, we have shown that AGOs are appropriate for detecting and tracking the relative abundance of Ae. aegypti, Ae. albopictus, and Cx. quinquefasciatus both spatially and temporally across a large and diverse urban landscape. We therefore suggest that AGOs are an inexpensive and streamlined option for vector surveillance of not only Ae. aegypti but also Ae. albopictus and Cx. quinquefasciatus in large metropolitan areas of the southern USA where all 3 species coexist.

AKNOWLEDGMENTS

We thank Gilberto Felix and Roberto Barrera for providing the CDC AGOs. We also thank the summer field team of undergraduate researchers: Ariana Alvarez, Jessica Buitron, Joshua Darden, Trina Fenning, Jonathan Hernandez, Alejandro Moya, and Crystal Serrano. We also thank Gabriel Hamer for advice on residential field collections. This research was supported, in part, by the US Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344 and the City of San Antonio Metropolitan Health District.

REFERENCES CITED

Barrera R, Amador M, Acevedo V, Caban B, Felix G, Mackay AJ. 2014a. Use of the CDC autocidal gravid ovitraps on chikungunya virus incidence in Aedes aegypti (Diptera: Culicidae) in areas with and without traps. J Med Entomol 54:387–395.

Barrera R, Mackay A, Amador M. 2013. An improved trap to capture adult container-inhabiting mosquitoes. J Am Mosq Control Assoc 29:358–368.

Burrrett-Cadena N. 2013. Mosquitoes of the southeastern United States. Tuscaloosa, AL: Univ. of Alabama Press.

Carbajo AE, Curto SI, Schweigmann NJ. 2006. Spatial distribution pattern of oviposition in the mosquito Aedes aegypti in relation to urbanization in Buenos Aires: southern fringe bionomics of an introduced vector. Med Vet Entomol 20:209–218.

CDC [Centers for Disease Control and Prevention]. 2018. ArboNET, disease maps 2010–2017 chikungunya, dengue, and ZIKV human cases [Internet]. Atlanta, GA: Centers for Disease Control and Prevention [accessed December 17, 2018]. Available from: https://wwwncdcgov/arbonet/maps/ADB_Diseases_Map/index.html.

Chaves LF, Hamer GL, Walker ED, Brown WM, Ruiz, MO, Kitron UD. 2011. Climatic variability and landscape heterogeneity impact urban mosquito diversity and vector abundance and infection. Ecosphere 2:1–21.

Cilek JE, Knapp JA, Richardson AG. 2017. Comparative efficiency of Biogents gravid Aedes trap, CDC autocidal gravid ovitrap, and CDC gravid trap in northeastern Florida. J Am Mosq Control Assoc 33:103–107.

City of San Antonio. 2018. Historic districts of San Antonio—Interactive Map [Internet]. San Antonio, TX: City of San Antonio [accessed December 5, 2018]. Available from: https://qagis.sanantonio.gov/ohpsearch/viewer/view.html.

Clements AN. 1999. The biology of mosquitoes. Volume 2. Sensory reception and behavior. Wallingford, United Kingdom: CAB International.

Cornel AJ, Holeman J, Nieman CC, Lee Y, Smith C, Amorino M, Brisco KK, Barrera R, Lanzaro GC, Mulligan FS III. 2016. Surveillance. insecticide resistance and control of an invasive Aedes aegypti (Diptera: Culicidae) population in California. F1000Research 5:194.

Darsie Jr. RF, Ward RA. 2005. Identification and geographical distribution of the mosquitoes of North America, north of Mexico. 2nd Edition. Gainesville, FL: Univ. Press of Florida.

Facchinelli L, Valerio L, Pombi M, Reiter P, Costantini C, Della Torre A. 2007. Development of a novel sticky trap for container-breeding mosquitoes and evaluation of its sampling properties to monitor urban populations of Aedes albopictus. Med Vet Entomol 21:183–195.

Farajollahi A, Kesavaraju B, Price DC, Williams GM, Healy SP, Gaugler R, Nelder MP. 2009. Field efficacy of BG-Sentinel and industry-standard traps for Aedes albopictus (Diptera: Culicidae) and West Nile virus surveillance. J Med Entomol 46:919–925.

Florida R, Mellander C. 2015. Segregated city: the geography of economic segregation in America’s metros. Toronto, Canada: Martin Prosperity Institute.
Fredericks AC, Fernandez-Sesma A. 2014. The burden of dengue and chikungunya worldwide: implications for the southern United States and California. *Ann Global Health* 80:466–475.

Griffith GE, Bryce SB, Omernik JM, Rogers A. 2007. *Ecoregions of Texas*. Austin, TX: Texas Commission on Environmental Quality.

Hawley WA. 1988. The biology of *Aedes albopictus*. *J Am Mosq Control Assoc* Supp 1:1–39.

Kröckel U, Rose A, Eiras AE, Geier M. 2006. New tools for surveillance of adult yellow fever mosquitoes: comparison of trap catches with human landing rates in an urban environment. *J Am Mosq Control Assoc* 22:229–238.

LaDeau SL, Allan BF, Leisnham PT, Levy MZ. 2015. The ecological foundations of transmission potential and vector-borne disease in urban landscapes. *Func Ecol* 29:889–901.

LaDeau SL, Leisnham PT, Biehler D, Bodner D. 2013. Higher mosquito production in low-income neighborhoods of Baltimore and Washington, DC: understanding ecological drivers and mosquito-borne disease risk in temperate cities. *Int J Environ Res Public Health* 10:1505–1526.

Leisnham PT, LaDeau SL, Juliano SA. 2014. Spatial and temporal habitat segregation of mosquitoes in urban Florida. *PloS One* 9:pe91655.

Mackay AJ, Amador M, Barrera R. 2013. An improved autocidal gravid ovitrap for the control and surveillance of *Aedes aegypti*. *Parasit Vector* 6:225.

Ritchie SA, Buhagiar TS, Townsend M, Hoffmann A, Van Den Hurk AF, McMahon JL, Eiras AE. 2014. Field validation of the gravid *Aedes* trap (GAT) for collection of *Aedes aegypti* (Diptera: Culicidae). *J Med Entomol* 51:210–219.

Rozeboom LE, Rosen L, Ikeda J. 1973. Observations on oviposition by *Aedes* (S) *albopictus* Skuse and A(S) *polynesiensis* Marks in nature. *J Med Entomol* 10:397–399.

Sivagnaname N, Gunasekaran K. 2012. Need for an efficient adult trap for the surveillance of dengue vectors. *Ind J Med Res* 136:739.

Tedesco C, Ruiz M, McLafferty S. 2010. Mosquito politics: local vector control policies and the spread of West Nile Virus in the Chicago region. *Health Place* 16:1188–1195.

Tempelis CH, Hayes RO, Hess AD, Reeves WC. 1970. Blood-feeding habits of four species of mosquito found in Hawaii. *Am J Trop Med Hyg* 19:335–341.

Tun-Lin W, Kay BH, Barnes A, Forsyth S. 1996. Critical examination of *Aedes aegypti* indices: correlations with abundance. *Am J Trop Med Hyg* 54:543–547.

United States Census Bureau. 2019a. *United States Census Bureau Quick Facts San Antonio* [Internet]. Suitland, MD: United States Census Bureau [accessed September 5, 2019]. Available from: https://www.census.gov/quickfacts/fact/table/sanantoniocitytexas/POP060210.

United States Census Bureau. 2019b. *Fastest growing cities primarily in the South and West* [Internet]. Suitland, MD: United States Census Bureau [accessed September 5, 2019]. Available from: https://www.census.gov/newsroom/press-releases/2019/subcounty-population-estimates.html.

Walker KR, Joy TK, Ellers-Kirk C, Ramberg FB. 2011. Human and environmental factors affecting *Aedes aegypti* distribution in an arid urban environment. *J Am Mosq Control Assoc* 27:135–141.

Weather Underground. 2018. Weather in U.S. Cities—San Antonio, TX [Internet]. Atlanta, GA: The Weather Company [accessed December 5, 2018]. Available from: https://www.wunderground.com/weather/us/tx/san-antonio.

Wen TH, Lin MH, Teng HJ, Chang NY. 2015. Incorporating the human-*Aedes* mosquito interactions into measuring the spatial risk of urban dengue fever. *Appl Geog* 62:256–266.

Williams CR, Long SA, Webb CE, Bitzhenner M, Geier M, Russell RC, Ritchie SA. 2007. *Aedes aegypti* population sampling using BG-sentinel traps in north Queensland Australia: statistical considerations for trap deployment and sampling strategy. *J Med Entomol* 44:345–350.

Wise de Valdez MR. 2017. Mosquito species distribution across urban, suburban, and semi-rural residences in San Antonio, Texas. *J Vect Ecol* 42:184–188.