A tale of two cities: *Aedes* Mosquito surveillance across the Texas-Mexico Border

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ABSTRACT

Cross border situations complicate epidemiologic risk assessments in transboundary regions such as the US-Mexico border. Countries have different health policies, mosquito control policies, and mosquito surveillance systems. We established a binational *Aedes* mosquito surveillance program in Reynosa, Tamaulipas, and McAllen, Texas by replicating a part of the Mexican Integrated Vector Monitoring System (IVMS) across the international border. The entomologic surveillance of the IVMSs is based on ova collection cups (ovitraps) and for the binational project, the surveillance protocol was modified to include an Autocidal Gravid Ovitrap (AGO) in the center of every city-block (100 m^2) distribution of four ovitraps. We measured the weekly abundance of *Aedes* eggs and adult females in 72 clusters (cluster = one AGO and four ovitraps) in Reynosa and 67 clusters in McAllen from Epidemiologic Week (EW) 17 to EW 36. The mean weekly egg counts were 34 and 22 in McAllen and Reynosa respectively. The female adult mosquito counts were more than 5 in 12 out of 20 (60%) weeks in McAllen, and in 5 out of 16 (31%) weeks in Reynosa. For every increase of one female mosquito, the egg counts in the corresponding ovitraps increased by 2.33% (95% HDI: 2.31%–-2.42%) in McAllen and by 0.6% (95% HDI: 0.5%–0.62%) in Reynosa. Counter knowledge, weekly increase of temperature had a negative influence in adult and egg counts in Reynosa and McAllen. Precipitation had a positive influence on egg counts in McAllen.

Additional index words: ovitraps, *Aedes aegypti*, *Aedes albopictus*, Autocidal Gravid Ovitrap (AGO)

Aedes aegypti and Aedes albopictus are vectors for arboviral diseases such as Zika, dengue fever, and chikungunya (Montgomery et al. 2017, WHO 2014, Leta et al. 2018). Human migration, urbanization, crowding, poverty, and climate change are some of the transmission drivers of mosquito-borne pathogens (Hotez 2018). The spread of these diseases in transboundary regions presents especially complex scenarios, because countries usually have different health policies, mosquito control policies, and human and mosquito surveillance systems (Esteve-Gassent et al. 2014). Persons living on both sides of the boundary between southern Texas and northern Mexico share a common history, culture, and language. These populations also have a unique risk for transmission of vector-borne diseases, due to the number of daily commuters crossing the border, the existence of mosquito breeding sites in homes and public areas, and

other factors (Hotez 2012).

Since 2008, Mexico has been using a successful nationwide system known as the Integrated Vector Monitoring System (IVMS) which includes an element of *Aedes* surveillance, based on ova collection traps (ovitraps) (Hernández-Ávila et al. 2013, CENAPRECE 2017). The IVMS is a collaboration between two agencies of Mexico's Ministry of Health—the Division of Vector-Borne Diseases in the National Center for Preventive Programs and Disease Control (CENAPRECE), and the Division of Medical Geography and Systems in the National Institute of Public Health (INSP) (Hernández-Ávila et al. 2013). The information collected by the IVMS has many uses, including estimating the adult mosquito population, estimating indexes of the risk of transmission of *Aedes*-borne diseases, and evaluating the effectiveness of interventions to control *Aedes*, a container-inhabitant mosquito. The City of McAllen has a proactive Mosquito Control Surveillance Program in partnership with several institutions (e.g., Texas A&M Health Science School of Rural Public Health, Texas A&M Agrilife), which allows to study mosquito species and especially the diseases they carry (Health & Code Enforcement 2020).

Sporadic local *Aedes* mosquito-borne disease transmission occurs in southern Texas (Monaghan 2016), particularly when the incidence is high in the bordering region of northern Mexico. The most recent binational outbreak of dengue virus in this region occurred in 2013 (Thomas 2016). In January 2016, the first local mosquito-borne transmission of chikungunya virus in Texas occurred in Cameron County

Control (VC) officials and entomology and epidemiology experts from both sides of the US-Mexico border created a work plan for a binational *Aedes* surveillance project. The study's main assumption was that components of the IVMS used in northern Tamaulipas, Mexico would be valuable and effective in a city in South Texas. The objectives were twofold, (1) to test if the IVMS methodology can be used in McAllen, Texas, and (2) to establish a binational partnership between Mexico and US with he ultimate goal to control-prevent mosquito borne diseases. We summarize here our key study outcomes and discuss their potential applications for those working to decrease diseases transmitted by mosquitoes in US-Mexico border region populations. We also compare the data collected across the border and examine the known factors (temperature and precipitation) of abundance of the *Aedes* eggs and adults.

MATERIALS AND METHODS

Study Phases. The study period had three phases: 1) protocol development, planning, and trap placement; 2) trap surveillance and data collection for 23 consecutive weeks, from Epidemiologic Week (EW) 14 (April 3, 2017) to EW 36 (September 8, 2017); and 3) data review, cleaning, and analysis.

Study Area. The study areas are in the sister cities of McAllen, Texas, and Reynosa, Tamaulipas (Table 1). For McAllen, we selected the study area based on previously published locations of breeding sites and identification of *Aedes* spp. mosquitoes (Vitek 2014). This information was verified in the field by the McAllen's

Table 1. Population size, climate, and other characteristics of Reynosa, Tamaulipas, and McAllen, Texas, and neighborhoods included in the binational surveillance project.

City	Average temperature 2017 [°C] **	Average air humidity 2017 [%] **	Neighborhood	Estimated population*
Reynosa	24.2	64.75	Balcones	24271
			Independencia	4211
			Satelite	6726
McAllen	26.5	68	Balboa	11541
			Victoria Square	7740
			La Hermosa & El Rancho	5051

*See (INEGI 2013).
**See (The TITI Tudorancea Bulletin 2018).

(WHO 2016). For 2016 and 2017, 11 of the 366 laboratory-confirmed Zika virus disease cases in Texas (CDC 2017) were due to local mosquito-borne transmission. These cases occurred to people living in the Lower Rio Grande Valley (Texas Department of State Health Services 2018).

In February 2017, a collaborative group of Vector

VC staff before the start of our binational project. The choice of neighborhoods was also based on the recommendations of the local VC authorities, residents' receptivity, and personal safety of trap monitors. The decision was then made to locate the project in four McAllen and three Reynosa neighborhoods (Fig 1). Two neighborhoods in McAllen, La Hermosa and

(Fig. 1) Study Area. Black lines indicate the limit of the neighborhoods included in the binational surveillance project in (A) McAllen, Texas and (B) Reynosa, Mexico. McAllen, Texas neighborhoods 1. Vitoria Square, 2 La Hermosa & El Rancho, and 3 Balboa. Reynosa Tamaulipas neighborhoods 1 Satelite, 2 Independencia, and 3 Balcones de Alcala. Figure elaborated in ArcGIS Desktop 10.0 by the Medical Geography Area of the National Institute of Public Health.

el Rancho are found in the same census tract, thus the information of these two neighborhoods is condensed in the analysis of results.
(See figure 1).
(See table 1).

The Data Center/Geographic Medicine Group of INSP used the IVMS mapping software to create maps of the optimal suggested locations for the ovitraps in McAllen. Within the McAllen neighborhoods, city blocks with homes were included and industrial and work areas were excluded in the ovitrap distribution exercise. This exercise followed the IVMS fieldwork guidelines, which recommend ovitrap density as one per corner of a city block; that is, four ovitraps in a square area that measures approximately 100 m x 100 m (CENAPRECE 2017). The ovitraps used in McAllen were donated by CENAPRECE and were the same as those used in Reynosa.

Autocidal Gravid Ovitraps (AGOs). To improve comparability between a newly established ovitrap-based surveillance system in McAllen and the long-existing system in Reynosa, the protocol design team decided to include a second surveillance trap type. AGOs are containers of similar shape but larger than ovitraps. AGOs contain water and grass and are used to attract and capture female adult *Aedes* mosquitoes and can be used without interference to the ovitrap monitoring (Mackay & Barrera 2013, NOAA 2017). In our project, AGOs were new to, and set up to be monitored by, equally experienced staff on both sides of the border.

Entomologists from CDC's Dengue Branch, Division of Vector-Borne Diseases, donated the AGOs and

(Fig. 2) Example of the distribution of clusters (outlined by black circles) and neighborhood in (A) McAllen and (B) Reynosa. Orange squares represent the location of AGO traps. Yellow circles represent the location of ovitraps. Blue arrows serve as reference for the visual representation of distance among traps. Figure elaborated in ArcGIS Desktop 10.0 by the Medical Geography Area of the National Institute of Public Health.

the sticky paper used for them. For deciding the number of AGOs we could include in our project, we first estimated the workforce needed to place, read, and maintain them properly. To work within the design pattern used in Mexico for the ovitraps, we decided to include one AGO in the approximate center of every square (100 m^2) distribution of four ovitraps (Fig 2).

The egg abundance measured weekly in the ovitraps was expected to have a biological and mathematical relationship to the number of female adult *Aedes* mosquitoes found in the AGOs. To explore this relationship, we defined a cluster (a grouping consisting of one AGO and the four ovitraps that surround it) as the unit of analysis. We also assessed the potential influence of temperature and precipitation on this relationship.
(See Fig 2).

Table 2. Number of ovitraps and Autocidal Gravid Ovitraps (AGOs) and distance between them in Reynosa and McAllen, by neighborhood.

City	Neighborhood (name)	Ovitraps (n)	Autocidal gravid ovitraps (n)	Distance between AGO and ovitraps (average meters)
Reynosa	Balcones	160	40	51.06
	Independencia	53	15	41.12
	Satelite	65	17	30.53
McAllen	La Hermosa & El Rancho	84	21	71.35
	Victoria Square	104	26	75.95
	Balboa	80	20	81.94

Aedes Traps. In Reynosa, the three neighborhoods selected for the study had 288 established ovitraps. For the binational project, these continued to be monitored as routine by the city's VC staff. The Reynosa group incorporated the placement, reading, and maintenance of the AGOs into their entomologic surveillance duties. In McAllen, in the four neighborhoods selected for the study, 278 ovitraps were placed, read, and maintained by eight biology work-study students from the University of Texas Rio Grande Valley (UTRGV). Personnel from the VC unit of the McAllen Health and Code Enforcement Department and Hidalgo County Health and Human Services Department monitored the AGOs in McAllen. Ovitrap and AGO maintenance includes replacing weekly the strips of white natural cotton batting fabric (Pellon) for egg laying or the sticky paper for mosquito trapping and preventing their desiccation.

All the ovitrap and AGO monitors from both sides of the border attended study-specific trainings at the Texas A&M AgriLife Research Extension Center. The classroom trainers were entomologists from the University of Texas in El Paso, the VC staff from Reynosa, and VC personnel from CENAPRECE and INSP. In addition, an entomologist from the CDC Dengue Branch gave specific training for placement, reading, and maintenance of AGOs in the field in McAllen, with the Reynosa VC personnel in attendance.

After the project's ovitraps and AGOs were installed, their locations were georeferenced using Android mobile phones. The INSP data center staff created a new temporary component (Binational Project Database) within the IVMS server. For each trap, a unique identification number was generated and saved. In Reynosa, an ovitrap monitor reads 40 traps per day, 5 days a week, and uploads his or her findings into the system's password-protected database daily. In McAllen, on average, each monitor read 34 ovitraps per day once a week and input the results on that day into a secure database. AGOs were also read weekly, and cleaned and maintained as necessary, in both cities.

Fieldwork in McAllen. In McAllen, residents were not familiar with entomologic surveillance that places traps in their home and monitors the traps weekly. Before trap placement and monitoring started, personnel from the McAllen Health and Code Enforcement Department and the UTRGV student monitors handed out educational pamphlets, gave talks describing the objectives of the mosquito surveillance project, and invited the homeowner's voluntary participation. With the resident's permission, they placed the traps in or as close as possible to the location suggested by the mapping/distribution plans generated by IVMS-INSP for McAllen. The participating homeowners cooperated with the monitors by helping to keep traps in their location and away from pets and children who could disrupt them. When conducting their field activities, the trap monitors used reflective vests and one or two visible official identification cards.

Statistical Analyses. We analyzed and compared the weekly egg counts and number of female adult *Aedes* mosquitoes during the period of entomologic surveillance. The results from the neighborhoods of La Hermosa and El Rancho, which belong to the same census tract, were grouped for this purpose. We analyzed the possible influence of weather covariates of weekly temperature and weekly precipitation on the number of eggs and adult *Aedes* mosquitoes. Weekly temperature and precipitation were obtained from the closest climatological station of each one of the cities in this study, Reynosa and McAllen (NOAA 2017).

We used a Bayesian statistical analysis to assess whether there was a relationship between numbers of collected eggs and female adult mosquitoes. We used a zero-inflated Poisson distribution to model the number of eggs collected in each cluster. We used a log-linear relation between the abundance of the eggs and the number of adult female mosquitoes collected by each AGO in each cluster, as well as the weather covariates. The model considered the egg counts from the four ovitraps in each cluster as repeated measures (Gelman 2006). We also used a zero-inflated Poisson distribution to model the counts of the female adult
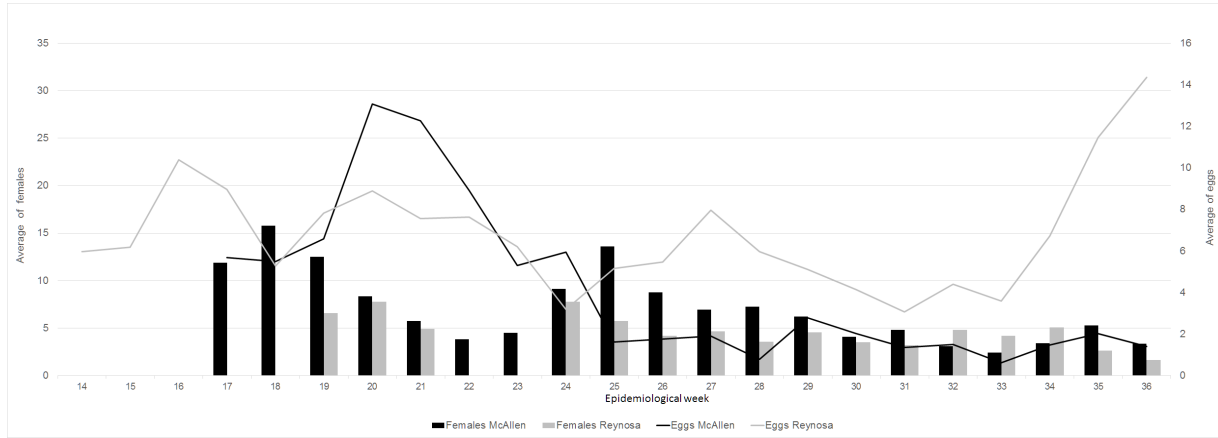
(Fig. 3) The weekly average female Aedes mosquito count was 4.7 in Reynosa and 7.1 in McAllen.

mosquitos. The model was coded using R and its toolbox, RJAGS (Wabersich 2014). Missing counts of adult mosquitoes and eggs (e.g., lost ovitraps) were stochastically imputed using the zero-inflated Poisson distribution (Gelman 2006). We used a Bayes factor (BF) to assess the statistical significance of the factors: adult counts, weekly temperature, and weekly precipitation. We also used the BF to test the difference between the relationship of egg counts and adult counts in McAllen versus Reynosa. The BF was calculated using the Savage-Dickey method (Wagenmakers et al. 2010). The BF results were additionally supported by using the 95% high density interval (HDI) of the factors or the difference between them (Guerra, Liu & Núñez 2008, Kroese 2014). See Appendix I for more details.

RESULTS

We formed 72 clusters consisting of one AGO and four ovitraps in Reynosa, and 67 clusters in McAllen (10 of these had a 1:3 AGO to ovitrap ratio) (Table 2). The average distance between the traps in a cluster was 41 meters in Reynosa and 76 meters in McAllen (Table 2).

During the cleanup and pre-analysis review of the AGOs data, we found unresolvable issues in the data quality from the first 3 weeks of monitoring in McAllen, and we excluded the data from these weeks from further analysis from both cities. Therefore, the final study period for analysis was 20 consecutive weeks (from EW 17 to EW 36). For Reynosa and McAllen, the numbers of adult *Aedes aegypti* mosquitoes were 591 males and 4,751 females, and 365 males and 7,311 females respectively (Table 3). Of the adult mosquitoes in McAllen, 129 (1.7%, 106 females and 23 males) were identified as *Aedes albopictus* (Table 4). No *Ae. albopictus* were observed by the AGO monitors in Reynosa.
(See Table 3).
(See Table 4).

The weekly average female *Aedes* mosquito count was 4.7 in Reynosa and 7.1 in McAllen (Fig 3). The egg counts in McAllen were highest from EW 20 to EW 22, when the weekly average egg count was 25 eggs (the average weekly egg count of the other 17 weeks was 6.2 eggs). There was not a corresponding increase in the adult *Aedes* mosquitoes captured in the AGOs during those epidemiologic weeks in McAllen, nor increases in egg counts of AGO trappings in Rey-

Table 3. Number and sex of *Aedes aegypti* mosquitoes and egg counts in Reynosa and McAllen, by neighborhood.

City	Neighborhood	Clusters (n)	Female (n)	Male (n)	Egg counts
Reynosa	Balcones de Alcala	40	2,584	291	18,198
	Independencia	15	1,157	177	4,929
	Satelite	17	1,010	123	8,887
	Total	**72**	**4,751**	**591**	**32,014**
McAllen	Balboa	20	2,801	93	10,031
	Victorian Square	26	3,400	201	19,332
	La Hermosa & El Rancho	21	1,110	71	16,643
	Total	**67**	**7,311**	**365**	**46,006**

Table 4. Number and sex of *Aedes albopictus* mosquitoes in McAllen, by neighborhood.

City	Neighborhood	Clusters (n)	Female (n)	Male (n)
McAllen	Balboa	20	25	5
	Victorian Square	26	61	13
	La Hermosa & El Rancho	21	20	5
	Total	**67**	**106**	**23**

nosa (Fig 3). During the monitoring period, the project team met weekly by phone and thus could investigate possible reasons for the peak in egg counts recorded in McAllen (EW 20-22). The group discovered that from EW 19 through EW 22, the Pellon fabric strips for the ovitraps in McAllen were replaced with brown anchor germination paper, which could probably yield higher egg counts than the ovitraps fitted with Pellon strips. However, we do not have enough data to test this idea.

The observed peak in the average weekly egg counts (11) for Reynosa was during EW 34 to EW 36, compared to the average weekly egg counts (6) for EW 17 to EW 33. There was not a corresponding increase in the number of adult female mosquitoes captured by the AGOs in Reynosa for EWs 34–36. The female adult mosquito counts in AGOs were >5 12 (60%) of 20 weeks and 5 (31%) of 16 weeks for McAllen and Reynosa. The highest adult female mosquito weekly average was 7.8 in EW 24 in Reynosa and 13.6 in EW 25 in McAllen.

In the statistical analysis of the egg-adult (female) relationship, we found that for every increase of one adult mosquito in McAllen, the corresponding egg counts increased by 2.33% (95% HDI: 2.32%–-2.42%). For Reynosa, the increase in egg counts was 0.6% (95% HDI: 0.5%–0.62%) per each female adult mosquito increase. The difference in the relationship between female adults and eggs counts in McAllen compared to Reynosa is highly significant based on a BF = 2.85 x 10-59, and a 95% HDI given as (0.0169, 0.0184). Weekly temperature and precipitation had a negative association with adult and egg counts in Reynosa and adult count in McAllen. Precipitation, however, had a positive influence on egg counts in McAllen. This is, as the temperature increased one Celsius degree, the number of adult mosquitoes decreased by 23.6% (95% HDI: 20.6% - 25.8%) in McAllen and by 9.5% (95% HDI: 7.78% - 10.95%) in Reynosa. As the precipitation increased one millimeter, the number of adult mosquitoes decreased by 1.98% (95% HDI: 1.39% - 2.47%) in McAllen and by 0.99% (95% HDI: 0.60% - 0.80%) in Reynosa. As the temperature increased one Celsius degree, the number of eggs decreased by 4.87% (95% HDI: 3.92% - 6.76%) in McAllen and by 16.97% (95% HDI: 16.31% - 17.72%) in Reynosa. As the precipitation increased one millimeter, the number of adult mosquitoes increased 3.04% (95% HDI: 3.25% - 3.67%) in McAllen but decreased by 0.199% (95% HDI: 0.099% - 0.299%) in Reynosa (for details in the mathematical model see SI).

DISCUSSION

In 2017, officials from Hidalgo County, Texas, diagnosed and reported eight cases of Zika virus disease (ZVD), and epidemiologic and laboratory investigations determined that those cases were locally transmitted (Texas Department of State Health Services 2018). That year was also when Hidalgo County residents, VC officials, and UTRGV officials collaborated with their counterparts in Reynosa, Tamaulipas, to establish a binational *Aedes* mosquito entomologic surveillance system. We believe that community participation in the entomologic surveillance project increased awareness of a public health concern among Hidalgo County residents and health officials and had a positive influence on the detection of the mosquito-borne cases of ZVD in Hidalgo County.

Egg counts in the McAllen ovitraps were consistently higher than the ones in Reynosa. A peak in average egg counts in McAllen from EW 20 to EW 22 was due to a change in practice and not a biological difference. This is a reminder that surveillance systems used to measure events across time and place need to be consistent in their methods to prevent introduction of spurious results.

Consistent with the ovitrap information, the AGOs had higher *Aedes* spp. mosquito densities in McAllen than in Reynosa. AGOs in Reynosa had fluctuating weekly average mosquito counts from May to November ranging from 1.6 to 7.8, 31% of 26 weeks had counts >5, and there was no discernible upward slope in mosquito numbers in the months that are postulated as peak vector months (July to September) in North America (Monaghan et al. 2016). For 2017, the epidemiologic curve for ZVD cases in Reynosa started an acceleration in mid-August and peaked in late October (Thomas et al. 2016).

Aedes albopictus were observed in McAllen, while in Reynosa, only the more recognized home dwelling *Aedes aegypti* mosquito was reported from AGOs. This finding may be related to the proximity of the traps to the homes in Reynosa. The traps in McAllen had to be placed outside the patio limits of homes, not inside the patios next to the homes as in Reynosa. High temperatures, low humidity, high human density, and high urban land cover make a more suitable habitat for *Ae. aegypti* (Landau & van Leeuwen 2012; Sallam et al. 2017). In addition, Ae. *aegypti* is able to

outcompete *Ae. albopictus* for larval resources (Juliano 2009). Another biological explanation is related to the presence of vegetation. Vegetation coverage, such as natural or irrigated landscapes with native and introduced vegetation, has played a significant role in the presence of mosquitos (Landau & Leeuwen 2012). *Aedes albopictus* has been reported in areas with some type of vegetation compared to areas that have a lack of it (Champion & Vitek 2014). Both, backyards and front-yards of homes in McAllen have some type of vegetation (e.g., grass), compared with homes in Reynosa that lack this type of vegetation. Systematic studies to understand the abundance of both mosquito species in this transboundary region of Texas-Mexico could be of great value to understand mosquito population dynamics.

In the paired comparisons between ovitraps and AGOs, the relationships were positive and similar in both cities. This modeling also allowed for a statistical comparison of results between the two cities and found that the increase in ovitrap percentile egg counts in relation to adult females was significantly higher in McAllen than in Reynosa. One explanation for this finding, as well as for the finding of a larger total number of eggs and adult mosquitoes counted in McAllen than in Reynosa across the study period, could be related to the placement of the ovitraps as explained above. Another explanation could be related to the existence of a larger number of potential breeding sites for female *Aedes* mosquitoes to lay their eggs found in the patios in Reynosa (compared to the potential breeding site competition in McAllen), as well as the geographic differences between the clusters established in the two cities (the distance between traps in a cluster was approximately twice as long in McAllen than in Reynosa). The potential breeding sites could also explain why the weekly temperature and precipitation had a negative influence on adult and egg counts in Reynosa and McAllen, while the positive influence in egg counts in McAllen could be an expected result.

The surveillance method used in Reynosa, Tamaulipas, was successfully reproduced in McAllen, Texas. Entomologic surveillance aims are to improve knowledge of the distribution and local abundance of *Aedes aegypti* and *Aedes albopictus* (CDC 2016). The information gathered by entomologic surveillance is useful to cities to guide control activities targeting the interruption of mosquito-borne arbovirus transmission. Critical products of this binational effort include 1) creation of a database for entomologic surveillance data from McAllen in the Mexican IVMS platform, 2) creation of a new database module for AGO data in IVMS, and 3) highly positive collaboration between the United States and Mexico on a topic highly related to human health.

CONCLUSION

Ovitraps are a sensitive, inexpensive, indirect sur-

veillance tool that when used year-round serve to estimate the abundance of *Aedes* mosquito populations across time. AGOs provide direct measurements of adult mosquito abundance and identification of the mosquito species and sex. Any method used for vector monitoring should be focused on the goals of the monitoring-what surveillance or research questions are being asked, or what practical approach is needed for a specific region. Practical tools for the surveillance and control of *Aedes* spp. are fundamental to developing vector control programs (Mackay & Barrera 2013).

The use of existing successful methods in areas that share similar suitable habitats offers a cost-efficient and timely opportunity to obtain information for improving mosquito control in areas with known or potential risk of mosquito-borne disease transmission. Entomologic surveillance also offers opportunities for early detection and to prevent expansion of *Aedes albopictus* (Flacio & Tonolla 2016). The IVMS approach for vector surveillance offers numerous advantages to establish such monitoring programs.

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APPENDIX I

SUPPORTING INFORMATION - STATISTICAL MODEL AND ANALYSIS

A zero-inflated Poisson distribution is defined as

$$f_{ZIP}(x|\mu,p) = \begin{cases} p + (1-p)f_P(0|\mu), & x = 0; \\ f_P(x|\mu) & , & x = 1,2,3, \dots \end{cases}$$

where $f_P(x|\mu) = \frac{\mu^x}{x!}e^{-\mu}$ for $x = 0,1,2, \dots$ is the Poisson mass function. A zero-inflated Poisson model accounts for the excessive proportion of zero counts in traps beyond the proportion $f_P(0|\mu) = e^{-\mu}$ allowed by the Poisson model.

We postulate a zero-inflated Poisson for all of the four counts $Y_{t,c}$ of trap type $t = A, O$ for AGO and ovitrap, respectively, and of city $c = M, R$ for McAllen and Reynosa, respectively; that is

$$Y_{t,c} \sim f_{ZIP}(x|\mu_{t,c}, p_{t,c}) \text{ with } t = A, O \text{ and } c = M, R$$

A log-linear regression of the form

$$\log(\mu_{A,c}) = \alpha_{0,c} + \alpha_{1,c}\text{temperature} + \alpha_{2,c}\text{precipitation}$$

and

$$\log(\mu_{O,c}) = \beta_{0,c} + \beta_{1,c}Y_{A,c} + \beta_{2,c}\text{temperature} + \beta_{3,c}\text{precipitation}$$

for $c = M, R$; is used to estimate the abundance of the trapped adult female mosquitoes and eggs, respectively, and find the relation of the latter with the number of adult female mosquitoes. The counts collected $y_{A,c}$ are made over time and for different clusters/locations/blocks; whereas repeated measures are done for $y_{O,c}$ are made per each cluster/location/block.

We used the software R and its MCMC's Gibbs Sampling toolbox RJAGS to code the model and carry out Bayesian analysis of the data. We used uniform distributions on the interval $(0, 1)$ as priors for $p_{t,c}$ for all t and c and (diffuse) normal distribution $N(0,1000)$ with mean 0 and precision $.001$ as priors for $\alpha_{i,c}$ and $\beta_{j,c}$ for $i = 0,1,2,3$ and $j = 0,1,2,3,4$. The posterior distribution of all of the parameters as well as of the quantity $\beta_{1,M} - \beta_{1,R}$ is found after a burn-in period of 1000, and runs of 10,000 with thinning of 100.

To test hypotheses like $\mathcal{H}_0 : \beta_{j,c} = 0$ against the $\mathcal{H}_1 : \beta_{j,c} \neq 0$, we use the Bayes-factor (BF) defined by the Savage-Dickey density ratio [1, Page 114]

$$BF_{01} = \frac{\Pr(Data|\mathcal{H}_0)}{\Pr(Data|\mathcal{H}_1)} = \frac{\Pr(\beta_{j,c} = 0|Data, \mathcal{H}_1)}{\Pr(\beta_{j,c} = 0|\mathcal{H}_1)}$$

In the Savage-Dickey density ratio approach, the BF_{01} is the ratio of the posterior to the prior distributions of the parameter calculated at zero. In over all, the smaller the value of the $BF_{01} \ll 1$ the more support the data gives to $\mathcal{H}_1$ against $\mathcal{H}_0$, [1, Page 105].

For order restricted hypotheses like $\mathcal{H}_0 : \beta_{1,M} = \beta_{1,R}$ against $\mathcal{H}_1 : \beta_{1,M} > \beta_{1,R}$ we use the same methods in [1, Page 129], in which $\beta_{1,M} - \beta_{1,R}$ is the parameter we use the posterior and prior distributions to find BF_{01}.

Note that if X and $Y \sim N(0, \sigma)$ are independent then $X - Y \sim N(0, \sigma/\sqrt{2})$ and $[X - Y|X > Y]$ has the folded normal distribution $FN(0, \sigma/\sqrt{2})$ with a probability density function

$$f(x|\sigma) = \begin{cases} \dfrac{2}{\sigma\sqrt{\pi}} e^{-x^2/\sigma^2}, & x \geq 0; \\ 0 & , & x < 0. \end{cases}$$

Hence, the difference $\beta_{1,M} - \beta_{1,R}$ has a prior $FN(0, 1000/\sqrt{2})$ of value $\dfrac{2}{1000\sqrt{\pi}} \approx .00113$ when the difference is zero. Note that $\beta_{i,c}$ $N(0, 1000)$ with value $\dfrac{1}{1000\sqrt{2\pi}} \approx .000399$ when it is zero. We also use the posterior distributions to find 95% High Density Intervals (HDI), or credible intervals, for the parameters as well as for $\beta_{1,M} - \beta_{1,R}$ to support the tests of hypotheses.

APPENDIX II – RESULTS OF THE STATISTICAL ANALYSIS

In Table 1, the estimates of the parameters, their 95% HDI and Bayes factors are reported. As the value of the BF gets smaller than one, the higher the support given to the significance of the parameter by the data. The 95% HDI is used as a conclusive tool for significance.

Table 1. Estimates of the parameters, their 95% HDI, and the Bayes factor testing that the parameter is significant and testing whether $\beta_{1,M} > \beta_{1,R}$.

Location Parameter	Estimate (Median)		BF_{01}		95% HDI	
	McAllen	**Reynosa**	**McAllen**	**Reynosa**	**McAllen**	**Reynosa**
Adults (AGO)						
Probability of excessive zeros	$.18$	$.60$	8.02×10^{-15}	9.91×10^{-46}	$(.16, .21)$	$(.57, .63)$
Intercept	9.5	5.5	4.94×10^{-72}	1.77×10^{-28}	$(8.5, 10.3)$	$(5.03, 5.95)$
Temperature	$-.27$	$-.10$	1.91×10^{-55}	5.87×10^{-9}	$(-.299, -.231)$	$(-.116, -.081)$
Precipitation	$-.02$	$-.01$	4.66×10^{-1}	2.69×10^{-3}	$(-.025, -.014)$	$(-.008, -.006)$
Eggs ($Ovitraps$)						
Probability of excessive zeros	$.39$	$.22$	7.9×10^{-29}	1.062×10^{-20}	$(.36, .41)$	$(.20, .25)$
Intercept	3.57	6.9	0	5.76×10^{-64}	$(3.12, 3.05)$	$(6.71, 7.12)$
Number of adults	$.023$	$.006$	2.87×10^{-90}	4.25×10^{-6}	$(.023, .024)$	$(.005, .0062)$
Temperature	$-.05$	$-.186$	4.66×10^{-1}	1.07×10^{-34}	$(-.07, -.04)$	$(-.195, -.178)$
Precipitation	$.03$	$-.002$	2.63×10^{-32}	5.16×10^{-2}	$(.032, .036)$	$(-.003, -.001)$
$\beta_{1,M} - \beta_{1,R}$	$.018$		2.85×10^{-59}		$(.0169, .0184)$	