Georgia's Collaborative Approach to Expanding Mosquito Surveillance in Response to Zika Virus: A Case Study

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Abstract

Zika virus (ZIKV) was declared an international public health emergency by the World Health Organization on February 1, 2016. Due to the known and estimated range of the ZIKV mosquito vectors, southern and central US states faced increased risk of ZIKV transmission. With the state of Georgia hosting the world's busiest international airport, a climate that supports the ZIKV vectors, and limited surveillance (13 counties) and response capacity, the Department of Public Health (DPH) was challenged to respond and prevent ZIKV transmission. This case study describes and evaluates the state's surveillance capacity before and after the declaration of ZIKV as a public health emergency.

Method: We analyzed surveillance data from the DPH to compare the geographical distribution of counties conducting surveillance, total number, and overall percentage of mosquito species trapped in 2015 to 2016. Counties conducting surveillance before and after the identification of the ZIKV risk were mapped using ArcMap 10.4.1. Using SAS (version 9.2) (SAS Institute, Inc, Cary, NC), we performed the independent 2 sample *t* test to test for differences in prevalence in both years, and a χ^2 analysis to test for differences between numbers of species across the 13 counties. In addition, weighted frequency counts of mosquitoes were used to test (χ^2) an association between major mosquito vector species and 7 urban counties. Lastly, using data from 2012-2016, a time-trend analysis was conducted to evaluate temporal trends in species prevalence.

Results: From 2015 to 2016, surveillance increased from 13 to 57 (338% increase) counties geographically dispersed across Georgia. A total of 76,052 mosquitoes were trapped and identified in 2015 compared to 144,731 (90.3% increase) in 2016. Significant differences between species (P<.001) and significant associations (P<.0001) between 7 urban counties and major mosquito vectors were found. Significant differences in prevalence were found between several species and year highlighting species-year temporal trends.

Conclusions: The DPH collaborative response to ZIKV allowed a rapid increase in its surveillance footprint. Existing and new partnerships were developed with the military and local health departments to expand and share data. This additional surveillance data allowed DPH to make sound public health decisions regarding mosquito-borne disease risks and close gaps in data related to vector distribution.

Zika virus (ZIKV), a mosquito-borne disease, was declared an international public health emergency by the World Health Organization (WHO) on February 1, 2016 due to confirmed reports of various adverse health effects from multiple countries.[1] The state of Georgia Department of Public Health (DPH) lacked sufficient monitoring and surveillance capacity to properly assess the risk of ZIKV transmission, as well as trained staff to respond to potential local outbreaks of the disease. This limited capacity was a result of federal budget reductions that affected funding earmarked for mosquito monitoring and surveillance programs. Once a strong program that had a large number of county health departments conducting mosquito surveillance and several trained staff, the program had been reduced to one state level position and a few counties conducting surveillance. This case study describes and evaluates Georgia's rapid response from the perspective of those challenges.

Overview

Zika virus is a mosquito-borne *Flavivirus* (family Flaviviridae) first discovered in 1947 in the Zika forest of Uganda from captive monkeys used in yellow-fever surveillance and later isolated in humans in 1952.[2] Unlike West Nile virus (WNV) that circulates between birds and mosquitoes with humans serving as dead-end hosts,[3] ZIKV can be transmitted from human-to-human via the bite of an infected *Aedes* spp mosquito.[1] From the 1960s through the 1980s, the disease was found in mosquitoes from several Asian countries with few human cases. It eventually traveled east, resulting in a large outbreak on Yap Island in 2007 and additional outbreaks in French Polynesia in 2013.[2] In 2015, Brazil reported unusual cases of rash and ultimately associated a high number of babies born with microcephaly and cases of guilliain-barré syndrome to ZIKV, resulting in the international public health emergency order.[2]

Research and analysis of previous outbreaks indicated that the primary vector responsible for transmitting ZIKV is the *Aedes* spp mosquito with the urban dwelling *Ae. aegypti* (L.) the likely vector in the Americas.[4] A daytime biter of humans, this mosquito prefers tropical to somewhat temperate climates and lays eggs in containers around urban areas.[4] A secondary ZIKV vector is *Ae. albopictus* (Skuse), the Asian tiger mosquito. This mosquito also lay eggs in containers, but feeds on humans and other animals, thus lowering the risk of transmission.[4] However, *Ae. albopictus* can survive in cooler areas, increasing its potential distribution across the United States. The Centers for Disease Control and Prevention (CDC), using several limited data sources, developed 2 maps (Figure 1) that estimate the potential geographic range of *Ae. aegypti* and *Ae. albopictus*.[4]

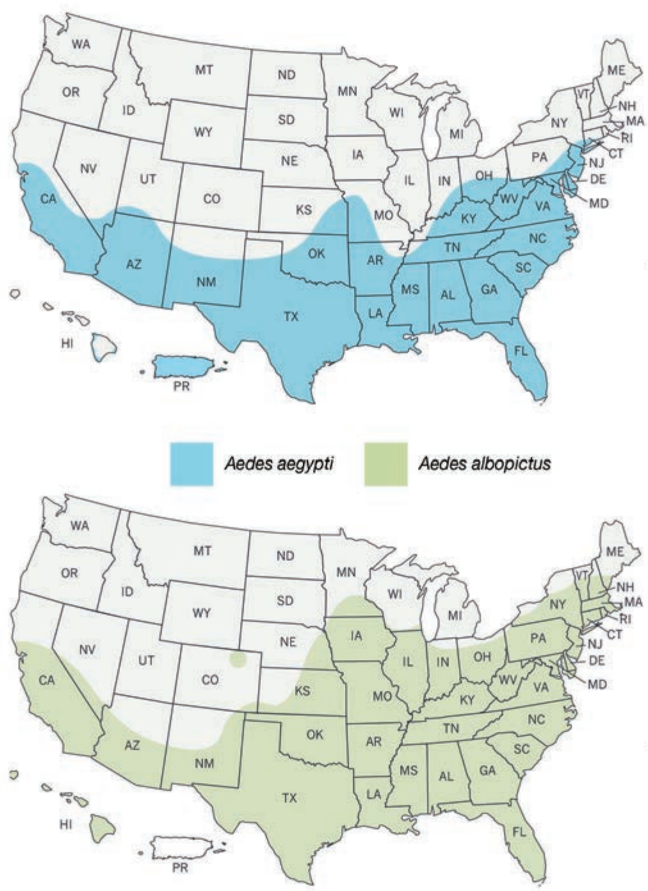

Figure 1. Estimated range of *Aedes albopictus* and *Aedes aegypti* in the United States, 2016. The maps represent the best estimate by CDC of the potential range of the named mosquitoes. Maps courtesy of the Centers for Disease Control and Prevention.[4]

The potential distribution of these 2 vectors placed several states in the southern to central half of the United States on alert for potential transmission of ZIKV and raised the alarm for public health officials in Georgia. Unfortunately, the maps demonstrate the lack of surveillance across the country, as it only estimates the potential range of the 2 ZIKV vectors. This data gap is a result of public health budget cuts and lack of priority placed on mosquito surveillance in the last decade. Consequently, this negatively affected the state's ability to critically assess the actual risks of ZIKV transmission for its citizens.

National Funding Trends

Understanding national funding trends is important to explaining the gaps in surveillance across the United States. The primary mission of public health and mosquito control programs is to inform, prevent, and protect the public from injury and disease. This mission is achieved through disease and vector surveillance programs that provide critical data used to quickly respond and control threats. Mosquito surveillance, coupled with clinical (human and animal) surveillance programs, are critically important because they can detect the abundance and distribution of vectors, monitor for viral diseases, aid in quantifying human risks, and predict changes in the dynamics of disease transmission.[6-8] Unfortunately, funding and support of surveillance programs have decreased over time, leaving a patchwork of jurisdictions conducting surveillance and resulting in significant gaps in vector data.[9]

West Nile virus (WNV), the last major new and exotic arboviral outbreak in the United States, generated significant media attention and heightened the public's fear.[10-12] This outbreak highlighted a general lack of capacity for public health and mosquito control agencies to conduct human and vector surveillance and rapidly respond to disease events.[13] To improve detection, monitoring, and control capacity for WNV (which eventually spread to 48 states), the CDC provided significant funding to all 50 states and 6 major cities through its Epidemiology and Laboratory Capacity (ELC) grant.[13] This funding was eventually expanded to cover over 20 mosquito-borne and tick-borne diseases and allowed states and jurisdictions to increase human and vector surveillance, mosquito trapping and identification, viral testing, avian surveillance systems; and develop response plans.[14]

In 2002, approximately $34.7 million was provided to states to fund these important programs, but by 2014, this had been reduced by approximately 75% to $9.2

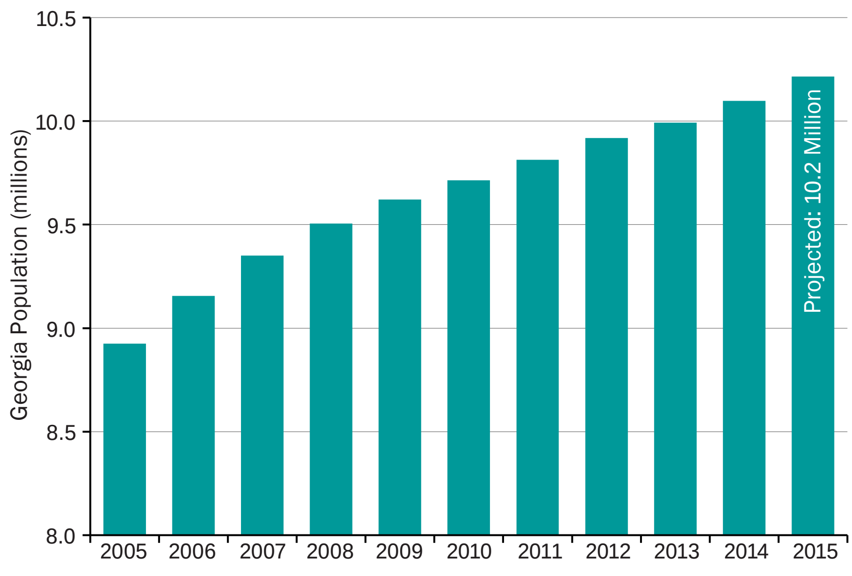

Figure 2. Population of the state of Georgia by year, 2005-2015.

Second, Georgia lacks statewide surveillance and vector control which are limited to just 13 counties conducting surveillance and 6 counties providing comprehensive mosquito control services. Third, previous surveillance has determined that *Ae. albopictus* is present in every county,*[15] but with limited surveillance, the true distribution of *Ae. aegypti* is unknown having only been recently found in 2 counties. *Ae. aegypti* had been a common species in Georgia until the introduction of *Ae. albopictus* in the 1990s. This lack of surveillance data prevents accurate quantification of human risks. Lastly, due to the federal funding cuts, the DPH has limited capacity to conduct comprehensive surveillance and mapping of vector abundance and evaluate insecticide resistance, and limited ability to provide emergency vector control.

million.[14] A CDC report based on a follow-up survey conducted by the Council of State and Territorial Epidemiologists indicated that since 2005, 22% of funded jurisdictions eliminated active human surveillance, 13% eliminated mosquito surveillance, 70% eliminated mosquito trapping, and 64% stopped avian surveillance.[13] Since 2005, the number of counties conducting routine mosquito surveillance in Georgia was reduced by 78%, from 60 to 13 counties, and all public health funding for arboviral testing and avian surveillance was eliminated (R. Kelly, unpublished data*). This report concluded that the state's ability to rapidly detect and respond to emerging disease threats is "compromised,"[13] thus placing states, including Georgia, at a disadvantage in responding to vector-borne diseases.

Georgia Preparedness

Georgia, like many states, faces several challenges to monitoring and responding to emerging arboviral diseases, with ZIKV highlighting this issue. In addition to the CDC estimating that the range of ZIKV vectors spans the entire state, several additional issues raise the risk of ZIKV transmission. First, Georgia is home to the world's busiest international airport, thus hosting visitors and tourists from ZIKV endemic countries. Additionally, many Georgia citizens travel to tourist destinations that have active ZIKV circulating. This raised the risk that a traveler could become infected and return to Georgia, thus spreading ZIKV to local mosquitoes.

*Unpublished arboviral summary statistics report prepared quarterly and annually by author R. Kelly and distributed internally within DPH, public health departments, MC agencies, and academic partners.

These challenges are compounded by the fact that Georgia's population is over 10 million people and growing (Figure 2), and has the largest number of counties (159), second only to the state of Texas.[16] These counties range from urban to suburban, with approximately 108 (68%) of the counties classified as rural (less than 35,000 population).[17] With the population of the state steadily increasing, and a public health program with limited resources, more people are potentially at risk of exposure to emerging vector-borne diseases. However, faced with these challenges, the DPH used the expertise of its State Entomologist and the environmental health program to evaluate its weaknesses and implement a rapid, collaborative response to the threat of ZIKV.

Purpose

The purpose of this case study was to describe and compare the DPH's mosquito surveillance capacity in 2015 before ZIKV was declared a public health emergency to the 2016 surveillance capacity following that declaration. Statistical comparisons were made between years on the number of counties conducting surveillance and differences in prevalence and species, in addition to a time trend analysis of mosquito species distribution. These data were used to evaluate the state's rapid response to the threat of ZIKV and the risk of autochthonous vector transmission based on the presence of the ZIKV vectors.

Methods

Mosquito surveillance trapping data provided by the DPH and surveillance data collected in collaboration with DPH were analyzed. The geographical distribution of counties conducting surveillance, total number, and overall percentage of mosquito species collected in 2015 were compared to 2016 data. The distribution of counties conducting surveillance was mapped using ArcMap 10.4.1 (Esri, Inc, Redlands, CA).

Statistical comparisons were made for the 13 counties conducting mosquito surveillance between 2015 and 2016 to test for differences in response before and after the ZIKV emergency declaration. To test differences in prevalence (number of mosquitoes trapped/100,000 population) in both years, the overall number of mosquitoes was compared using the independent 2 sample *t* test. A χ^2 analysis was performed to test for statistical differences between numbers of species trapped across all 13 counties. In addition, weighted frequency counts of mosquitoes were used to conduct a test of association (χ^2) between the major vector species of mosquitoes and the geographic county in 7 urban counties. The counties included in this χ^2 analysis were Chatham, Fulton, Glynn, Liberty, Lowndes, Muscogee, and Richmond. Lastly, a time-trend analysis was conducted using surveillance data from 2012-2016 to test differences in species prevalence over time. Statistical significance was established at the significance level 0.05.

Results

In 2015, prior to the declaration that ZIKV represented a public health emergency, Georgia had 13 counties conducting surveillance, with the DPH medical entomologist (one full time equivalent/statewide) providing routine surveillance in 4 of those counties. In 2016 (March-December), the DPH expanded surveillance to 57 counties (338% increase) geographically dispersed in urban and rural areas (Figure 3).

This rapid expansion of surveillance was a result of hiring new staff and collaborating with the local health departments (LHDs) and the military. Table 1 shows that 76,052 mosquitoes were trapped and identified in 2015 compared to 144,731 mosquitoes trapped in 2016, representing a 90% increase. Forty-four mosquito species were identified in both years with *Culex quinquefasciatus* (Say), Georgia's primary WNV vector, representing the highest percentage of mosquitoes trapped in both years (79.45% and 62.53% respectively). In reference to ZIKV vectors, *Ae. aegypti* represented only 0.108% and 0.018% respectively of the total mosquitoes trapped each year, and were found in Muscogee County only, home to Fort Benning. *Aedes albopictus* represented only 1.50% and 3.703% of the total mosquitoes trapped respectively each year, reported from 11/13 (84%) counties in 2015 and 42/57 (74%) counties in 2016.

Overall Mosquito Prevalence

To test differences in overall prevalence (number of mosquitoes/100,000 population) of mosquitoes trapped in both years from the 13 counties that have historically conducted surveillance, the number of mosquitoes was compared using the independent 2 sample *t* test. The value of the number of mosquitoes was normalized

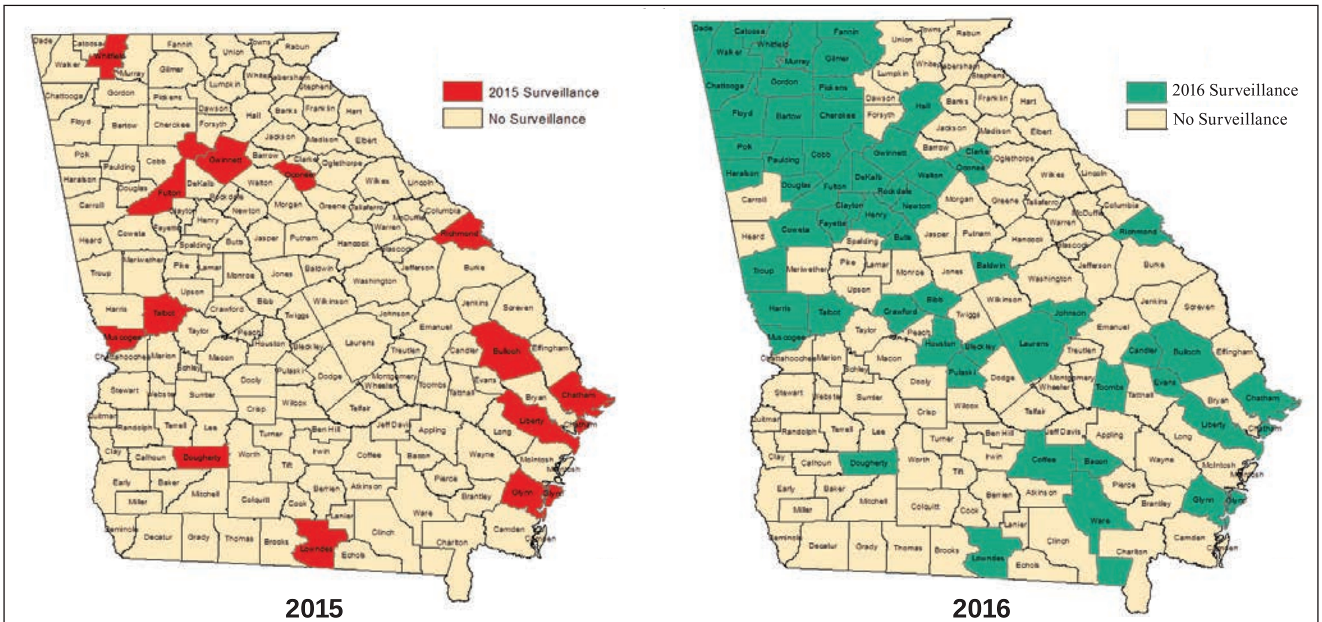

Figure 3. Georgia counties conducting mosquito surveillance in collaboration with the Georgia Department of Public Health in 2015 (13 counties) and 2016 (57 counties).

Table 1. Mosquito Species Collected, 2015-2016.

Species*	2015 Totals	13 Counties Percentages	2016 Totals	57 Counties Percentages
Ae. aegypti	82	0.108%	26	0.018%
Ae. albopictus	1,141	1.500%	5,360	3.703%
Ae. cinereus	0	0.000%	4	0.003%
Ae. japonicus	0	0.000%	1	0.001%
Ae. vexans	162	0.213%	6,536	4.516%
Aedes/Ochlerotatus spp.	6	0.008%	120	0.083%
An. barberi	0	0.000%	1	0.001%
An. crucians	25	0.033%	1,873	1.294%
An. punctipennis	26	0.034%	486	0.336%
An. quadrimaculatus	61	0.080%	265	0.183%
Anopheles spp.	5	0.007%	134	0.093%
Cq. perturbans	1,265	1.663%	5,969	4.124%
Cs. inornata	130	0.171%	14	0.010%
Cs. melanura	906	1.191%	996	0.688%
Culex spp.	4,996	6.569%	10,830	7.483%
Cx. coronator	262	0.345%	604	0.417%
Cx. erraticus	300	0.394%	2425	1.676%
Cx. nigripalpus	5,657	7.438%	11,071	7.649%
Cx. peccator	0	0.000%	12	0.008%
Cx. quinquefasciatus	60,423	79.450%	90,505	62.533%
Cx. restuans	100	0.131%	389	0.269%
Cx. salinarius	350	0.460%	2,746	1.897%
Cx. territans	1	0.001%	33	0.023%
Ma. titillans	0	0.000%	98	0.068%
Oc. japonicus	8	0.011%	52	0.036%
Oc. atlanticus	1	0.001%	757	0.523%
Oc. canadensis	0	0.000%	117	0.081%
Oc. fulvus pallens	0	0.000%	1	0.001%
Oc. infirmatus	2	0.003%	45	0.031%
Oc. mitchellae	0	0.000%	9	0.006%
Oc. sticticus	0	0.000%	31	0.021%
Oc.taeniorhynchus	0	0.000%	5	0.003%
Oc. triseriatus	25	0.033%	78	0.054%
Or. signifera	3	0.004%	23	0.016%
Ps. ciliata	0	0.000%	25	0.017%
Ps. cyanscens	2	0.003%	30	0.021%
Ps. columbiae	88	0.116%	332	0.229%
Ps. ferox	10	0.013%	106	0.073%
Ps. howardii	3	0.004%	34	0.023%
Psorophora spp.	6	0.008%	0	0.000%
Tx. rutilus	1	0.001%	52	0.036%
Ur. iowii	0	0.000%	13	0.009%
Ur.sapphrina	2	0.003%	115	0.079%
Unknown	3	0.004%	2,408	1.664%
Total	76,052		144,731	

*Data for distribution of all species statistically significant ($P \leq .05$).

using the log transformation and the normality was confirmed with Kolmogorov-Smirnoff test. While the total number of mosquitoes trapped increased from 2015 to 2016 for the 13 counties, this analysis shows there was no statistically significant differences ($P=.7901$) in the overall prevalence of mosquitoes trapped before and after ZIKV was declared an international public health emergency (Table 2A).

Table 2A. The 2-sample *t* test for difference in mosquito prevalence between 2015 and 2016.

Year	Method	Mean	95% CI
2015		6.34	4.79, 7.88
2016		6.63	4.86, 8.39
Diff (1-2)	Pooled	-0.29	-2.51, 1.93
Diff (1-2)	Satterthwaite	-0.29	-2.51, 1.94

Table 2B. The significance of the *t* test assuming equal and unequal variances.

Method	Variances	*df*	*t* value	*P* value
Pooled	Equal	24	-0.27	.7901
Satterthwaite	Unequal	23.589	-0.27	.7902

Table 2C. Results for the test of equality of variances between the 2 samples.

Method	Num *df*	Den *df*	F-value	*P* value
Folded F	12	12	1.30	.65

Table 2B shows the significance of the *t* test assuming equal and unequal variances. Table 2C shows the results for the test of equality of variances between the 2 samples

Species Analysis

To test for differences in the prevalence of individual mosquito species trapped in 2015 versus 2016 for the 13 counties, a χ^2 analysis was performed. Results show significant differences ($P<.001$) in the distribution of all mosquito species trapped in those years (Table 1). However, while there were significant differences in prevalence, this does not tell us the behaviors associated with individual species.

By combining both years (2015, 2016) of mosquito data, a secondary χ^2 analysis was conducted to test for an association between Georgia's primary arboviral vector species and urban counties with a large population of people at risk. Adjusting for inconsistent or missing data, weighted frequency counts of mosquitoes were used in the analysis. While the previous *t* test results (Table 2) indicate that overall difference in prevalence of mosquitoes is not significant between 2015 and 2016, there

Table 3A. Weighted frequency counts and corresponding weighted row percentages of important mosquito species stratified by county.

	Chatham	Fulton	Glynn	Liberty	Lowndes	Muscogee	Richmond	Total
Ae. aegypti	2 1.67%	2 1.67%	2 1.67%	2 1.67%	2 1.67%	108 90.00%	2 1.67%	120
Ae. albopictus	26 0.70%	871 23.46%	72 1.94%	53 1.43%	177 4.77%	653 17.59%	1,861 50.12%	3,713
Ae. vexans	2 0.07%	94 3.23%	2 0.07%	2 0.07%	2 0.07%	101 3.47%	2,704 93.02%	2,907
Cs. melanura	196 10.36%	2 0.11%	2 0.11%	2 0.11%	1,686 89.11%	2 0.11%	2 0.11%	1,892
Culex spp.	13,985 99.30%	28 0.20%	2 0.01%	2 0.01%	2 0.01%	17 0.12%	48 0.34%	14,084
Cx. nigripalpus	1,417 8.56%	2 0.01%	529 3.20%	2 0.01%	13,556 81.90%	2 0.01%	1,044 6.31%	16,552
Cx. quinquefasciatus	58,184 42.09%	8,472 6.13%	41,910 30.32%	85 0.06%	23,776 17.20%	778 0.56%	5,031 3.64%	138,236
Total	73,812	9,471	42,519	148	39,201	1,661	10,692	177,504

Table 3B. Chi-square value with corresponding *P* value (α=0.05).

Statistic	*df*	Value	*P* value
χ^2	36	143,393	<.0001

is a significant association (*P*<.0001) between urban counties and major vector species as shown in Table 3. However, while χ^2 tests can provide information on distribution of species between years, it does not provide detailed information on behavior of individual species, trends, and patterns over time.

Time Trend Species Analysis

A time-trend species analysis using generalized linear models (Proc GLM in SAS 9.2) was conducted on mosquito data from 2012 to 2016 to evaluate temporal trends in prevalence of mosquitoes. Statistically significant differences were observed over the 5-year period in species prevalence (*P*<.0001). While time (in years) was not significantly associated with change in overall prevalence, (*P*<.1219) its differential effect on species specific change in prevalence was significant (interaction term – *P*<.0001) (Table 4).

Looking more closely at the specific species estimates in Table 5, it can be seen that certain species had significantly different prevalence compared to the reference group, ie, *Oc. sticticus* (Meigen), throughout the 5-year period. This reference group was chosen due to low numbers of species trapped. These species were *Ae. albopictus* (S.) (*P*<.0001), *Ae. vexans* (Meigen) (*P*=.0240), *Cq. perturbans* (Walker) (*P*<.0001), *Cs. melanura* (Coquillett) (*P*<.0001), *Culex* spp. (*P*<.0001), *Cx. coronator* (Dyer and Knab) (*P*=.0463), *Cx. erraticus* (Dyer and Knab) (*P*<.0001), *Cx. nigripalpus* (Theobald) (*P*<.0001), *Cx. quinquefasciatus* (Say) (*P*<.0001), *Cx. restuans* (Theobald) (*P*=.0004), *Cx. salinarius* (Coquillett) (*P*<.0001) and *Oc. triseriatus* (Say) (*P*<.0001).

Table 4. Time trend analysis showing the type III sums of squares and corresponding *P* values (α=0.05) for the variables species, year, and the interaction term.

	df	Type III SS	Mean Square	F-value	*P* value
Species	41	1589.943667	38.779114	14.25	<.0001
Year	1	6.521391	6.521391	2.40	.1219
Year species	41	318.828534	7.776306	2.86	<.0001

For associated species-year trends in Table 5, *Cs. melanura* (*P*<.0042), *Culex* spp. (*P*<.0013), *Cx. erraticus* (*P* <.0271), *Cx. nigripalpus* (*P*<.0074), *Cx. restuans* (*P*<.0433) and *Cx. salinarius* (*P*<.0266) were found to have a significant difference in change of prevalence with each year compared to the reference species *Oc. sticticus*.

Comment

The public health entomology program, which includes mosquito surveillance, falls under the DPH Environmental Health (EH) Section. This program is managed by a medical entomologist who holds graduate degrees in public health and entomology and who was originally hired under Epidemiology and Laboratory Capacity funding in 2002 to manage the WNV outbreak. The state medical entomologist provides technical assistance and consultation to LHDs, mosquito control agencies and the general public and was largely responsible for overseeing Georgia's rapid response to ZIKV. In 2015, surveillance and identification of mosquitoes was limited to just 13 counties in Georgia. With this limited data, DPH provided quarterly surveillance reports to partner agencies for planning and risk assessment purposes.

When ZIKV was declared an international public health emergency,[1] the DPH recognized its weaknesses and formed a core team of professionals to develop and lead a response. This diverse team was comprised of EH, medical entomology, medical epidemiology, communications, emergency preparedness, and leadership. An assessment was conducted to ascertain agency strengths, weaknesses, and overall needs to develop a response. This evaluation assessed geographical gaps in mosquito data and surveillance staff needs, opportunities for new or expanded partnerships that could enhance a response and facilitate data sharing, training of existing staff, and funding needs. Leadership made the ZIKV response a priority and identified existing grant funding, which significantly contributed to a rapid response. The assessment guided DPH in utilizing those funds to hire additional surveillance staff and assign them regionally across the state, updated existing surveillance and response plans originally written for WNV, provided rapid training to new and existing staff across the state in surveillance and response, purchased equipment, and expanded collaborations with the military to share data and respond to this threat.

Table 5. The results of the PROC GLM (SAS 9.2) procedure showing changes in the log of mosquito prevalence by year and the differential trends in log of mosquito prevalence by year.*

Parameter	Estimate	Standard Error	*t* value	*P* value
Intercept	0.18	0.61	0.29	.76
Ae. albopictus	5.34	1.20	4.44	<.0001
Ae. vexans	1.84	0.81	2.26	.02
Cq. perturbans	2.84	0.71	4.00	<.0001
Cs. melanura	3.03	0.72	4.21	<.0001
Culex spp.	4.02	0.75	5.33	<.0001
Cx. coronator	1.50	0.75	1.99	.0463
Cx. erraticus	4.00	0.79	5.01	<.0001
Cx. nigripalpus	4.07	0.68	5.91	<.0001
Cx. quinquefasciatus	6.79	0.66	10.16	<.0001
Cx. restuans	2.48	0.69	3.55	.0004
Cx. salinarius	2.97	0.69	4.30	<.0001
Oc. triseriatus	1.62	0.70	2.29	.02
Oc. sticticus	Ref			
year species *Cs. melanura*	-1.29	0.45	-2.87	.004
year species *Culex* spp.	-1.51	0.46	-3.23	.001
year species *Cx. erraticus*	-1.10	0.50	-2.21	.02
year species *Cx. nigripalpus*	-1.15	0.43	-2.68	.007
year species *Cx. restuans*	-0.88	0.43	-2.02	.04
year species *Cx. salinarius*	-0.95	0.43	-2.22	.02
year species *Oc. sticticus*	Ref			

*Only results significant at α=0.05 are shown.

As the results in Table 1 indicate, DPH successfully and rapidly expanded its surveillance footprint by 338%, from 13 counties in 2015 to 57 counties in 2016, representing 36% of the state. While the overall number of counties conducting surveillance seems low, given there are 159 counties, it should be noted that this rapid expansion occurred in just 8 months (May-December) and all major urban population centers have active surveillance. In addition, the distribution of surveillance covered all regions of the state. This expansion led to the overall number of mosquitoes trapped increasing by 90.3%, from 2015 to 2016, allowing better decision making. Rapid expansion was achieved because the DPH leadership made the ZIKV response a top priority and streamlined the hiring and purchasing processes. Prior to hiring new staff (March-April), the environmental health program updated its WNV surveillance and response plan by tailoring it for ZIKV. In addition, a training curriculum, standard operating procedures, job description for surveillance staff, and regions were established. The DPH collaborated with regional public health departments to provide office and storage space for the new surveillance staff, a critical component for a successful program.

In April and May, 5 new surveillance staff members were hired and provided 2 weeks of just-in-time training on mosquito surveillance techniques and identification, with priority placed on ZIKV vectors, risk communication, data management, and vector control. Each new staff member was assigned a region to cover and provided with surveillance and response equipment (traps, larvicides, backpack sprayers, microscope, educational material). In addition, the state entomologist provided ongoing training and consultation throughout the year, and assisted new staff with establishing surveillance sites throughout their region. To assist the new regional staff, the DPH provided training, surveillance equipment, and funding to existing LHD environmental health staff across the state, efforts which were invaluable in expanding the surveillance footprint across Georgia.

Historically, Georgia's mosquito surveillance objectives were driven by the threat of WNV, and mosquito trapping was prioritized to capture the primary WNV vector, *Cx. quinquefasciatus.* This is highlighted in Table 1, with *Cx. quinquefasciatus* as the highest percentage of mosquitoes trapped overall in 2015 and 2016 at 79.4% (60,423) and 62.5% (90,505) respectively. However, the threat of ZIKV required surveillance staff to shift some focus away from the WNV vector and prioritize trapping in urban/suburban areas to target container-breeding *Ae. aegpyti* and *Ae. albopictus.* While overall counts and percentages of both ZIKV vectors were low in 2015 and 2016, it is important to note that this shift in surveillance focus is demonstrated in Table 1 by an increase in *Ae. albopictus* trapped (1.5% to 3.7%) and a decrease in WNV vectors trapped (79.4% to 62.5%). *Aedes aegypti*, the primary ZIKV vector, was trapped in one county (Muscogee) for both years and overall numbers decreased from 82 mosquitoes in 2015 to 26 in 2016, representing an 83% decrease. While surveillance has been limited, *Ae. aegpyti* was only found in Muscogee County and Chatham County in the last decade, suggesting that *Ae. albopictus* has outcompeted this species given its propensity for surviving in surburban/urban areas.[18]

The next 4 highest percentages of mosquitoes trapped in 2016 were *Cx. nigripalpus*, *Culex* spp, *Ae. vexans*, and *Cq. perturbans*. The number of *Ae. vexans* exploded in 2016 to 6,583 mosquitoes compared to 2015 at 162. This increase came in the aftermath of Hurricane Matthew, which left behind ideal breeding conditions for this inland floodwater species, resulting in standing water in low-land and grassy areas of southeast Georgia. It's important to point out that the top 5 mosquitoes captured are major vectors of Eastern Equine Encephalitis (EEE), St. Louis Encephalitis (SLE), and WNV, either serving to amplifying the virus enzootically, or as a primary or bridge vector to humans.[19-21]

Statistical Analysis

To determine if there were any statistical differences or associations in the DPH surveillance program before and after the ZIKV emergency declaration, a series of statistical tests were run comparing data between the same 13 counties historically conducting surveillance. The *t* test examined the overall prevalence of mosquitoes per 100,000 population. While this test did not show statistically significant differences in prevalence, it should be noted that the overall number of mosquitoes trapped increased by 66%, from 76,052 to 126,584 mosquitoes in these 13 counties. This increase demonstrated the rapid expansion of surveillance in response to ZIKV.

A series of χ^2 analyses were conducted to test for any differences between both years for the same counties at the species level. Overall, there were significant differences found in several of the mosquito species trapped between years. Of importance to ZIKV, there was a statistically significant increase in *Ae. albopictus* from 2015 to 2016 and a statistically significant decrease in *Ae. aegypti* between those years. In addition, there was a statistically significant decrease in the number of *Cx. quinquefasciatus*. This was likely due to a shift in focus on targeting the ZIKV vectors which have different breeding habitats. However, Georgia experienced a dry late spring and summer with abnormally cooler nights, which could have affected both vector species.

When Georgia's primary disease vector species was statistically compared to large urban counties, a significant association between species and county was found. This is critically important because the majority of the state's population is found in these large urban counties, putting more people at risk for arboviral diseases and demonstrating the ongoing need for surveillance.

To determine if there were any temporal trends in the distribution of species over time, a time-trend analysis was conducted on mosquito data from 2012 through 2016. This analysis demonstrated that over a 5-year period, there were significant differences in prevalence for several important disease vector species in Georgia that transmit WNV (*Cx. quinquefasciatus*) , EEE (*Cs. melanura, Ae. vexans, Culex* spp), SLE (*Cx. nigripalpus)* and LaCrosse encephalitis (*Oc. triseriatus*), in addition to nuisance species. Of note is the significant prevalence of *Oc. triseriatus* over the 5-year period. This mosquito represents Georgia's primary vector for LaCrosse encephalitis and demonstrates potential risk, as it has been trapped consistently over the 5-year period. It can adapt to its surroundings and lay eggs in forest or urban container environments,[22] highlighting the critical importance of continued surveillance for this species and other major disease vectors. Knowing these temporal trends allows public health and mosquito control professionals to predict risks and better prepare.

Military Collaboration

While Georgia was able to expand its surveillance capacity rapidly with internal resources, it is important to point out the vital collaborations and contributions made by the military. These collaborations were essential because military personnel travel to ZIKV endemic countries and many of them live off base, necessitating a need to partner and share data. In past years when WNV was the focus of concern, the DPH Vector-borne and Zoonotic Section formed a cooperative agreement with the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) to share mosquito surveillance and testing data collected within the State. Unfortunately, when USACHPPM-South moved its headquarters from Georgia to Fort Sam Houston, Texas, that collaboration was largely lost.

In 2016, as mosquito surveillance was being increased in Georgia, a connection with the military was sought again. Not having one central agency made this process somewhat difficult, as each base had to be approached individually, but ultimately several connections were made. As one example, Dobbins Air Reserve Base Bioenvironmental Engineers (BEE) partnered with the DPH as part of the Department of Defense initiative to combat ZIKV and other mosquito-borne diseases. One of DPH's new vector surveillance coordinators, along with BEE personnel, laid traps at the Dobbins firing range, an area of frequent mosquito complaints. Mosquitoes collected were identified, and education, source reduction, and chemical control were used to reduce mosquito numbers in the area and reduce risk to military personnel. Follow up surveillance was done, and plans were made to continue this partnership in 2017. This important partnership was published by the US Air Force News Service as shown in Figure 4.[23]

Figure 4. Georgia Department of Public Health vector surveillance coordinator installing mosquito traps at the Dobbins Air Reserve Base.[23]

In addition, Fort Benning, Fort Stewart, Hunter Army Airfield, and Robins Air Force Base agreed to share mosquito surveillance and testing data with the DPH. This not only provides additional information to the DPH concerning disease risks, but also provides mosquito control both on and off the bases with the information they need to reduce mosquito populations and disease risk. It should be noted that Fort Gordon has had a long-standing collaboration with the Richmond County Mosquito Control Program, a division of the local health department.

Conclusion

The collaborative response to ZIKV allowed DPH to rapidly increase its surveillance footprint across the state and train new and existing staff on outbreak response. With these new monitoring and response capabilities, the DPH can make sound public health decisions regarding disease risks and quickly respond to local outbreaks of ZIKV or other vector borne diseases.

Enhanced Capabilities

The Georgia DPH was able to rapidly expand its surveillance capacity statewide because its leadership recognized the seriousness and potential impact of ZIKV on the state and prioritized vector-borne diseases and surveillance. This allowed the agency to maximize existing resources to expand surveillance capacity and reignite historic and develop new collaborations with various entities, most importantly the LHDs and the military. This expanded surveillance network provided a clearer picture of the types of mosquitoes potentially exposing the public to mosquito-borne diseases and allowed DPH to better quantify risks and provide public education. Statistical analysis of the data validates the need for ongoing expanded surveillance.

In evaluating the risk of ZIKV transmission, recent historic data for the primary vector of ZIKV, *Ae. aegypti*, was isolated to just 2 counties in Georgia. Expanded surveillance in 2016 confirmed a low presence of *Ae. aegypti* having been found in just one county, suggesting the primary vector for Zika has been displaced by *Ae. albopictus.* This also suggests a reduced risk of autochthonous transmission of Zika virus in Georgia due to the affinity of *Ae. Albopictus* for feeding on both humans and animals. However, this should be interpreted with caution due to unstandardized reporting techniques for each county, lack of systematic surveillance in every county, and a dry spring and summer that reduced overall number of mosquitoes trapped. The DPH is working with all counties to improve the quality of data reported, and will continue to assess the abundance and distribution of *Ae. aegypti* each year to evaluate risks. In addition, while DPH expanded surveillance to 57 counties which comprise approximately 36% of the state's 159 counties, the agency continues to work with the LHDs to establish additional surveillance sites with the goal of 100% of counties conducting mosquito surveillance. This will allow better interpretation of overall mosquito abundance and distribution across the state.

Public Health Implications

By increasing the number of counties involved in surveillance and knowing the specific species of mosquitoes throughout the state, the DPH can better predict and quantify the risks of disease transmission in specific regions of Georgia. However, increasing and maintaining surveillance comes with its own challenges, with stable funding being the largest obstacle to a robust surveillance system. The DPH was able to prioritize existing funding to kick start a rapid response and was subsequently awarded grants from the CDC specifically for ZIKV, but these funding streams are temporary and allocated for a specific disease. It is critically important that funding for monitoring, surveillance, and response becomes a permanent federal funding source, and that it does not follow the same path as WNV funding reductions of the past. If so, the United States may not be prepared to respond to the next emerging arboviral disease, and the results could be disastrous for a population that has no natural immunity.

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