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Forum

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Heterogeneity of Mosquito (Diptera: Culicidae) Control Community Size, Research Productivity, and Arboviral Diseases Across the United States

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Abstract

Multiple factors lead to extensive variation in mosquito and mosquito-borne virus control programs throughout the United States. This variation is related to differences in budgets, number of personnel, operational activities targeting nuisance or vector species, integration of Geographical Information Systems, and the degree of research and development to improve management interventions through collaboration with academic institutions. To highlight this heterogeneity, the current study evaluates associations among the size of a mosquito control community, the research productivity, and the mosquito-borne virus human disease burden among states within the continental United States. I used the attendance at state mosquito and vector control meetings as a proxy for the size of the mosquito control community in each state. To judge research productivity, I used all peer-reviewed publications on mosquitoes and mosquito-borne viruses using data originating in each state over a 5- and 20-yr period. Total neuroinvasive human disease cases caused by mosquito-borne viruses were aggregated for each state. These data were compared directly and after adjusting for differences in human population size for each state. Results revealed that mean meeting attendance was positively correlated with the number of publications in each state, but not after correcting for the size of the population in each state. Additionally, human disease cases were positively correlated with the number of publications in each state. Finally, mean meeting attendance and human disease cases were only marginally positively associated, and no correlation existed after correcting for human population size. These analyses indicated that the mosquito control community size, research productivity, and mosquito-borne viral human disease burden varied greatly among states. The mechanisms resulting in this variation were discussed and the consequences of this variation are important given the constantly changing environment due to invasive mosquito species and arboviruses, urbanization, immigration, global travel, and climate change.

Key words: arbovirology, mosquito control, mosquito-borne disease, public health entomology

Mosquito and mosquito-borne disease control and prevention in the United States are principally organized by local agencies at the municipality, county, or state level. The ability of these agencies to secure sufficient budgets to build the infrastructure to conduct ongoing surveillance and implement control programs is a determinant of the strength of these programs and typically is related to human population size. Additionally, the ability of these programs to conduct research, either in house or through collaborations with academic partners, allows these programs to adapt to the ever-changing conditions given invasive species (e.g., newly introduced mosquito species and viruses), advancements in control tools (e.g., new insecticides, ultra low volume sprayers, and traps), advancements in diagnostic capability, and a changing environment (e.g., urbanization, immigration, and climate change). Despite the convergence of many cities and states throughout the United States on the same mosquito-related challenges and approaches to resolving these challenges, extensive variation exists which leads to different mosquito control "cultures" with regard to the technique, magnitude, and effectiveness of interventions.

At the most fundamental level, each city, county, and state faces the challenges of securing financial resources to conduct mosquito and mosquito-borne disease control programs. Many well-funded programs exist in regions of the United States with large nuisance mosquito populations, as exemplified by the numerous large and well-developed mosquito control programs along the Atlantic, Pacific, and Gulf coasts targeting brackish water species of mosquitoes that thrive in those regions. The nuisance of mosquitoes leads to a greater public awareness and increases their willingness to pay for mosquito control more than the disease risk posed by mosquito-borne viruses (Dickinson and Paskewitz 2012).

In addition to a sufficient budget, each city, county, and state requires a history of leadership and coordination to build the infrastructure for large regional mosquito control programs. For example, Dr. John B. Smith (1858–1912) was a Professor of Entomology at Rutgers University and is acknowledged as being responsible for laying the foundation for organized mosquito control in the twentieth century (Patterson 2009). The New Jersey Agricultural Experiment Station (now the Rutgers Center for Vector Biology) remains strong in basic and applied research working in close cooperation with the vector control agencies throughout the state. Likewise in California, the leadership and accomplishments of Dr. William C. Reeves (1916–2004) was instrumental in allowing California to develop from their first Mosquito Abatement Districts in 1915 to having extensive programs coordinated by the Mosquito and Vector Control Association of California (University of California 2004, Patterson 2009). In particular, the accomplishments of Reeves in advancing the field of arbovirology and redirecting control programs from *Aedes* and to *Culex* for the management of Western equine encephalitis and St. Louis encephalitis viruses allowed California to quickly adapt control programs to West Nile virus (WNV) following its invasion in 2003. In the southern United States, Dr. Jimmy Olson (1942–2015) maintained a strong medical entomology program at Texas A&M University and was instrumental in enhancing statewide mosquito control programs through collaborative applied research programs and educational outreach.

Although nuisance mosquitoes were the primary reason for the antimosquito movement at the turn of the twentieth century, the awareness of the ability of mosquitoes to transmit pathogens resulting in human disease was also critical. The discovery that mosquitoes could transmit viruses (a.k.a. arthropod-borne viruses or arboviruses) occurred during the 1890s by Walter Reed and colleagues (Staples and Monath 2008), which is the same decade that Sir Ronald Ross discovered that mosquitoes could transmit human malaria (Cox 2010). Yellow fever epidemics had plagued the United States for over two centuries, with the last epidemic in 1905 in New Orleans, and successful mosquito control campaigns are attributed to limiting the severity of that epidemic. In addition, human malaria was a major public health problem in the southeastern United States and was successfully eliminated due in part to large coordinated efforts by the Tennessee Valley Authority in the 1930s and the National Malaria Eradication Program in the 1940s and 1950s (Derryberry and Gartrell 1952). The importance of mosquitoes as vectors led many newly established mosquito control programs to be called “mosquito and vector control.” More recently, the invasion of the United States by WNV in 1999, was a catalyst for enhancing many mosquito surveillance and control programs throughout the United States. WNV has resulted in >780,000 human illnesses and >1,550 deaths since 1999 (Petersen et al. 2013), and the increased surveillance and control for the virus was partially facilitated by an increase in federal funds provided by the Centers for Disease Control and Prevention, but these funds have mostly dissipated.

Due to differences in landscape, budget, historical leadership, and mosquito-borne disease burden, the mosquito control culture around the United States is highly variable. On one end of the spectrum is a city or state that has essentially no organized mosquito surveillance or control program and at the other end of the spectrum is a well-funded and highly coordinated area-wide program. Because the distribution of mosquitoes and the pathogens they transmit don’t conform to geo-political boundaries (Lounibos 2002), this variation in mosquito control programs has important consequences. The ability of each city, county, or state to communicate with neighbors and exchange information and collaborate particularly after a disease outbreak or natural disaster is critical to a successful program, especially in a constantly changing environment.

The objective of the current study was to identify associations among the size of a state’s mosquito control community, the research productivity, and the arbovirus disease burden in the continental United States. The spatial scale of this analysis is at the level of the state, and the epidemiological data that were analyzed were limited to mosquito-borne viruses resulting in human neuroinvasive disease in the past half century. Given that the size of a mosquito control community in each state is difficult to quantify, I used the attendance at state mosquito and vector control meetings as a proxy. To judge research productivity, I used all peer-reviewed publications describing research on mosquitoes and mosquito-borne viruses within each state over recent (5 yr) and longer time periods (20 yr).

Materials and Methods

Meeting Attendance

Data on attendance at annual meetings focused on mosquito control and vector-borne disease were obtained by contacting representatives from each state for the 5-yr period from 2009 to 2013 (Table 1). Multistate regional meetings that are associated with the American Mosquito Control Association as well as state-level meetings were included. For regional meetings, the total meeting attendance was allocated to each participating state weighted by the total state population. Some states have two meetings each year (e.g., a spring workshop and a fall conference) but the smaller meetings were not included in the analysis. In most cases, representatives from each state or region had archived attendance records. In three states (Missouri, Nevada, Idaho) and one regional association (Mid-Atlantic Mosquito Control Association) where these records did not exist, the representatives estimated the attendance for each year.

Publications

The goal of the quantitative synthesis of peer-reviewed publications is to produce an index that captures the volume of research utilizing data from a state. The Web of Science search engine was used to find peer-reviewed publications related to mosquitoes and mosquito-borne viruses for each state. The literature was searched over a 5-yr period (2009 to 2013) and a 20-yr period (1993 to 2013) and used keyword searches of State + “West Nile virus,” “St. Louis encephalitis,” “eastern equine encephalitis,” “western equine encephalitis,” “LaCrosse encephalitis,” “dengue virus,” and “mosquito.” Each of these searches (i.e., “state + key word”) was a separate query and the search term “state + mosquito” generally returned the largest number of matches. Each peer-reviewed publication resulting from these key-word searches was reviewed and only those publications utilizing data (mosquito collections, animal collections, or human data) collected from within the target state were included in the analysis. In the case of publications that reported on field-collected data from multiple states, each represented state was credited with the publication. When a publication was exclusively a large spatial analysis using human arbovirus disease data for every state in the United States, the publication did not count for any state. When the published studies were exclusively laboratory experiments, they did not count for any state. The affiliations of the authors were not considered while compiling the publications for each state.

Arboviral Disease

The total number of human mosquito-borne viral disease cases for each state in the continental United States was aggregated using data from the Centers for Disease Control and Prevention website (http://www.cdc.gov/westnile/statsmaps/index.html, last accessed February

Table 1. Mosquito control organization name, meeting name, and the aggregate of all meeting attendence from 2009 to 2013

State	First organization	Meeting name	Second organization	Meeting name	2009	2010	2011	2012	2013	Mean attendance
Alabama	Alabama Vector Management Society	AVMS Annual Meeting			71.0	63.0	111.0	115.0	115.0	95.0
Alaska	Northwest Mosquito and Vector Control Assoc.	NWMVCA Annual Meeting			6.4	4.5	6.1	6.5	5.9	5.9
Arizona	Vector-borne and Zoonotic Diseases Program	Annual Vector-Borne & Zoonotic Disease Conference & Workshop			218.0	150.0	150.0	56.0	66.0	128.0
Arkansas	None	None			0.0	0.0	0.0	0.0	0.0	0.0
California	Mosquito and Vector Control Assoc. of California	MVCAC Annual Conference			467.0	487.0	392.0	426.0	532.0	460.8
Colorado	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting			26.1	26.1	26.1	26.1	19.9	24.9
Connecticut	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			12.8	15.5	16.8	13.0	15.7	14.8
Delaware	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference			1.2	1.3	1.3	1.5	1.4	1.4
Florida	Florida Mosquito Control Assoc.	FMCA Annual Meeting			216.0	216.0	213.0	187.0	247.0	215.8
Georgia	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference	Georgia Mosquito Control Assoc.	GMCA Annual Meeting	62.6	64.3	64.1	66.4	65.4	64.6
Idaho	Idaho Mosquito and Vector Control Assoc.	IMVCA Fall and Spring Conference	Northwest Mosquito and Vector Control Assoc.	NWMVCA Annual Meeting	59.0	54.9	58.4	59.2	57.9	57.9
Illinois	Illinois Mosquito and Vector Control Assoc.	IMVCAC Annual Meeting			107.0	95.0	87.0	118.0	112.0	103.8
Indiana	Indiana Vector Control Assoc.	IVCA Annual Conference			100.0	85.0	97.0	100.0	79.0	92.2
Iowa	North Central Mosquito Control Assoc.	North Central MCA Annual Meeting			16.2	15.2	18.6	15.6	20.7	17.3
Kansas	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting			14.3	14.3	14.3	14.3	11.0	13.7
Kentucky	None	None			0.0	0.0	0.0	0.0	0.0	0.0
Louisiana	Louisiana Mosquito Control Assoc.	LMCA Annual Meeting			129.3	196.0	169.0	188.0	176.0	171.7
Maine	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			4.7	5.7	6.2	4.8	5.8	5.5
Maryland	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference			7.5	8.5	8.4	9.7	9.2	8.7
Massachusetts	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			23.9	28.8	31.3	24.2	29.3	27.5
Michigan	Michigan Mosquito Control Assoc.	MMCA Annual Conference			98.0	101.0	65.0	94.0	101.0	91.8
Minnesota	North Central Mosquito Control Assoc.	North Central MCA Annual Meeting			28.4	26.7	32.5	27.4	36.3	30.3
Mississippi	Mississippi Mosquito & Vector Control Assoc.	MMVCA Annual Meeting			149.0	126.0	134.0	139.0	129.0	135.4
Missouri	Missouri Mosquito and Vector Control Assoc.	MMVCA Annual Conference			50.0	50.0	50.0	50.0	50.0	50.0
Montana	Northwest Mosquito and Vector Control Assoc.	NWMVCA Annual Meeting			8.8	6.3	8.5	9.0	8.1	8.1
Nebraska	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting	Nebraska Mosquito & Vector Control Assoc.	NMVCA Annual Conference	89.3	99.3	104.3	109.3	72.1	94.8
Nevada	Informal meeting annually in April	Annual meeting			25.0	25.0	25.0	25.0	25.0	25.0
New Hampshire	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			4.7	5.7	6.2	4.8	5.8	5.4
New Jersey	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting	New Jersey Mosquito Control Assoc.	NJMCA Annual Meeting	219.7	224.3	204.6	208.2	217.2	214.8
New Mexico	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting			10.3	10.3	10.3	10.3	7.9	9.8
New York	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			70.1	84.7	92.0	71.0	86.0	80.8
North Carolina	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference			12.5	14.1	13.9	16.2	15.2	14.4
North Dakota	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting	North Central Mosquito Control Assoc.	North Central MCA Annual Meeting	7.4	7.1	7.9	7.2	7.6	7.5
Ohio	Ohio Mosquito Control Assoc.	OMCA Annual Meeting			50.0	50.0	40.0	38.0	39.0	43.4
Oklahoma	None	None			0.0	0.0	0.0	0.0	0.0	0.0
Oregon	Northwest Mosquito and Vector Control Assoc.	NWMVCA Annual Meeting			34.2	24.2	32.8	34.7	31.4	31.5

(continued)

Table 1. Continued

State	First organization	Meeting name	Second organization	Meeting name	2009	2010	2011	2012	2013	Mean attendance
Pennsylvania	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference	Pennsylvania Vector Control Assoc.	PVCA Annual Conference	113.2	118.3	103.1	121.0	103.7	111.8
Rhode Island	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			3.8	4.5	4.9	3.8	4.6	4.3
South Carolina	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference	South Carolina Mosquito Control Assoc.	SCMCA Annual Meeting	126.0	107.8	87.7	97.8	82.4	100.4
South Dakota	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting	North Central Mosquito Control Assoc.	North Central MCA Annual Meeting	8.6	8.3	9.3	8.5	8.9	8.7
Tennessee	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference	Tennessee Mosquito and Vector Control Assoc.	TMVCA Annual Meeting	8.2	9.3	9.2	70.7	65.0	32.5
Texas	Texas Mosquito Control Assoc.	TMCA Annual Meetings			47.7	59.0	55.0	75.0	80.0	63.3
Utah	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting	Utah Mosquito Abatement Assoc.	UMAA Annual Convention	152.4	140.4	153.4	146.4	139.0	146.3
Vermont	Northeastern Mosquito Control Assoc.	NMCA Annual Meeting			2.2	2.7	2.9	2.3	2.7	2.6
Virginia	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference	Virginia Mosquito Control Assoc.	VMCA Annual Meeting	132.5	120.8	120.7	123.6	103.8	120.3
Washington	Northwest Mosquito and Vector Control Assoc.	NWMVCA Annual Meeting			60.6	43.0	58.2	61.6	55.7	55.8
West Virginia	Mid-Atlantic Mosquito Control Assoc.	MAMCA Annual Conference			2.3	2.7	2.6	3.0	2.9	2.7
Wisconsin	North Central Mosquito Control Assoc.	North Central MCA Annual Meeting			30.1	28.3	34.5	29.0	38.5	32.1
Wyoming	West Central Mosquito and Vector Control Assoc.	WCMVCA Annual Meeting			2.9	2.9	2.9	2.9	2.2	2.7

4, 2016) and the USGS Disease Maps website (http://diseasemaps.usgs.gov/, last accessed February 4, 2016). The arboviruses and inclusion years (in parentheses) included West Nile virus (1999–2013), St. Louis Encephalitis (1964–2010), Eastern equine encephalitis (1964–2010), LaCrosse encephalitis (1964–2010), Western equine encephalitis (2003–2013), and Dengue (2010–2013). The inclusion years were dictated by available data provided by the CDC and USGS. Disease reports were reviewed and only cases that met the neuroinvasive disease criteria (for the encephalitis viruses) and only included locally acquired cases (for Dengue) were included in the analysis.

Statistical Analyses

Meeting attendance, publications, and arboviral human disease data were gathered for the 48 continental United States, plus the District of Columbia. Data were presented and analyzed as raw values for each state as well as standardized per population of a state × 100,000 (United States Census Bureau 2013 Population Estimates; Table 1). I performed linear regressions to compare all pairwise relationships between meeting attendance data, publications, and arboviral disease. The dependent variables (either publications or disease cases) were log (x +1) transformed to improve normality. Separate models were performed for each independent variable on both the raw data and the population-adjusted data. Scatterplots are presented with untransformed data for ease of interpretation. Means are presented with standard errors. Linear regressions were performed in Program R (R Development Core Team 2015).

Results

All states had either their own mosquito and vector control annual meeting or were part of a regional association with an annual meeting, except three states: Arkansas, Kentucky, and Oklahoma (Table 1). The mean number of attendees for all states from 2009 to 2013 was 62.0 ± 11.6. The mean for each year was 63.1, 61.9, 60.0, 61.7, and 63.1, showing that over this time period, the number of attendees was stable. California, Florida, and New Jersey have the largest meeting attendance but after correcting for population size, the states with the highest adjusted meeting attendance were Nebraska, Utah, and Mississippi.

There were a total of 372 publications in all states combined for the 5-yr period (2009 to 2013), meeting the selection criteria related to mosquitoes and arboviruses. The mean number of publications per state over the 5-yr period was 7.6 ± 1.5 and median was 4 (Table 2). There were a total of 1,161 publications for the 20-yr period (1993 to 2013), meeting the selection criteria for state + mosquitoes and arboviruses. The mean number of publications for each state over the 20-yr period was 23.7 ± 4.7 with a median of 12. The three states with the highest number of publications for both the 5-yr and 20-yr periods were California, New York, and Florida. After correcting for population size, the states with the highest adjusted number of publications were North Dakota, South Dakota, and Montana for the 5-yr period and Wyoming, North Dakota, and Montana for the 20-yr period.

The total number neuroinvasive arboviral human disease cases for all states combined was 26,199, with a mean of 534.7 ± 96.7 per state and median of 307 (Table 2). States with the lowest number of arboviral human disease cases reported were Maine ($n = 1$), Vermont ($n = 3$), and New Hampshire ($n = 16$), and those with the highest number were Texas ($n = 3{,}522$), Illinois ($n = 2{,}234$), and California ($n = 2{,}033$). Once adjusted for population size in each

Table 2. Data showing 5-yr mean mosquito control meeting attendance (2009–2013), 20-yr total publications (1993–2013), 5-yr total publications (2009–2013), and total arboviral neuroinvasive human disease (1964–2013) for each state

State	State abbr.	Population est. July 1, 2013	5-yr mean attendance	5-yr mean attendance/ state pop. × 100,000	20-yr total pubs	20-yr total pubs/state population × 100,000	5-yr total pubs	5-yr total pubs/state pop. × 100,000	Total arboviral human disease cases	Total human disease/state pop. × 100,000
Arkansas	AR	2959373	0.00	0.000	9	0.304	2	0.068	286	9.664
District of Columbia	DC	646449	0.00	0.000	5	0.773	4	0.619	57	8.817
Kentucky	KY	4395295	0.00	0.000	1	0.023	0	0.000	196	4.459
Oklahoma	OK	3850568	0.00	0.000	7	0.182	2	0.052	382	9.921
Maryland	MD	5928814	8.65	0.146	11	0.186	1	0.017	193	3.255
Delaware	DE	925749	1.35	0.146	5	0.540	1	0.108	24	2.592
North Carolina	NC	9848060	14.37	0.146	28	0.284	3	0.030	302	3.067
West Virginia	WV	1854304	2.71	0.146	11	0.593	2	0.108	628	33.867
Texas	TX	26448193	63.34	0.239	77	0.291	23	0.087	3522	13.317
Ohio	OH	11570808	43.40	0.375	27	0.233	6	0.052	1984	17.147
Connecticut	CT	3596080	14.78	0.411	30	0.834	7	0.195	77	2.141
Maine	ME	1328302	5.46	0.411	3	0.226	2	0.151	1	0.075
Massachusetts	MA	6692824	27.50	0.411	8	0.120	1	0.015	124	1.853
New Hampshire	NH	1323459	5.44	0.411	4	0.302	1	0.076	16	1.209
New York	NY	19651127	80.75	0.411	128	0.651	37	0.188	587	2.987
Rhode Island	RI	1051511	4.32	0.411	7	0.666	1	0.095	19	1.807
Vermont	VT	626630	2.58	0.411	3	0.479	3	0.479	3	0.479
Kansas	KS	2893957	13.65	0.472	5	0.173	2	0.069	384	13.269
Colorado	CO	5268367	24.86	0.472	24	0.456	12	0.228	1176	22.322
New Mexico	NM	2085287	9.84	0.472	14	0.671	6	0.288	259	12.420
Wyoming	WY	582658	2.75	0.472	18	3.089	3	0.515	165	28.318
Tennessee	TN	6495978	32.48	0.500	30	0.462	10	0.154	491	7.559
Iowa	IA	3090416	17.27	0.559	12	0.388	4	0.129	376	12.167
Minnesota	MN	5420380	30.28	0.559	7	0.129	3	0.055	618	11.401
Wisconsin	WI	5742713	32.09	0.559	19	0.331	4	0.070	723	12.590
Georgia	GA	9992167	64.58	0.646	20	0.200	5	0.050	245	2.452
Montana	MT	1015165	8.13	0.801	15	1.478	7	0.690	153	15.071
Oregon	OR	3930065	31.46	0.801	6	0.153	0	0.000	28	0.712
Washington	WA	6971406	55.81	0.801	12	0.172	2	0.029	37	0.531
Illinois	IL	12882135	103.80	0.806	48	0.373	22	0.171	2234	17.342
Missouri	MO	6044171	50.00	0.827	3	0.050	1	0.017	478	7.908
Pennsylvania	PA	12773801	111.84	0.876	19	0.149	4	0.031	349	2.732
Nevada	NV	2790136	25.00	0.896	6	0.215	4	0.143	122	4.373
Michigan	MI	9895622	91.80	0.928	15	0.152	3	0.030	1011	10.217
South Dakota	SD	844877	8.71	1.031	10	1.184	6	0.710	441	52.197
North Dakota	ND	723393	7.45	1.031	16	2.212	6	0.829	307	42.439
Florida	FL	19552860	215.80	1.104	110	0.563	36	0.184	786	4.020
California	CA	38332521	460.80	1.202	165	0.430	47	0.123	2033	5.304
Indiana	IN	6570902	92.20	1.403	4	0.061	1	0.015	853	12.981
Virginia	VA	8260405	120.25	1.456	26	0.315	8	0.097	126	1.525
Arizona	AZ	6626624	128.00	1.932	11	0.166	6	0.091	800	12.073
Alabama	AL	4833722	95.00	1.965	24	0.497	14	0.290	329	6.806
South Carolina	SC	4774839	100.37	2.102	22	0.461	6	0.126	56	1.173
New Jersey	NJ	8899339	214.82	2.414	70	0.787	31	0.348	273	3.068
Idaho	ID	1612136	57.91	3.592	5	0.310	4	0.248	190	11.786
Louisiana	LA	4625470	171.66	3.711	26	0.562	8	0.173	1079	23.327
Mississippi	MS	2991207	135.40	4.527	12	0.401	6	0.201	990	33.097
Utah	UT	2900872	146.29	5.043	6	0.207	2	0.069	128	4.412
Nebraska	NE	1868516	94.82	5.074	17	0.910	3	0.161	558	29.863

state, the states with the lowest disease prevalence were Maine, Vermont, and Washington and those with the highest were South Dakota, North Dakota, and West Virginia.

There was a significant positive relationship between meeting attendance and the 5-yr number of publications for each state ($F = 27.3$, $df = 47$, $r^2 = 0.35$, $P < 0.001$; Fig. 1A) and also for the 20-yr number of publications ($F = 26.5$, $df = 47$, $r^2 = 0.35$, $P < 0.001$; Supp. Fig. 1A [online only]). After correcting the meeting attendance and number of publications for the population size of each state, there was no longer a significant relationship for the 5-yr publications ($F = 0.16$, $df = 47$, $r^2 = -0.02$, $P = 0.69$; Fig. 1B) or the 20-yr publications ($F = 0.13$, $df = 47$, $r^2 = -0.02$, $P = 0.72$; Supp. Fig. 1B [online only]).

There was a significant positive relationship between the number of human arbovirual disease cases and the 5-yr number of

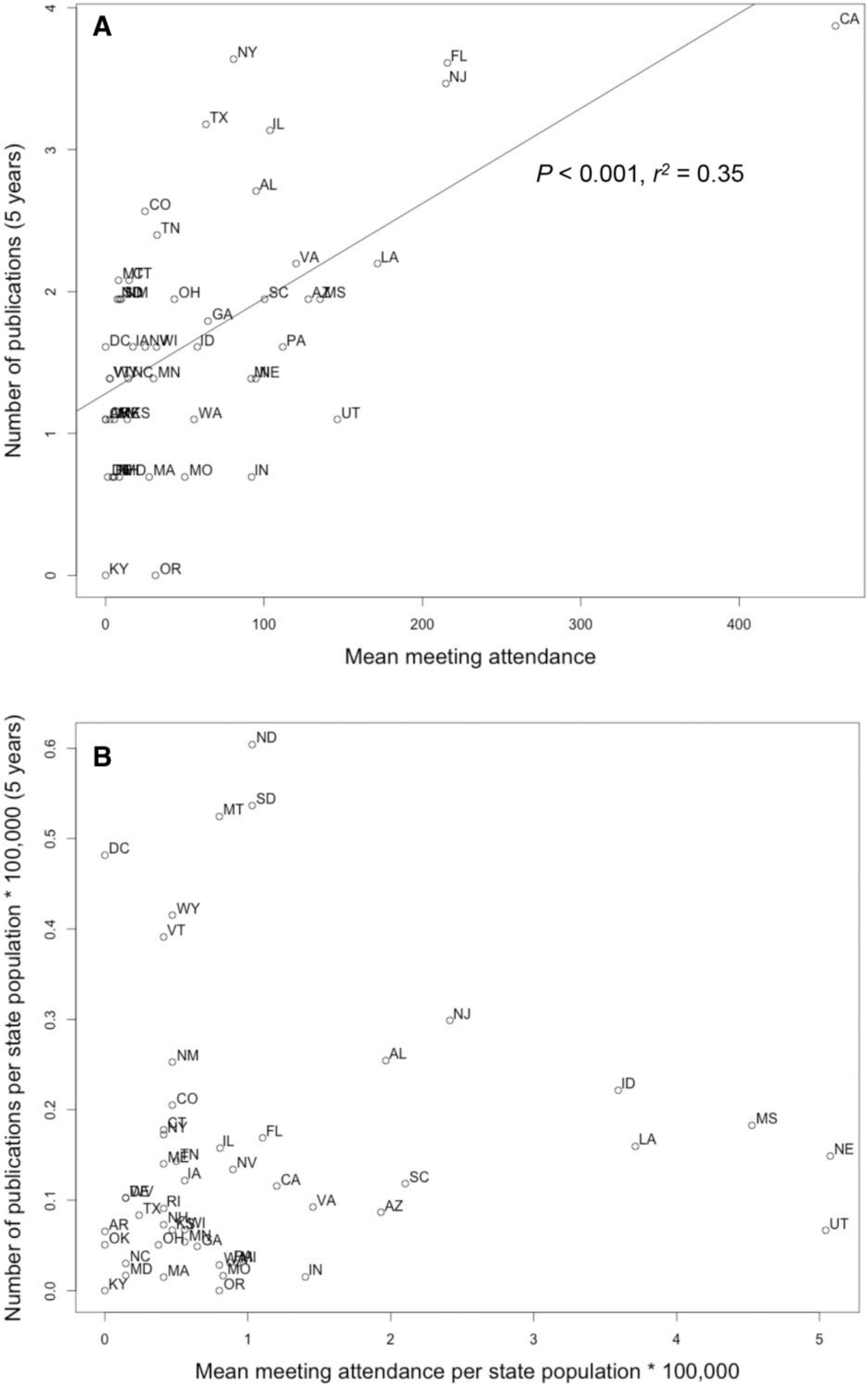

Fig. 1. Scatterplots showing relationship between the number of publications and annual mean meeting attendance for a 5-yr period (2009–2013) for each state (**A**) and these same data corrected per human population in each state (**B**).

publications for each state ($F = 18.2$, df = 47, $r^2 = 0.26$, $P < 0.001$; Fig. 2A) and also for the 20-yr number of publications ($F = 18.9$, df = 47, $r^2 = 0.27$, $P < 0.001$; Supp. Fig. 2A [online only]). After correcting the human disease cases and number of publications for the size of each state population, a significant positive relationship remained for the 5-yr publications ($F = 18.7$, df = 47, $r^2 = 0.27$, $P < 0.001$; Fig. 2B) and the 20-yr publications ($F = 18.8$, df = 47, $r^2 = 0.27$, $P < 0.001$; Supp. Fig. 2B [online only]).

There was a significant positive relationship between meeting attendance and the number of human arboviral disease cases for each state ($F = 9.1$, df = 47, $r^2 = 0.15$, $P < 0.004$; Fig. 3A) but not when attendance and disease was corrected for population size ($F = 2.6$, df = 47, $r^2 = 0.03$, $P < 0.11$; Fig. 3B).

Discussion

These data highlight the heterogeneity of the mosquito control community size, research productivity, and arboviral human disease cases within the continental United States. Using mean attendance at annual mosquito and vector control meetings at each state as a proxy for the size of the community, there is a positive relationship with the number of publications. This positive association was consistent for studies published in the 5-yr and 20-yr periods, suggesting that the research productivity of each state has been stable. California, Florida, and New Jersey help drive this positive relationship by having both high meeting attendance and high numbers of publications. Interestingly, this positive relationship between meeting attendance and the number of publications disappears once correcting each dataset per state population size. In this context, we see a pattern where states such as North Dakota and Montana have low meeting attendance and high numbers of publications per capita and whereas states such as Utah, Nebraska, and Mississippi have high meeting attendance and low numbers of publications. The high number of publications in the Great Plains states is consistent with the high incidence of WNV human disease observed in those regions (Sugumaran et al. 2009) and also the impact of WNV on birds (e.g., greater sage-grouse and American white pelican; Rocke et al. 2005, Clark et al. 2006).

The number of publications in the 5-yr and 20-yr period is also positively associated with human arboviral neuroinvasive disease cases reported by each state. This positive association was driven by states such as Texas, Illinois, and California that have high numbers of arboviral disease cases and also large numbers of publications. Once correcting these data for the population size of each state, the positive association remains but is driven by states such as South Dakota, North Dakota, and Wyoming. This again is reflective of the high WNV human disease incidence in the Great Plains states which has yielded numerous publications (Wimberly et al. 2008, Carson et al. 2012).

The number of arboviral human disease cases was marginally positively associated with the mean attendance at annual mosquito and vector control meetings in each state. This positive relationship was driven by one outlier, California, which had high meeting attendance and high arboviral human disease cases. Once removing this outlier, the pattern was no longer significant. Also, once correcting the number of disease cases and meeting attendance for the population size of each state, there was no relationship between the size of the mosquito control community and the incidence of neuroinvasive disease in the states, suggesting that states with high disease burdens do not have comparably high mosquito control communities. States such as South Dakota and North Dakota have a high incidence of human arboviral disease but low meeting attendance. However, states in the Great Plains also have low population density which makes organized mosquito control difficult. In contrast, states such as Utah and Idaho have high meeting attendance but low incidence of human disease, supporting the observation that the large mosquito control communities in these states are focused on nuisance mosquito problems, principally *Aedes dorsalis* (Meigen) (Crane et al. 1983). It is also important to note that local vector control programs may influence the transmission of arboviruses and the human disease burden (Tedesco et al. 2010) so that the comparison of arboviral disease burden with mosquito control community size is complicated by the potential for management activities to have mitigated the risk of mosquito-borne virus transmission to humans.

Limitations of this analysis include that the attendance at the annual mosquito control meeting does not necessarily reflect all the government and academic personnel focused on mosquitoes and mosquito-borne viruses in a state. For example, in Texas, the annual James Steele Conference on Diseases in Nature Transmissible to Man, co-sponsored by the Texas Department of State Health Services Zoonosis Control Branch and the Texas Health Institute, is a meeting that is independent from the Texas Mosquito Control Association Annual Meeting, yet features many talks on mosquitoes and mosquito-borne viruses. Other states may have similar additional meetings that were not included in this analysis. Beyond attendance at annual meetings, metrics relevant to mosquito and vector control programs that would have been valuable include total annual budgets, total employees, total mosquito trap locations operated, or total amounts of control products deployed. These data would be subdivided by different cities or counties within each state and would thus be very difficult to obtain for a nation-wide comparison. Regarding the number of publications utilizing data from each state, these papers are not solely the product of applied mosquito control agencies. Many studies on mosquitoes and mosquito-borne viruses in each state are affiliated with academia and funded by federal grants or other funds external to the state. Many county or regional mosquito abatement programs conduct research and development to optimize control techniques, but these activities rarely result in peer-reviewed publications, and thus were not included in this study. In addition, my metric for publications were extensive searches of the literature, but were not completely comprehensive. For example, not all journals or publications, especially conference proceedings, are referenced with Web of Science. However, any bias in missing publications should have been true for all states, which means the metrics produced should represent the variation that exists in the number of publications.

Each county or state depends on the quality of the intervention programs by its neighbors. In recent years, several invasive mosquito species have emerged in isolated areas (e.g., *Aedes notoscriptus* (Skuse)) in California (California Department of Public Health [CDPH] 2015), and several of these have become established and spread through the United States (e.g., *Ae. albopictus* (Skuse) and *Ae. japonicus* (Theobald) (Kaufman and Fonseca 2014, Ogden et al. 2014)). Also, introduced arboviruses arrive in areas of the United States and either remain focal (e.g., Dengue virus) or rapidly spread through the entire United States (e.g., WNV). The ability of each state to detect and manage these new mosquitoes or arboviruses is critical to the U.S. public health (Vazquez-Prokopec et al. 2010). This is especially relevant given the risk of chikungunya and Zika viruses entering the United States given the detection of imported human cases and autochthonous transmission in Mexico (Pan American Health Organization). Additionally, communication

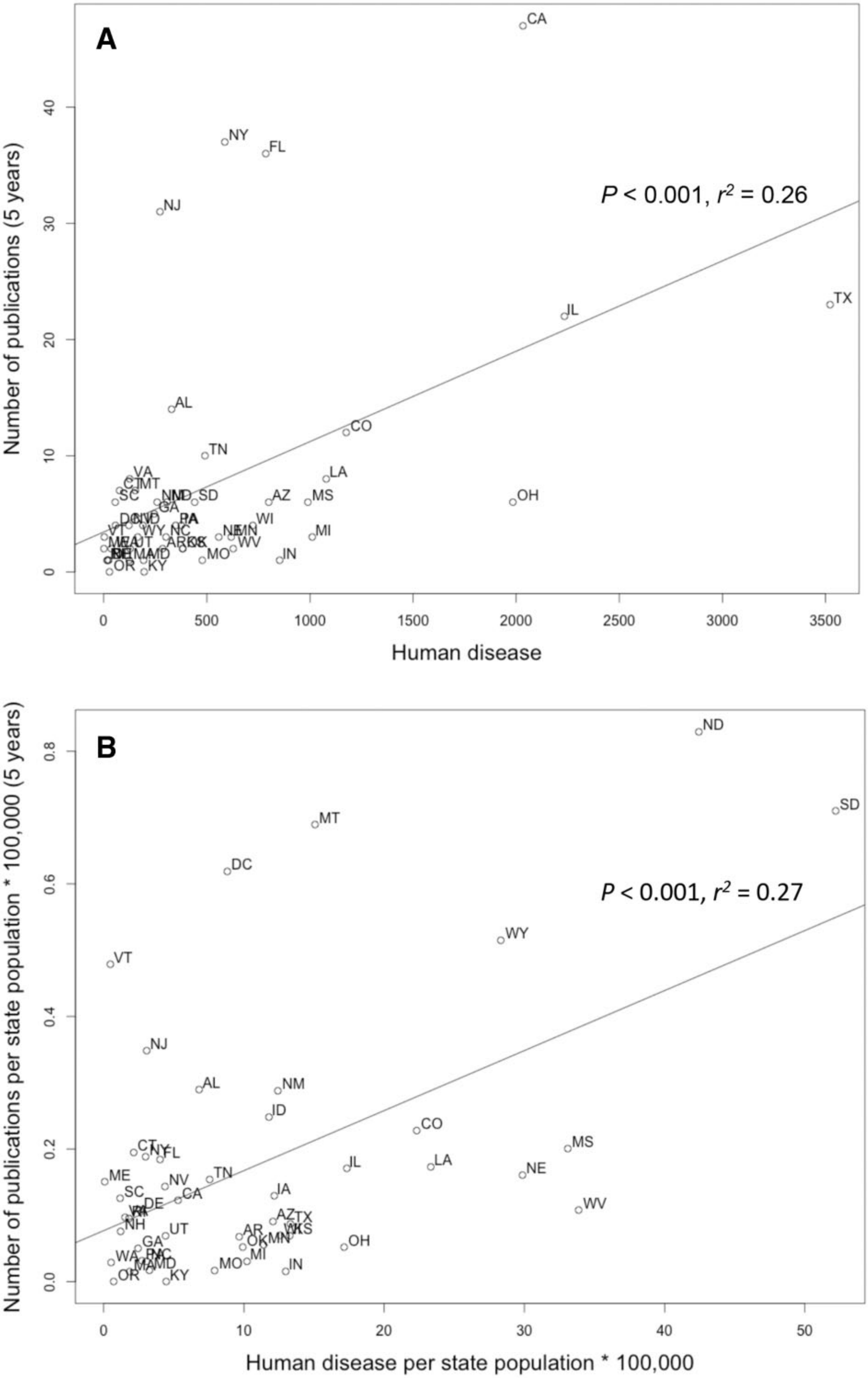

Fig. 2. Scatterplots showing relationship between the number of publications for a 5-yr period (2009–2013) and total neuroinvasive arboviral human disease for each state (**A**) and these same data corrected per human population in each state (**B**).

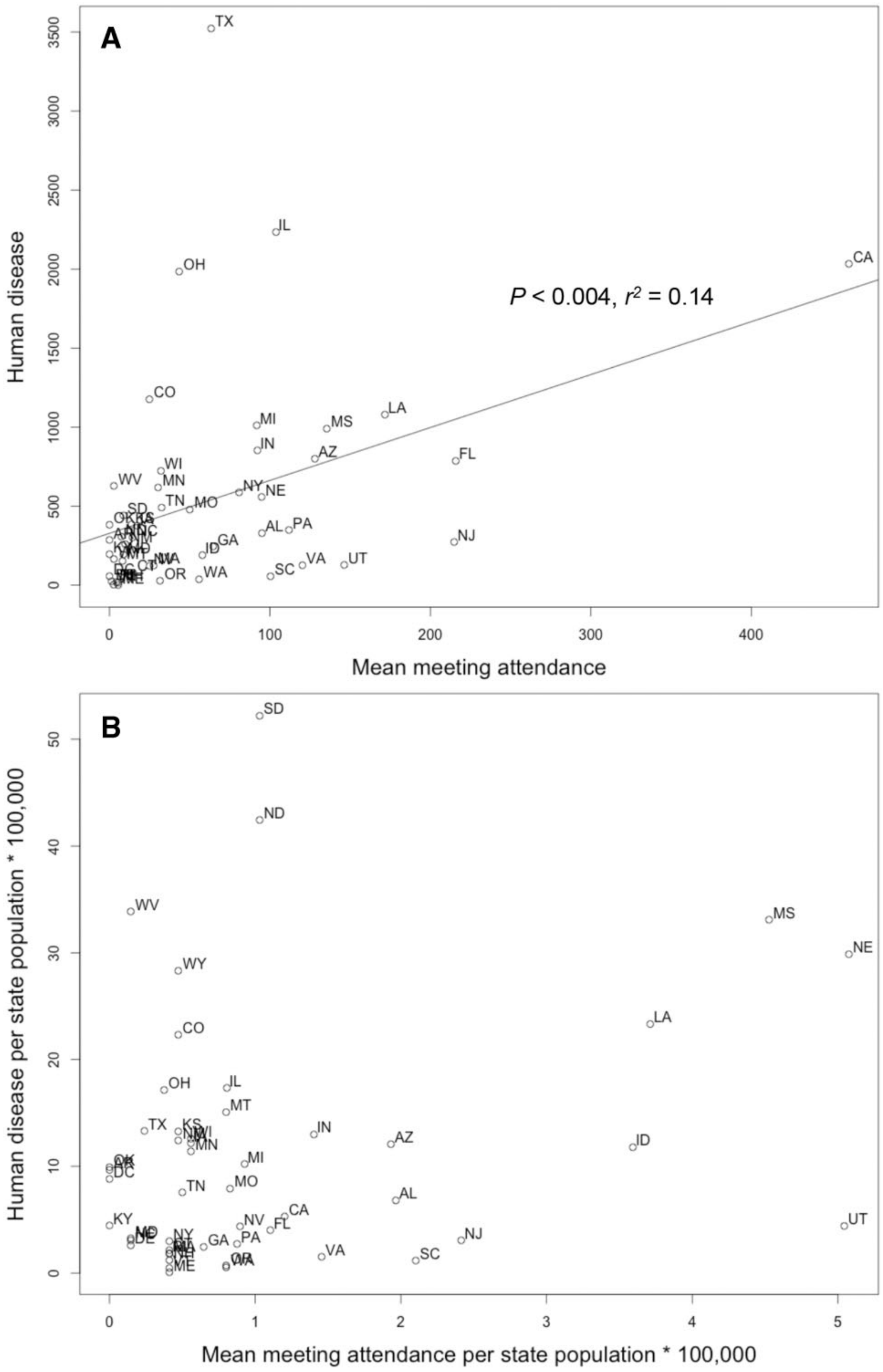

Fig. 3. Scatterplots showing relationship between the total neuroinvasive arboviral human disease for each state and mean meeting attendance for a 5-yr period (2009–2013) for each state (**A**) and these same data corrected per human population in each state (**B**).

among states on the topic of insecticide resistance will assist in efforts to minimize the development and spread of resistance.

The heterogeneity in mosquito control community size, the number of related publications, and human arboviral disease cases among states has important policy considerations. In some cases, these data can help suggest states that should have a larger mosquito control community given the disproportionate burden of arboviral disease. For example, the Great Plains states have experienced a continued high incidence of arboviral disease, especially in the wake of WNV driven by *Culex tarsalis* Coquillett in rural locations. States with high incidence of arboviral disease but low human populations such as South Dakota, North Dakota, and Wyoming do not have their own state mosquito control associations and instead are members of multistate associations, thus their meeting attendance, a proxy for mosquito control community size, is small. Representatives from these states could use the results from this analysis to suggest that more financial resources are needed in their state given this disparity. This rural context of high arboviral disease burden and low population densities is a challenge from a mosquito control perspective and could be more efficiently managed by vaccine programs.

Much of the heterogeneity observed in mosquito control community size and number of publications is presumably due to financial resources. Gathering mosquito control budgets for each state would have been difficult, but some states such as California provide these data in the Mosquito and Vector Control Association of California annual yearbook (MVCAC 2015). This document provides fiscal data for 229 agencies in California, mostly mosquito abatement districts, with combined annual revenue of US$156,469,767. These funds come as property taxes, service charges, benefit assessment, or contracts. In California, mosquito abatement districts are initiated by a petition of 10% or more of the registered voters in the proposed area. A public hearing is held and county board supervisors approve if it is in the best interest of the public. Once approved, mosquito abatement districts charge an annual service fee to all properties in the service area to pay for mosquito surveillance and control. The state legislation in California provides a means for 38 abatement districts (mostly county-level) to have annual budgets in excess of 1 million dollars, and three districts (Sacramento-Yolo, Greater LA County, and Orange County) have budgets over 10 million each. These figures help explain why California has the largest annual meeting size and more publications than any other state, not correcting for population size.

Texas provides a different example along a spectrum in terms of how mosquito control is funded. Very few counties in Texas have dedicated taxes that fuel mosquito abatement programs. Some counties that occur along the Gulf Coast with large nuisance mosquito populations, principally *Ae. sollicitans* (Walker) and *Ae. taeniorhynchus* (Wiedemann), have dedicated "Mosquito Control Funds," broken down in the Fiscal Year 2015 budget. These counties include Orange (US$1,198,890), Brazoria (US$3,009,709), and Galveston (US$1,473,750) within their respective FY2015 mosquito control fund annual budgets. Most counties in Texas do not have dedicated funds in the county budget for mosquito control, which makes it difficult to extract the amount dedicated to mosquito surveillance and control. For example, the FY2015 budget for Dallas Co. includes US$1,010,845 the Environmental Health Division but this Division is responsible for the public's safety in the areas of animal control, general sanitation, and vector control within the county. Further complicating the situation is that some cities within Dallas County are covered by the county-level mosquito control program whereas others are independent. In addition, less populated counties have a single employee responsible for mosquito control as well as health inspections and code enforcement. Harris County has the largest mosquito control program in the state of Texas and was established due to a major outbreak of St. Louis Encephalitis in 1964 and in 1995 became a division within the Public Health & Environmental Services with revenue received through the general county funds. The annual budget for the Harris County Mosquito Control Division is around 5 to 6 million, which fluctuates each year depending on the need for aerial mosquito control. Unlike neighboring counties, the Commissioners Court of Harris County approved a policy in which the Division's primary responsibility is the surveillance and control of mosquito-borne diseases.

Whatever the mechanism, the result is that Texas is vastly underfunded compared to a state like California for mosquito surveillance and control operations. This difference in funds is reflective in the differences in the meeting attendance observed in this study, with California ranking at number 12 in meeting attendance per state population, whereas Texas ranks 41. In addition, California has 37 of 58 counties (63.8%) that collect mosquitoes and test for at least one arbovirus (CDPH 2015), whereas Texas has 34 of 254 counties (13.4%) that collect mosquitoes and test for at least one arbovirus (Texas Department of State Health Services). This difference is alarming given that Texas has more arboviral disease cases than any other state and ranked 12th in disease cases once correcting for population size. Furthermore, the position of Texas at the southern edge of the United States, with a longer border with Mexico than any other state, puts Texas at the "front-line" with regard to emerging or re-emerging viruses such as dengue, chikungunya, and Zika viruses (Andrus et al. 2013, Higgs 2016).

In conclusion, this study summarizes data that highlight the variation in mosquito control community size, the number of related publications, and human arboviral disease cases among states. Much of the heterogeneity in mosquito control community size is determined by the annual financial resources received to sustain these programs. Organized mosquito control in some cities and counties is vastly underfunded compared to others, and not all of this disparity is due to variation in cost of living or average household income. Often in the face of an abnormal mosquito challenge (e.g., hurricane or mosquito-borne disease epidemic), many local agencies wait for "top down" funds from a higher level of government, such as state or federal. However, these brief infusions of funds do not allow local agencies to sustain the infrastructure needed for an effective program. Instead, a solution to this problem could be to revisit "bottom-up" sources of funds, where local citizens pay for organized mosquito control programs. This is already occurring throughout the United States, with California as an example showing that citizen dollars help allow the mosquito control community to receive an annual budget of 156.5 million. Halasa et al. (2012) found that New Jersey citizens were willing to pay three times more than what existing taxes yield for the annual budget of mosquito control. The fear for the invasion of Zika virus into the United States, which likely leads to pregnancy complications (Martines et al. 2016), will magnify this willingness to pay. Based on the local citizen willingness to pay for mosquito control, local legislation should allocate the appropriate amount of taxes and service fees so that a sustained mosquito control program can exist. Doing so would enhance mosquito control programs and help mitigate problems of nuisance mosquitoes and mosquito-borne diseases.

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Supplementary Data

Supplementary data are available at *Journal of Medical Entomology* online.

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