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AN UPDATED CHECKLIST OF THE MOSQUITOES OF OKLAHOMA INCLUDING NEW STATE RECORDS AND WEST NILE VIRUS VECTORS, 2003–06

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ABSTRACT. The mosquito fauna of Oklahoma has not been evaluated since 1965 and no report has been published concerning species associated with urban areas in the state. Mosquito collections were conducted as part of the West Nile virus (WNV) surveillance program between April and November from 2003 to 2006, using standard collection methods. A total of 74,756 adults were collected in 26 urban centers in 16 counties of Oklahoma. Altogether, 40 species were recorded during this study period, bringing the total mosquito species recorded in Oklahoma to 62 species in 9 different genera and 18 subgenera. An updated checklist of Oklahoma mosquito fauna is included with a comparison to historical records. New state records include 3 species: *Aedes muelleri*, *Anopheles perplexens*, and *Culex coronator*. In addition to updating the checklist, 12 species of mosquitoes were tested for WNV. Pools of *Culex pipiens* complex represented the highest proportion testing positive for WNV (134/766, 17.5%), followed by *Cx. tarsalis* (13/192, 6.8%) and *Aedes albopictus* (5/215, 2.3%). West Nile virus–positive mosquitoes were detected earliest in June 2005 and latest in November 2004. Infected *Cx. pipiens* complex testing positive for WNV were more prevalent in the eastern and central areas of Oklahoma, whereas positive *Cx. tarsalis* were found mainly in the western areas of the state. This distinct geographical difference needs to be monitored and followed up to ensure optimal mosquito control efforts in Oklahoma communities with mosquito control capabilities.

KEY WORDS *Aedes albopictus*, Asian tiger mosquito, invasive species, Oklahoma, distribution

INTRODUCTION

The first published study on mosquito taxa in Oklahoma was carried out by Rozeboom between the summers of 1938 and 1940 and consisted of larval dipper collections and light traps for adult mosquitoes (Rozeboom 1942). Forty species were identified in this initial survey, but the northeastern corner and south-central areas of Oklahoma were not sampled. Griffith (1952) increased the list of mosquito species by another 11 species by sampling in different locations. A subsequent survey was completed in 1965 by Parsons in which personal larval and adult collections were reported together with records from the K.C. Emerson Museum (housed in the Department of Entomology and Plant Pathology, Noble Research Center at Oklahoma State University) and state collection records and was published in 1971 (Parsons and Howell 1971). This last published listing included 58 species of mosquitoes from 9 different genera. Harrison et al. (1973) later confirmed the presence of *Aedes taeniorhynchus* (Wiedemann) in Oklahoma.

Thirty years after the last published checklist, West Nile virus (WNV) surveillance was initiated in Oklahoma between 2003 and 2006. The first identification of WNV in Oklahoma was a dead crow (*Corvus Brachyrhynchos*) collected in July 2002 in Tulsa County. Oklahoma's WNV surveillance program expanded in 2003 through a cooperative study with the Oklahoma State University (OSU) to monitor mosquitoes from select locations. By 2003, the virus had spread through 62 of 77 counties in Oklahoma (Johnson et al. 2015). While 2004 and 2005 were milder, WNV infection in animals and humans was detected in 44 and 40 counties, respectively (Oklahoma State Department of Health 2015). The continued reduction of cases and funding for surveillance after 2005 led to a downsizing of the mosquito surveillance network, which was not prepared for the explosion of West Nile cases in 2012 in urban areas in the Great Plains region (Murray et al. 2013). In addition to identifying WNV vectors in Oklahoma, this sampling effort provided an opportunity to verify current lists and add new species. As effective mosquito control efforts and surveillance for mosquito-borne diseases depend on knowledge of mosquito species in local areas, the aim of this paper is to present the data from the mosquito surveys, update the checklist of mosquitoes in Oklahoma to current nomenclature, and identify the principal vectors of WNV.

MATERIALS AND METHODS

Adult mosquitoes were collected in 26 urban centers in 16 counties around Oklahoma (Fig. 1) in the spring, summer, and fall months of 2003–06 (Table 1). West Nile virus data for 2003 were not included in Table 2. Combinations of 3 trapping methods were used to ensure that a representative sample of mosquito species was collected from a given area. Adult mosquitoes were collected

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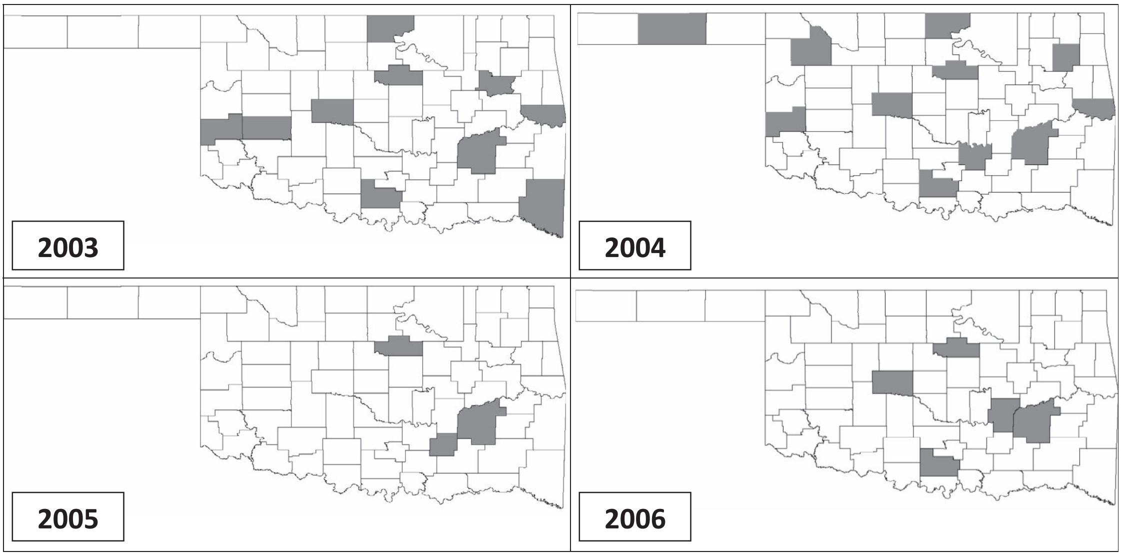

Fig. 1. Oklahoma counties sampled by West Nile virus surveillance, 2003 and 2006.

using new standard miniature blacklight traps and Centers for Disease Control and Prevention (CDC) miniature light traps using CO_2 released from cylinders at 250 ml/min plus octenol or CO_2 sachets plus octenol. Additionally, CDC gravid traps baited with fermented Bermuda grass infusion were used. The sampling methods used were chosen primarily to collect mosquitoes in urban centers that could be involved in the transmission of WNV. With such an urban focus, it is highly possible that rare species that require different trapping methods were not collected. The references to *Culex pipiens* L. complex recorded in the text and tables are the *Culex pipiens/quinquefasciatus* complex. Rainfall records for the surveillance period were obtained from historical records (Weather Underground 2014).

Sites were chosen based on reported mosquito activity, access to sites either in public parks or on private properties, and reduced risk of vandalism and theft. Oklahoma State University personnel were directly involved in trapping efforts in Stillwater while, in other areas, OSU Extension, County Health and Fire Department personnel, and volunteers were relied on for their local knowledge, connections, and willingness to collect and preserve mosquito samples from traps until acquisition by OSU personnel. Mosquitoes were transported to the OSU mosquito facilities on ice packs in coolers, euthanized by freezing at $-20°C$, and stored at $-80°C$ until processing by OSU personnel. Adult mosquitoes were identified to species by an experienced technician using the keys of Darsie and Ward (1981, 2005). After identification, 25–50 mosquitoes from a species were placed into a vial and frozen until screened for WNV by OSU personnel using commercial VecTest® kits (Medical Analysis System, Inc., Camarillo, CA) at OSU facilities. Mosquito pools were then transported to Oklahoma State Department of Health in Oklahoma City for confirmation by reverse transcriptase–polymerase chain reaction (RT-PCR), using a method standardized for public health surveillance (Lanciotti et al. 2000). Pool infection rates reported were taken from positive RT-PCR assay results. Voucher specimens were deposited in the K.C. Emerson Entomology Museum at Oklahoma State University. To revise the checklist to current taxonomic data, published lists were compared with the traditional taxonomic classification used in the online catalog of the Walter Reed Biosystematics Unit (WRBU 2013). All mosquitoes species listed were then brought into conformity with the traditional mosquito classification scheme as listed by WRBU (2013).

RESULTS

Surveys 2003 to 2006

Forty different species (37 previously recorded and 3 newly reported) were identified during the study period from 26 urban sites in 16 counties in Oklahoma (Fig. 1 and Table 1). The number of adult mosquitoes collected ranged from 3,301 (2003) to 26,881 (2006), while numbers of sites sampled each summer ranged between 5 (2006) and 14 (2004). The number of species collected varied between 25 (2003) and 37 (2004), with sampling periods ranging from April to November. There were slight differences in rainfall totals between sites, with more rainfall recorded in 2004 (Fig. 2).

Culex pipiens complex (50.5%), *Aedes albopictus* (Skuse) (12.4%), and *Ae. vexans* (Meigen) (11.6%) accounted for 74.5% of the mosquitoes collected

Table 1. Numbers and percentages of mosquito species collected in West Nile virus mosquito surveys in Oklahoma between 2003 and 2006.

	2003	%	2004	%	2005	%	2006	%	Total	%
No. sampling sites	11		14		6		5			
No. counties sampled	10		11		3		5			
No. species identified	25		37		29		27			
Sampling period	Jul 29–Oct 14		Apr 5–Oct 7		Apr 25–Nov 8		May 8–Nov 9			
Culex pipiens complex	1,391	42.14	1,863	10.47	15,574	58.23	18,887	70.27	37,715	50.45
Aedes albopictus	521	15.78	1,419	7.97	2,812	10.51	4,495	16.72	9,247	12.37
Ae. vexans	395	11.97	4,700	26.40	2,433	9.09	1,146	4.26	8,674	11.60
Cx. erraticus	200	6.06	2,029	11.35	2,143	8.01	807	3.00	5,179	6.93
Cx. tarsalis	142	4.30	3,210	18.03	313	1.17	534	1.99	4,199	5.62
Cx. salinarius	10	0.30	1,406	7.90	289	1.08	19	0.07	1,724	2.31
Psorophora cyanescens	70	2.12	41	0.23	1,560	5.83	32	0.12	1,703	2.28
Ae. sollicitans	5	0.15	742	4.17	95	0.36	19	0.07	861	1.15
Anopheles punctipennis	32	0.97	328	1.84	290	1.08	29	0.11	679	0.91
An. quadrimaculatus	66	2.00	229	1.29	332	1.24	39	0.15	666	0.89
Ps. columbiae	224	6.78	90	0.51	258	0.96	49	0.18	621	0.83
Ae. dorsalis			586	3.29					586	0.78
Ae. trivittatus			309	1.74	87	0.33	143	0.53	539	0.72
Cx. restuans	26	0.79	191	1.07	54	0.20	261	0.97	532	0.71
Ae. triseriatus	16	0.48	83	0.47	112	0.42	179	0.67	390	0.52
Ae. epactius	42	1.27	111	0.62	132	0.49	99	0.37	384	0.51
Coquillettidia perturbans	72	2.19	117	0.66	8	0.03	5	0.02	202	0.27
Culiseta inornata	7	0.22	66	0.37	40	0.15	8	0.03	121	0.16
Uranotaenia sapphirina	2	0.06	42	0.24	39	0.15	8	0.03	91	0.12
Ps. discolor			1	0.01	52	0.19	37	0.14	90	0.12
Ps. ferox			40	0.22	6	0.02	37	0.14	81	0.11
Ps. signipennis			61	0.34	18	0.07			79	0.11
Ps. ciliata	10	0.30	18	0.10	42	0.16	9	0.03	79	0.11
Orthopodomyia signifera	14	0.43	6	0.03	28	0.10	18	0.07	66	0.09
Cx. territans	1	0.03	17	0.10	23	0.09	12	0.04	53	0.07
An. crucians	1	0.03	22	0.12	4	0.01			27	0.04
An. barberi			5	0.03	6	0.02	6	0.02	17	0.02
An. perplexens			3	0.02	4	0.01	1	0.00	8	0.01
Ae. hendersoni	5	0.15	1	0.01	1	0.00			7	<0.01
Ae. muelleri	6 larvae	0.43							6	<0.01
Ps. howardii	1	0.03	2	0.01	1	0.00	1	0.00	5	<0.01
Ae. atlanticus	1	0.03	3	0.02					4	<0.01
Ae. taeniorhychus			4	0.02					4	<0.01
An. pseudopunctipennis	1	0.03							1	<0.01
Cx. coronator	1	0.03							1	<0.01
Cs. incidens			1	0.01					1	<0.01
Ae. zoosophus			1	0.01					1	<0.01
Ps. mathesoni			1	0.01					1	<0.01
Toxorhynchites rutilis septentrionalis			1	0.01						<0.01
Ae. dupreei							1	0.00	1	<0.01
Unknown	39	1.18	69	0.31					108	0.14
Total	3,301	100.00	17,818	100.00	26,756	100.00	26,881	100.00	74,756	

during the survey period and were the 3 most abundant species collected in 2003, 2005, and 2006 (Table 1). In 2004, *Ae. vexans*, *Cx. tarsalis* Coquillett, and *Cx. erraticus* (Dyar and Knab) were the most abundant. None of the other 37 species identified during the survey period accounted for >7% of the totals for all 4 years.

New species

During the survey period, 3 new species were added to the list of mosquitoes found in Oklahoma. One adult female *Cx. coronator* Dyar and Knab was collected from a light trap in McAlester, OK, on August 24, 2003. This was followed in 2004 by the collection of a single *Cx. coronator* larva in Sallisaw, OK. Four *Ae. muelleri* Dyar larvae were collected from a concrete water tank in McAlester, OK, on September 23, 2003, with 2 additional dead larvae collected from the same tank on October 3, 2003. *Anopheles perplexens* Ludlow was collected in 2004 from 3 sites in northern Oklahoma. Three adults were collected from traps from Elk City, Ponca City, and Stillwater, and 3 adults were reared from larvae.

Table 2. Summary of West Nile virus (WNV) surveillance data from Oklahoma between 2004 and 2006.

Description	Details	2004	2005	2006	Total
% total mosquitoes tested	All places	72%	69%	92%	
First positive WNV pool	Date	Jul 21	Jul 27	Jun 8	
	Place (County)	Goodwell (Texas County)	Stillwater (Payne County)	Stillwater (Payne County)	
	Species	*Culex tarsalis*	*Cx. pipiens*	*Cx. pipiens*	
Last positive WNV pool	Date	Sep 27	Nov 1	Oct 8	
	Place (County)	McAlester (Pittsburg County)	Stillwater (Payne County)	Stillwater (Payne County)	
	Species	*Cx. pipiens*	*Cx. pipiens*	*Cx. pipiens*	
Total no. mosquitoes (no. pools tested)	All places	12,868 (686)	18,464 (371)	24,694 (499)	56,026 (1,556)
No. pools tested (% positive)	*Cx. pipiens*	82 (7.4%)	308 (12.3%)	376 (23.9%)	766 (17.5%)
	Cx. tarsalis	174 (7.0%)	6 (16.7%)	12 (0.0%)	192 (6.8%)
	Cx. salinarius	69 (0.0%)	5 (0.0%)		74 (0.0%)
	Cx. erraticus	1 (0.0%)		15 (0.0%)	16 (0.0%)
	Cx. restuans	31 (0.0%)		5 (0.0%)	36 (0.0%)
	Cs. inornata	8 (0.0%)			8 (0.0%)
	Aedes albopictus	74 (0.0%)	50 (2.0%)	91 (4.4%)	215 (2.3%)
	Ae. vexans	175 (0.0%)			175 (0.0%)
	Ae. triseriatus	10 (0.0%)	2 (0.0%)		12 (0.0%)
	Other[1]	62 (0.0%)			62 (0.0%)

[1] Includes *Psorophora columbiae* (4), *Ae. epactius* (1), *Ps. ferox* (1), *Culex* species (31), unknowns (2), and mosquitoes from Tulsa (23).

Species list for Oklahoma

The current number of mosquito species in Oklahoma stands at 62 (Table 3): *Aedes* (23 species), *Anopheles* (7 species), *Coquillettidia* (1 species), *Culex* (12 species), *Culiseta* (2 species), *Orthopodomyia* (2 species), *Psorophora* (10 species), *Toxorhynchites* (1 species), and *Uranotaenia* (3 species).

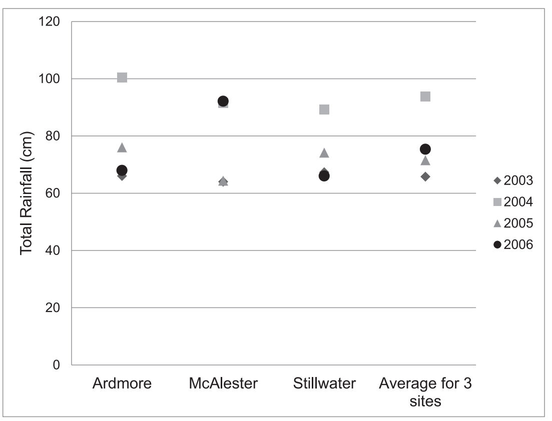

Fig. 2. Total rainfall (cm) between 2003 and 2006 at 3 different sampling sites.

Clarifications from historical checklists

Aedes epactius (Dyar and Knab): *Ae. atropalpus* Coquillett in Oklahoma have been misidentified in past surveys as they are geographically separated from locations where *Ae. epactius* is present (O'Meara and Craig 1970). As such, it was not included in the list of Oklahoma mosquitoes (Table 3). Further clarification is needed, however, as O'Brien and Reiskind (2013) list both species in their heartworm (*Dirofilaria immitis* Leidy) vector survey in central Oklahoma.

Aedes fulvus pallens Ross: Darsie and Ward (2005) does not consider *Ae. bimaculatus* (Coquillett) to be close to Oklahoma and it appears to have been misidentified by past surveys. As such, it was not included in the list of Oklahoma mosquitoes (Table 3).

The names of 5 species have been updated since the historical publications: 1) *Ae. sticticus* (Meigen) (formerly reported as *Ae. hirsuteron*) Theobald; 2) *Ae. zoosophus* Dyar and Knab (previously reported as *Ae. alleni* (Turner)); 3) *Cx. stigmatosoma* Dyar (formerly reported as *Cx. peus* Speiser); 4) *Cx. territans* Walker (formerly reported as *Cx. restuans* Theobald); and 5) *Ps. columbiae* (Dyar and Knab) (formerly reported as *Ps. confinnis* [Lynch-Arribalzaga]).

Table 3. Updated checklist of mosquitoes of Oklahoma using traditional names (WRBU 2013). X denotes collection reported by author.

No.	Taxon	Rozeboom (1942)	Griffith (1952)	Parsons and Howell (1971)	Darsie and Ward (2005)	Total West Nile virus surveys 2003–06
	Genus *Aedes*					
	Subgenus *Aedes*					
1	*Aedes cinereus*		X	X	X	
	Subgenus *Aedimorphus*					
2	*Ae. vexans*	X		X	X	X
	Subgenus *Ochlerotatus*					
3	*Ae. atlanticus*	X		X	X	X
4	*Ae. canadensis*	X		X	X	
5	*Ae. dorsalis*	X		X	X	X
6	*Ae. dupreei*		X	X	X	X
7	*Ae. epactius*	X		X	X	X
8	*Ae. fulvus pallens*	X		X	X	
9	*Ae. mitchellae*		X	X	X	
10	*Ae. muelleri*					X
11	*Ae. nigromaculis*	X		X	X	
12	*Ae. spencerii*			X	X	
13	*Ae. sollicitans*	X		X	X	X
14	*Ae. sticticus*	X		X	X	
15	*Ae. taeniorhynchus*			X	X	X
16	*Ae. thelcter*		X	X	X	
17	*Ae. tormentor*		X	X	X	
18	*Ae. trivittatus*	X			X	X
	Subgenus *Protomacleaya*					
19	*Ae. hendersoni*			X	X	X
20	*Ae. triseriatus*	X		X	X	X
21	*Ae. zoosophus*	X		X	X	X
	Subgenus *Stegomyia*					
22	*Ae. aegypti*	X		X	X	
23	*Ae. albopictus*				X	X
	Genus *Anopheles*					
	Subgenus *Anopheles*					
24	*Anopheles barberi*	X		X	X	X
25	*An. crucians*	X		X	X	X
26	*An. franciscanus*		X	X	X	
27	*An. perplexens*					X
28	*An. pseudopunctipennis*	X		X	X	X
29	*An. punctipennis*	X		X	X	X
30	*An. quadrimaculatus*	X		X	X	X
	Genus *Coquillettidia* Dyar					
	Subgenus *Coquillettidia* Dyar					
31	*Coquillettidia perturbans*	X		X	X	X
	Genus *Culex*					
	Subgenus *Culex*					
32	*Culex coronator*					X
33	*Cx. nigripalpus*			X	X	
34	*Cx. pipiens* complex (*Cx. pipiens*/*quinquefasciatus*)	X	X	X	X	X
35	*Cx. restuans*	X		X	X	X
36	*Cx. salinarius*	X		X	X	X
37	*Cx. stigmatosoma*		X	X	X	
38	*Cx. tarsalis*	X		X	X	X
39	*Cx. thriambus*		X	X	X	
	Subgenus *Melanoconion*					
40	*Cx. erraticus*	X		X	X	X
41	*Cx. peccator*	X		X	X	
	Subgenus *Neoculex*					
42	*Cx. apicalis*	X		X	X	
43	*Cx. territans*			X	X	X
	Genus *Culiseta*					
	Subgenus *Climacura*					

Table 3. Continued.

No.	Taxon	Rozeboom (1942)	Griffith (1952)	Parsons and Howell (1971)	Darsie and Ward (2005)	Total West Nile virus surveys 2003–06
44	*Culiseta melanura*	X		X	X	
	Subgenus *Culiseta*					
45	*Cs. incidens*		X	X	X	X
46	*Cs. inornata*	X		X	X	X
	Genus *Orthopodomyia*					
47	*Orthopodomyia alba*			X	X	
48	*Or. signifera*	X		X	X	X
	Genus *Psorophora*					
	Subgenus *Grabhamia*					
49	*Psorophora columbiae*	X		X	X	X
50	*Ps. discolor*	X		X	X	X
51	*Ps. signipennis*	X		X	X	X
	Subgenus *Janthinosoma*					
52	*Ps. cyanescens*	X		X	X	X
53	*Ps. ferox*	X		X	X	X
54	*Ps. horrida*	X		X	X	
55	*Ps. longipalpus*			X	X	
56	*Ps. mathesoni*	X		X	X	X
	Subgenus *Psorophora*					
57	*Ps. ciliata*	X		X	X	X
58	*Ps. howardii*	X		X	X	X
	Genus *Toxorhynchites*					
	Subgenus *Lynchiella*					
59	*Toxorhynchites rutilis septentrionalis*	X		X	X	X
	Genus *Uranotaenia*					
	Subgenus *Pseudoficalbia*					
60	*Uranotaenia anhydor syntheta*		X	X	X	
	Subgenus *Uranotaenia*					
61	*Ur. lowii*			X	X	
62	*Ur. sapphirina*	X		X	X	X
		40	11	57	59	40

WNV surveillance

Between 2004 and 2006, a total of 1,556 pools consisting of 56,026 mosquitoes from 12 species of mosquitoes in 3 genera were tested for WNV of which 152 pools (9.8%) were positive (Table 2). Pools of *Cx. pipiens* complex comprised the greatest number tested (49.2%), followed by *Ae. albopictus* (13.8%) and *Cx. tarsalis* (12.3%). Pools of *Culex pipiens* complex represented the highest proportion testing WNV positive (17.5%, 134/766), followed by *Cx. tarsalis* (6.8%, 13/192) and *Ae. albopictus* (2.3%, 5/215). No pools of *Cx. salinarius* Coquillett, *Cx. restuans*, *Cx. erraticus*, *Cs. inornata* (Williston), *Ae. vexans*, *Ae. triseriatus* (Say), *Ae. epactius*, *Ps. columbiae*, or *Ps. ferox* (von Humbolt) tested positive for WNV.

The WNV-positive mosquitoes were detected over a 5-month period each year, with the earliest detection occurring on June 8, 2006, and latest on November 1, 2005 (Table 2). While potential vector species were collected throughout the state, WNV-positive *Cx. pipiens* complex mosquitoes were found only in the central and eastern areas, whereas WNV-positive *Cx. tarsalis* were collected in central and western areas of Oklahoma (Fig. 3).

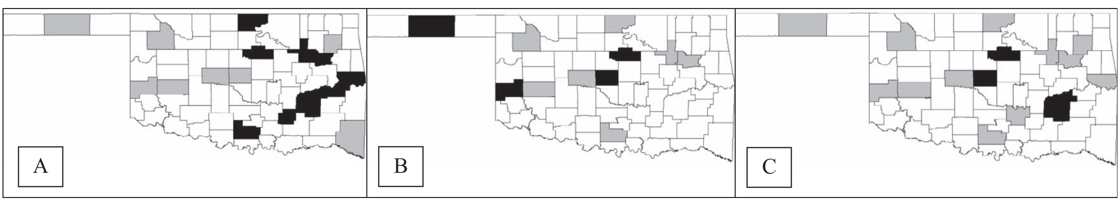

Fig. 3. Distribution of West Nile virus (WNV)–positive mosquitoes in Oklahoma between 2004 and 2006. Counties where (A) *Culex pipiens* complex, (B) *Culex tarsalis*, and (C) *Aedes albopictus* were collected (shaded gray) and where pools of WNV-positive mosquitoes were detected (shaded black).

DISCUSSION

The Oklahoma WNV mosquito surveillance data presented here confirmed the presence of 37 species of mosquitoes previously reported in the state and added 3 new species, *Ae. muelleri*, *An. perplexens*, and *Cx. coronator*, which had not been previously recorded. This increased the total recorded mosquito species in Oklahoma to 62. The most abundant taxa collected during this period were *Cx. pipiens* complex, *Ae. albopictus*, and *Ae. vexans* (Table 1). The biased collection of urban species of mosquitoes was due mainly to the main focus of the study being WNV surveillance. As such, the use of CDC light and gravid traps are known to collect more *Culex* spp. and *Aedes* spp., while more specialized collecting methods are required for rarer species (Farajollahi et al. 2009, Obenauer et al. 2010). *Culex pipiens* complex mosquitoes were common in urban and suburban areas where they lay their egg rafts in storm sewer catch basins, ground pools, ditches, effluent from sewage treatment plants, and other sites with highly eutrophic conditions (Yee and Skiff 2014). *Aedes albopictus*, found in most Oklahoma counties (Noden et al. 2015), were also common in urban areas, breeding in containers and other smaller water-filled vessels (Juliano and Lounibos 2005). While *Cx. pipiens* complex mosquitoes prefer to feed on birds, *Ae. albopictus* prefer humans and other mammals (Lindsey et al. 2008). Both species are known vectors for a variety of pathogens (Kramer et al. 2008).

West Nile virus was detected in pools of *Cx. pipiens* complex, *Cx. tarsalis*, and *Ae. albopictus*. While WNV has been reported as occurring in all 3 species of mosquitoes, *Cx. pipiens* complex and *Cx. tarsalis* are considered major bridge vectors for WNV throughout the USA (Lindsey et al. 2008). West Nile virus has been detected in all 3 species in northern Texas (Bradford et al. 2005) and in *Cx. pipiens* and *Cx. tarsalis* in New Mexico (Pitzer et al. 2009). Unlike other studies, WNV was not detected in *Ae. vexans*, *Ps. columbiae*, *Cs. inornata* (Pitzer et al. 2009), *Ae. salinarius*, or *Ps. ferox* (Cupp et al. 2007). No testing was performed on *Ae. dorsalis* (Meigen), *Ae. sollicitans* (Walker), *Ae. trivittatus* (Coquillett), or *Ps. signipennis* (Coquillett) in which WNV was detected in New Mexico (Pitzer et al. 2009). Based on these results, the principal vectors for WNV in Oklahoma are most likely *Cx. pipiens* complex and *Cx. tarsalis*.

While both species of *Culex* were collected in various parts of Oklahoma, WNV-positive *Culex* seemed to be geographically associated with only infected *Cx. pipiens* complex identified in eastern and central Oklahoma and infected *Cx. tarsalis* in the western and central areas of the state. Geographical differences have also been reported in Texas, with higher prevalence of WNV in *Cx. tarsalis* in the north-central areas (on the Oklahoma border) and *Cx. pipiens quinquefasciatus* Say in more central eastern areas around Dallas (Warner et al. 2006). *Culex tarsalis* has been implicated in WNV transmission activity in West Texas (Bradford et al. 2005), New Mexico (Lujan et al. 2014), Arizona (Colborn et al. 2013), and California (Kwan et al. 2010).

The abundance of *Cx. pipiens* complex, *Ae. albopictus*, and *Ae. vexans* was similar during 2003, 2005, and 2006 (Table 1). However, there was a major shift in the species of mosquitoes collected in 2004 due to the inclusion of western Oklahoma county sites and more rainfall during this period (Figs. 1 and 2). Most likely, the increased rainfall in western Oklahoma in 2004 filled the numerous playa lakes (catchment areas) on farms throughout the region and increased the numbers of *Cx. tarsalis* collected in Beckham and Texas counties (Fig. 1 and Table 1). As much as 90.2% of the *Cx. tarsalis* were collected in these 2 western counties during 2004, with an almost equal prevalence of WNV detected that year in both *Cx. pipiens* complex and *Cx. tarsalis* (Table 2). The increased rainfall in 2004 appears to have also enhanced the species of mosquitoes collected in urban areas. Seventy-one percent of mosquitoes collected in 2004 consisted of 6 species: the floodwater mosquitoes (*Ae. vexans*, *Ae. sollicitans*, and *Ae. dorsalis*) and the permanent-water mosquitoes (*Cx. tarsalis*, *Cx. salinarius*, and *Cx. erraticus*). These 6 species accounted for only 23%, 20%, and 9% of the totals collected in 2003, 2005, and 2006, respectively. This suggested that rainfall differences in one year can have a dramatic effect on mosquito populations and their subsequent impact on public and veterinary health. For example, while *Cx. salinarius* accounted for $<1\%$ of mosquitoes collected in 2003, 2005, and 2006, it was 8% of the total collected in 2004, with 76% originating in the city of Ardmore. As WNV (CDC 2012) and dog heartworm (Ludlam et al. 1970, Ernst and Solcombe 1984, Paras et al. 2014) have been detected in all 6 species, the ability of these mosquitoes to breed when conditions are favorable makes them difficult to control.

Three new species were identified in Oklahoma during the surveillance period. Two species (*Ae. muelleri* and *An. perplexens*) are not medically important, while *Cx. coronator* is a potential WNV vector (Alto et al. 2014). The identification of *Ae. muelleri* and *An. perplexens* in Oklahoma was notable when comparing the regional distribution maps published by Darsie and Ward (2005). According to these maps, *Ae. muelleri* is found only in a small region in Texas while *An. perplexens* is considered to be found only in the eastern United States. It is possible that the *An. perplexens* described in Nebraska in 2000 (Moore

2001) has moved southward through Kansas into Oklahoma.

The distribution and importance of *Cx. coronator* in the state needs further focused study. This mosquito species has invaded much of the southeastern USA since moving north from Texas after 2000 (Gray et al. 2008). It has since been reported in Mississippi (Varnado et al. 2005), Louisiana (Debboun et al. 2005), Florida (Smith et al. 2006), Alabama (McNelly et al. 2007), Georgia (Kelly et al. 2008), and South Carolina (Moulis et al. 2008). Normally collected with other species in a variety of water bodies and locations (Moulis et al. 2008), it is not a dominant invader when compared with *Ae. albopictus* (Yee and Skiff 2014). The first report of the presence and description of *Cx. coronator* in Oklahoma was made by one of the authors (K. Bradley) during a State Vector Control Conference PowerPoint presentation. While this slide has been cited in the literature (a site that is no longer accessible) as evidence that the species is present in Oklahoma, to date no official publication has substantiated this observation. Another identification of a single larva in 2004 and the subsequent inclusion in a species listing from Payne County in the north-central region of Oklahoma (Paras et al. 2014) demonstrates this species has invaded new territory since its first description in south-central Oklahoma. A reported vector for WNV (CDC 2012, Alto et al. 2014), the extent this invasive mosquito will play in arbovirus transmission in the southern USA remains uncertain.

While 64.5% of the species on the checklist were collected at one or more sampling sites during the 4 years of surveillance, 16 (26%) of the historically reported species in Oklahoma have not been observed since 1965 (Parsons 1965). As several are competent vectors for WNV and canine heartworm, it is important to establish whether they still are in the state and whether they could pose a local threat should rainfall increase one year. Of the "missing" species, the most important for disease transmission potential and risk is *Ae. aegypti* (L.), which has not been reported in Oklahoma since 1938 (Rozeboom 1938). The last published record of this species was in central Oklahoma in Edmond (Jones and Coyner 1933) and Stillwater (Rozeboom 1938). However, it appears to have been identified again in 2013 by Department of Defense surveillance in Lawton, OK (K. Bradley, unpublished data). The current distribution of this vector remains unknown. One possible reason for the disappearance of *Ae. aegypti* from Oklahoma could be the 1999 invasion by *Ae. albopictus*, which effectively outcompetes *Ae. aegypti* during the larval stage (Juliano and Lounibos 2005).

Even though the focus of mosquito collections was on WNV surveillance in urban areas, this 4-year survey demonstrates Oklahoma's diverse and abundant mosquito fauna throughout its 11 unique ecozones. In total, 40 species were identified, including 3 new state records. This information will be valuable in developing mosquito ecological studies and control programs in the anticipation of future arboviral outbreaks.

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