Active surveillance to update county scale distribution of four tick species of medical and veterinary importance in Oklahoma

Jessica R. Mitcham[1], Anne W. Barrett[2], Jeff M. Gruntmeir[2], Taylor Holland[2], Jaclyn E. Martin[1], Eileen M. Johnson[2], Susan E. Little[2], and Bruce H. Noden[1]✉

[1]*Department of Entomology and Plant Pathology, Oklahoma State University, College of Agricultural Sciences and Natural Resources, 127 Noble Research Center, Stillwater, OK 74078, U.S.A., bruce.noden@okstate.edu*

[2]*Department of Veterinary Pathobiology, Center for Veterinary Health Sciences, Oklahoma State University, 250 McElroy Hall, Stillwater, OK 74078, U.S.A.*

Received 1 July 2016; Accepted 8 September 2016

ABSTRACT: The incidence of tick-borne disease continues to increase in humans and companion animals in the United States, yet distribution maps for several tick vectors in Oklahoma, including *Dermacentor variabilis*, *Dermacentor albipictus*, *Ixodes scapularis,* and *Amblyomma maculatum,* are not available or are outdated. To address this issue, county-scale tick records from peer-reviewed literature and passive collections were reviewed for Oklahoma. Additionally, dry ice traps, tick drags, and harvested deer were utilized to actively collect adult ticks throughout the state. Through these methods, *D. variabilis, D. albipictus, I. scapularis,* and *A. maculatum* were identified in 88% (68/77), 45.4% (35/77), 66.2% (51/77), and 64.9% (50/77) of the counties in Oklahoma, respectively. Baseline maps were developed for the distribution of *D. variabilis* and *D. albipictus* and distribution maps were updated for *I. scapularis* and *A. maculatum*. This data confirms that these four species of ticks continue to be widespread within Oklahoma with a western expansion of the range of *I. scapularis* within the state. These results assist efforts to better understand the epidemiology of the different diseases caused by pathogens transmitted by these tick species within the Great Plains region. ***Journal of Vector Ecology* 42 (1): 60-73. 2017.**

Keyword Index: Active surveillance, *Amblyomma*, *Dermacentor*, geographic distribution, *Ixodes*, Oklahoma.

INTRODUCTION

The incidence of tick-borne disease continues to increase in humans and companion animals in the United States (CDC 2015). One area of concern is the south-central region of the U.S. that has seen an increase in ehrlichiosis, Rocky Mountain spotted fever, and tularemia among human populations, and ehrlichiosis and hepatozoonosis among veterinary species (Openshaw et al. 2010, Dahlgren et al. 2011, Starkey et al. 2013, Carmichael et al. 2014, Little et al. 2014). While it is apparent that the incidence of these diseases is increasing, the distribution maps for principal tick vectors in this region are not available, are outdated, or are based on passive collections (Dennis et al. 1998, Cortinas and Spomer 2014, James et al. 2015, Eisen et al. 2016). By actively monitoring the distribution of a specific tick species, evidence can be gathered that can help explain tick-borne disease patterns within a given area (Jobe et al. 2007, Rand et al. 2007, Hamer et al. 2010, Rydzewski et al. 2012, Lee et al. 2013, Wang et al. 2014). These data also serve as a critical link to begin educating communities about the risks for possible exposure to various tick-borne pathogens (Bayles and Allan 2013).

The risk of tick-borne pathogen activity in Oklahoma has been described in humans and veterinary species (Openshaw et al. 2010, Dahlgren et al. 2011, Starkey et al. 2013, Carmichael et al. 2014, Little et al. 2014). Public health risk for these infections has particular impact on Native American communities (Demma et al. 2006, Holman et al. 2009, Folkema et al. 2012). The incidence of Rocky Mountain spotted fever and ehrlichiosis in human populations in Oklahoma has increased dramatically in the past 15 years, with the highest incidence occurring in the eastern portion of the state (K. Bradley, personal communication). While increased incidence of different tick-borne diseases is notable, there is relatively little information on the distribution of important tick species that transmit various pathogens in Oklahoma. Currently, no published records exist for distributions of *Dermacentor variabilis* or *Dermacentor albipictus* within the state and the currently available distribution maps for *Ixodes scapularis* (Dennis et al. 1998, Eisen et al. 2016) and *Amblyomma maculatum* (Barker et al. 2004) are based on surveys carried out 10-15 years ago. Establishing baselines and updating distributions will assist in gaining a better understanding of the various factors involved in the patterns of disease incidence in the state. The purpose of this study, then, was to establish and update distribution maps for four important tick species involved in the transmission of a variety of pathogens in the state of Oklahoma. This study was part of a larger study updating the distribution of the lone star tick in Oklahoma (Barrett et al. 2015).

MATERIALS AND METHODS

Tick species records from Oklahoma

Details of collection methods were published by Barrett et al. (2015). Briefly, in addition to reports summarized from peer-reviewed literature (Table 1), records were compiled from archived specimens archived since the 1940s in the K.C. Emerson Entomology Museum (Oklahoma State University) and from issues of the United States Department of Agriculture's (USDA) Cooperative Economic Insect Reports (CEIR). Due to the lack of

a baseline distribution map for *D. variabilis*, submissions reported on VectorMap, an online database where specimens are linked to places of collection, were included. Updated distribution maps for *I. scapularis* and *A. maculatum* were based on earlier surveys (Table 1).

Active collection of ticks

Active collection of ticks took place during two seasons: 1) between May and July, 2014, in which 60 counties were sampled across Oklahoma and 2) between October and November, 2014 in which eight counties [Beaver Co., Blaine Co., Cleveland Co., Custer Co., Dewey Co., Ellis Co., Grady Co., and Major Co.] were sampled. The summer collection period utilized standard dry ice traps and dragging and flagging as the primary collection methods (Barrett et al. 2015). Additional active collection efforts during autumn, 2014 consisted of collecting ticks from harvested deer during Oklahoma Department of Wildlife and Conservation (ODWC) controlled hunts in several Wildlife Management Areas (WMAs). Ticks were collected directly from harvested deer either by study personnel or by ODWC personnel. It was not possible to link the numbers of *I. scapularis* and *D. albipictus* specifically to Dewey, Blaine, or Major counties. The Canton WMA, in which the deer were harvested and ticks were collected by ODWC personnel at a central location, covers part of all three counties. Although it is not possible to link numbers of adult ticks recovered to a specific county in the WMA, it is highly probable that the tick species are found in all three counties. All ticks were stored in 70% ethyl alcohol and identified with standard keys (Keirans and Litwak 1989, Keirans and Durden 1998).

Data summation

Counties were classified as established or reported for each tick species using criteria described by Dennis et al. (1998). A tick species was considered 1) established in a county if six or more ticks, or more than one life stage, were collected or reported in one time period, or 2) reported in a county if less than six ticks, or only one life stage, was collected at one time period. Counties described in the USDA-CEIR or museum specimens were considered to have established populations of a specific tick species if enumeration meeting the above standards was met. As it was not possible to determine whether ticks reported on VectorMap were collected at the same time, we could only use the data to report the species present in a particular county. In the current study, only adult ticks were collected during the active collections in 2014. Distribution maps for tick species were created using DIVAGIS (Version 7.5.0.0 (http://www.diva-gis.org/).

RESULTS

Dermacentor variabilis

Dermacentor variabilis was reported (n=48) or established (n=20) in 88% (68/77) of the counties in Oklahoma (Figure 1). For 50/68 counties, the presence of *D. variabilis* was confirmed through review of peer-reviewed publications, museum collections, or publicly available records (Table 2). Active surveillance during the summer of 2014 added 18 counties to this distribution.

Dermacentor albopictus

Dermacentor albipictus was reported (n=20) or established (n=15) in 45.4% (35/77) of the counties in Oklahoma (Figure 2). For 32/35 counties, the presence of *D. albipictus* was confirmed through review of peer-reviewed publications, museum collections, or publicly available records (Table 3). Active surveillance in October/November, 2014 added three counties to this distribution (Figure 2).

Ixodes scapularis

Prior to this study, passive surveillance recorded *I. scapularis* in 61% (47/77) of Oklahoma counties, mainly in the eastern and central portion of the state (Figure 3). Active surveillance confirmed *I. scapularis* in eight counties in summer, 2014 and added another four counties in autumn, 2014 to the current distribution (Figure 3, Table 4), advancing the documented distribution of this tick further to the west in the state. Overall, *I. scapularis* is currently reported (n=34) or established (n=17) in 66.2% (51/77) counties in Oklahoma.

Amblyomma maculatum

Passive surveillance records identified *A. maculatum* in 62.3% (48/77) counties in Oklahoma (Table 5). Active surveillance in summer, 2014 confirmed *A. maculatum* in five counties and added two previously unreported counties to the current distribution (Figure 4). Overall, *A. maculatum* has been reported (n=40) or established (n=10) in 64.9% (50/77) counties in Oklahoma (Table 5).

DISCUSSION

Establishing baseline distribution maps and updating historical maps are critical to understanding how tick populations are spread over diverse eco-zones as well as evaluating changes in the potential risk for specific tick-borne diseases in a specific geographic area. Given the dramatic increase of tick-borne diseases in human and animal populations in Oklahoma over the last 15 years (Openshaw et al. 2010, Dahlgren et al. 2011, Starkey et al. 2013, Little et al. 2014, Carmichael et al. 2014), it is critical to understand where the tick species that are responsible for transmitting specific pathogens are distributed. By using active surveillance, the current study added an additional 18 counties of reported and established populations to the list compiled from published studies for distribution of *D. variabilis*. *Ixodes scapularis* collected from controlled deer hunts added six additional counties to the distribution for *I. scapularis* and indicated that the species has possibly moved further westward in the state than previously reported (Dennis et al. 1998, Eisen et al. 2016). Active surveillance also added two new counties to the historical distribution of *A. maculatum* and three counties to a baseline distribution map for *D. albipictus*. Active surveillance during strategic sampling times within a six-month period demonstrated that these four tick species of medical and veterinary importance are more widespread throughout the state than previously thought.

This study established a baseline distribution map for the presence of *D. variabilis* in Oklahoma. An important vector for the transmission of several pathogens that impact human and animal health, *D. variabilis* is a known vector for agents that cause

Table 1. Publications documenting presence of *D. variabilis*, *D. albipictus*, *I. scapularis,* and *A. maculatum* in Oklahoma.

Species	Collection method	Citations
Dermacentor variabilis	Unknown	Eddy, 1940
	Various mammals examined	Ellis, 1955
	Various animals examined	Clymer et al. 1970
	Stray Dogs examined	Parrish, 1970
	CO_2 Traps	Semtner et. al. 1975
	Stray Dogs examined	Koch and Dunn 1980
	Dogs examined	Koch, 1982
	Small mammals examined	Gage et al. 1992
	Dogs examined	Barrett et al. 2014
Dermacentor albipictus	Unknown	Eddy, 1940
	Elk examined	Patrick and Hair 1975
	Collected from harvested white-tailed deer	Smith 1977
	Cattle examined	Ewing et al. 1997
	Dragging, cattle examined	Polito et al. 2013
Ixodes scapularis	Unknown	Eddy 1940
	Collected from harvested white-tailed deer	Smith 1977
	Flagging, dragging, deer surveys, small-medium sized mammal surveys, CO_2 baiting, and tick submissions	Dennis et al. 1998, Eisen et al. 2016
Amblyomma maculatum	Collected from harvested white-tailed deer	Smith, 1977
	Collected from various hosts	Barker et al. 2004
	Collected from cattle, flagging	Personal communication, Talley, OSU

diseases, including Rocky Mountain spotted fever (*Rickettsia rickettsii*), afebrile spotted fever group rickettsiosis (SFGR) (*R. montanensis*), tularemia (*Franciscella tularensis*), bovine anaplasmosis (*Anaplasma marginale*), and equine piroplasmosis (*Theileria equi*). Over the past 10-15 years, Oklahoma has become one of the top two states for incidence of SFGR (Openshaw et al. 2010) in addition to ranking sixth for incidence of tularemia (CDC 2013). Anaplasmosis also continues to be a significant concern for livestock in the state. Establishing the presence of *D. variabilis* throughout most of the state, including the arid western counties as well as the moist, humid eastern counties, is a first step to identifying the ecological factors involved with maintaining this important tick vector species in the region.

This study also established a baseline distribution map for *D. albipictus*, a one-host tick found on horses, cattle, elk, white-tailed deer, and feral swine (Sanders et al. 2013) in the Oklahoma/Texas region. A known vector for *A. marginale*, the causative agent of bovine anaplasmosis, very little is known concerning the ecology and habits of this tick in the southern Great Plains region, especially in regards to interactions with cattle (Drummond 1967).

Active surveillance through controlled deer hunts in western Oklahoma counties extended the known distribution of *I. scapularis* farther west in the state than previously reported (Dennis et al. 1998). One of the most important tick vectors of disease agents in the United States, this species is known to transmit the agents of Lyme disease (*Borrelia burgdorferi*), human granulocytic anaplasmosis (*A. phagocytophilum*), human babesiosis (*Babesia microti*), human ehrlichiosis (*E. muris*-like agent), and *Borrelia miyamotoi* in other regions of the United States (Hamer et al. 2012, Salkeld et al. 2014). The identification of this important species on deer collected in a wildlife management area in the arid, dry western portion of Oklahoma should not be taken as evidence of these disease agents in the region due to feeding preferences (Garvin et al. 2015), but does provide an opportunity for future research.

We recognize that a significant portion of this study was taken from active surveillance methods used to track the presence of *A. americanum* throughout the state (Barrett et al. 2015). As such, the flagging and CO_2 methods utilized were not ideal for collection of the four species reported in this paper (Semtner and Hair 1975, Ginsberg and Ewing 1989). However, given that limitation, it was notable that all species other than *D. albipictus* were collected using these sampling techniques, indicating that when used as part of an active surveillance strategy, these two sampling methods are able to draw enough adult ticks from the surrounding habitat to monitor distribution in a given area (Semtner and Hair 1975). Another limitation encountered in the successful surveillance of *I. scapularis* and *D. albipictus* involved the reduction in ODWC-sponsored deer checking stations during deer hunting season. Oklahoma, like many other states, has converted to an online check process that has significantly changed our ability to readily collect these two important tick species within the state.

In conclusion, an updated distribution of four important tick species in Oklahoma was determined during strategic sampling times within a six-month period using active collection methods and passive monitoring. Baseline distribution maps

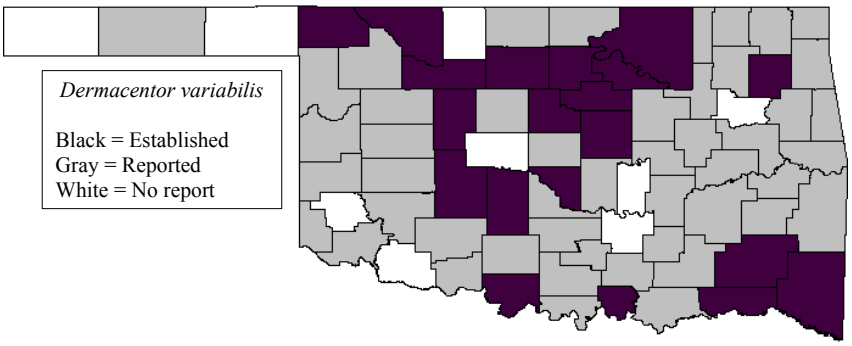

Figure 1. Counties in Oklahoma where *Dermacentor variabilis* are reported or established based on summary of the peer-reviewed literature and surveillance completed in the present paper.

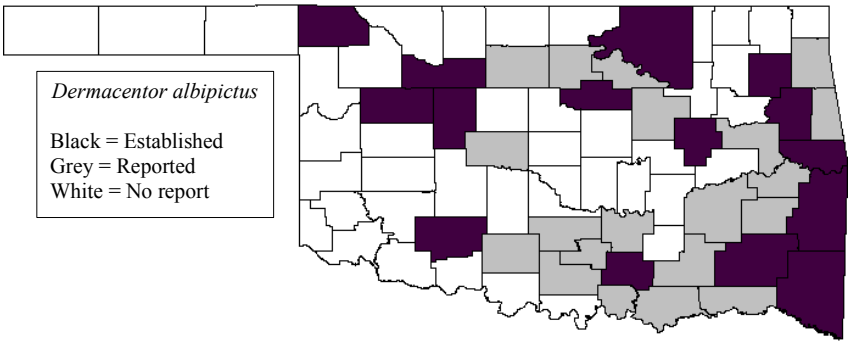

Figure 2. Counties in Oklahoma where *Dermacentor albipictus* are reported or established based on summary of the peer-reviewed literature and surveillance completed in the present paper.

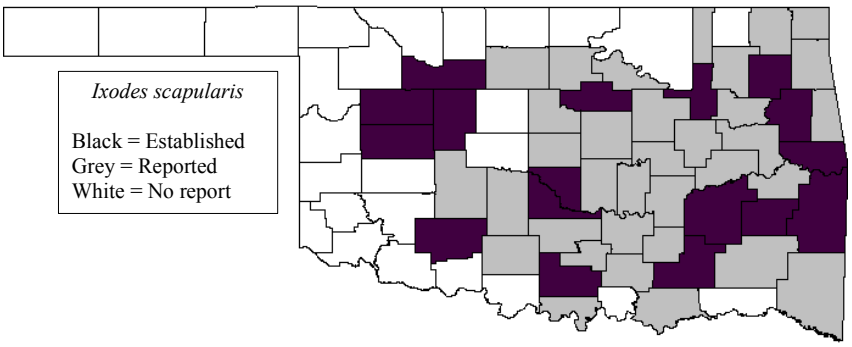

Figure 3. Counties in Oklahoma where *Ixodes scapularis* are reported or established based on summary of the peer-reviewed literature and surveillance completed in the present paper.

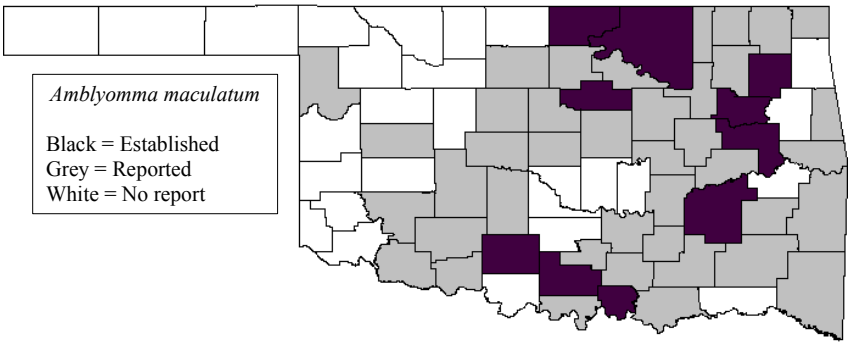

Figure 4. Counties in Oklahoma where *Amblyomma maculatum* are reported or established based on summary of the peer-reviewed literature and surveillance completed in the present paper.

Table 2. Counties in Oklahoma where *D. variabilis* are established or [reported].

Counties	Peer-reviewed Literature	VectorMap	K.C. Emerson Entomology Museum	USDA-CEIR	Active collection in 2014	Current Status of County
		no. of reports	no. of ticks	no. of reports	no. of ticks	
Adair	R	0	1	NR	ND	Reported
Alfalfa	NR	0	NR	NR	0	
Atoka	NR	0	2	[4]	ND	Reported
Beaver	NR	0	NR	NR	0	
Beckham	NR	0	NR	NR	1	Reported
Blaine	R	0	>6	1	1	Established
Bryan	NR	0	1	NR	ND	Reported
Caddo	NR	0	>6	1	6	Established
Canadian	NR	0	NR	NR	0	
Carter	R	0	2	NR	ND	Reported
Cherokee	R	0	NR	NR	ND	Reported
Choctaw	R	0	NR	1	ND	Established
Cimarron	NR	0	NR	NR	0	
Cleveland	R	0	2	NR	14	Established
Coal	NR	0	1	NR	1	Reported
Comanche	R	10	1	NR	ND	Reported
Cotton	NR	0	NR	NR	3	Reported
Craig	R	0	1	NR	0	Reported
Creek	R	0	NR	NR	0	Reported
Custer	NR	0	NR	NR	3	Reported
Delaware	R	0	NR	NR	5	Reported
Dewey	NR	0	NR	[1]	2	Reported
Ellis	NR	0	1	NR	1	Reported
Garfield	R	2	NR	NR	6	Established
Garvin	NR	0	1	NR	2	Reported
Grady	NR	0	NR	NR	6	Established
Grant	NR	0	NR	NR	2	Reported
Greer	NR	0	NR	NR	0	
Harmon	NR	0	NR	NR	3	Reported
Harper	NR	0	>6	2	0	Established
Haskell	R	0	NR	NR	0	Reported
Hughes	NR	0	NR	NR	1	Reported
Jackson	NR	4	3	[1]	0	Reported
Jefferson	NR	0	>6	NR	2	Established
Johnston	R	0	NR	NR	ND	Reported
Kay	R	0	NR	NR	0	Reported
Kingfisher	NR	0	1	NR	4	Reported
Kiowa	R	0	NR	NR	1	Reported
Latimer	R	0	NR	NR	ND	Reported
Le Flore	R	1	NR	NR	1	Reported

Table 2 continued. Counties in Oklahoma where *D. variabilis* are established or [reported].

Counties	Peer-reviewed Literature	VectorMap	K.C. Emerson Entomology Museum	USDA-CEIR	Active collection in 2014	Current Status of County
		no. of reports	no. of ticks	no. of reports	no. of ticks	
Lincoln	R	0	>6	1	0	Established
Logan	R	0	>6	1	0	Established
Love	NR	0	NR	NR	2	Reported
Major	NR	0	>6	NR	1	Established
Marshall	R	0	>6	1	0	Established
Mayes	NR	0	>6	1	0	Established
McClain	R	0	NR	NR	3	Reported
McCurtain	R	1	NR	1	ND	Established
McIntosh	R	0	NR	NR	ND	Reported
Murray	R	0	NR	NR	3	Reported
Muskogee	R	1	1	NR	ND	Reported
Noble	R	0	>6	6	0	Established
Nowata	R	0	NR	NR	0	Reported
Okfuskee	R	0	NR	NR	0	Reported
Oklahoma	R	0	4	[1]	0	Reported
Okmulgee	NR	0	2	NR	0	Reported
Osage	R	0	NR	NR	8	Established
Ottawa	R	0	1	NR	0	Reported
Pawnee	R	0	1	2	8	Established
Payne	R	3	>6	34	ND	Established
Pittsburg	R	3	NR	NR	ND	Reported
Pontotoc	NR	0	NR	NR	0	
Pottawatomie	NR	0	NR	NR	5	Reported
Pushmataha	R	0	NR	1	0	Established
Roger Mills	NR	0	NR	NR	1	Reported
Rogers	R	0	1	NR	0	Reported
Seminole	NR	0	NR	NR	0	
Sequoyah	R	0	NR	[1]	0	Reported
Stephens	NR	0	1	NR	2	Reported
Texas	NR	0	1	NR	0	Reported
Tillman	NR	0	NR	NR	0	
Tulsa	NR	0	1	[1]	0	Reported
Wagoner	NR	0	NR	NR	0	
Washington	R	0	NR	NR	1	Reported
Washita	NR	0	1	NR	1	Reported
Woods	NR	0	>6	NR	0	Established
Woodward	R	0	NR	NR	1	Reported

E – Established, R-Reported, NR-Not reported, ND- Not determined.

Table 3. Counties in Oklahoma where *Dermacentor albipictus* are established or [reported].

Counties	Peer-reviewed Literature*	K.C. Emerson Entomology Museum	USDA CEIR	Active collection in 2014	Current Status of County
		no. of ticks	no. of reports	no. of ticks	
Adair	NR	1	[2]	ND	Reported
Alfalfa	NR	NR	NR	ND	
Atoka	NR	NR	[1]	ND	Reported
Beaver	NR	NR	NR	ND	
Beckham	NR	NR	NR	ND	
Blaine	NR	NR	NR	14*	Established
Bryan	R	NR	NR	ND	Reported
Caddo	NR	NR	NR	ND	
Canadian	NR	NR	[1]	ND	Reported
Carter	NR	2	NR	ND	Reported
Cherokee	R	NR	6	ND	Established
Choctaw	NR	NR	[6]	ND	Reported
Cimarron	NR	NR	NR	ND	
Cleveland	NR	NR	NR	ND	
Coal	NR	NR	NR	ND	
Comanche	R	>6	4	ND	Established
Cotton	NR	NR	NR	ND	
Craig	NR	NR	NR	ND	
Creek	NR	1	NR	ND	Reported
Custer	NR	NR	NR	ND	
Delaware	R	NR	NR	ND	Reported
Dewey	NR	NR	1	14*	Established
Ellis	NR	NR	NR	ND	
Garfield	NR	5	NR	ND	Reported
Garvin	NR	NR	[1]	ND	Reported
Grady	NR	NR	NR	ND	
Grant	NR	NR	NR	ND	
Greer	NR	NR	NR	ND	
Harmon	NR	NR	NR	ND	
Harper	R	>6	NR	ND	Established
Haskell	NR	NR	[1]	ND	Reported
Hughes	NR	NR	NR	ND	
Jackson	NR	NR	NR	ND	
Jefferson	NR	NR	NR	ND	
Johnston	NR	>6	2	ND	Established
Kay	NR	NR	NR	ND	
Kingfisher	NR	NR	NR	ND	
Kiowa	NR	NR	NR	ND	
Latimer	R	NR	[1]	ND	Reported
Le Flore	R	NR	4	ND	Established

** Collected from harvested deer from Canton WMA located in three counties.*
E-Established, R-Reported, R-Not reported, ND- Not determined.

Table 3 continued. Counties in Oklahoma where *Dermacentor albipictus* are established or [reported].

Counties	Peer-reviewed Literature*	K.C. Emerson Entomology Museum	USDA CEIR	Active collection in 2014	Current Status of County
		no. of ticks	no. of reports	no. of ticks	
Lincoln	NR	NR	NR	ND	
Logan	NR	NR	NR	ND	
Love	NR	NR	NR	ND	
Major	NR	NR	NR	14*	Established
Marshall	NR	NR	[1]	ND	Reported
Mayes	NR	NR	3	ND	Established
McClain	NR	NR	NR	ND	
McCurtain	R	>6	[10]	ND	Established
McIntosh	NR	NR	NR	ND	
Murray	R	NR	[2]	ND	Reported
Muskogee	NR	NR	[1]	ND	Reported
Noble	NR	1	[3]	ND	Reported
Nowata	NR	NR	NR	ND	
Okfuskee	NR	NR	NR	ND	
Oklahoma	NR	NR	NR	ND	
Okmulgee	NR	>6	NR	ND	Established
Osage	NR	NR	4	ND	Established
Ottawa	NR	NR	NR	ND	
Pawnee	R	NR	NR	ND	Reported
Payne	NR	4	7	ND	Established
Pittsburg	R	NR	[4]	ND	Reported
Pontotoc	NR	2	NR	ND	Reported
Pottawatomie	NR	NR	NR	ND	
Pushmataha	R	NR	20	ND	Established
Roger Mills	NR	NR	NR	ND	
Rogers	NR	NR	NR	ND	
Seminole	NR	NR	NR	ND	
Sequoyah	NR	>6	[4]	ND	Established
Stephens	NR	NR	[4]	ND	Reported
Texas	NR	NR	NR	ND	
Tillman	NR	NR	NR	ND	
Tulsa	NR	NR	NR	ND	
Wagoner	NR	NR	NR	ND	
Washington	NR	NR	NR	ND	
Washita	NR	NR	NR	ND	
Woods	NR	NR	NR	ND	
Woodward	NR	NR	NR	ND	

Table 4. Counties in Oklahoma where *Ixodes scapularis* are established or [reported].

Counties	Peer-reviewed Literature	K.C. Emerson Entomology Museum	USDA-CEIR	Active collection in 2014	Current Status of County
		no. of ticks	no. reports	no. of ticks	
Adair	R	NR	NR	ND	Reported
Alfalfa	NR	NR	NR	0	
Atoka	R	NR	4	ND	Established
Beaver	NR	NR	NR	0	
Beckham	NR	NR	NR	0	
Blaine	NR	NR	NR	9*	Established
Bryan	R	NR	NR	ND	Reported
Caddo	R	NR	NR	0	Reported
Canadian	NR	NR	NR	0	
Carter	R	>6	NR	ND	Established
Cherokee	E	>6	11	ND	Established
Choctaw	NR	NR	NR	ND	
Cimarron	NR	NR	NR	0	
Cleveland	NR	1	NR	100	Established
Coal	R	NR	NR	0	Reported
Comanche	R	>6	3	ND	Established
Cotton	NR	NR	NR	0	
Craig	R	NR	NR	0	Reported
Creek	R	4	NR	1	Reported
Custer	NR	NR	NR	14	Established
Delaware	R	NR	NR	1	Reported
Dewey	NR	NR	NR	9*	Established
Ellis	NR	NR	NR	0	
Garfield	R	3	NR	0	Reported
Garvin	R	NR	NR	0	Reported
Grady	NR	5	NR	5	Reported
Grant	NR	NR	NR	0	
Greer	NR	NR	NR	0	
Harmon	NR	NR	NR	0	
Harper	NR	NR	NR	0	
Haskell	R	NR	NR	0	Reported
Hughes	R	NR	NR	0	Reported
Jackson	NR	NR	NR	0	
Jefferson	NR	NR	NR	0	
Johnston	R	NR	NR	ND	Reported
Kay	NR	NR	NR	0	
Kingfisher	NR	NR	NR	0	
Kiowa	NR	NR	NR	0	
Latimer	R	>6	1	ND	Established
Le Flore	E	NR	NR	ND	Established

* Collected from harvested deer from Canton WMA located in three counties.
E-Established, R-Reported, NR-Not reported, ND- Not determined

Table 4 continued. Counties in Oklahoma where *Ixodes scapularis* are established or reported.

Counties	Peer-reviewed Literature	K.C. Emerson Entomology Museum	USDA-CEIR	Active collection in 2014	Current Status of County
		no. of ticks	no. reports	no. of ticks	
Lincoln	R	1	NR	0	Reported
Logan	R	NR	NR	5	Reported
Love	R	NR	NR	0	Reported
Major	NR	NR	NR	9*	Established
Marshall	NR	NR	NR	0	
Mayes	R	6	1	0	Established
McClain	E	NR	NR	0	Established
McCurtain	R	5	[2]	ND	Reported
McIntosh	R	NR	NR	ND	Reported
Murray	R	NR	NR	0	Reported
Muskogee	R	NR	[1]	ND	Reported
Noble	NR	4	NR	0	Reported
Nowata	NR	NR	NR	0	
Okfuskee	R	NR	NR	0	Reported
Oklahoma	R	1	NR	0	Reported
Okmulgee	R	NR	NR	2	Reported
Osage	NR	NR	NR	0	
Ottawa	R	4	NR	0	Reported
Pawnee	R	NR	NR	1	Reported
Payne	R	>6	3	ND	Established
Pittsburg	R	6	1	ND	Established
Pontotoc	R	NR	NR	0	Reported
Pottawatomie	R	NR	NR	0	Reported
Pushmataha	R	1	NR	0	Reported
Roger Mills	NR	NR	NR	0	
Rogers	R	1	NR	0	Reported
Seminole	R	2	NR	0	Reported
Sequoyah	R	6	NR	0	Established
Stephens	NR	NR	[1]	0	Reported
Texas	NR	NR	NR	0	
Tillman	NR	NR	NR	0	
Tulsa	R	1	1	6	Established
Wagoner	R	1	NR	0	Reported
Washington	R	NR	NR	0	Reported
Washita	NR	NR	NR	0	
Woods	NR	NR	NR	0	
Woodward	NR	NR	NR	0	

* Collected from harvested deer from Canton WMA located in three counties.
E-Established, R-Reported, NR-Not reported, ND- Not determined

Table 5. Counties in Oklahoma where *Amblyomma maculatum* are established or [reported].

Counties	Peer-reviewed Literature	K.C. Emerson Entomology Museum	USDA CEIR	Active collection in 2014	Current Status of County
		no. of ticks	no. reported	no. of ticks	
Adair	R	NR	NR	ND	Reported
Alfalfa	NR	NR	NR	0	
Atoka	R	NR	NR	ND	Reported
Beaver	NR	NR	NR	0	
Beckham	NR	NR	NR	0	
Blaine	NR	NR	NR	0	
Bryan	R	NR	NR	ND	Reported
Caddo	R	2	NR	0	Reported
Canadian	R	2	NR	0	Reported
Carter	R	>6	NR	ND	Established
Cherokee	NR	NR	NR	ND	
Choctaw	NR	NR	NR	ND	
Cimarron	NR	NR	NR	0	
Cleveland	NR	NR	NR	0	
Coal	R	4	NR	0	Reported
Comanche	R	NR	NR	ND	Reported
Cotton	NR	NR	NR	3	Reported
Craig	R	2	NR	0	Reported
Creek	R	1	NR	0	Reported
Custer	NR	1	NR	0	Reported
Delaware	NR	NR	NR	0	
Dewey	NR	NR	NR	0	
Ellis	R*	1	NR	0	Reported
Garfield	R	1	NR	1	Reported
Garvin	NR	NR	NR	0	
Grady	R	4	NR	0	Reported
Grant	NR	NR	NR	0	
Greer	NR	NR	NR	0	
Harmon	NR	NR	NR	0	
Harper	NR	NR	NR	0	
Haskell	NR	NR	NR	0	
Hughes	R	3	NR	0	Reported
Jackson	NR	NR	NR	0	
Jefferson	NR	NR	NR	0	
Johnston	NR	2	[5]	ND	Reported
Kay	R	>6	NR	0	Established
Kingfisher	R	1	NR	0	Reported
Kiowa	NR	1	NR	1	Reported
Latimer	R	1	NR	ND	Reported
Le Flore	R	NR	NR	ND	Reported

*Personal Communication

E-Established, R-Reported, NR-Not reported, ND- Not determined

Table 5 continued. Counties in Oklahoma where *Amblyomma maculatum* are established or [reported].

Counties	Peer-reviewed Literature	K.C. Emerson Entomology Museum	USDA CEIR	Active collection in 2014	Current Status of County
		no. of ticks	no. reported	no. of ticks	
Lincoln	R	NR	NR	0	Reported
Logan	R	2	NR	0	Reported
Love	R	1	NR	0	Reported
Major	NR	NR	NR	0	
Marshall	R	>6	NR	0	Established
Mayes	R	>6	[8]	0	Established
McClain	NR	NR	NR	0	
McCurtain	NR	2	NR	ND	Reported
McIntosh	R	2	NR	ND	Reported
Murray	R	NR	NR	0	Reported
Muskogee	R	>6	NR	ND	Established
Noble	R	1	[1]	0	Reported
Nowata	R	NR	[1]	0	Reported
Okfuskee	R	1	NR	0	Reported
Oklahoma	R	4	NR	0	Reported
Okmulgee	R	1	NR	0	Reported
Osage	R	1	NR	16	Established
Ottawa	R	NR	NR	0	Reported
Pawnee	R	NR	[1]	0	Reported
Payne	R	>6	NR	2	Established
Pittsburg	R	6	NR	ND	Established
Pontotoc	R	NR	NR	0	Reported
Pottawatomie	NR	NR	NR	0	
Pushmataha	R	NR	NR	0	Reported
Roger Mills	NR	NR	NR	0	
Rogers	R	5	[1]	0	Reported
Seminole	NR	NR	NR	0	
Sequoyah	R	NR	NR	0	Reported
Stephens	R	6	NR	0	Established
Texas	NR	NR	NR	0	
Tillman	NR	NR	NR	1	Reported
Tulsa	R	4	NR	0	Reported
Wagoner	R	>6	1	0	Established
Washington	R	1	[1]	1	Reported
Washita	NR	NR	NR	0	
Woods	NR	NR	NR	0	
Woodward	NR	NR	NR	0	

E-Established, R-Reported, NR-Not reported, ND- Not determined

were developed for *D. variabilis* and *D. albipictus* for the state of Oklahoma and additional counties were added to distribution maps for *I. scapularis* and *A. maculatum*. It is anticipated that these results will assist efforts to better understand the epidemiology of the different diseases associated with these tick species within the Great Plains region (Bartholomew et al. 1995, Cortinas and Spomer 2014). Accurate distribution maps for each species studied will be increasingly important as more tick-borne pathogens are identified and climate changes occur across the central plains of the U.S.

Acknowledgments

We thank the Oklahoma Department of Wildlife Conservation as well as the U.S. Fish and Wildlife Service, specifically, Thad Potts, Weston Storer, Rex Umber, Scott Parry, Colby Farquhar, and Levi Feltman for their assistance and support with field collections. We thank Rick Grantham for access and assistance with the K.C. Emerson Museum Collection. We thank Tom Creider with the Oklahoma State Parks Department as well as many private individuals who allowed access to lands for this study. We also thank Dr. Hassan Melouk and Dr. Wyatt Hoback for constructive comments on an earlier version of this manuscript. Funding was provided by the Krull-Ewing Endowment as well as NIFA/USDA Hatch Grant funds through the Oklahoma Agricultural Experiment Station (OKL-02909) at Oklahoma State University.

REFERENCES CITED

Barker, R.W. 2004. Occurrence of the Gulf Coast tick (Acari: Ixodidae) on the wild and domestic mammals in north-central Oklahoma. J. Med. Entomol. 41: 170-178.

Barrett, A.W., S. E. Little, and E. Shaw. 2014. "*Rickettsia amblyommii*" and *R. montanensis* infection in dogs following natural exposure to ticks. J. Med. Entomol. 14: 20-25.

Barrett, A.W., B.H. Noden, J.M. Gruntmeir, T.Holland, J.R. Mitcham, J.E. Martin, E.M. Johnson, and S.E. Little. 2015. County scale distribution of *Amblyomma americanum* (Ixodida: Ixodidae) in Oklahoma: Addressing local deficits in tick maps based on passive reporting. J. Med. Entomol. 52: 269-273.

Bartholomew, D.M., W.A. Rowley, M.G. Novak, and K.B. Platt. 1995. *Ixodes scapularis* and other ticks (Acari, Ixodidae) associated with Lyme disease in Iowa. J. Vector Ecol. 20: 1-6.

Bayles, B.R. and B.F. Allan. 2013. Social-ecological factors determine spatial variation in human incidence of tick-borne ehrlichiosis. Epidemiol. Inf. 142: 1911-1924.

Carmichael, R.C., J.R. Duell, T.C. Holbrook, B.H. Herrin, C.M. Leutenegger, T.P. O'Connor, and S.E. Little. 2014. Antibodies reactive to *Ehrlichia* spp. are common in Oklahoma horses. Vector Borne Zoonot. Dis. 14: 552-556.

Centers for Disease Control and Prevention (CDC). 2013. Tularemia - United States, 2001-2010. MMWR 62: 963-966.

Centers for Disease Control and Prevention (CDC). 2015. Tickborne diseases of the U.S. Accessed on 1/7/2016 at http://www.cdc.gov/ticks/diseases/.

Clymer, B.C., D.E. Howell, and J.A. Hair. 1970. Animal hosts of economically important ticks (Acarina) in East-Central Oklahoma. Ann. Entomol. Soc. Am. 63: 612-613.

Cortinas R. and S.M. Spomer. 2014. Occurrence and county-level distribution of ticks (Acari: Ixodoidea) in Nebraska using passive surveillance. J. Med. Entomol. 51: 352-359.

Dahlgren, F.S., E.J. Mandel, J.W. Krebs, R.F. Massung, and J.H. McQuiston. 2011. Increasing incidence of *Ehrlichia chaffeensis* and *Anaplasma phagocytophilum* in the United States, 2000-2007. Am. J. Trop. Med. Hyg. 85: 124-131.

Demma, L.J., R.C. Holman, C.A. Mikosz, A.T. Curns, D.L. Swerdlow, E.L. Paisano, and J.E. Cheek. 2006. Rocky Mountain Spotted Fever hospitalizations among American Indians. Am. J. Trop. Med. Hyg. 75: 537-541.

Dennis, D.T., T.S. Nekomoto, J.C. Victor, W.S. Paul, and J. Piesman. 1998. Reported distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the United States. J. Med. Entomol. 35: 629-638.

Drummond, R.O. 1967. Seasonal activity of ticks (Acarina: Metastigmata) on cattle in Southwestern Texas. Ann. Entomol. Soc. Am. 60: 439-447.

Eddy, G.W. 1940. The ticks of Oklahoma. MS thesis. Oklahoma Agricultural and Mechanical College.

Eisen R.J., L. Eisen, and C.B. Beard. 2016. County-scale distribution of *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae) in the continental United States. J. Med. Entomol. 53: 349-386.

Ellis Jr., L.L. 1955. A Survey of the ectoparasites of certain mammals in Oklahoma. Ecology 36: 12-18.

Ewing, S.A., R.J. Panciera, K.M. Kocan, N.L. Ge, R.J. Welsh, R.W. Olson, R.W. Barker, and L.E. Rice. 1997. A winter outbreak of anaplasmosis in a nonendemic area of Oklahoma: a possible role for *Dermacentor albipictus*. J. Vet. Diag. Invest. 9: 206-208.

Folkema, A.M., R.C. Holman, F.S. Dahlgren, J.E. Cheek, and J.H. McQuiston. 2012. Epidemiology of ehrlichiosis and anaplasmosis among American Indians in the United States, 2000-2007. Am. J. Trop. Med. Hyg. 87: 529-537.

Gage, K.L., C.E. Hopla, and T.G. Schwan. 1992. Cotton rats and other small mammals as hosts for immature *Dermacentor variabilis* (Acari: Ixodidae) in Central Oklahoma. J. Med. Entomol. 29: 832-842.

Garvin S.D., B.H. Noden, J.W. Dillwith, S.F. Fox, M.E. Payton, and R.W. Barker. 2015. Sylvatic infestation of Oklahoma reptiles with immature *Ixodes scapularis* (Acari: Ixodidae). J. Med. Entomol. 52: 873-878.

Ginsberg, H.S. and C.P. Ewing. 1989. Comparison of flagging, walking, trapping, and collecting from hosts as sampling methods for northern deer ticks, *Ixodes dammini*, and lone-star ticks, *Amblyomma americanum* (Acari:Ixodidae). Exp. Appl. Acarol. 7: 313-322.

Hamer, S.A., J.I. Tsao, E.D. Walker, and G.J. Hickling. 2010. Invasion of the Lyme disease vector *Ixodes scapularis*: Implications for *Borrelia burgdorferi* endemicity. Ecohealth 7: 47-63.

Hamer, S.A., G.J. Hickling, J.L. Sidge, E.D. Walker, and J.I. Tsao. 2012. Synchronous phenology of juvenile *Ixodes scapularis*, vertebrate host relationships, and associated patterns of *Borrelia burgdorferi* ribotypes in the midwestern United States. Ticks Tick Borne Dis. 3: 65-74.

Holman, R.C., J.H. McQuiston, D.L. Haberling, and J.E. Cheek. 2009. Increasing incidence of Rocky Mountain Spotted Fever

among the American Indian population in the United States. Am. J. Trop. Med. Hyg. 80: 601-605.

James, A.M., C. Burdett, M.J. McCool, A. Fox, and P. Riggs. 2015. The geographic distribution and ecological preferences of the American dog tick, *Dermacentor variabilis* (Say), in the U.S.A. Med. Vet. Entomol. 29: 178-188.

Jobe, D.A., J.A. Nelson, M.D. Adam, and S.A. Martin Jr. 2007. Lyme disease in urban areas, Chicago. Emerg. Infect. Dis. 13: 1799-1800.

Keirans, J.E. and T.R. Litwak. 1989. Pictorial key to the adults of hard ticks, Family Ixodidae (Ixodida: Ixodoidea), east of the Mississippi River. J. Med. Entomol. 26: 435-448.

Keirans, J.E. and L.A. Durden. 1998. Illustrated key to nymphs of the tick Genus *Amblyomma* (Acari: Ixodidae) found in the United States. J. Med. Entomol. 35: 489-495.

Koch, H.G. and J.E. Dunn. 1980. Ticks collected from small and medium-sized wildlife hosts in LeFlore County, Oklahoma. Southwest. Entomol. 5: 214-221.

Koch, H.G. 1982. Seasonal incidence and attachment sites of ticks (Acari: Ixodidae) on domestic dogs in southeastern Oklahoma and northwestern Arkansas, USA. J. Med. Entomol. 19: 293-298.

Lee, X., K. Hardy, D.H. Johnson, and S.M. Paskewitz. 2013. Hunter-killed deer surveillance to assess changes in the prevalence and distribution of *Ixodes scapularis* (Acari: Ixodidae) in Wisconsin. J. Med. Entomol. 50: 632-639.

Little, S.E., M.J. Beall, D.D. Bowman, R. Chandrashekar, and J. Stamaris. 2014. Canine infection with *Dirofilaria immitis*, *Borrelia burgdorferi*, *Anaplasma spp*., and *Ehrlichia spp*. in the United States, 2010-2012. Parasite Vectors 7: 257.

Openshaw, J.J., D.L. Swerdlow, J.W. Krebs, R.C. Holman, E. Mandel, A. Harvey, D. Haberling, R.F. Massung, and J.H. McQuiston. 2010. Rocky Mountain Spotted Fever in the United States, 2000-2007: Interpreting contemporary increases in incidence. Am. J. Trop. Med. Hyg. 83: 174-182.

Parrish, D.W. 1970. Fleas, ticks, and lice infesting dogs in north-central Oklahoma. Oklahoma Vet. 22: 15-18.

Patrick, C.D., and J.A. Hair. 1975. Ecological observations on *Dermacentor albipictus* (Packard) in eastern Oklahoma. J. Med. Entomol. 12: 393-394.

Polito, V.J., K.A. Baum, M.E. Payton, S.E. Little, S.D. Fuhlendorf, and M.V. Reichard. 2013. Tick abundance and levels of infestation on cattle in response to patch burning. Rangeland Ecol. Manag. 66: 545-552.

Rand, P.W., E.H. Lacombe, R. Dearborn, B. Cahill, S. Elias, C.B. Lubelczyk, G.A. Beckett, and R.P. Smith Jr. 2007. Passive surveillance in Maine, an area emergent for tick-borne diseases. J. Med. Entomol. 44: 1118-1129.

Rydzewski, J., N. Mateus-Pinilla, R.E. Warner, J.A. Nelson, and T.C. Velat. 2012. *Ixodes scapularis* (Acari: Ixodidae) distribution surveys in the Chicago Metropolitan Region. J. Med. Entomol. 49: 955-959.

Sanders, D.M., A.L. Schuster, P.W. McCadle, O.F. Strey, T.L. Blankenship, and P.D Teel. 2013. Ixodid ticks associated with feral swine in Texas. J. Vector Ecol. 38: 361-373.

Salkeld, D.J., S. Cinkovich, and N.C. Nieto. 2014. Tick-borne pathogens in northwestern California, USA. Emerg. Inf. Dis 20: 493-494.

Semtner, P.J. and J.A. Hair. 1975. Evaluation of CO_2-baited traps for survey of *Amblyomma maculatum* Koch and *Dermacentor variabilis* Say (Acarina: Ixodidae). J. Med. Entomol. 12: 137-138.

Smith, J.S. 1977. A survey of ticks infesting white-tailed deer in 12 southeastern states. MS thesis. University of Georgia.

Starkey, L.A., M.D. West, A.W. Barrett, J.M. Saucier, T.P. O'Connor, K.L. Paras, M.H. Reiskind, M.V. Reichard, and S.E. Little. 2013. Prevalence of antibodies to Spotted Fever group *Rickettsia spp*. and *Ehrlichia spp*. in coyotes (*Canis latrans*) in Oklahoma and Texas, USA. J. Wildl. Dis. 49: 670-673.

Wang, P., M.N. Glowacki, A.E. Hoet, G.R. Needham, K.A. Smith, R.E. Gary, and X. Li. 2014. Emergence of *Ixodes scapularis* and *Borrelia burgdorferi*, the Lyme disease vector and agent, in Ohio. Front. Cell. Infect. Microbiol. 4: 1-9.