

Tick species establishment in Oklahoma County, Oklahoma, U.S.A., identified by seasonal sampling in residential and non-residential sites

Mariah M. Small¹, Sean M. Lavery^{2✉}, Chad B. King¹, and Robert E. Brennan¹

¹University of Central Oklahoma, Department of Biology, Edmond, OK 73034, U.S.A.

²University of Central Oklahoma, Department of Mathematics and Statistics,
Edmond, OK 73034, U.S.A., slavery@uco.edu

Received 13 October 2018; Accepted 2 March 2019

ABSTRACT: In recent years, human tick-borne disease occurrence has risen in Oklahoma, U.S.A., but year-round data on tick presence in frequently used recreational areas is not widely available. In this study, ticks were collected monthly for one year at residential and non-residential sites in a suburban area of Oklahoma County, OK, U.S.A. At each trapping site, dry ice traps were used in both woodland and grassland areas and fabric tick drags were used in grassland areas. Four species were collected from each park: *Amblyomma americanum*, *Amblyomma maculatum*, *Dermacentor variabilis*, and *Ixodes scapularis*. Prior to this study, *A. americanum* was the only species with an established population in Oklahoma County. Consistent with this, *A. americanum* was collected in all months of the year and accounted for over 90% of ticks collected at each site. Based on our tick survey, we report that *A. maculatum*, *D. variabilis*, and *I. scapularis*, which were each collected in numbers greater than six within a single sampling occasion, are now each confirmed as established populations in Oklahoma County. *Journal of Vector Ecology* 44 (1): 105-111. 2019.

Keyword Index: Oklahoma, ticks, *Amblyomma*, residential, winter, distribution.

INTRODUCTION

Ticks and tick-borne pathogens have a worldwide distribution and impact medical, veterinary, and cattle industries (Brites-Neto et al. 2015). Within the United States, Oklahoma is one of the nation's leaders in spotted fever group rickettsiosis and ehrlichiosis diagnoses on an annual basis. In recent years, reported tick-borne disease occurrence in the human population has increased in Oklahoma, though relatively little research exists on the distribution of ticks in highly populated areas, especially on a year-round basis (Biggs et al. 2016). A large portion of tick research focuses on the months between April and October, resulting in a lack of information on tick activity and presence and abundance of tick species in winter months.

Various Oklahoma state parks have been surveyed for ticks and tick-borne diseases in the months of April through August, and three tick species, *Amblyomma americanum* (lone star tick), *Dermacentor variabilis* (American dog tick), and *Ixodes scapularis* (deer tick), were obtained by flagging vegetation (Mitcham et al. 2018). Recent studies have also found *A. americanum*, *A. maculatum* (Gulf coast tick), *D. variabilis*, and *I. scapularis* in urban parks during summer and fall months in Oklahoma (Noden et al. 2017). However, these studies provide data over relatively short sampling periods and no data in the months of November through May (Noden et al. 2017, Mitcham et al. 2018).

Over the past two decades, tick species distributions across the state of Oklahoma have been regularly updated to include species of interest (Dennis et al. 1998, Springer et al. 2015, Barrett et al. 2015, Eisen et al. 2016, Mitcham et al. 2017). Taking even these recent reports into account,

county-level information on tick distributions is lacking for both counties that have been understudied or species that have been underreported (Barrett et al. 2015, Mitcham et al. 2017). Presence of tick species is determined at the county level and is based on the definitions published by Dennis et al. (1998). A tick species is considered to be established in a county if "at least six ticks or two of the three tick stages are identified in a single collection period" (Dennis et al. 1998). *Amblyomma americanum* is an established tick species in 68 of 77 counties in Oklahoma, including Oklahoma County (Mitcham et al. 2017). In addition, *D. variabilis* is established in 20 counties, *I. scapularis* in 17 counties, and *A. maculatum* in ten counties in Oklahoma (Mitcham et al. 2017). A tick species is considered reported if a single tick, at any life stage, is identified in a county (Dennis et al. 1998). Based on this criterion, *D. variabilis* has been reported in 48 counties, *I. scapularis* in 34 counties, and *A. maculatum* in 40 counties, including in Oklahoma County (Mitcham et al. 2017).

Because tick presence is dependent upon host availability, habitat, and abiotic conditions, environmental changes, such as urbanization, have the potential to influence or alter tick distribution and tick-borne pathogen presence and risk (Ogden and Lindsay 2016). Only in recent years have studies addressed tick populations and tick-borne pathogens in urban areas (Noden et al. 2017). The impacts of urbanization can cause fluctuations in host abundance and availability, host distribution, and species prevalence ultimately impacting tick presence and survival (Ogden et al. 2005, LaDeau et al. 2015). Tick distributions are driven by host availability, host preference, and tolerance to various environmental factors, such as humidity, temperature, and photoperiod (Parola and Raoult 2001), and recent studies have shown relationships

between vegetation types and tick species presence (Estrada-Pena 2001). Noden and Dubie (2017) noted a potential relationship between the expansion of *Juniperus virginiana* (eastern red cedar) and *A. americanum* in Oklahoma, which suggests potential differences in tick species distribution between woodland and grassland areas.

With approximately 787,000 residents, Oklahoma County is the most populated county in the state of Oklahoma, U.S.A. It is important that the distribution of tick species is updated consistently in Oklahoma County to better understand the risks of tick-borne disease occurrence within the population. This year-long study aimed to improve our understanding of the distribution of tick species in Oklahoma County, OK, U.S.A., by sampling different habitats in residential and non-residential areas for one continuous year.

MATERIALS AND METHODS

Study area

Tick collection occurred in a suburban area north of Oklahoma City, OK, U.S.A. During the sampling period (June, 2016 through June, 2017), average rainfall for this area was 76 to 100 cm (Brock et al. 1995, McPherson et al. 2007) and average daily temperatures varied between 0° C and 32° C (Brock et al. 1995, McPherson et al. 2007). The sampling two sites were located in areas zoned by the Edmond Zoning and Planning Committee for residential and non-residential purposes in Edmond, OK, an urban city with a population of approximately 90,000 covering 219 km².

The residential site is zoned as a single-family dwelling district and is considered the most restrictive residential district with a minimum lot area of 557.4 m². The non-residential site is zoned for general agricultural use and the only type of residences allowed are single-family detached dwellings which are only permitted to house employees of the property. If the property is a farm or ranch, it must consist of 80 acres or more for a single-family detached dwelling to be allotted. In addition, the minimum lot area is 20,234 m².

Collection sites are shown in Figure 1. The residential site is an area of 113 ha. with recreational amenities and allows access to the public year-round. The area contains trails leading around the park and to surrounding neighborhoods, multiple playgrounds, baseball fields, and a disc golf course. The non-residential site is an area of 53 ha with public access through the spring and summer months. The area contains hiking trails, primitive camping spots, and beach, boating, and fishing access to Arcadia Lake.

Collection methods

Woodland and grassland habitats were sampled at each park using dry ice and drag collection methods continuously for 13 months beginning in June of 2016. We conducted exploratory sampling in June, 2016, followed by an additional 12 consecutive months of sampling from July, 2016 through June, 2017. For tick collection, dry ice traps were built and executed according to Barrett et al. (2015). Dry ice traps were set along randomly selected transects and constructed on site using 30.5 x 30.5 cm cardboard squares with inverted masking tape around the perimeter of the cardboard and approximately 110 g of dry ice at the center. Traps were left in place for 90 min (Barrett et al. 2015). Fabric drags were made from 0.836 m² pieces of white fleece material, weighted at the leading and trailing ends by a piece of wooden dowel (Barrett et al. 2015). Tick drags were used in grassland areas during the 90-min dry ice trapping periods. Dragging took place at a minimum of 30 m away from tick traps and the amount of time spent using the drags was recorded (Dantas-Torres et al. 2013).

At each site, three grassland and three woodland transects were identified at the beginning of the study and mapped using GPS (Figure 1). At each sampling occasion, two woodland and two grassland transects were randomly selected for collection, and five traps were placed along each transect at least 4.5 m apart. Transects ran parallel to park trails, roads, or areas with human amenities such as parking lots, playgrounds, and buildings. Following collection,



Figure 1. Residential (left image, Mitch Park) and non-residential (right image, Edmond Park) trapping sites, each with woodland (blue) and grassland (red) transects (Google Earth Pro, 2019)

adult tick species were identified by their mouth parts and coloration (Keirans and Litwak 1989). A stereo microscope (Olympus SZ51) was used to identify nymphs by their mouth parts, shape, and coloration (Keirans and Durden 1998). In addition, sex and life stage were recorded and ticks were placed in 96 well plates with 70% ethanol, followed by -20° C storage.

Data analysis

To better understand the presence of ticks at each sampling site, we applied a binomial generalized linear mixed model (GLMM) using the R package 'lme4' (Bates et al. 2015) with the 'glmer()' function. Due the number of captures across all recorded species, we have restricted this analysis to include only *A. americanum*, the most abundant species. We treated site status (residential or non-residential) and trapping location within a park (woodland or grassland) habitat, along with their interaction, as fixed effects and included a random intercept account for the grouping of individual traps along trapping transects and sampled at different sampling occasions. We predicted the presence of one or more adult (both sexes combined) or nymph (unsexed) ticks at a trap over a possible 480 capture opportunities for each life stage (two sites by two habitats by 12 sampling occasions by ten traps).

RESULTS

Tick collection totals and seasonal observations

A total of 2,450 ticks was collected over the year, with approximately twice as many ticks collected from the residential site than the non-residential site (Table 1). Of these ticks, 431 were collected during exploratory sampling in June, 2016, including 17 female and ten male *A. maculatum* at the residential site, and a total of 396 *A. americanum* across both sites and habitats. The remaining 2,019 ticks were collected by fabric drags (96 in total) or at dry ice traps (1,923 in total). At least 90% of the ticks collected at each sampling site were *A. americanum* (Table 1) and at each site four tick species were collected during the year. *A. americanum* ticks were collected during all months of the year with peaks occurring in the summer months for both adults (males and females combined) and nymphs (Figure 2). At both residential and non-residential sites, more female *A. americanum* ticks were collected than males. *D. variabilis* and *A. maculatum* ticks were only collected in the spring, summer, and fall (Figure 3) and *I. scapularis* was collected only between late fall and spring (Figure 3). While only 12 (of 64) *I. scapularis* were collected from dry ice traps, 52 were collected using fabric drags, the highest total for fabric drags across all species.

Establishment of species

Relative to the other species collected in this study, *A. maculatum* was more commonly captured in the grassland habitats than all other species (Table 1). Traps placed in the woodland habitats frequently had more ticks than those placed in the grassland habitats. *A. americanum* ticks were the most commonly caught species in the woodland habitat,

followed by *D. variabilis*, *A. maculatum*, and *I. scapularis*. To document establishment for each of *D. variabilis*, *A. maculatum*, and *I. scapularis* (Table 2), we noted the occasions where capture totals exceeded six individuals at a single sampling occasion. Captures in excess of six individuals were recorded for *D. variabilis* on three occasions at the residential site (nine in July, 2016, six in May, 2017, 12 in July, 2017) and once at the non-residential site (eight individuals in February, 2017). In addition to captures during exploratory sampling, nine *A. maculatum* were captured in during a single sampling occasion in May, 2017. Finally, captures of *I. scapularis* exceeded six individuals on December, 2016 and January, 2017 (21 and ten individuals, respectively).

Amblyomma americanum presence

Across both sampling sites, 90 of 480 total traps contained one or more of either life stage of *A. americanum*. Of the dry ice traps containing *A. americanum*, the median number captured was three individuals and the mean was 10.88 individuals. Tick presence was lower at the non-residential park (Edmond Park), in both woodland and grassland habitats, than at Mitch Park (Figure 4, Table 1). Tick collection totals were lower in grassland habitats than in woodland habitats, with a maximum of four *A. americanum* present in a single trap. For both adult and nymph *A. americanum*, presence was significantly lower in grassland habitats, but presence did not significantly differ between residential and non-residential sites (Tables 1 and 3).

DISCUSSION

Oklahoma is one of the nation's annual leaders in human tick-borne disease occurrence (Eisen et al. 2008, Drexler et al. 2016, Heitman et al. 2016). Therefore, determining presence of ticks in residential and non-residential parks in a highly populated county of Oklahoma is important in understanding potential tick exposure risk to humans and their pets. By sampling in different landscapes and habitats, we can provide important baseline information for the presence, abundance, and spatial distribution of tick species during all seasons of the year.

Each species was collected in greater abundance at the residential location (Table 1). This could be caused by host prevalence and abundance, habitat, weather conditions, and trapping methods (Koch 1984, Perkins et al. 2006, Kilpatrick et al. 2014). Pesticides are not used routinely at either park (C. Dishman, Edmond City Parks and Recreation, pers. comm), however, the residential park is surrounded by a school and neighborhoods, which may have more pesticide use, potentially resulting in a concentrated area of tick populations in the park. In addition, primary tick hosts, such as the white-tailed deer (*Odocoileus virginiana*), have been found to flourish in urban landscapes and their activity may impact tick prevalence (Grund et al. 2002, Kilpatrick et al. 2014). To better understand host presence in this landscape, studies involving host abundance and presence are urgent. Approximately 91% of the total ticks were collected from the woodland habitats. This could be due to the cooler temperatures and higher

Table 1. Summary of tick capture totals for ticks collected by two sampling methods from July, 2016 to June, 2017 at residential and non-residential parks in Oklahoma County.

Species	Residential		Non-residential		Total
	Dry ice	Fabric drag	Dry ice	Fabric drag	
<i>A. americanum</i>	1,188	4	661	5	1,858
<i>A. maculatum</i>	17	13	4	0	34
<i>D. variabilis</i>	34	8	7	14	63
<i>I. scapularis</i>	10	39	2	13	64
Total	1,249	64	674	32	2,019

Table 2. Conditions for establishment of tick populations for *A. maculatum*, *D. variabilis*, and *I. scapularis* in Oklahoma County. First date with capture totals in excess of six individuals by species and collection method. A total of 19 *A. maculatum* were captured during exploratory sampling on June 4, 2016 at the residential site.

Species	Method	Date	Total captures
<i>A. maculatum</i>	Fabric drag	5-16-2017	9
<i>D. variabilis</i>	Dry ice	7-11-2016	9
<i>I. scapularis</i>	Fabric drag	12-26-2016	21

Table 3. Generalized linear mixed model results for prediction of *A. americanum* adult presence in a dry ice trap with random intercept by transect and sampling occasion. Random effects components: adults (variance by transect = 0. 6746, by variance sampling occasion = 2.3822) and nymphs (variance by transect = 0. 7047, variance by sampling occasion = 0.3618).

		Estimate	Std. Error	z-value	p-value
Adults (AIC = 334.8, BIC = 359.8, logLik = -161.4, dev = 322.8, residual df = 474)	Intercept	-4.5006	0.9444	-4.766	1.88x10 ⁻⁶
	Residential site	-0.7930	1.1731	-0.676	0.499
	Woodland habitat	5.0033	1.0010	4.998	5.78x10 ⁻⁷
	Site-by-area interaction	-0.2276	1.3990	-0.163	0.871
Nymphs (AIC = 335.0, BIC = 360.0, logLik = -161.5, dev = 323.0, residual df = 474)	Intercept	-3.9689	0.8983	-4.418	9.96x10 ⁻⁶
	Residential site	-1.3530	1.1277	-1.200	0.23
	Woodland habitat	4.0220	0.8916	4.511	6.45x10 ⁻⁶
	Site-by-area interaction	-0.2241	1.3671	-0.164	0.87

humidity, resulting in less desiccation of the ticks than in the more open grassland habitat. Koch (1984) found that *A. americanum* survival rates were lowest in a meadow habitat compared to two forested habitats.

Amblyomma americanum was present every month at both parks. Its primary host is the white-tailed deer and it transmits the human pathogens *Rickettsia spp.*, *Ehrlichia spp.*, and *Francisella tularensis* (Barrett et al. 2015). *A. americanum* nymphs were collected in all months of the year with the greatest occurrences being in May and June (Figure 4). Bouzek et al. (2013) found host-seeking activity among *A. americanum* nymphs began in March and continued through

mid-August, with peak activity occurring in June through August. Their data also suggested that temperatures of the previous year had a direct impact on the number of nymphs and adults present at the sampling time and that temperature impacts developmental rates (Bouzek et al. 2013).

The percentage of each species collected in this study is consistent with results obtained by collecting ticks from horses in central Oklahoma and from state parks across Oklahoma (though sampling strategies were different). Of 1,721 ticks collected from horses in central Oklahoma, over 92% were *A. americanum*, 2% were *A. maculatum*, 5% were *D. variabilis*, and less than 1% were *I. scapularis* and *D.*

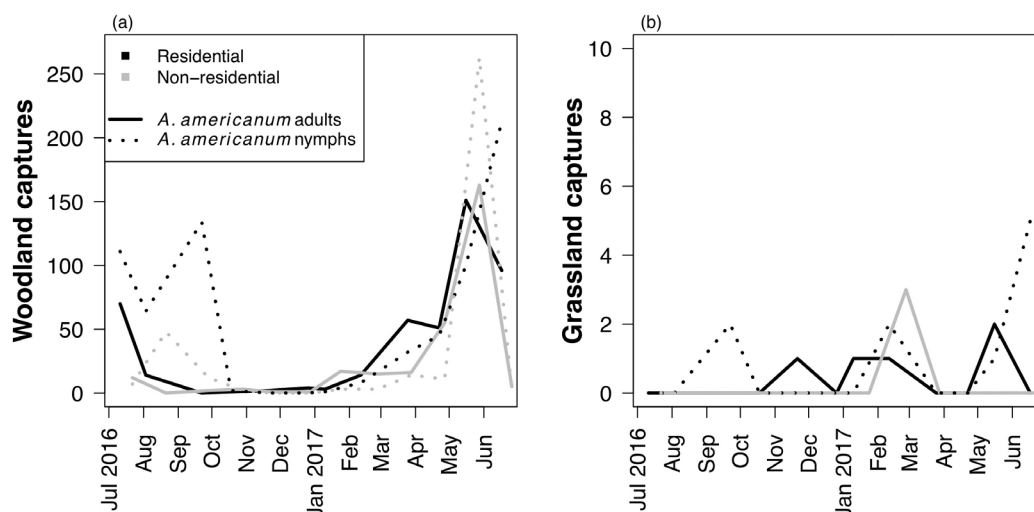


Figure 2. *A. americanum* tick capture totals (adults as solid lines, nymphs as dotted lines) in (a) woodland and (b) grassland habitats at residential (black, Mitch Park) and non-residential (gray, Edmond Park) sites in Oklahoma County.

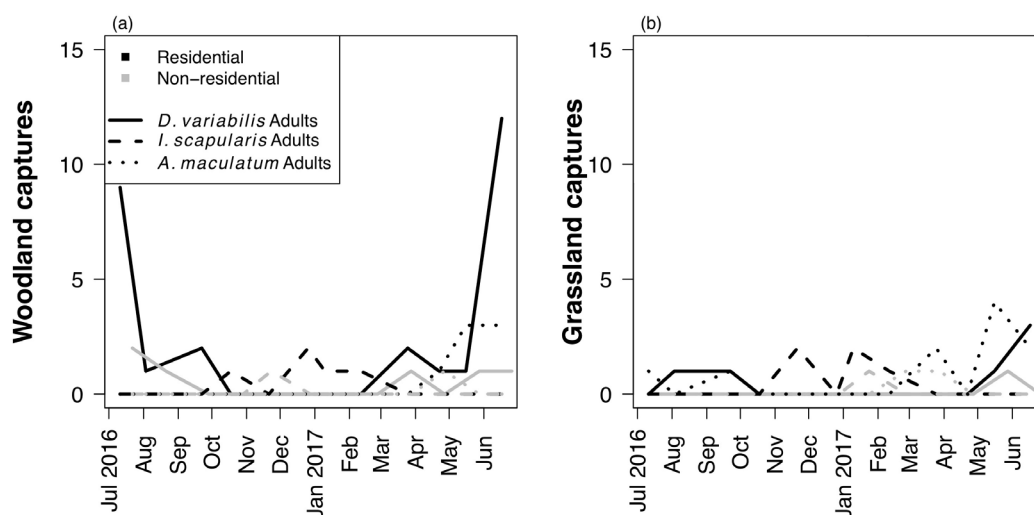


Figure 3. Capture totals for non-*A. americanum* tick species in (a) woodland and (b) grassland habitats at residential (black, Mitch Park) and non-residential (gray, Edmond Park) sites in Oklahoma County.

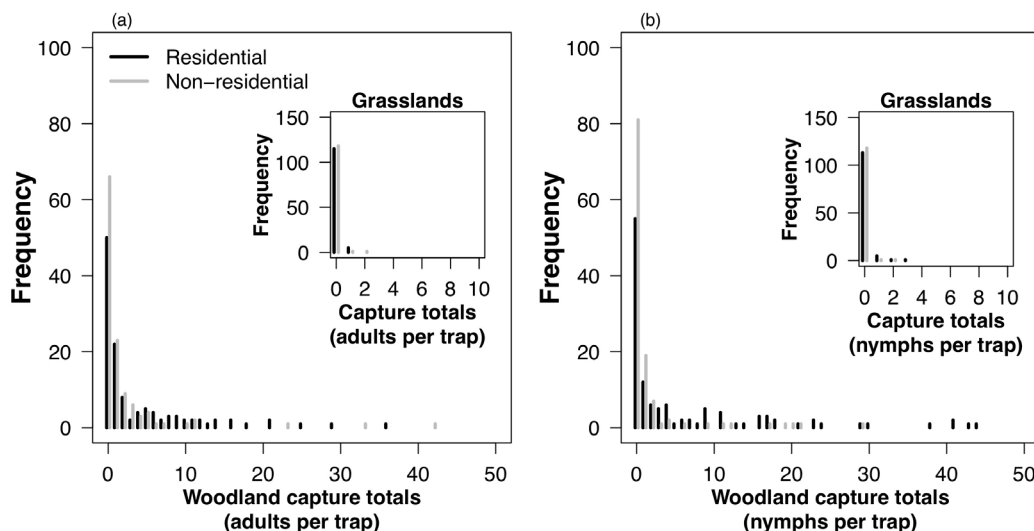


Figure 4. Frequency of total captures in dry ice traps for (a) adult and (b) nymph *A. americanum* ticks in woodland (main panels) and grassland habitats (inset) at residential (black, Mitch Park) and non-residential (gray, Edmond Park) sites. Not included in the plot is data from a single capture of 177 *A. americanum* nymph ticks at one non-residential woodland trap.

albiticus (Duell et al. 2013). However, this data is limited to sampling in the months of May through July, 2010. Recently, Mitcham et al. (2018) reported collection results from April through August, 2014, in which 1,035 ticks were collected by flagging vegetation in state parks throughout Oklahoma. Approximately 94% of ticks collected were *A. americanum*, 3.5% were *D. variabilis*, and 2% were *I. scapularis* (Mitcham et al. 2018).

Our study also documented the presence and absence of ticks across all months of a one-year period. The *A. maculatum* tick was collected in six months, *D. variabilis* in eight months, and the *I. scapularis* in six months. Updates to tick species distribution maps, based on active and passive surveillance of tick species in Oklahoma counties have been issued in recent years and determined species as reported or established (Barrett et al. 2015, Mitcham et al. 2017). Sampling for our study took place in Oklahoma County, where established populations of *A. americanum* have already been documented. Our results also show that *A. maculatum*, *D. variabilis*, and *I. scapularis* occur in established populations in Oklahoma County (Table 2).

If tick collection was restricted to April through August, *I. scapularis* would not have been captured nor confirmed as an established population in Oklahoma County. This species is responsible for the transmission of *Borrelia burgdorferi*, the causative agent of Lyme disease which causes approximately 30,000-40,000 annual cases per 100,000 people of the population in the U.S. (Adams et al. 2017). Though Oklahoma has few cases of Lyme disease per year, without accurate representation of the spatio-temporal distribution of this tick species, the prevalence and potential risk of encountering this disease will remain unknown in Oklahoma (Adams et al. 2017). In addition, uncertainty in the seasonality of *A. americanum* and *D. variabilis* behavior limits our understanding of the risk of encountering ticks in the winter months.

In this study, individuals of four tick species were found to be abundant in residential and non-residential sites and active in all months of the year in a suburban area in Oklahoma County. Though this study consisted of one year of sampling, it provides foundational data for future studies. Additionally, long-term study could provide a better understanding of the presence of tick populations in residential and non-residential areas. The results of this study can be used to better inform local citizens about where and when ticks are commonly found in these public spaces. Future research should aim to better understand the relationship between tick populations and residential habitats, in addition to exploring seasonal variability in tick presence, abundance, and activity throughout Oklahoma.

Acknowledgments

Funding and support for this project was provided by the University of Central Oklahoma Office of Research and Sponsored Programs Faculty On-Campus Grant program, the Office of High-Impact Practices, and 3M Corporation, St. Paul, MN. We thank Dr. Susan Little and Mr. Jeff Gruntmeir

at Oklahoma State University for their guidance in collection methods. We also thank Dr. Bruce Noden at Oklahoma State University for providing a constructive review of this paper. Finally, we appreciate the insightful questions and helpful suggestions of the reviewers.

REFERENCES CITED

- Adams, D.A., K.R. Thomas, R.A. Jajosky, L. Foster, G. Baroi, P. Sharp, D.H. Onweh, A.W. Schley, and W.J. Anderson. 2017. Summary of notifiable infectious diseases and conditions – United States, 2015. *MMWR* 64: 1-143.
- 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.
- Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. *J. Statist. Software* 67: 1-48.
- Biggs, H.M., C.B. Behravesh, K.K. Bradley, F.S. Dahlgren, N.A. Drexler, J.S. Dumler, S.M. Folk, C.Y. Kato, R.R. Lash, M.L. Levin, R.F. Massung, R.B. Nadelman, W.L. Nicholson, C.D. Paddock, B.S. Pritt, and M.S. Traeger. 2016. Diagnosis and management of tickborne rickettsial diseases: Rocky Mountain spotted fever and other spotted fever group rickettsioses, ehrlichioses, and anaplasmosis – United States. *MMWR* 65: 1-44.
- Bouzek, D.C., S.A. Fore, J.G. Bevell, and H.J. Kim. 2013. A conceptual model of the *Amblyomma americanum* life cycle in Northeast Missouri. *J. Vector Ecol.* 38: 74-81.
- Brites-Neto, J., K.M.R. Duarte, and T.F. Martins. 2015. Tick-borne infections in human and animal population worldwide. *Vet. Wld.* 8: 301-315.
- Brock, F.V., K.C. Crawford, R.L. Elliott, G.W. Cuperus, S.J. Stadler, H.L. Johnson, and M.D. Eilts. 1995. The Oklahoma Mesonet: A technical overview. *J. Atmos. Ocean. Technol.* 12: 5-19.
- Dantas-Torres, F., R.P. Lia, G. Capelli, D. Otranto. 2013. Efficiency of flagging and dragging for tick collection. *Exp. App. Acarol.* 61: 119-127.
- 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.
- Drexler, N.A., F.S. Dahlgren, K.N. Heitman, R.F. Massung, C.D. Paddock, and C.B. Behravesh. 2016. National surveillance of spotted fever group rickettsioses in the United States, 2008– 2012. *Am. J. Trop. Med. Hyg.* 94: 26-34.
- Duell, J.R., R. Carmichael, B.H. Herrin, T.C. Holbrook, J. Talley, and S.E. Little. 2013. Prevalence and species of ticks on horses in central Oklahoma. *J. Med. Entomol.* 50: 1330- 1333.
- Eisen, R.J., P.S. Mead, A.W. Meyer, L.E. Pfaff, K.K. Bradley, and L. Eisen. 2008. Ecoepidemiology of tularemia in the Southcentral United States. *Am. J. Trop. Med. Hyg.* 78:

- 586-594.
- 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.
- Estrada-Pena, A. 2001. Forecasting habitat suitability for ticks and prevention for tick-borne diseases. *Vet. Parasitol.* 98: 111-132.
- Grund, M.D., J.B. McAninch, and E.B. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. *J. Wildl. Manag.* 66: 123- 130.
- Heitman, K.N., F.S. Dahlgren, N.A. Drexler, R.F. Massung, and C.B. Behravesh. 2016. Increasing incidence of ehrlichiosis in the United States: a summary of national surveillance of *Ehrlichia chaffeensis* and *Ehrlichia ewingii* infections in the United States, 2008–2012. *Am. J. Trop. Med. Hyg.* 94: 52-60.
- Jongejan, F. and G. Uilenberg. 2004. The global importance of ticks. *Parasitology* 129: S3- S14.
- 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.
- 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.
- Kilpatrick, H.J., A.M. Labonte, and K.C. Stafford, III. 2014. The relationship between deer density, tick abundance, and human cases of lyme disease in a residential community. *J. Med. Entomol.* 51: 777-784.
- Koch, H.G. 1984. Survival of the *A. americanum* tick, *Amblyomma americanum*, (Acari: Ixodidae), in contrasting habitats and different years in Southeastern Oklahoma, USA. *J. Med. Entomol.* 21: 69-79.
- LaDeau, S.L., B.F. Allan, P.T. Leisnham, and M.Z. Levy. 2015. The ecological foundations of transmission potential and vector-borne disease in urban landscapes. *Funct. Ecol.* 29: 889-901.
- McPherson, R. A., C. Fiebrich, K. C. Crawford, R. L. Elliott, J. R. Kilby, D. L. Grimsley, J. E. Martinez, J. B. Basara, B. G. Illston, D. A. Morris, K. A. Kloesel, S. J. Stadler, A. D. Melvin, A.J. Sutherland, and H. Shrivastava. 2007. Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.* 24: 301–321.
- Mitcham, J.R., J.L. Talley, and B.H. Noden. 2018. Risk of encountering questing ticks (Ixodidae) and the prevalence of tickborne pathogens in Oklahoma State Parks. *Southwest. Entomol.* 43: 303-315.
- Mitcham, J.R., A.W. Barrett, J.M. Gruntmeir, T. Holland, J.E. Martin, E.M. Johnson, S.E. Little, and B.H. Noden. 2017. Active surveillance to update county scale distribution of four tick species of medical and veterinary importance in Oklahoma. *J. Vector Ecol.* 42: 60-73.
- Noden, B.H. and T. Dubie. 2017. Involvement of invasive eastern red cedar (*Juniperus virginiana*) in the expansion of *Amblyomma americanum* in Oklahoma. *J. Vector Ecol.* 42: 178-183.
- Noden, B.H., S.R. Loss, C. Maichak, and F. Williams. 2017. Risk of encountering ticks and tick-borne pathogens in a rapidly growing metropolitan area in the U.S. Great Plains. *Ticks Tick-Borne Dis.* 8: 119-124.
- Ogden, N.H., M. Bigras-Poulin, C.J. O'Callaghan, I.K. Barker, L.R. Lindsay, A. Maarouf, K.E. Smoyer-Tomic, D. Waltner-Toews, and D. Charron. 2005. A dynamic population model to investigate effects of climate on geographic range and seasonality of the tick *Ixodes scapularis*. *Parasitology* 35: 375-389.
- Ogden, N.H. and L.R. Lindsay. 2016. Effects of climate and climate change on vectors and vector-borne diseases: ticks are different. *Trends Parasitol.* 32: 646-656.
- 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.
- Parola, P. and D. Raoult. 2001. Ticks and tickborne bacterial diseases in humans: an emerging infectious threat. *Ticks Tickborne Dis.* 32: 897–928.
- Perkins, S.E., I.M. Cattadori, V. Tagliapietra, A.P. Rizzoli, and P.J. Hudson. 2006. Localized deer absence leads to tick amplification. *Ecology* 87: 1981-1986.
- Springer, Y.P., C.S. Jarnevich, D.T. Barnett, A. J. Monaghan, and R.J. Eisen. 2015. Modeling the present and future geographic distribution of the lone star tick, *Amblyomma americanum* (Ixodida: Ixodidae), in the continental United States. *Am. J. Trop. Med. Hyg.* 93: 875-890.