2013

Ixodid ticks associated with feral swine in Texas

David M. Sanders
U.S. Air Force Research Laboratory/USAFSAM

Anthony L. Schuster
U.S. Army Medical Component, Armed Forces Research Institute of Medical Sciences

P Wesley McCardle
U.S. Army Medical Component, Armed Forces Research Institute of Medical Sciences

Otto F. Strey
Department of Entomology, Texas A&M AgriLife Research, Texas A&M University

Terry L. Blankenship
Welder Wildlife Foundation

See next page for additional authors

Authors
David M. Sanders, Anthony L. Schuster, P Wesley McCardle, Otto F. Strey, Terry L. Blankenship, and Pete D. Teel

Ixodid ticks associated with feral swine in Texas

David M. Sanders[1], Anthony L. Schuster[2], P. Wesley McCardle[2], Otto F. Strey[3], Terry L. Blankenship[4], and Pete D. Teel[3]✉

[1]*U.S. Air Force Research Laboratory/USAFSAM, Wright-Patterson AFB, OH 45433-7408, U.S.A.*
[2]*U.S. Army Medical Component, Armed Forces Research Institute of Medical Sciences, Bangkok, Thailand*
[3]*Department of Entomology, Texas A&M AgriLife Research, Texas A&M University, College Station, TX 77843-2475, U.S.A., pteel@tamu.edu*
[4]*Welder Wildlife Foundation, P.O. Box 1400, Sinton, TX 78387-1400, U.S.A.*

Received 14 February 2013; Accepted 6 September 2013

ABSTRACT: Ixodid ticks were collected from feral swine in eight Texas ecoregions from 2008-2011. Sixty-two percent of 806 feral swine were infested with one or more of the following species: *Amblyomma americanum, A. cajennense, A. maculatum, Dermacentor albipictus, D. halli, D. variabilis,* and *Ixodes scapularis*. Juvenile and adult feral swine of both sexes were found to serve as host to ixodid ticks. Longitudinal surveys of feral swine at four geographic locations show persistent year-round tick infestations of all gender-age classes for tick species common to their respective geographic locations and ecoregions. *Amblyomma americanum, A. cajennense, A. maculatum* and *D. variabilis* were collected from 66% of feral swine harvested through an abatement program in seven ecoregions from March to October in 2009. These results indicate westward geographic expansion of *D. variabilis*. Summary results show feral swine are competent hosts for ixodid species responsible for the transmission of pathogens and diminished well-being in livestock, wildlife, and humans. ***Journal of Vector Ecology* 38 (2): 361-373. 2013.**

Keyword Index: Ticks, Ixodidae, feral swine, pigs.

INTRODUCTION

Feral swine (*Sus scrofa domesticus),* European wild boar (*Sus scrofa scrofa*), and their crosses have increased in abundance and distribution across the United States in recent years (SCWDS 2012). These sub-species have crossbred for many decades and there is no practical field-method to differentiate them. The feral swine population in Texas has been estimated between 1-4 million animals (Taylor et al. 1998, Mapston 2004, Timmons et al. 2012). Successful expansion of feral pigs is due in part to high reproductive capacity, life expectancy, use of wide-ranging resources and adaptability (Mungall and Sheffield 1994).

Feral swine are found in 94% of the 254 Texas counties and all 10 recognized vegetation areas in Texas (Rollins et al. 2007). Approximately 134 million acres, or 79% of the state's surface is estimated to support feral swine activity (Timmons et al. 2012). Physical damage to real property and agricultural losses in Texas are estimated to be $52 million per year (IRNR 2011) and $800 million nationwide (Pimentel et al. 2005). However, feral pig hunting generates revenue for land owners, as well as specialty meat and by-products for local-to-global markets (Rollins et al. 1993, Witmer et al. 2003, and Mapston 2004).

Anecdotal accounts from various sources (e.g. hunters, government trappers and landowners) indicate tick infestations of feral swine are common place across Texas. Coombs and Springer (1974) reported finding *Amblyomma cajennense, A. maculatum*, and *Ixodes scapularis* infesting 10 feral swine harvested from October to February in the Aransas National Wildlife Refuge on the Texas Gulf Coast. Tick infestations of feral swine in Georgia (Hanson and Karstad 1959) and Florida (Allan et al. 2001, Griener et al. 1984) consisted of *Amblyomma americanum, A. maculatum, Dermacentor variabilis,* and *Ixodes scapularis*. One specimen of *A. auricularium*, native to armadillos in Central America, was collected from a feral swine in Florida (Allen et al. 2001).

The feral pig is recognized by the International Union for Conservation of Nature as one of the world's worst 100 alien invasive species (Lowe et al. 2000). International records of feral pigs as hosts for ticks and their potential roles in zoonotic disease include Spain (De la Fuente et al. 2004, Ruiz-Fons et al. 2006, Ortuno et al. 2007), Bangladesh, India, and Pakistan (Islam et al. 2006, Ghosh et al. 2007) where combined, at least 9 species of multi- and one-host ticks have been associated with Eurasian wild boar, or semi-domestic/feral swine, respectively.

Spatial overlap and resource competition between feral swine and domestic animals (swine, goats, sheep, cattle or horses), as well as wildlife (deer, and antelope), is increasing (Seward et al. 2004, Corn et al. 2009, Wycoff et al. 2009). These interactions present opportunities for pathogens and parasites to be re-introduced resulting in catastrophic revenue and production losses (Cooper et al. 2010). Feral swine pose risks to domestic and commercial herds by introduction of more than eleven previously known parasites and pathogens of domestic swine (Clark et al. 1983, New et al. 1994, Bengtson and Rogers 2001, Mullen and Durden 2009, Giurgiutiu et al. 2009, Meng et al. 2009, Smith et al. 2011) including tularemia (*Francisella tularensis* McCoy & Chapin) and the African swine fever virus by ixodid and argasid ticks, respectively (Greiner et al. 1984, Witmer et al. 2003). Feral swine trapped within 10 km of domestic swine facilities in Texas and fitted with geo-positioning sensors visited domestic swine pens more frequently than empty control pens (Wyckoff et al. 2009).

The aim of this study was to quantify patterns of tick infestations of feral swine along climatic gradients in Texas.

MATERIALS AND METHODS

Study sites

Longitudinal studies were initiated at 5 sites to provide contrasting ecological settings in different ecoregions of Texas (Gould et al. 1960). Sites were selected based upon presence of feral swine and the logistical and managerial limitations associated with animal trapping and tick collection from our base station in College Station, TX. The Camp Bullis Military Training Reservation, located in Bexar County and northwest of San Antonio, TX, is situated predominantly within the Edwards Plateau ecoregion and in close proximity to both the Blackland Prairie and South Texas Plains ecoregions. The Welder Wildlife Refuge (WWR) is located in San Patricio County northeast of Sinton, TX, and situated in the transitional area of the Gulf Prairies and Marshes and South Texas Plains ecoregions along the Aransas River. The Fort Hood Military Reservation and training ground is located in Bell and Coryell Counties between Austin and Waco, TX, and situated in the Cross Timbers and Prairies ecoregion. Two sites, Anderson Ranch located in eastern Brazos County near the Navasota River, and the George Beto Unit of the Texas Department of Corrections located in Anderson County along the Trinity River, are both situated in the Post Oak Savannah ecoregion. Detailed descriptions of each eco-region with respect to elevation, topography, annual precipitation and temperature, climax grass species and woody plants can be found in Correll and Johnston (1970) and Gould et al. (1960). The ecology of the Welder Wildlife Refuge is provided in detail by Drawe et al. (1978, 1991) including gradients of five habitat-types (mesquite, chaparral, grassland, live oak, riparian) and canopy cover. Trapping activities were initiated at the Welder Wildlife Refuge and Camp Bullis Military Reservation in June and July 2008, respectively, at Anderson Ranch in June 2009, Fort Hood in January 2010, and the George Beto Corrections Unit in May 2010.

Feral pig and tick collection

Feral swine were trapped and sampled on a periodic basis throughout the year as weather and logistical considerations permitted. The sampled animals were classified by gender and age (juvenile and adult). Members of family groups trapped simultaneously were treated as individuals. Harvested pigs weighing under 23 kg and with no obvious signs of having had a litter (females) were classified as juveniles while those over 23 kg were classified as adults. Age separation by weight was used for expediency in the field, and was relatively consistent with weight by age classification using dentition methods for feral swine in Texas (Taylor et al. 1998).

Feral swine were trapped using corral, or box traps similar to those described by AgriLife Extension (2012). Traps were pre-baited with dry, whole, feeder corn (*Zea mays*) prior to actual trap dates to allow swine to become habituated to the traps being in their surroundings (Schulyer et al. 2002). The day prior to trapping, traps were set mid- to late afternoon and checked as soon as possible following daylight. On overcast days, when swine are known to be active later in the morning, traps were checked two hours after daylight to avoid disturbing any swine that might still be feeding.

Feral swine were killed using a 0.22 caliber pistol or rifle with low velocity ammunition (Animal Use Protocol No. 2008-131). Within 30 minutes of death, representative samples of parasites were taken from auxiliaries, head and ears, neck, belly, and groin during approximately 30 minute inspection per animal. Ticks collected from each pig were immediately placed in 80% ethanol, labeled as to animal number, date, location, age and sex, then transported to the Tick Research Laboratory, Texas A&M AgriLife Research, Texas A&M University, College Station, TX for identification and storage. On occasion, engorged nymphs were placed in zippered plastic bags with moistened paper toweling, deposited into a cooler for storage, transported to the Tick Research Laboratory, placed in an incubator at 90% RH/30° C for molting and subsequent identification to species. Lice and fleas and corresponding blood samples were taken and stored for analyses as part of separate studies. Samples were collected immediately after shooting to avoid loss of ectoparasites and before coagulation of blood. All carcasses were disposed of in compliance with state and local laws and in accordance with the landowner or land manager's requests.

Adult ticks were identified to species with the aid of taxonomic keys of Keirans and Clifford (1978), Keirans and Litwak (1989), and Yunker et al. (1986). Tick data were combined with corresponding animal host data in Microsoft Excel files by site location to facilitate data management and analysis. Nymphal ticks not collected for molting to adults were identified to genus using Keirans and Durden (1998).

A poisson generalized linear model (R Core Team 2013) was used to assess whether tick species richness on feral swine might be effected by a gradient of 3 climatic zones, pig gender or age (H_o: no difference by climatic zone), and whether abundance by tick species might be effected by zone, pig gender or age. An analysis of deviance provided an assessment of main effects and interactions using likelihood ratio tests. For analysis of species abundance, the data sets were separated by species and summarized over the main effects of climatic zone, pig age and gender. Since over dispersion is a common problem with abundance models and with data containing a high proportion of zeroes, the species abundance were modeled using a negative binomial error distribution. The three climatic treatment zones for this analysis have been previously characterized and defined as ecoregions by Gould et al. (1960). For this analysis, a west-central climatic zone was comprised of data from Camp Bullis and Fort Hood military reservations representing the most arid ecological setting (confluence of Edwards Plateau, Blackland prairie and South Texas plains ecoregions), an east-central climatic zone comprised of data from the Anderson Ranch and George Beto Correctional Unit representing the intermediate ecological setting (Post Oak Savannah), and the Gulf Coast climatic zone comprised of data from the Welder Wildlife Refuge representing the most mesic ecological setting (confluence of Gulf prairies and marshes with South Texas plains ecoregions).

Expanded survey

Additional samples of ticks were obtained from feral swine by personnel working with the Texas A&M AgriLife Extension Service - Wildlife Services feral swine abatement program using aerial shooting technology (Campbell et al. 2010). Animal examinations began within 30-60 min of kill and conducted as described above. Ticks were placed in 80% ETOH and labeled with animal identification number, date, location, age and sex. These samples provided a source of geographically expanded collections over additional counties and ecoregions.

RESULTS

Table 1 summarizes the age and gender of feral swine collected by study site and the prevalence of tick infestations (all species combined) over the entire project. A total of 806 feral pigs were harvested during the 2008-2011 longitudinal and expanded surveys with a tick infestation period prevalence of 62% (497 animals). Of the 806 animals, there were 214 boars, 217 sows, 175 juvenile males, and 200 juvenile females. A total of 4,369 ticks were collected and identified from the 497 infested animals. Seven species of adult ticks were identified including *Amblyomma americanum, A. cajennense, A. maculatum, Dermacentor albipictus, D. halli, D. variabilis,* and *Ixodes scapularis*, as were nymphs of *A. americanum* (35), *A. cajennense* (148), and *D. variabilis* (1).

Analysis of species richness among longitudinal survey data organized into 3 climatic zones (Table 1) revealed a highly significant difference for climatic zone (Pr<0.001), and pig age (Pr=0.001), and a significant interaction between climatic zone, pig age, and pig gender (Pr=0.02). Overall, adult pigs had higher species richness than juvenile pigs, and the 3-way interaction was partially explained by a decline in species richness between the east-central and Gulf Coast climatic zones in adult males versus juvenile females. Species abundance for *A. americanum* was highly significant for climatic zone and independent of pig age and gender interaction (Pr<0.001). Species abundance for *A. cajennense* was not modeled for climatic zone as all were collected in the Gulf Coast zone, and this analysis showed no effect on abundance due to pig gender or age. Species abundance for *A. maculatum* was highly significant for climatic zone (Pr<0.001) lowest west-central to highest Gulf Coast zone, and abundance was significantly greater on adult swine (Pr=0.003). There was a significant 3-way interaction for species abundance of *D. variabilis* (Pr=0.02). This interaction reflected lower abundance of ticks on female swine than males, regardless of age, in the west-central climatic zone, while the pattern was reversed in the Gulf Coast zone. In the east-central climatic zone adult females had lower abundance of this tick species than adult males, while the pattern was reversed in juveniles.

The interaction of climatic zone, swine age and gender for both tick species richness and abundance is likely influenced by variable trapping success across sites and dates. Absence of trapped animals in some age and gender classes by date and site were common (Tables 2, 3, 4, and 5). Trapping success was influenced by human activity and possibly by competitive food resources, age and gender factors (growth, reproduction, comparative body sizes, herd dynamics) influencing family units over the temporal and spatial characteristics of each site. For example, the May 2010 trapping at the George Beto Correctional Unit caught 57 pigs, 74% (42 pigs) infested with *A. americanum*, *A. maculatum*, and *D. variabilis*. On the two successive trapping dates only 6 feral swine were caught due to human interference and animal theft, despite clear evidence of abundant feral swine. No further efforts were made to trap feral swine at this site.

Eight of 17 swine (47%) harvested at the Camp Bullis Military Reservation were infested with *A. americanum, A. maculatum, Ixodes scapularis*, and a partially engorged *D. albipictus* female. Despite substantial sign of feral swine abundance, the lower than expected trapping success was attributed to human activity associated with military training exercises. The discovery of *I. scapularis* and *D. albipictus* in March is notable in that these ticks are active through winter months as host-seeking adults and larvae, respectively.

At Fort Hood Military Reservation, *Dermacentor variabilis* was the most consistently collected tick species from feral swine across seven months (March – September). *Amblyomma americanum* was collected in March and April 2010; *A. maculatum* from June-September and *I. scapularis* from January to March (Table 2). Twenty-eight percent of feral swine (51/185) were tick infested at the time of their capture. This site produced the most consistent month-to-month data set (Table 2) due in part to civilian personnel collaboration on base. Though variable month-to-month, all gender and age classes of feral swine were found to be infested with ixodid ticks. Monthly collections of feral swine exceeding 30 animals occurred from March to June with infestations by month ranging from 10-33%. In the succeeding 3 month period (July-Sept) only 22 animals were harvested, but the level of tick infestation was 90-100%. Variation in feral swine and tick collections may have been due to human activity and/or progressively more severe drought conditions that intensified in late 2010 and early 2011.

Feral swine infestations at the Brazos County, Anderson Ranch site included *A. americanum* in every month sampled; *A. maculatum* was recovered from infested swine monthly from June through September, with male ticks only being found in February and March; *D. variabilis* was recovered in March, and again in June and July; *I. scapularis* in January and March. This site, situated in the Navasota River watershed in the Post Oak Savannah ecoregion, was sampled nine times from 2009-2011, with 138 feral swine harvested. Seventy percent of these animals (96) across all gender and age classes were tick infested with from one-to-three three-host

Table 1. Summary of the number and percentage of tick infested and total feral swine harvested by age and gender classes in longitudinal surveys at 5 collection sites from July 2008 to March 2011, and from one-time feral swine harvests conducted at various state-wide locations by Texas A&M AgriLife Extension, Wildlife Services in 2009.

Location	Boars	Sows	Juvenile Males	Juvenile Females	All Swine
********* Longitudinal Survey Collection Sites **********					
East-central climatic zone:					
George Beto Unit, TDC	4/5 (80%)	9/11 (82%)	11/20 (55%)	19/27 (70%)	43/63 (68%)
Anderson Ranch	21/25 (84%)	28/38 (74%)	15/30 (50%)	32/45 (71%)	96/138 (70%)
West-central climatic zone:					
Camp Bullis Military Reservation	3/4 (75%)	1/2 (50%)	4/10 (40%)	0/1	8/17 (47%)
Fort Hood Military Reservation	19/55 (35%)	18/47 (38%)	7/51 (14%)	7/32 (22)	51/185 (28%)
Gulf Coast climatic zone:					
Welder Wildlife Refuge	44/55 (80%)	37/39 (95%)	28/31 (90%)	35/44 (79%)	144/169 (85%)
*********** One-time State-wide Collections ***********					
Texas A&M AgriLife Extension Wildlife Services	55/70 (79%)	53/80 (66%)	15/33 (45%)	32/51 (63%)	155/234 (66%)
Total Feral Swine	146/214 (68%)	146/217 (67%)	80/175 (46%)	125/200 (63%)	497/806 (62%)

Table 2. Feral swine and ticks collected at U.S. Army training base Fort Hood, TX (Bell and Coryell Counties, TX) from January 2010 to January 2011 in the Cross Timbers and Prairies ecoregion.

Month	Total Swine	Male-Adult	Male-Juvenile	Female-Adult	Female-Juvenile	Tick species[1] collected / percentage (%)			
						Aa	Am	Dv	Is
Jan ’10	1/2	0	1/1	0	0/1	0	0	0	1/1
Ticks	1	0	1	0	0	-	-	-	100
Feb ’10	1/9	1/1	0/4	0/3	0/1	0	0	0	2/2
Ticks	2	2	0	0	0	-	-	-	100
Mar ’10	3/31	1/6	1/14	0/4	1/7	0	0	1/3	2/3
Ticks	3	1	1	0	1	-	-	33.3	66.7
Apr ’10	5/36	3/16	0/6	2/10	0/4	2/5	0	3/5	0
Ticks	5	3	0	2	0	40	-	60	-
May ’10	4/39	1/10	1/15	2/6	0/8	1/5	1/5	1/5	2/5
Ticks	5	1	2	2	0	20	20	20	40
Jun ’10	16/46	7/15	1/8	4/14	4/9	0	33/54	21/54	0
Ticks	54	23	1	25	5	-	61.1	38.9	-
Jul ’10	5/5	0	1/1	4/4	0	0	34/37	3/37	0
Ticks	37	0	3	34	0	-	91.9	8.1	-
Aug '10	9/10	3/4	2/2	3/3	1/1	0	45/57	12/57	0
Ticks	57	25	6	19	7	-	78.9	21.1	-
Sep '10	5/5	2/2	0	3/3	0	0	2/5	3/5	0
Ticks	5	2	0	3	0	-	40	60	-
Jan '11	2/2	1/1	0	0	1/1	0	0	3/3	0
Ticks	3	2	0	0	1	-	-	100	-

[1]*Aa* = *Amblyomma americanum*; *Am* = *A. maculatum*; *Dv* = *Dermacentor variabilis*; *Is* = *Ixodes scapularis*.

Table 3. Feral swine and ticks collected at Anderson Ranch, Brazos County, TX, from June, 2009 to March, 2011 in the Post Oak Savannah ecoregion.

Month	Total Swine	Male-Adult	Male-Juvenile	Female-Adult	Female-Juvenile	Tick species[1] collected / percentage (%)			
						Aa	Am	Dv	Is
Jun '09	5/5	1/1	1/1	0	3/3	26/38	7/38	5/38	0
Ticks	38	27	3	0	8	68.4	18.4	13.2	-
Jul '09	2/3	1/1	1/1	0/1	0	8/21	12/21	1/21	0
Ticks	21	13	8	0	0	38.1	57.1	4.8	-
Feb '10	4/6	1/1	0/2	1/1	2/2	4/6	2/6	0	0
Ticks	6	3	0	1	2	66.7	33.3	-	-
Mar '10	12/12	3/3	1/1	7/7	1/1	27/33	2/33	0	4/33
Ticks	33	13	1	17	2	81.8	6.1	-	12.1
Apr '10	6/10	0	2/5	2/3	2/2	16/16	0	0	0
Ticks	16	0	4	4	8	100	-	-	-
Aug '10	4/10	1/1	2/4	0	1/5	9/14	5/14	0	0
Ticks	14	6	7	0	1	64.3	35.7	-	-
Sep '10	2/2	1/1	0	1/1	0	2/5	3/5	0	0
Ticks	5	4	0	1	0	40	60	-	-
Jan '11	26/42	8/12	0/3	8/13	10/14	32/51	0	0	19/51
Ticks	51	22	0	14	15	62.7	-	-	37.3
Mar '11	35/48	5/5	8/13	9/12	13/18	212/213	0	1/213	0
Ticks	213	117	24	21	51	99.5*	-	0.5**	-

Aa = *Amblyomma americanum*; *Am* = *A. maculatum*; *Dv* = *Dermacentor variabilis*; *Is* = *Ixodes scapularis*.
*Collected (%) includes 33 nymphs that were identified as *Amblyomma* and most probably *A. americanum*.
***Dermacentor sp*. nymph that was most probably *D. variabilis*.

Table 4. Feral swine and ticks collected from June, 2008 through March, 2011 at the Welder Wildlife Refuge, San Patricio County, TX, located in the transitional area between the Gulf Prairies and Marshes and South Texas Plains ecoregion.

Month	Total Swine	Male-Adult	Male-Juvenile	Female-Adult	Female-Juvenile	Tick species[1] collected / percentage (%)			
						Ac	Am_	Dv	Dh
Jun '08	35/36	8/8	9/10	6/6	12/12	529/567	32/567	6/567	0
Ticks	567	87	187	125	168	93.3*	5.6	1.1	-
Jan '09	12/13	2/2	3/3	4/4	3/4	97/116	4/116	14/116	1/116
Ticks	116	24	45	32	15	83.6*	3.4	12.1	0.9
Mar '09	2/2	1/1	0	1/1	0	88/91	3/91	0	0
Ticks	91	62	0	29	0	96.7	3.3	-	-
Apr '09	2/4	0	0	1/1	1/3	81/86	4/86	1/86	0
Ticks	86	0	0	35	51	94.2	4.6	1.2	-
May '09	7/7	0	0	5/5	2/2	544/583	37/583	2/583	0
Ticks	583	0	0	444	139	93.3*	6.4	0.3	-
Sep '09	15/15	5/5	4/4	1/1	5/5	694/888	189/888	5/888	0
Ticks	888	356	212	52	268	78.2	21.3	0.5	-
Nov '09	2/2	1/1	0	0	1/1	109/113	4/113	0	0
Ticks	113	68	0	0	45	96.5	3.5	-	-
Feb '10	52/72	22/33	3/4	18/20	9/15	156/175	18/175	1/175	0
Ticks	175	84	6	68	17	89.1	10.3	0.6	-
Feb '11	10/11	3/3	7/8	0	0	126/131	2/131	3/131	0
Ticks	131	66	65	0	0	96.2*	1.5	2.3	-
Mar '11	7/7	2/2	2/2	1/1	2/2	87/88	0	1/88	0
Ticks	88	39	21	22	6	98.9*	-	1.1	-

Ac = *Amblyomma cajennense*; *Am* = *A. maculatum*; *Dv* = *Dermacentor variabilis*; *Dh* = *D. halli*.
*Collected (%) includes 148 nymphs that were identified as *Amblyomma* and most probably *A. cajennense*.

Table 5. Feral swine and ticks sampled by Texas AgriLife Extension, Wildlife Services personnel from March through October, 2009 in an aerial shooting program for feral pig abatement across 15 Texas counties in 7 ecoregions[1].

Month	Total Swine	Male-Adult	Male-Juvenile	Female-Adult	Female-Juvenile	Ecoregion[1]	County	Tick species[1] collected (%)			
								Aa*	Ac	Am	Dv
March	9/23	6/12	0	3/10	0/1	GP&M	Colorado	0	0	6.9	0
Ticks	29	23	0	6	0	RP	Hall	0	0	0	51.7
						RP	Scurry	0	0	0	41.4
April	15/15	8/8	0	7/7	0	GP&M	Aransas	0	7.4	4.9	87.7
Ticks	81	45	0	36	0						
May	42/57	14/20	3/3	23/31	2/3	HP, RP	Dickens	0	0	0	5.8
Ticks	276	90	7	169	10	HP, RP	Motley	0	0	0	12.7
						HP, RP	Roberts	0	0	0	4.7
						RP	Willbarger	0	0	0.4	74.6
						HP	Yoakum	0	0	0	1.8
July	48/91	14/16	7/23	9/18	18/34	POS, PW	Camp	10.9	0	28.3	4.8
Ticks	166	78	9	35	44	BP, POS	Hopkins	7.2	0	1.8	1.8
						HP, RP	Roberts	0	0	0	40.4
						PW	Upshur	0.6	0	0.6	0
						POS, PW	Wood	1.8	0	1.2	0.6
August	31/35	6/7	5/7	11/11	9/10	EP, RP	Coke	0	0	0	3.4
Ticks	58	7	7	28	16	BP, POS	Hopkins	34.5	0	31	19
						POS, PW	Wood	5.2	0	6.9	0
September	8/10	5/5	0	0/2	3/3	EP, RP	Coke	0	0	0	18.2
Ticks	11	8	0	0	3	EP, RP	Nolan	0	0	0	9.1
						RP	Willbarger	27.2	0	9.1	36.4
October	2/3	2/2	0	0/1	0	RP	Willbarger	0	0	100	0
Ticks	2	2	0	0	0						

[1]BP = Blackland Prairies; EP = Edwards Plateau; GP&M=Gulf Prairies & Marshes; HP = High Plains; POS = Post Oak Savannah; PW = Piney Woods; RP = Rolling Plains; Gould et al. 1960.

[2]*Aa* = *Amblyomma americanum*; *Ac* = *A. cajennense*; *Am* = A. *maculatum*; *Dv* = *Dermacentor variabilis*.

*Collected (%) includes 17 nymphs that were identified as *A. americanum*.

tick species (Table 3). There was a periodic absence of adult female and juvenile swine trapped in June-July, 2009 and August-September, 2010.

The most predominant tick species at the Welder Wildlife Refuge site was *A. cajennense*, exceeding 90% of all ticks removed from feral swine in seven of the ten sample dates confirming year round activity on this host (Table 4). *Amblyomma maculatum* and *D. variabilis* were collected from feral swine in nine of ten, and eight of ten sample dates, respectively, indicating adult tick activity for these species throughout most of the year. A single female *Dermacentor halli* was removed from a feral pig in January, 2009. *Amblyomma americanum* and *Ixodes scapularis* were absent. The Welder Wildlife Refuge site in San Patricio County shares parts of 5 watersheds and is situated along the Aransas River. This site was sampled ten times from June, 2008 to March, 2011 (Table 4). A total 169 animals was harvested with 144 animals (85%) infested with ticks at time of capture. Tick infested feral pigs were harvested on every trap date. There were periodic absences of one or more gender and age classes in the trapped populations of feral swine, notably males in the April-May period of 2009. Feral swine were infested with ticks year-round with the highest overall tick burdens observed in the sample months of May, June, and September.

The feral swine abatement program provided additional feral swine and tick collections from March to October, 2009. These collections are summarized in Table 5 and show prevalence of *A. americanum, A. cajennense, A. maculatum,* and *D. variabilis* on feral swine by county and ecoregion outside of the longitudinal study sites. These data provide further evidence that all gender and age-classes of feral swine serve as hosts for ixodid ticks in 15 additional counties located in 7 ecoregions representing northeast, coastal, and northwestern Texas. *Amblyomma americanum, A. maculatum* and *D. variabilis* were all present on feral swine harvested in four northeastern and northern counties. *Amblyomma cajennense, A. maculatum* and *D. variabilis* were all present in Aransas County, located adjacent to the long-term study site at the Welder Wildlife Refuge and where *A. cajennense* was the predominate tick on feral swine.

The county-level distributions of all seven ixodid tick species from both the longitudinal survey and abatement program collections are summarized in Figure 1 for *A. americanum, A. cajennense,* and *A. maculatum*, and Figure 2 for *D. albipictus, D. halli, D. variabilis* and *I. scapularis*. These distributions approximate those expected for all species except *D. variabilis*. Figure 2 shows collections of *D. variabilis* extending westward across ecoregions of the Edwards Plateau and High Plains to the New Mexico Border.

DISCUSSION

This study confirms feral swine are competent hosts for ixodid ticks in Texas, including species commonly posing risks to the health and well-being of livestock, wildlife and humans. All gender and age-classes were found to provide a year-round host resource for these parasites. The propensity for feral swine to occupy canopied habitats and riparian zones with forays on to upland sites (Campbell et al. 2010) likely contribute to landscape-level processes that affect tick dispersal and maintenance. Canopied vegetation communities dominated by Oak, mesquite, or mixed-brush species (Correll and Johnston 1970, Drawe et al. 1978) provide optimal microclimates for off-host tick survivorship (Teel et al. 2010) and resources for numerous small, medium and large-sized tick hosts. Feral swine should be considered as an integral part of tick-host-landscape interactions. The discovery of *D. halli* on feral swine in San Patricio County is a new host record for a tick that is normally found on javelina or collared pecary, *Pecari tajacu* (McIntosh 1931). While this tick has never been reported in large numbers, the overlapping landscape usage by javelina and feral swine along the Coastal prairies and marshes of Texas, and the relatively greater abundance of feral swine may favor population growth of this tick species.

The discovery *D. albipictus* on feral swine at Camp Bullis Military Reserve is believed to be a new host record for this tick. This one-host tick is an annual pest on cattle, horses and deer in Texas from October to March, especially along a broad corridor from southwest Texas through the Edwards plateau to Oklahoma (Teel et al. 1990). Other North American hosts include mule deer, elk, and moose. Completion of the feeding phase for a one-host tick requires extended contact with the host. The on-host developmental period from larvae to first engorged females for *D. albipictus* has been estimated to be approximately 26 days on cattle (Drummond et al. 1969). Another one-host tick, *Rhipicephalus (B.) microplus*, is known to infest swine (Islam et al. 2006).

Study results show an expanded geographic range for *D. variabilis*. The previous estimated distribution of *D. variabilis* in Texas approximated the eastern half of the state (CDC 2012). It is unknown whether this is related to the westward expansion of feral swine, or the ability of *D. variabilis* to now tolerate the more xeric environments of western Texas. Finding *D. variabilis* across Texas to New Mexico expands potential exposure to *Rickettsia rickettsii* and *Anaplasma marginale*. Adult *A. maculatum* collections from feral swine at the Anderson Ranch, Brazos County and Welder Wildlife Refuge, San Patricio County locations reflect differential seasonal activity for male and female ticks (data not shown). Males were collected from January through April, while with rare exception, females were not collected from feral swine until May; thereafter both sexes reached peak abundance on feral swine in August and September. This pattern of differential male and female activity of *A. maculatum* has been described on cattle in this region (Sleeba et al. 2010). Patterns of infestation are of interest because of the different seasonal phenologies exhibited between the inland (Oklahoma-Kansas) and coastal (Texas) populations of *A. maculatum* (Teel et al. 2010).

We were surprised by the absence of the spinose ear tick, *Otobius megnini*, despite intense scrutiny of the ears. *Otobius megnini* is noted as commonly infesting cattle, sheep, goats, horses, deer, and several sources include swine as a host for this tick (Cooley and Kohls 1944, Griffiths 1964, Ivens et al. 1978). It is unclear by these sources whether the inclusion of

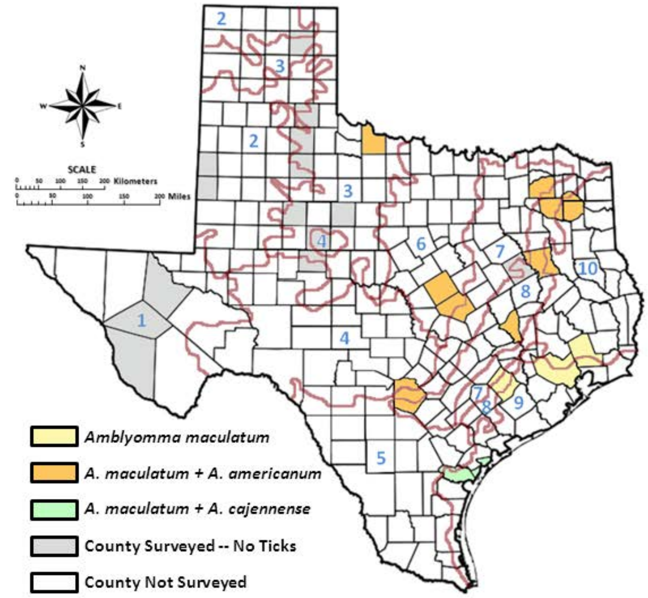

Figure 1. County-level distribution and eco-region association of feral swine infested with *Amblyomma americanum, A. cajennense*, and *A. maculatum* resulting from longitudinal and expanded surveys conducted in Texas 2008-2011. Ecoregions are 1 Trans-Pecos, 2 High Plains, 3 Rolling Plains, 4 Edward Plateau, 5 South Texas Plains, 6 Cross Timbers and Prairies, 7 Blackland Prairie, 8 Post Oak Savannah, 9 Gulf Prairies and Marshes, and 10 Piney Woods.

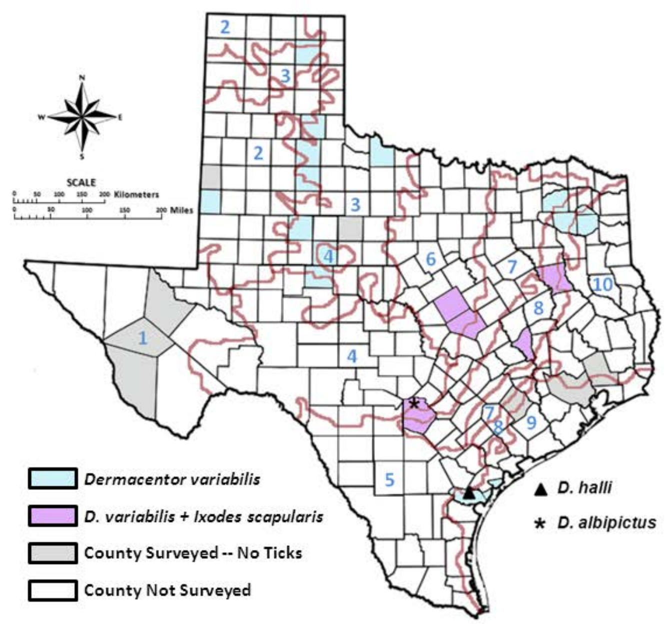

Figure 2. County-level distribution and eco-region association of feral swine infested with *Dermacentor albipictus, D. halli, D. variabilis*, and *Ixodes scapularis* resulting from longitudinal and expanded surveys conducted in Texas 2008-2011. Ecoregions are 1 Trans-Pecos, 2 High Plains, 3 Rolling Plains, 4 Edward Plateau, 5 South Texas Plains, 6 Cross Timbers and Prairies, 7 Blackland Prairie, 8 Post Oak Savannah, 9 Gulf Prairies and Marshes, and 10 Piney Woods.

this host is for swine kept in close proximity to other livestock as domestic swine. If so, the omission of this tick in our study may be related to a spatial decoupling of hosts on open landscapes.

Our findings lead us to expect additional ixodid species will be collected from feral swine as further studies are conducted over the state. Our examinations of captured feral swine did not extend into south, or far west Texas where feral pigs are known to extend into the geographic distribution of other ticks such as *Amblyomma imitator*, *A. triste*, *Rhipicephalus* (*Boophilus*) *annulatus*, and *R.* (*B.*) *microplus. Amblyomma imitator* is found along the lower Gulf Coast, is easily confused with *A. cajennense*, and these two species have a similar host range (Hilburn et al. 1989) *Amblyomma triste*, a South American species of the *A. maculatum* taxonomic group, has recently been found on deer in west Texas (Mertins et al. 2010). Islam et al. (2006) describe recovery of adult *R. (B.) microplus* from pigs in Bangladesh. Perez de Leon et al. (2012) raise concern for involvement of feral swine in the US Cattle Fever Tick Eradication Program along the Texas-Mexico border. The destructive behavior of feral swine is known to compromise integrity of game fences, and they may also serve as a transport host.

Future research should seek to estimate the success of immature tick feeding on feral swine. The comparatively small number of immature ticks obtained in this study, due to limitations of time and labor in the field, indicate we have not fully explored the role of this host in supporting the population of each tick species, nor the exposure and role of feral swine as a reservoir for the maintenance of tick-borne pathogens. Military bases, such as Fort Hood, TX, and Camp Bullis, TX included in these studies, provide locations for field exercises that expose soldiers to arthropod-borne pathogens. Both military and civilian parties are interested in protecting soldiers from exposure to native pathogens, as well as preventing the introduction of foreign/exotic pathogens following overseas deployments. The abundance of feral swine and their utilization by a broad range of ixodid ticks suggest these animals pose a significant risk toward increased exposure to ticks and consequently tick-borne pathogens. Feral swine abatement may become an important consideration for management from both preventive medicine and environmental perspectives. Companion studies estimating feral swine exposure to *Rickettsia, Ehrlichia*, and *Borrelia*, (Sanders 2011[5]) indicate feral swine may serve as a sentinel animal for tick-borne zoonotic pathogens.

Acknowledgments

We gratefully acknowledge collaborations with the Welder Wildlife Foundation, Camp Bullis Military Reservation, Fort Hood Military Reservation, the Texas Department of Corrections and Anderson Ranch LLC for permitting and supporting the long-term studies. In particular, we are indebted to Mr. Lucas Cooksey, Mr. Kevin Cagle, Dr. Fred Anderson, and Major Michael Owen for their assistance. We are similarly indebted to Ms. Jeneane Romaines and her staff of the Texas A&M AgriLife Extension, Wildlife Services, feral hog abatement program for samples collected on a state-wide scale. This project was supported in parts by Texas A&M AgriLife Research Project TEX08911, the Department of Defense Education Program, Deployed Warfighter Protection Program, and the Air Force Research Laboratory. The conclusions and opinions expressed by the authors in this manuscript do not reflect the opinions of the US Army, US Air Force, or the Department of Defense.

REFERENCES CITED

AgriLife Extension. 2012. http://feralhogs.tamu.edu/

Allan, S.A, L. Simmons, and M.J. Burridge. 2001. Ixodid ticks on white-tailed deer and feral swine in Florida. J. Vector Ecol. 26: 93-102.

Bengtson, S.D. and F. Rogers. 2001. Prevalence of sparganosis by county of origin in Florida feral swine. Vet. Parasitol. 97: 239-242.

Campbell, T.A., D.B. Long, and B.R. Leland. 2010. Feral swine behavior relative to aerial gunning in southern Texas. J. Wldl. Manag. 74: 337-341.

CDC. 2012. http://www.cdc.gov/ticks/maps/american_dog_tick.html

Clark, R.K., D.A. Jessup, D.W. Hird, R. Ruppanner, and M.E. Meyer. 1983. Serologic survey of California wild hogs for antibodies against selected zoonotic disease agents. J. Am. Vet. Med. Assoc. 183: 1248-1251.

Cooley, R.A. and G.M. Kohls. 1944. *The Argasidae of North America, Central America and Cuba*, p. 27. Univ. of Notre Dame Press, Notre Dame, IN, 151 pp.

Coombs, D.W. and M.D. Springer. 1974. Parasites of feral pig x European wild boar hybrids in southern Texas. J. Wildl. Dis. 10: 436-441.

Cooper, S.M., H.M. Scott, G.R. de la Garza, A.L. Deck, and J.C. Cathey. 2010. Distribution and interspecies contact of feral swing and cattle on rangeland in south Texas: implications for disease transmission. J. Wildl. Dis. 46: 152-164.

Corn, J.L., J.C. Cumbee, R. Barfoot, and G.A. Erickson. 2009. Pathogen exposure in feral swine populations geographically associated with high densities of transitional swine premises and commercial swine production. J. Wildl. Dis. 45:713-721.

Correll, D.S. and M.C. Johnston. 1970. *Manual of the Vascular Plants of Texas*. Texas Research Foundation. Renner, Texas. 1,881 pp.

De la Fuente, J., V. Naranjo, F. Ruiz-Fons, J. Vicente, A. Estrada-Pena, C. Almazan, K.M. Kocan, M.P. Martin, and C. Gortazar. 2004. Prevelance of tick-borne pathogens in ixodid ticks *(Acari: Ixodidae)* collected from European wild boar *(Sus scrofa*) and Iberian red deer *(Cervus elaphus hispanicus)* in central Spain. Eur. J. Wildl. Res. 50: 187-196.

[5]Sanders, D. 2011. Ticks and tick-borne pathogens associated with feral swine in Edwards Plateau and Gulf Prairies and Marshes ecoregions of Texas. Doctoral dissertation. TAMU.

Drawe, D. L., A. D. Chamrad, and T. W. Box. 1978. Plant communities of the Welder Wildlife Refuge. Contribution No. 5, Series B, Revised. Welder Wildlife Foundation, Sinton, TX.

Drawe, D. L., A. D. Chamrad, and T. W. Box. 1991. Influence of grazing on vegetation and cattle on the Welder Wildlife Foundation Refuge, 1983-1987 [Pamphlet]. Contribution No. B-11. Welder Wildlife Foundation, Sinton, TX.

Drummond, R.O., T.M. Whetstone, S.E. Ernst, and W.J. Gladney. 1969. Biology and Colonization of the winter tick in the laboratory. J. Econ. Entomol. 62: 235-238.

Ghosh, S., G.C. Bansal, S.C. Gupta, D. Ray, M.Q. Khan, H. Irshad, M. Shahiduzzaman, U. Seitzer, and J.S. Ahmed. 2007. Status of tick distribution in Bangladesh, India and Pakistan. Parasitol. Res. 101 (Suppl. 2): 207-216.

Giurgiutiu, D., C. Banis, E. Hunt, J. Mincer, C. Nicolardi, A. Weltman, D. Stanek, S. Matthews, C. Siegenthaler, C. Blackmore, R. Tiller, B. De, and K. Stauffer. 2009. *Brucella suis* infection associated with feral swine hunting-three states, 2007-2008. MMWR 58: 618-621.

Gould, F.W., G.O. Hoffman, and C.A. Rechenthin. 1960. Vegetational areas of Texas. Texas A&M University, Texas Agricultural Experiment Station, Leaflet No. 492

Greiner, E.C., P.P. Humphrey, R.C. Belden, W.B. Frankenberger, D.H. Austin, and E. P. Gibbs. 1984. Ixodid ticks on feral swine in Florida. J. Wildl. Dis. 20: 114-119.

Griffiths, H.J. 1964. External parasites. In: H.W. Dunne (ed.) *Diseases of Swine*. 2nd ed., Iowa State University Press, Ames, Iowa. pp. 511-523.

Hanson, R.P. and L. Karstad. 1959. Feral swine in the southeastern United States. J. Wildl. Manag. 23: 64-74.

Hilburn, L. R., S. J. Gunn, and C. Castillo. 1989. Comparison of the isozyme phenotypes of the morphologically similar ticks *Amblyomma cajennense* and *A. imitator* (Acari: Ixodidae) from south Texas. J. Med. Entomol. 26: 23-29.

IRNR (Institute of Renewable Natural Resources TAMU). 2011. Feral hog statewide population growth and density. http://feralhogs.tamu.edu/files/2011/05/FeralHog-FactSheet.pdf.

Islam, M.K., M.A. Alim, N. Tsuji, M. and M.H. Mondal. 2006. An investigation into the distribution, host-preference and population density of Ixodid ticks affecting domestic animals in Bangladesh. Trop. Anim. Hlth. Prod. 38: 485-490.

Ivens, V.R., Mark, D.L. and Levine, N.D. 1978. Principal parasites of domestic animals in the United States. Biological and diagnostic information. Urbana-Champaign, Colleges of Agriculture and Veterinary Medicine, University of Illinois, Special Publication 52. vi + 270.

Keirans, J.E. and C.M. Clifford. 1978. The genus *Ixodes* in the United States: a scanning electron microscope study and key to the adults. J. Med. Entomol. (Suppl. 2): 1-149.

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.

Lowe S., M. Browne, S. Boudjelas, and M. De Poorter. 2000. 100 of the world's worst invasive alien species. A selection from the Global Invasive Species Database. IUCN, Auckland, NZ.12 pp.

Mapston, M.E. 2004. Feral hogs in Texas. Texas Cooperative Extension Pamphlet B-6149. Published by Texas A&M Press, College Station.

McIntosh, A. 1931. Description of a tick, *Dermacentor halli* from the Texas peccary, with a key to the North American species of *Dermacentor*. Proc. U.S. Nat. Mus. 82: 6 pp.

Meng, X.J., D.S. Lindsay, and N. Sriranganathan. 2009. Wild boars as sources for infectious diseases in livestock and humans. Phil. Trans. R. Soc. B. 364: 2697-2707.

Mertins, J.W., A.S. Moorhouse, J.T. Alfred, and J.J. Hutcheson. 2010. *Amblyomma triste* (Acari: Ixodidae): new north American collection records, including the first from the United States. J. Med. Entomol. 47: 536-542.

Mullen, G. and L. Durden. 2009. *Medical and Veterinary Entomology*. 2nd Ed. Academic Press/Elsevier Science. San Diego. xvii + 637 pp.

Mungall, E.C and W.J. Sheffield. 1994. *Exotics on the Range: The Texas Example. Part II. The New Animals.* pp. 67-73. Texas A&M University Press, College Station. 265 pp.

New, J.C., Jr., K. Delozier, C.E. Barton, P.J. Morris, and L.N.D. Potgieter. 1994. A serologic survey of selected viral and bacterial diseases of European wild hogs, Great Smokey Mountains National Park, USA. J. Wildl. Dis. 30: 103-106.

Ortuno, A., M. Quesada, S. Lopez-Claessans, J. Castella, I. Sanfeliu, E. Anton, and F. Sequra-Porta. 2007. The role of wild boar *(Sus scrofa) in* the eco-epidemiology of *R. slovaca* in northeastern Spain. Vector-Borne and Zoonot. Dis. 7: 59- 64.

Perez de Leon, A.A, P.D. Teel, A.N. Auclair, M.T. Messenger, F.D. Guerrero, G. Schuster, and R.J. Miller. 2012. Integrated strategy for sustainable cattle fever tick eradication in USA is required to mitigate the impact of global change. Front. Physiol. Vol. 3. Article 195. (doi:10.3389/fphys.2012.00195)

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol. Econ. 52: 273-288.

R Core Team. 2013. R: A language and environment for statistical computing. R. Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Rollins, D., B.J. Higginbotham, K.A. Cearley, and R.N. Wilkins. 2007. Appreciating feral hogs: extension education for diverse stakeholders in Texas. Human-Wildl. Confl. 1: 192-198.

Rollins, D. 1993. Statewide attitude survey on feral hogs in Texas. In: C.W. Hanselka and J.F. Cadenhead (eds.). Feral swine: A compendium for resource managers. pp. 1-8 Texas Agricultural Extension Service, Kerrville, TX, U.S.A.

Ruiz-Fons F, Fernandez-de-Mera, IG, Acevedo P, Hofle U, Vicente J, de la Fuente J, Gortazar C. 2006. Ixodid ticks parasitizing Iberian red deer *(Cervus elaphus hispanicus)* and European wild boar *(Sus scrofa) from* Spain: Geographical and temporal distribution. Vet. Parasitol. 140: 133-142.

Schulyer, P.T., D.K. Garcelon, and S. Escover. 2002. Eradication of feral pigs (Sus scrofa) on Santa Catalina Island, California, USA. In: C.R. Veitch and M.N. Clout (eds.). Turning the tide: the eradication of invasive species: Proceedings of the International Conference on Eradication of Island Invasives. Auckland, New Zealand: IUCN. pp. 274-296.

SCWDS. 2012. www.vet.uga.edu/scwds/rangemaps.php

Seward, N.W., K.C. VerCauteren, G.W. Witmer, and R.M. Engeman. 2004. Feral swine impacts on agriculture and the environment. Wildl. Dam. Man., Internet Center for Sheep and Goat Research J. http://digitalcommons.unl.edu/ecwdmsheepgoat/12.

Sleeba, S.B., P.D. Teel, M.T. Longnecker, and O.F. Strey. 2010. Host selection by questing female *Amblyomma maculatum* Koch, to cattle with feeding male ticks in southern Texas. Vet. Parasitol. 172: 105-108.

Smith, T.C., Harper, A.L., Nair, R., Wardyn, S.E., Hanson, B.M., Ferguson, D.D., and A.E. Dressler. 2011. Emerging swine zoonoses. Vector Borne Zoonot. Dis. 11: 1-10.

Taylor, R.B., E.C. Hellgren, T.M. Gabor, and L.M. Ilse. 1998. Reproduction of feral pigs in Southern Texas. J. Mammal. 79: 1325-1331.

Teel, P.D., T.W. Fuchs, J.E. Huston, M.T. Longnecker, and S.L. Pickel. 1990. Effects of sequential infestations of *Dermacentor albipictus* and *Amblyomma americanum* (Acari: Ixodidae) on overwintering beef cows in west-central Texas. J. Med. Entomol. 27: 632-641.

Teel, P.D., H.R. Ketchum, D.E. Mock, W.E. Wright, and O.F. Strey. 2010. The Gulf Coast tick: A review of the life history, ecology, distribution, and emergence as an arthropod of medical and veterinary importance. J. Med. Entomol. 47: 707-722.

Timmons, J.B., B. Higginbotham, R. Lopez, J.C. Cathey, J. Mellish, J, Griffin, A. Sumrall, and K. Skow. 2012. Feral hog population growth, density and harvest in Texas. Texas A&M AgriLife Extension, Special Publication SP-472, 8 pp.

Witmer, G.W., R.B. Sanders, and A.C. Taft. 2003. Feral swine—are they a disease threat to livestock in the United States? Proceed. 10th Wildl. Damage Mgnt. Conf., Univ. Nebraska, pp. 315-325.

Wycoff, A.C., S.E. Henke, T.A. Campbell, D.G. Hewitt, and K.C. VerCauteren. 2009. Feral swine contact with domestic swine: a serologic survey and assessment of potential for disease transmission. J. Wildl. Dis. 45: 422-429.

Yunker C.E., J.E. Keirans, C.M. Clifford, and E.R. Easton. 1986. Dermacentor Ticks (Acari: Ixodoidea: Ixodidae) of the New World: A Scanning Electron Microscope Atlas. Proc. Entomol. Soc. Wash. 88: 609-627.