SPATIAL AND TEMOPORAL SURVEY OF FERAL PIG ECTOPARASITES IN THREE TEXAS WILDLIFE DISTRICTS

A Dissertation

by

ANTHONY LAWRENCE SCHUSTER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2011

Major Subject: Entomology

Spatial and Temporal Survey of Feral Pig Ectoparasites in Three Texas Wildlife Districts

Copyright 2011 Anthony Lawrence Schuster

SPATIAL AND TEMPORAL SURVEY OF FERAL PIG ECTOPARASITES IN THREE TEXAS WILDLIFE DISTRICTS

A Dissertation

by

ANTHONY LAWRENCE SCHUSTER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Chair of Committee,	Pete D. Teel
Committee Members,	Albert Mulenga
	Thomas Craig
	Leon Russell
	William Sames, III
Head of Department,	David W. Ragsdale

December 2011

Major Subject: Entomology

ABSTRACT

Spatial and Temporal Survey of Feral Pig Ectoparasites in Three Texas Wildlife Districts. (December 2011)

Anthony Lawrence Schuster, B.S., Mississippi State University; M.Agr., Texas A&M University

Chair of Advisory Committee: Dr. Pete D. Teel

Feral pigs, European wild boars and their crosses are ubiquitous and found in all ecological zones from Florida to California. These introduced animals are recorded in 39 US states and four Canadian provinces. Texas currently has an estimated population of 1-4 million pigs with the potential to exceed 4 million based on suitable habitat estimates. Feral pigs can modify local flora and fauna and cause significant physical damage with their rooting activities. They can also reintroduce parasites and pathogens to previously parasite and pathogen free herds of domestic cattle, horses, sheep, and goats. The two overarching objectives of this research were to determine what role feral pigs have in the maintenance and possible distribution of fleas, lice, and ticks common to the three wildlife districts, and if they serve as bridging hosts for the same (or other) arthropods and their natural hosts. The supporting objectives were to establish host records of fleas, lice, and ticks parasitizing feral pigs; determine species assemblies within each of the three wildlife districts; and to compare species assemblies among the wildlife districts.

Feral pigs (564) were taken from June 2008 to March 2011 using box, corral, and panel traps in three wildlife districts. Two hundred fifty six fleas, *Pulex porcinus* (Jordan and Rothschild), were collected from all gender and age classes of feral pigs at the South Texas Plains wildlife district. No fleas were collected at either the Hill Country or Post Oak Savannah wildlife districts. This is the first report of these fleas on feral pigs. Lice and ticks were collected from all gender and age classes of feral pigs from all sample sites. Only hog lice, *Haematopinus suis*, were collected at all three sample sites. Seven species of ticks were collected from the three sites: *Amblyomma americanum*, *A. cajennense*, *A. maculatum*, *Dermacentor albipictus*, *D. halli*, *D. variabilis*, and *Ixodes scapularis*. *Amblyomma cajennense* was collected only at the South Texas Plains sample site; *A. americanum* and *I. scapularis* were collected only at the Hill Country and Post Oak sample sites.

This study reports that feral pigs are serving as hosts for one species of flea, one species of lice and seven species of ticks common to Texas.

To Carol Lea Schuster

18 September 1932 - 10 June 2011

Thank you, we love you, and we miss you.

ACKNOWLEDGEMENTS

I acknowledge my Creator and my Savior through whom all things are possible. I would like to thank my committee chair, Dr. Teel, and my committee members, Dr. Mulenga, Dr. Craig, Dr. Russell, and Dr. Sames, for their patience, guidance and support throughout the course of this research. Your unflappable enthusiasm for this project has kept me motivated throughout. Dr. Teel, I knew I had found the right chair when I discovered you were fond of mules. I knew that it would require someone with the patience to work with Asses to keep me on track and focused. Not only are you an avid fan of a spectacular animal such as the Acari, but you are a connoisseur of Asses both small and large. I remain a Big Ass fan. Dr. Mulenga, although I was not able to spend as much time as I would have preferred in your lab, I can say now that not only can I spell PCR, but I might actually have a better understanding of that wonderful witchcraft you practice. Dr. Craig, it is with great melancholy that I look back and ponder the exquisite fun it would have been to have taken one of your classes back in 1975, and what a different path that event might have precipitated for me. Dr. Russell, I will never tell anyone that I am an epidemiologist or that I truly understand the craft (never ever) but I will gladly say I once took a class with the kindest and finest world class epidemiologist I have ever met. Dr. Sames, I have admired your scientific work for many years and greatly appreciate your efforts to keep me straight and honest. I am humbled by the world class scientific knowledge, expertise and humanitarian focus exemplified by all the committee members.

I would like to thank the following individuals and/or groups for their physical assistance and/or access to their property so that I might trap feral pigs. Without your very generous assistance this project would not have gotten any further than the concept portion of the plan. Thank you to Dr. Fred Anderson, Anderson Ranch LLC for allowing me free access to his family property in Brazos County. Thank you to Mr. Kevin Cagle and his staff for their amazingly generous support at Fort Hood, Bell and Coryell Counties. Thank you to Dr. Terry Blankenship and the Welder Foundation for allowing me to experience the unlimited beauty of the Welder Wildlife Refuge. Thank you to Major Michael Owen of the Texas Department of Criminal Justice-Beto Unit, Anderson County for allowing me access to Tennessee Colony property and the assistance of his excellent staff. To Mr. David Long, USDA-APHIS-Wildlife Services, Kingsville, your traps were immeasurably important to our trapping efforts at Welder, as was your willingness to share your field knowledge.

Special thank you shouts go to my new brothers. To my Air Force brother, Capt. David Sanders, Ph.D. Dude, when I arrived, you worked hard getting me running as soon as my feet got close to the ground. Your selfless sharing of precious time, knowledge and equipment in the field made my efforts so much less complicated. Your constant council in the office kept me sane and focused. I look forward to bumping into you as we continue the Big Fight. To my Aggie brother, Dr. Russell Farrow, thank you for dropping everything you were doing (on many occasions) to help me survive my first epidemiology course. You also dropped everything you were doing to help process field collections, most often with zero forewarning, as if my work was more important than your own without complaint.

Mr. Otto Strey. What can I say that you don't already know? You have pushed so many students through this university that you should have your own Ph.D. Your map making skills and seemingly endless wildlife knowledge was always given in a cheerful and helpful way, and your company was always greatly appreciated.

I would like to acknowledge my extended family for their support and motivation over the past 37 years of my education process. I have watched many of my much younger family members achieve academic excellence and they have kept me inspired. I would like to mention every single one of my many aunts, uncles, cousins and siblings by name, but space will not allow. Each of you has kept an unwavering faith in me. I would like to acknowledge my fraternal grandparents, Mike and Anna Z. Schuster, who although restricted in their own educational opportunities, constantly promoted education for others. Their five children achieved: two M.S. and two Ph.D. degrees. My parents, Carol and Dr. Mike Schuster, have always promoted education and their seven children have produced one B.S., one M.S., and two Ph.D. degrees. Dr. Greta Schuster, I remain one of your most ardent admirers, you have unlimited energy and ability to help the people of Texas, regardless of the subject. No one could ask for better in-laws than the two I received over 25 years ago, Tommy and Wanda Tomlin. Three degrees since the beginning and yet you keep on giving. You are the best grandparents, friends, and counsel any son-in-law could hope to have, thank you.

Thank you to my ‘other-brother’ Pat McCaa, you have been as big a part of this journey as anyone and have been supporting me almost as long as I have been fighting the fight. I greatly appreciate all your support in the past and I take great comfort in knowing it will continue into the future.

Special thanks go to LTC Doug Burkett, USAF, who was able to squeeze out funding from the Deployed Warfighter and Protection Program to help a couple struggling graduate students, despite the fact that we weren’t attending his alma mater. Sir, I didn’t choose to go to that secular university in Gatesville, but first-hand experience tells me Gators are pretty good eats!!

To LTC Sang Pak, Ph.D., US Army, Sir, I have used your name in vain many times in the past three years. I look forward to making up for my lack of faith, and as you said, I will always appreciate the end results.

I know I have not acknowledged everyone who has made this journey a success, and to those who I have omitted, I humbly apologize.

Finally, to my family: Tami, Ashley, Laura, and Melissa. Thank you for your love, support, inspiration and acceptance of my own short comings. Thank you for suffering through another two year separation, the advanced bouts of irritability and the often seemingly unintelligible conversations I had with you (and with myself) in the pursuit of this degree. I look forward to watching you three ladies continue on your own educational journey which you have begun so well. It would have been so very much less fun and so much more difficult to focus without your love and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Feral swine (*Sus scrofa domestica* E.), European wild boar (*Sus scrofa scrofa* L.), and their crosses are ubiquitous and are found in all ecological regions across the southern United States from Georgia to California (Figure 1). These two sub-species have crossbred for many decades and there is no practical field-method to differentiate them into distinct groups as feral swine or wild boar. For these reasons, this document will use the term feral pig/pigs to apply collectively to European wild boars, domesticated hogs that have become feral, and all hybrids of the two. The Wildlife Services Division of the Texas AgriLife Extension Service estimates Texas has a feral pig population of between 1-4 million animals (Taylor et al. 1998, Mapston 2004, Mellish et al. 2011), and these pigs occupy 94% of all counties (Figure 2) and all 10 recognized vegetation areas in Texas (Rollins et al. 2007) (Figure 3). Mellish et al. (2010) estimated that over 79% of the state's 170 million acres or about 134 million acres can support feral pig activity (Figure 4). 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). On the other hand feral pig hunting generates money for state wildlife services, private land owners, as well as specialty meat markets globally (Rollins 1993, Witmer et al. 2003, and Mapston 2004).

This dissertation follows the style of the Journal of Vector Ecology.

Interactions between feral pigs and domestic or agronomic animals such as pigs, goats, sheep, cattle or horses, as well as wildlife such as deer, and antelope, are increasing (Seward et al. 2004, Corn et al. 2009 and Wycoff et al. 2009). These interactions present an opportunity for pathogens, previously eradicated from domestic populations of pigs, cattle, or sheep, to be re-introduced into those specific pathogen free populations and which may result in catastrophic revenue and production losses (Cooper et al. 2010). Past and current feral pig infectious disease research is focused on the threat that feral pigs could contaminate clean domestic/commercial herds and is based on the previously known parasites and pathogens of domestic pigs and their long established disease cycles. Some bacterial and parasitic pathogens of feral pigs that can be potentially transmitted to humans and cause disease include: anthrax (*Bacillus anthracis* Cohn), brucellosis (*Brucella suis* Huddleson), cystiscercosis (*Taenia solium* L.), echinococcosis (*Echinococcus granulosa* Batsch), leptospirosis (*Leptospira spp* Noguchi), bubonic plague (*Yersinia pestis* (Lehman & Neumann) van Loghem), sparganosis (*Spirometra mansonoides* Mueller), tuberculosis (*Mycobacterium tuberculosis* Koch), tularemia (*Francisella tularensis* McCoy & Chapin), and trichinosis (*Trichinella spiralis* Owen) (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).

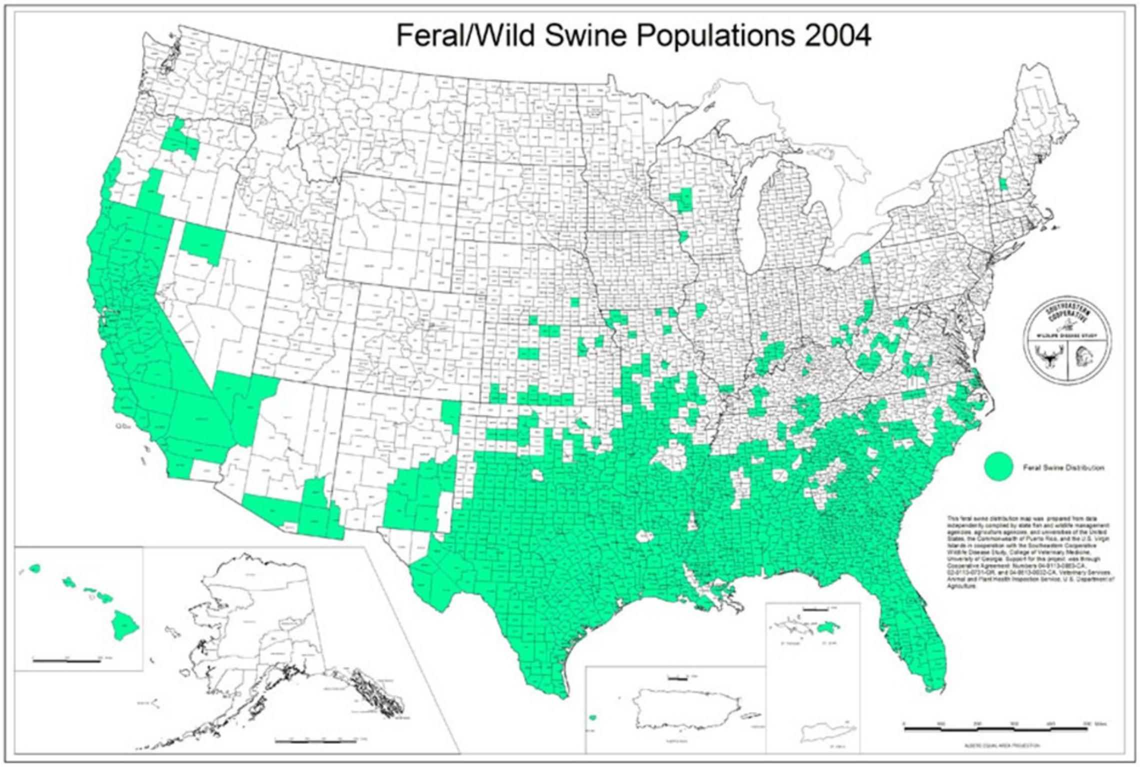


Figure 1. Estimated feral swine distribution in the United States, 2004. www.scwds.org

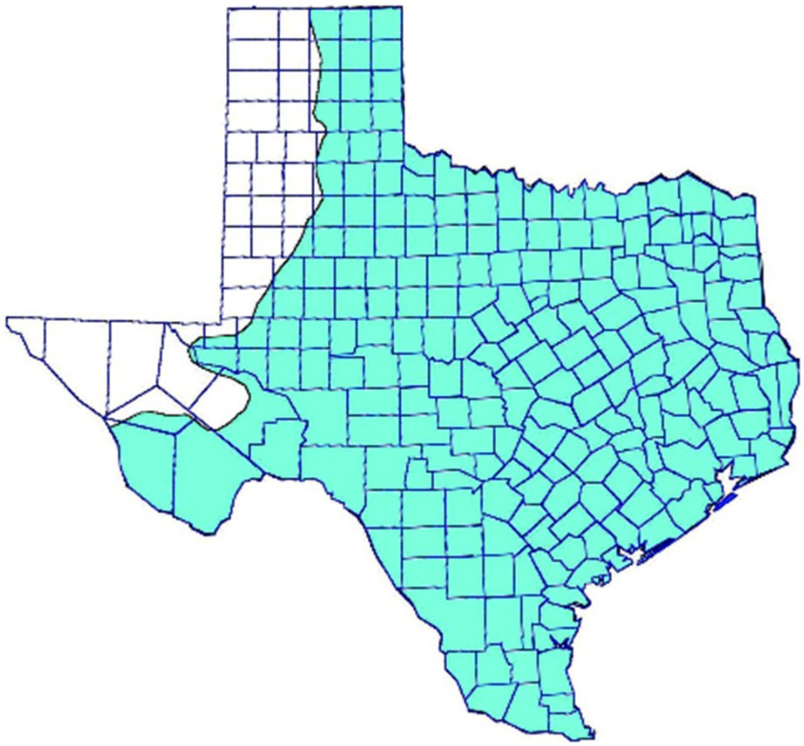


Figure 2. Estimated feral swine distribution in Texas, 2004. www.tpwd.state.tx.us.

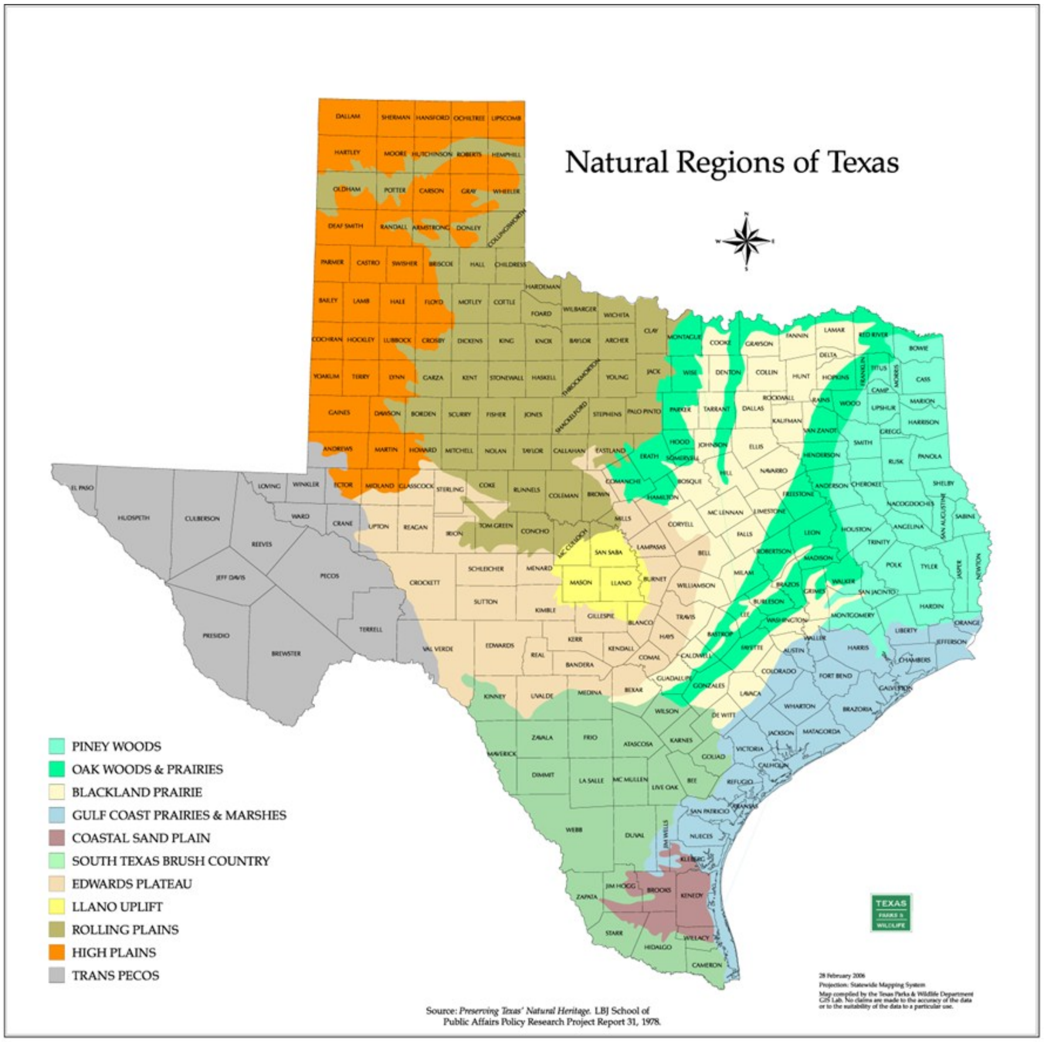


Figure 3. Identification and distribution of natural vegetational regions of Texas. www.tpwd.state.tx.us

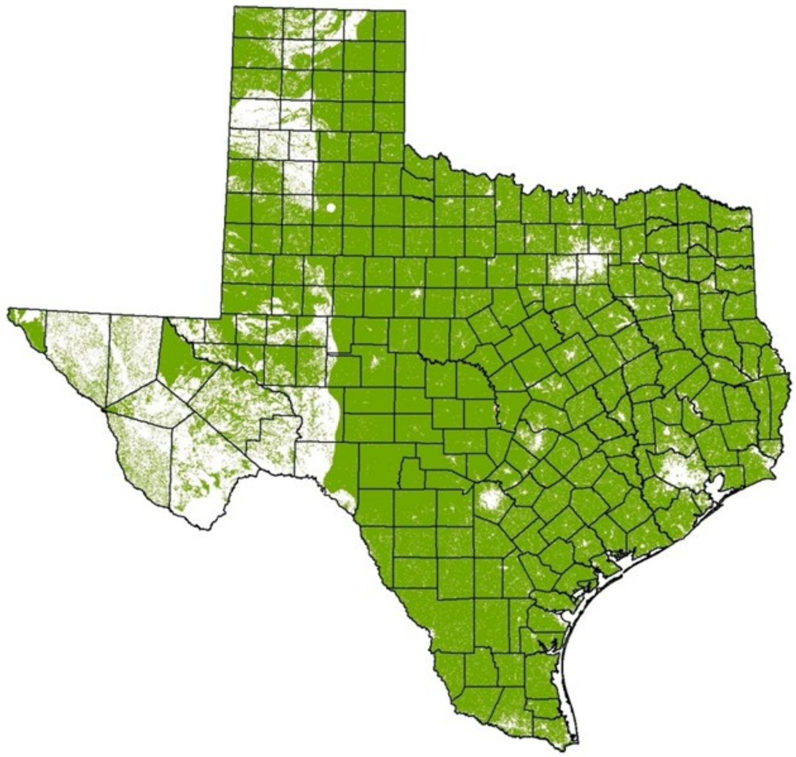


Figure 4. Global information system simulation of suitable habitat for feral pigs in Texas, 2011. As developed by Mellish *et al*. 2011.

The role of feral pigs in the cycling of zoonotic pathogens or vectors is understudied. Virtually no published research has been conducted in Texas to determine whether feral pigs serve as reservoirs for novel pathogens/parasites or if the pigs are serving as bridge hosts for arthropod vectors that transmit pathogens not previously associated with pigs. For example, Sanders (2011) reported the presence of the Gulf Coast tick, *Amblyomma maculatum* (Koch), in 10 Texas counties where it was previously unknown. *Amblyomma maculatum* is a vector of the bacterial pathogen *Rickettsia parkeri* (Lackman, Bell, Stoenner and Pickens) and the parasitic pathogen *Hepatozoon americanum* (Vincent-Johnson et al. 1997). Sanders (2011) also established records in Texas for 7 tick species collected from feral pigs: *Amblyomma americanum* (L.), *A. cajennense* (F.), *A. maculatum* (Koch), *Demacentor albipictus* (Packard), *D. halli* (McIntosh), *D. variabilis* (Say), and *Ixodes scapularis* (Say). *Amblyomma americanum*, *A. maculatum*, *D. halli*, *D. variabilis*, and *I. scapularis* are all three-host ticks that drop off and seek different hosts for each feeding period necessary to produce successive generations. Sanders (2011) was also the first report of *D. halli* and *D. albipictus* on feral pigs. Previously, *D. halli* was collected exclusively from the Collared Peccary (*Tayassu tajacu*) in Arizona, Texas, and New Mexico (Neal 1959, Samuel and Low 1970, Lewis 1972, Gruver and Guthrie 1996). Appendix A contains a map of the historic range of the collard peccary (A1) (Davis and Schmidly 2011). *Dermacentor albipictus* (winter tick) is a one-host tick that usually attaches to a single host and completes all three immature stages on that single host. The winter tick is normally associated with deer, moose, elk, or pastured domestic livestock. This tick is known to transmit bovine anaplasmosis and possibly the Rocky Mountain spotted fever pathogen.

Fleas and domestic pigs is a well-known association. The flea genus *Pulex* includes three species (*Pulex irritans*, *P. simulans*, and *P. porcinus*) which are found in Texas (Smit 1958, Lewis 1972). *Pulex irritans* Baker (human flea) and *P. simulans* Baker (false human flea) are recognized vectors and are known to feed on pigs (Beard et al. 1989, Durden et al. 2005, Mullen and Durden 2009). These flea species are vectors of salmonella and bubonic plague (Mullen and Durden 2009). *Pulex porcinus* Jordan and Rothschild (Peccary Flea) has been recorded from the collared peccary, and from white-tailed deer, *Odocoileus virginianus* at the Welder Wildlife Refuge (Samuel and Trainer

1970a, Meleney 1975) as well as from other vertebrates throughout Texas (Eads 1951). *Pulex irritans* is a generalist feeder and has been recorded as parasitizing a large number of vertebrates; also, it has a strong historical association with domestic pigs (Eads 1948, Lewis 1972, Durden et al. 2005, Mullen and Durden 2009). *Pulex simulans* appears to be a generalist mammalian feeder with a preference for carnivores (Mullen and Durden 2009, Tripp et al. 2009). Controversy as to the species validation and separation based on morphological characters of *P. irritans* and *P. simulans* continues despite multiple efforts in the past 30 years to consolidate them into one species (Layne 1971, De la Cruz and Whiting 2003, Dittmar et al. 2003, Mullen and Durden 2009). Although these two fleas have preferred hosts, they could be called generalists because they parasitize many species of mammals, especially carnivores (Lewis 1972, Mullen and Durden 2009) and they may harbor and vector disease pathogens not previously associated.

The only blood sucking louse recorded from domestic pigs is *Haematopinus suis* (Hog Louse). No studies have been published in the last 20 years to determine if *H. suis* is capable of transmitting any novel pathogens, or if any new lice might be parasitizing feral pigs. Swine pox virus and *Mycoplasma sui*s are the only pathogens associated with *H. suis* (Acholonu and Epps 2009, Groebel et al. 2009). There are no human pathogens known to be transmitted by *H. suis*. Table 1 lists pathogens that have been identified as being isolated from either fleas or lice.

Molecular diagnostic techniques continue to improve and several novel pathogens have been identified in fleas that affect companion, feral and domestic animals, and humans (Boostrom et al. 2002, Parola et al. 2002). Twenty eight flea species in North America are recognized vectors for plague (*Yersinia pestis*) (Eisen et al. 2009). Fleas are also vectors for pathogens that cause cat scratch disease (*Bartonella henslae*), murine typhus (*Rickettsia typhii*), and flea-borne spotted fever (*Rickettsia felis*) (Azad et al. 1997, Gillespie et al. 2009). Murine typhus is transmitted by the Oriental Rat Flea, *Xenopsylla cheopis*. This flea also transmits *Yersinia pestis* (bubonic plague) and is endemic and wide spread over a large part of Texas as demonstrated by 80 counties in west Texas and the Panhandle with positive cases of mammal plague diagnosed from 1976-2009 (TDSHS 2011). In Cameron County, increased reporting by medical providers and an active surveillance program led to an increase from 45 diagnosed human cases in 1998 to 149 cases in 2006 (Robinson 2008). Many cases of murine typhus are estimated to be unreported . Ninety percent of these cases occurred in Texas Department of State Health Services (TDSHS) Region 11, which serves the following counties: Aransas, Bee, Brooks, Cameron, Duval, Hidalgo, Jim Hogg, Jim Wells, Kenedy, Kleberg, Live Oak, McMullen, Nueces, Refugio, San Patricio, Starr, Webb, Willacy, and Zapata (Robinson 2008). Most of the work to identify fleas other than *X. cheopis* as vectors of the plague pathogen occurred prior to 1945 (Eisen et al. 2009). In 1958, Smit elevated *P. simulans* to a separate species, basically invalidating most studies involving *P. irritans* as a potential vector of the bubonic plague pathogen. No studies have been conducted since 1958 to determine whether *P. simulans* is a more or less competent vector of any diseases previously associated with the *P. irritans* complex (Wilson and Bishop 1966, Layne 1971, Lewis 1972, Eisen et al. 2009).

Sanders (2011) documented exposure to three previously unreported bacterial disease genera: *Rickettsia*, *Ehrlichia*, and *Borrelia* at 28%, 13%, and 2%, respectively, by serologic testing of harvested feral pigs throughout Texas. The American dog tick (*Dermacentor variabilis*), the lone star tick (*Amblyomma americanum*), and several biting flies of the family Tabanidae, genus *Chrysops,* are recognized vectors of tularemia. Sanders (2011) reported collecting these tick species from feral pigs. Presley (2011) reported 21% of blood tested from feral pigs in Bell and Coryell counties (central Texas), and 52% of feral pigs tested from Crosby County (Texas Panhandle) were positive for antibodies related to *Franciscella tularensis* exposure. Three samples from Crosby County were culture positive and two of the three pigs also tested positive for active infections of *F. tularensis. Francisella tularensis* is classified by the Center for Disease Control and Prevention as a Class A Bioterrorism disease organism that poses a risk to national security because the pathogen "*can be easily disseminated or transmitted from person to person; can result in high case fatality rates and have the potential for a major public health impact; might cause public panic and social disruption; and require special action for public health preparedness*" (CDC 2011a).

Chagas Disease is caused by infection with the protozoan pathogen *Trypanosoma cruzi*. Chagas disease has been endemic in Mexico and Central America for many years and affects over 100,000 people a year in these countries (CDC 2011b). The Chagas pathogen is transmitted in Texas by seven species of insects in the family Reduviidae (Kjos et al. 2009). Dogs infected with *T. cruzi* may die from acute infection within 12 months, but humans can present with acute or chronic infections with the chronic infection being inapparent for over 25 years (CDC 2011b, TDSHS 2011). The CDC estimates there are over 300,000 immigrants harboring *T. cruzi* pathogens from endemic regions in South and Central America but most are asymptomatic for the disease and now live and work in the United States. Chagas can be transmitted to humans transplacentally, by organ transplant, and by blood transfusion. Even though this disease is not on the Mandatory Reportable Diseases list (Sarkar et al. 2010) the risk of transmission by blood transfusion is high enough that the American Red Cross (AMRC) now tests 100% of its blood donors for Chagas (AMRC 2011). Texas has 97 counties where multiple species of reduviid vectors occur and 46 counties in which canine Chagas disease is endemic or emerging (Kjos et al. 2008). Although there is not a 100% overlap, the distribution of canine chagas cases diagnosed to date closely matches the known distribution of seven triatomine vectors reported from Texas (Kjos 2008).

Canine Chagas disease has increasingly been diagnosed in Texas in spite of there being only 7 autochthonous human cases in the United States. In 2009-2010 (July 2009-August 2010), the Texas Veterinary Medical Diagnostics Laboratory (TVMDL) diagnosed 148 cases of canine Chagas disease in 34 Texas counties with 18 of those cases diagnosed in Brazos County. Appendix A contains a map of counties where canine Chagas was diagnosed by the TVMDL lab from 2009-2010 (A2). During this same period the TVMDL diagnosed 17 cases of canine Chagas disease in from out of state dogs (TVMDL 2010). These cases do not include cases of canine chagas diagnosed at private veterinary practices, so it is suspected that many more cases of canine chagas are occurring. Contributing factors for Chagas disease endemicity in Texas canine populations are the abundance of triatomine vectors and the widespread overlap of domestic and peridomestic cycles which bring the dogs and arthropods into frequent contact with each other. Chagas disease is not a Texas Animal Health Commission reportable disease (TAHC 2011), nor is Chagas a reportable disease in humans (CDC 2011b). Feral pigs are reported from the same counties and environmental regions as the triatomid vectors and could possibly be maintaining and distributing the pathogens throughout the state. Experiments in the United States have demonstrated that domestic pigs could be infected with *T. cruzi* and could maintain an active infection or a carrier state (Diamond and Rubin1958, Marsden et al. 1970). Researchers in Mexico and Peru have demonstrated serologically that domestic pigs are naturally infected with *T. cruzi* and speculate the infections result from active feeding by local triatomid vectors on the pigs and by the pigs ingesting infected vectors (Salazar-Schettino et al. 1997, Fujita et al. 1994, Herrera et al. 2008). These and other findings suggest that feral pigs could have an important role in the maintenance and spread of many zoonotic disease cycles both old and new.

Feral pigs are recorded in all biological and ecological regions in Texas (SCWDS 2011, Mapston 2004).They are likely to come into contact with all of the arthropods listed from the US in Table 1, and therefore could potentially be exposed to any and all those identified bacterial, viral, and protozoal pathogens listed in Table 2. Table 3 lists bacterial and protozoal pathogens that have been collected from feral pigs in Spain. Many of the disease pathogens in Table 3 also are present in Texas and the US and could be transmitted by indigenous vectors. It is important to collect and to accurately identify the arthropods that feed on feral pigs so that the risks of pathogen transmission from pigs to humans and other animals can be determined.

I hypothesized: 1) feral pigs are serving as bridge hosts for arthropods; and 2) feral pigs by virtue of their ubiquitous distribution are expanding the distribution of arthropods into new habitats. As bridge hosts, feral pigs can serve as intermediate hosts for arthropods that have been displaced from or shared with their primary hosts. This allows for increased breeding potential of these arthropods, which may lead to larger populations, and wider species distribution. Arthropods that might be newly adapted to feeding on feral pigs can be further distributed throughout the state by natural or human-facilitated movement of feral pigs. Arthropods that have not been previously identified within the state might survive and spread throughout the state undetected and unidentified because of the lack of routine surveillance on feral pigs. Based on my review of the literature, I expected variation in the prevalence and variety of fleas, lice, and ticks among collection areas both seasonally and geographically across Texas. I expected there to be little or no differences in the species of arthropods feeding on feral pigs among any of the three study areas. I expected there to be more fleas at the southernmost site in the South Texas Plains district as compared to the Hill Country or Post Oak districts as a result of variation in climate and host communities. I expected geographical variation in the prevalence of parasites, with the highest numbers of arthropods in the South Texas Plains district, as compared to the Hill Country and Post

Oak districts based upon differences in climate and host communities. I expected geographic differences in tick species collected between the Post Oak and Hill country districts compared to the South Texas Plains, based upon climate variation.

My hypotheses were tested through comparison of species assemblages of all collected arthropods associated with harvested feral pigs from three wildlife districts. The specific objectives, by arthropod group and wildlife district: 1) compare host records for fleas feeding on feral pigs in three separate wildlife districts; 2) compare host records for lice feeding on feral pigs in the three separate wildlife districts; and 3) establish host records for ticks feeding on feral pigs in three separate wildlife district; 4) add to the host records for ticks, fleas, and lice in the South Texas Plains site.

Table 1. Global zoonotic agents isolated from fleas and lice. Modified from a table compiled by Sanders (2011).

Zoonotic Agent/Host	Vector of Record	Citation/Location
*Myxoma virus/*Rabbits	Flea *Spilopsyllus*	Mullen and Durden 2009; Europe, Australia
Bartonella felis	Flea *Ctenocephalides*	Mullen and Durden 2009; Global
Coxiella burnetii/Mammals	Flea Several	Mullen and Durden 2009; Global
Francisella tularensis/Mammals	Flea Several	Mullen and Durden 2009; Global
Rickettsia typhi/Mammals	Flea *Xenopsylla* *Ctenocephalides*	Mullen and Durden 2009; Global
Salmonella enteriditis/Humans	Flea *Pulex*, *Xenopsylla*	Mullen and Durden 2009; Eurasia
Yersinia pestis/ Humans, Rodents	Flea *Xenopsylla*	Mullen and Durden 2009; Global
Trypanosoma lewisi/Rats	Flea *Nosopsyllus Xenopsylla*	Mullen and Durden 2009; Global
Acanthocheilonema reconditum/Carnivores	Flea *Ctenocehalides*	Mullen and Durden 2009; Global
Mycoplasma suis	Louse *Haematopinus*	Foreyt 2001, Hoelzle 2008; Global
Pox Virus/Pigs	Louse *Haematopinus*	Mullen and Durden 2009; Global
Epidemic typhus	Louse *Pediculus*	Mullen and Durden 2009; Global

Table 2. Arthropods reported from European boar, or their crosses. Modified from a table compiled by Sanders (2011).

Citation	Arthropod Species	Location
Allan et al., 2001	Ticks *Amblyomma americanum Amblyomma auricularium Amblyomma maculatum Dermacentor variabilis Ixodes scapularis*	Florida, USA
Coombs and Springer, 1974	Ticks *Amblyomma cajennense Amblyomma maculatum Dermacentor variabilis Ixodes scapularis*	Aransas National Wildlife Refuge, Texas, USA
Greiner et al., 1984	Ticks *Amblyomma americanum Amblyomma maculatum Dermacentor variabilis Ixodes scapularis*	Florida, USA
Hanson and Karstad, 1959	Ticks *Amblyomma americanum Amblyomma maculatum Dermacentor variabilis* Lice *Haematopinus suis* Screwworm *Callitroga americana*	Butler's Island, Georgia, USA
Henry and Conley, 1970	Ticks *Dermacentor variabilis* Lice *Haematopinus suis*	Tellico Plains Wildlife Management Area, Tennessee, USA
Sanders, 2011	Ticks *Amblyomma americanum* *Amblyomma cajennense* *Amblyomma maculatum* *Dermacentor albipictus* *Dermacentor halli* *Dermacentor variabilis* *Ixodes scapularis*	Texas, USA
Smith et al., 1982	Ticks *Amblyomma americanum Amblyomma maculatum Dermacentor variabilis Ixodes scapularis* Mites *Demodex phylloides* *Sarcoptes scabiei* Lice *Haematopinus suis*	Southeastern United States
Ruiz-Fons et al., 2006	Ticks *Dermacentor marginatus* *Dermacentor reticulatus* *Hyalomma excavatum* *Hyalomma lusitanicum* *Hyalomma m. marginatum* *Rhipicephalus bursa* *Rhipicephalus sanguineus*	Spain

Table 3. Zoonotic agents isolated from *Sus* spp. Modified from a table compiled by Sanders (2011).

Zoonotic Agent	Wild Boar and/or Associated Vector	Citation/Location
Rickettsia conorii	Wild Boar *Dermacentor marginatus*	Ortuno et al. 2007; Spain
Rickettsia parkeri	Wild Boar *Dermacentor marginatus*	Ortuno et al. 2007; Spain
Rickettsia slovaca	Wild Boar *Dermacentor marginatus*	Ortuno et al. 2007; Spain
Rickettsia spp.	Wild Boar *Dermacentor* spp.	De la Fuente et al. 2007; Spain
Anaplasma spp.	Wild Boar *Hyalomma* spp. *Rhipicephalus* spp. *Dermacentor* spp	De la Fuente et al. 2007; Spain
Ehrlichia spp.	Wild Boar *Hyalomma* spp. *Rhipicephalus* spp. *Dermacentor* spp.	De la Fuente et al. 2007; Spain
Pirosplasmids	Wild Boar *Hyalomma* spp. *Rhipicephalus* spp. *Dermacentor* spp.	De la Fuente et al. 2007; Spain

CHAPTER II

MATERIALS AND METHODS

Site Descriptions

Study sites were established in the Post Oak, Hill Country, and South Texas Plains Wildlife Districts (Figure 5). Wildlife Districts were chosen as descriptive areas over traditional ecoregions. The wildlife districts are more distinct and infer a more restricted grouping based on animal habitats and not soil types or vegetational area.

Post Oak District. The sampling area (shown as B in Figure 5) is represented by two areas separated by approximately 113 miles. The most northern area is the George Beto Unit of the Texas Department of Criminal Justice (TDCJ) located in Anderson County (A3, Appendix A). This site is approximately 109 miles north-northeast of Texas A&M University, College Station (TAMU). The Beto Unit is one of five TDCJ units located in the Trinity River bottom area approximately 6 miles south of Tennessee Colony. The 5 units occupy approximately 21,000 acres along the western border of the Trinity River. Area two is 750 acres of the Anderson Ranch LLC located along the western edge of the Navasota River and south of Texas Highway 30 in Brazos County and approximately 6 miles east of TAMU (A4, Appendix A). As described by Correll and Johnston (1970), the Post Oak Savannah Vegetational Area is a transition zone between the Pineywoods Area and the Blackland Prairies Area and therefor shares characteristics of both (Figure 3).

Correll and Johnston (1970) characterize the Post Oak Savannah as gently rolling to hilly with an average elevation between 300-800 feet above sea level. This area has an average annual rainfall of 40 inches, with the high rainfall month usually being May or June. The climax grasses are little bluestem (*Schizachyrium scoparium* (Michx.) Nash.), Indian grass (*Sorghastrum nutans* (L.) Nash), switchgrass (*Panicum virgatum* L.), purpletop (*Tridens flavus* (L.) A.S. Hitchc.), silver blue stem (*Bothriochloa saccharoides* (Sw.) Rydb.), and Texas wintergrass (*Nassella leucotricha* (Trin. & Rupr.) Pohl). Overstory species are primarily post oak (*Quercus stellate* Wangenh.) and black jack oak (*Quercus marilandica* Münchh.) with other understory brush and weed species intermixed. The Blackland Prairies vegetational area is described as gently rolling to almost level with an annual rainfall of about 40 inches with the high rainfall month generally being in May. Climax grasses are the same as in the Post Oak Savannah with the addition of sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), hairy grama (*Bouteloua hirsuta* Lag.), and tall drop seed (*Sporobolus compositus var compositus* (Poir.) Merr.). Both areas have intermixed populations of pecan (*Carya illinoinensis* (Wangenh.) K. Koch) bois d'arc (*Maclura pomifera* C.K. Schneid.) and mesquite (*Prosopis glandulosa* Torr.).

Hill Country District. The sample site (shown as A in Figure 5) is approximately 220,000 acres situated at the conjunction of Coryell and Bell Counties site and is approximately 113 miles west-northwest of TAMU. The sample site is comprised of Fort Hood field training areas. Appendix A contains a satellite map of the area (A5), and a detailed map of training areas (A6). Correll and Johnston (1970) characterize this area as the Cross Timbers and Prairies vegetational area. Elevations vary from 590 feet to 1230 feet above sea level with approximately 90% of the study site below 853 feet. Average rain fall is 32 inches in late spring early summer. Summers are generally very hot and dry. Climax understory is little bluestem, big bluestem (*Andropogon gerardii* Vitman), Indian grass, switchgrass, Canada wild-rye, (*Elymus Canadensis* L.), sideoats and hairy grama, tall dropseed and Texas wintergrass. Woody vegetation is dominated by Ashe Juniper (*Juniperus asheii* J.Buckholz), Plateau live oak (*Quercus fusiformis* Small), Texas red oak (*Quercus buckleyi* Nixon & Dorr), and blackjack oak. White shin oak (*Quercus sinuate* var. *breviloba* (Torr.) C.H. Muller) shrubland-grassland mixtures develop where wildfires occur (Diggs et al. 1999, Pekins 2006). Riparian corridors are characterized by juniper-oak forests and forest belts of pecan, walnut (*Juglans microcarpa* Berl.), American sycamore (*Platanus occidentals* L.), eastern cottonwood (*Populus deltoids* Bartr. Ex Marsh), bur oak (*Quercus macrocarpa* Michx.), black willow (*Salix nigra* Marsh.), and red elm (*Ulmus rubra* Muhl.) (Diggs et al. 1999, Cagle 2011 personal communication).

South Texas Plains District. The site is the 7,800 acre Welder Wildlife Refuge in San Patricio County (Shown as C, Figure 5). It is located approximately 240 miles south-southwest of the TAMU campus. The refuge lies along the southern shoreline of the Aransas River. Appendix A contains a satellite map of the site (A7). Correll and Johnston (1970) place this area in the Gulf Prairies and Marshes vegetational area. The land is nearly level with a maximum elevation of 160 feet above sea level in the far western portion with numerous sluggish rivers, creeks, bayous, and sloughs. Annual rainfall averages 40 inches and usually falls uniformly throughout the year. Climax vegetation is briefly described as grassland or post oak savannah. Principle plants include big bluestem, seacoast bluestem (*Schizachyrium scoparium* var. *littoralis*), Indian grass, eastern gamagrass (*Tripsacum dactyloides*), and gulf muhly (*Muhlenburgia capillaris*). Interspersed invasive species include prickly pear (*Opuntia* spp.), mesquite (*Prosopis* spp.), oaks (*Quercus virginiana*), and huisache (*Acacia smallii*).

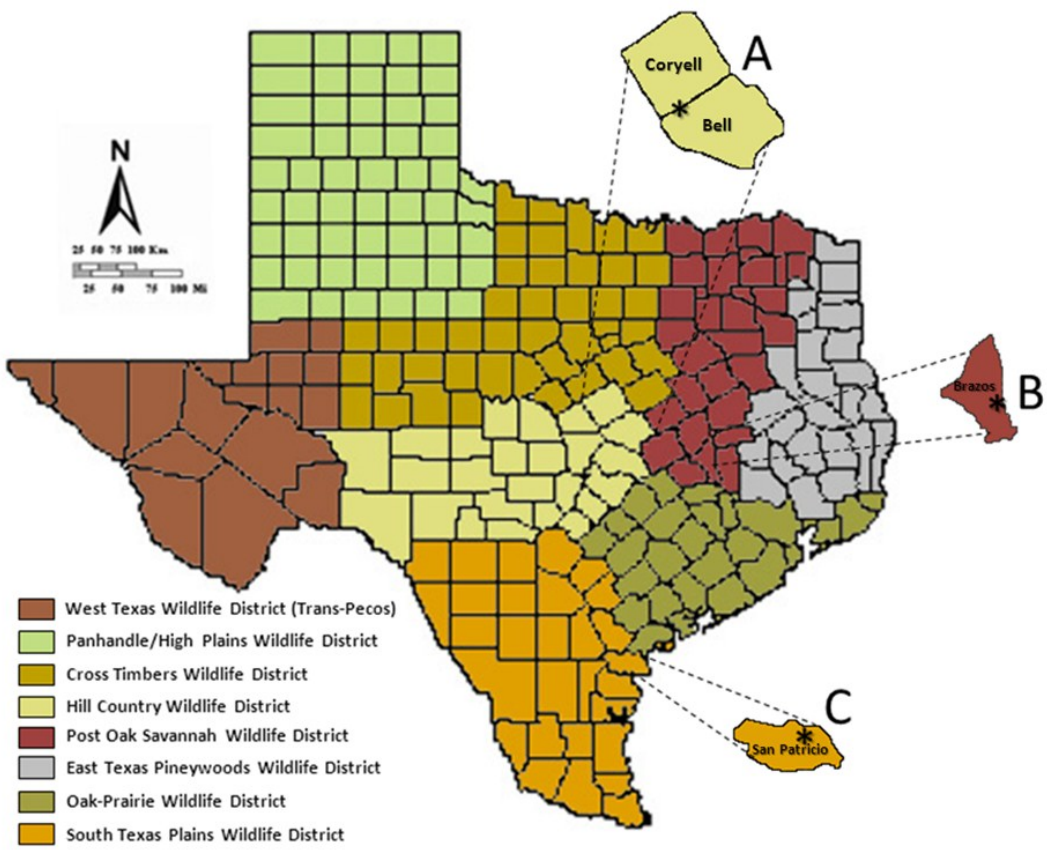


Figure 5. Texas wildlife districts map with call outs identifying the sample sites for feral pigs and their ectoparasites. Modified from www.tpwd.state.tx.us.

Feral Pig Collection

Pigs were trapped and sampled throughout the year or until at least a total of 25 pigs were harvested from each region per seasonal quarter for a total of 100 pigs per district for all four seasons per year. This sample size provided an estimation of fleas, lice and ticks on local pig populations for both gender and age classes (juvenile and adult) throughout the year. With no background data to base sample sizes on, this is a rough estimation of the pigs needed for this type of study. Members of family groups trapped simultaneously were treated as individuals and were sampled using the same methodology. Harvested pigs weighing under 50 pounds and with no obvious signs of having had a litter (females) were classified as juveniles while those over 50 pounds were classified as adults.

Pigs were trapped using corral, or box traps. Examples of corral and box traps can be found at Younger Brothers Steel Fabrication and Engineering, http://www.younger-bros.com/ or the Texas AgriLife website, http://feralhogs.tamu.edu/. Traps were pre-baited with dry, whole, feeder corn (*Zea mays* L.) prior to actual trap dates to allow pigs to become habituated to the traps being in their surroundings. The day prior to trapping, traps were set mid to late afternoon and checked as soon as possible following daylight on the actual trap day. The exception was on overcast days, when pigs are known to be active later in the morning. On those days, traps were checked two hours after daylight to avoid disturbing any pigs that might still be feeding.

Feral pigs were killed using a .22 caliber pistol or rifle with low velocity ammunition in accordance with the Texas A&M Institutional Animal Care and Use Committee approved animal use protocol number 2008-131. Ectoparasites and blood samples were then collected. Parasites were identified and will remain in storage at the Texas A&M University Tick Laboratory. Blood samples were taken and will be stored for future analysis as part of a separate study. Samples were collected immediately after shooting to avoid loss of ectoparasites and before coagulation of blood. Blood samples were taken by cardiac stick per the approved animal use protocol. Three Vaccutainer® type tubes were used for blood collection: a traditional serum separator (clot activator) tube, a whole blood preservative (ACD-B trisodium citrate) tube, and a molecular grade serum separator tube (clot activator and gel). All tubes or their equivalent were purchased from Bectin Dickinson (BD) (catalog numbers 367977**,** 364816**,** and 367986, respectively)**.** To ensure proper preservation of blood samples, a cold chain was maintained until samples were placed into a -80C freezer for storage. All carcasses were disposed of in compliance with state and local laws and in accordance with the landowner or land manager's requests.

<u>Ectoparasite Collection and Identification</u>

Fleas, ticks, and lice collected from each pig were immediately placed in 80% ethanol and transported to the Texas A&M Tick Laboratory for identification to species. Adult ticks were identified to species using the keys of Keirans & Clifford (1978), Keirans & Litwak (1989), and Yunker et al. (1986), and these data were added to the tick distribution and population records on feral pig database begun by Sanders (2011). Immature ticks were identified to genus.

Fleas were cleared as described by Eads (1950) and then identified based on the keys of Hubbard (1947), Eads (1950), Smit (1958), and Holland (1985). In short, fleas were separated and the abdomen pierced with an insect pin. Each flea was placed in a vial with 10% potassium hydroxide (KOH) solution of a sufficient volume to cover all fleas for 24 hours. After 24 hours the fleas were removed from the KOH and placed into distilled water where the liquefied interior tissues of the insect were evacuated by manual expulsion. After liquefied tissues were expulsed, the fleas were then put through serial solutions of ethanol (70%, 80%, and 95%) for 30 minutes each. From the final ethanol solution, the fleas were transferred to clove oil for 20 minutes, and then placed into a vial of xylene of sufficient volume to cover all fleas until they could be mounted. The fleas were mounted on a standard microscope slide with Canada balsam. Fleas were then identified to species, sexed, and the slides were labeled and placed in a drying oven for preservation until final storage at the TAMU Tick Laboratory.

Lice were collected from each pig and placed into 80% ethanol and transported to the TAMU Tick Laboratory for identification to species. Lice were identified to species using the keys of Kim et al. (1986). Lice will be retained at the TAMU Tick Laboratory in vials containing 80% ethanol.

CHAPTER III

SPATIAL AND TEMPORAL DISTRIBUTION OF TICKS ON FERAL PIGS IN THREE TEXAS WILDLIFE DISTRICTS

Materials and Methods

Materials and methods are as described in Chapter II. Briefly, feral pigs were trapped and harvested at specific study sites in three wildlife districts in east (Post Oak Savannah), central (Hill Country), and south Texas (South Texas Plains) from 2008 through 2011. Ticks, fleas, and lice were collected and placed into 80% ethanol until they could be returned to the TAMU Tick Laboratory for identification and storage. Blood samples were also collected from all pigs for a separate study. Ticks, fleas, and lice were identified at the TAMU Tick Laboratory to species, and sex using relevant keys. Immature ticks were identified to genus only. Tick data from this project will be combined with data collected by Sanders (2011) for a composite monograph on tick distribution on feral pigs in Texas.

Results

All Sites Combined. Five hundred and sixty four pigs were harvested in combination from all three sites. Feral pig collections from the Hill Country and South Texas sites were comprised of 56% and 57% adult animals, respectively. The Post Oak site had 37%, slightly fewer adult animals, than either of the other two sites. Forty nine percent of pigs collected from all sites were adults and 51% were juveniles. Fifty two percent of pigs from all sites were female and 48% male. The Post Oak district had the highest total number of females (61%), followed by the South Texas Plains (49%) and then the Hill Country (44%). The Hill Country had the highest total males (56%) followed by South Texas Plains (51%) and finally the Post Oak site had the fewest total males (39%). There are no published estimates of feral pig population or herd structure at any of the three sample sites.

A total of 3766 ticks, 265, fleas and 5019 lice were taken from the 564 pigs. Ninety seven percent of all pigs were infested with one or more parasite groups. Very few (3%) of all 564 harvested feral pigs were ectoparasite free. Fifty five percent of all infested pigs were infested with one parasite, whether it was by ticks only, fleas only, or lice only; 38% percent were infested with two parasite groups; and, 4% were infested with all three parasite groups.

The Hill Country District. The Hill Country (shown as A, Figure 5, Chapter II) represented by Fort Hood, was sampled 5 times from the winter of 2010 through the winter of 2011. Appendix A contains a satellite image showing a general layout of the installation (A5) and a detailed map of the training areas (A6). A summary of all pigs and associated arthropods collected from harvested pigs for this site is given in Table 4. The Hill Country had the second highest total number of pigs (191) collected among the three sites. Slightly more adults (57%) than juveniles (43%) were taken overall. Of the total pigs, 44% were female of which 60% were adults and 40% juveniles. Fifty six percent of total pigs were male with 53% of these adults, and 47% juvenile. Spring 2010 was the most productive of the 6 sampling periods in terms of numbers of pigs and arthropods collected. Of the 191 total pigs collected for this site, 55% were collected in the spring of 2010 followed by 32% in the summer of 2010. The spring 2010 pigs were comprised of a ratio of 6:1 adults to juveniles, which was reversed in a 1:6 ratio of adults to juveniles the following summer. The winter 2010, fall 2010, and winter 2011 collections constituted 6%, 3%, and 4% of the total pigs collected, respectively. Only juveniles were collected in fall 2010 and winter 2011 (Table 4).

Twenty six percent of the 191 pigs in this district were infested with ticks, with 14% infested by ticks only, and 12% percent infested with a combination of ticks and lice. No pigs harvested at this site had fleas. Thirty two percent of all females had ticks, with 62% of the juvenile females and 12% of the adult females having ticks (Table 5). Twenty one percent of males were infested with ticks, 98% of the adult males and 34% of the juvenile males (Table 6). The Hill Country had the lowest total number of ticks with four species collected: *Amblyomma maculatum* (Gulf Coast tick) with the highest numbers, followed by *Dermacentor variabilis* (American dog tick), *Ixodes scapularis* (blacklegged tick) and *A. americanum* (lone star tick). Despite thorough examination, no spinose ear ticks (*Otobius megnini* Dugès) or winter ticks (*Dermacentor albipictus*) were collected. Seasonal tick variation by species and percent of infested pigs is given in Table 7.

Table 4. Summary of seasonal distribution of arthropods collected from harvested feral pigs in the Hill Country wildlife district, Texas, 2010-2011.

Season	Total Pigs	Total Females	Total Males	Total Adults	Total Juveniles	Total Ticks	Total Lice	Total Fleas
Winter 2010	11	5	6	9	2	3	106	0
Spring 2010	106	39	67	90	16	13	821	0
Summer 2010	61	31	30	9	52	148	152	0
Fall 2010	5	3	2	0	5	5	2	0
Winter 2011	8	6	2	0	8	3	21	0
Composite	191	84	107	108	83	171	1102	0

Table 5. Seasonal distribution of ticks collected from harvested female feral pigs by age group in the Hill Country wildlife district, Texas, 2010-2011.

Season	Total Female	Adult Female	With Ticks	Total Ticks	AVG Ticks	Juvenile Female	With Ticks	Total Ticks	AVG Ticks
Winter 2010	5	2	1	1	1	3	1	2	2
Spring 2010	39	39	5	5	1	0	0	0	0
Summer 2010	31	9	0	0	0	22	16	16	1
Fall 2010	3	0	0	0	0	3	3	3	1
Winter 2011	6	0	0	0	0	6	1	1	1
Composite	84	50	6	6	1	34	21	22	1

Table 6. Seasonal distribution of ticks collected from harvested male feral pigs by age group in the Hill Country wildlife district, Texas, 2010-2011.

Season	Total Male	Adult Male	With Ticks	Total Ticks	AVG Ticks	Juvenile Male	With Ticks	Total Ticks	AVG Ticks
Winter 2010	6	6	0	0	0	0	0	0	0
Spring 2010	67	51	6	8	1	16	0	0	0
Summer 2010	30	0	0	0	0	30	14	58	4
Fall 2010	2	0	0	0	0	2	2	2	1
Winter 2010	2	0	0	0	0	2	1	2	2
Composite	107	57	6	8	1	50	17	62	4

Table 7. Summary of ticks by season and species collected from harvested feral pigs in the Hill Country wildlife district, Texas, 2010-2011. Numbers indicate total ticks of that species for all infested pigs for that season. Parenthesis indicates percent of pigs infested. Percent with ticks = any pig with any combination of ticks: ticks alone, ticks with fleas, ticks with lice, or ticks with fleas and lice. *A. amer* = *Amblyomma americanum*, *A. macu* = *Amblyomma maculatum*, Imm amb = immature *Amblyomma* spp., D. vari = *Dermacentor variabilis*, Imm Derm = immature *Dermacentor* spp., I. scap = *Ixodes scapularis*, Imm Ixodes = immature *Ixodes* spp.

Season	Total Pigs	With Ticks	*A. amer*	*A. macu*	*Imm Amb*	*D. vari*	*Imm Derm*	*I. scap*	*Imm Ixodes*
Winter 2010	11	2 (16)	0	0	0	0	0	4	0
Spring 2010	106	11 (10)	3	1	0	5	0	1	0
Summer 2010	61	30 (49)	0	112	0	36	0	0	0
Fall 2010	5	5 (100)	0	2	0	3	0	0	0
Winter 2011	8	2 (25)	0	0	0	0	0	3	0
Composite	191	50 (26)	3	115	0	44	0	8	0

Post Oak Savannah District. The Post Oak district site (Shown as B, Figure 6) is represented by the Anderson Ranch LLC, and Beto Unit of the TDCJ. Appendix A contains satellite images of the Beto Unit (A3) and the Anderson Ranch (A4). These sites were sampled seven times between the summer of 2009 and the spring of 2011. A summary of all pigs and associated arthropods collected from this district is given in Table 8. Juvenile pigs were more numerous (63%) than were adult pigs (37%). More female pigs were harvested (61%) with 38% being adult females and 62% being juvenile females. Thirty nine percent of all pigs harvested were males with 34% being adults and

66% being juveniles. Of the 204 pigs collected at this site, 39% were collected in the spring of 2010. Juveniles outnumbered adults 2:1 for the same sample period. Pigs collected summer 2009, winter 2009, summer 2010, fall 2010 winter 2011, and spring 2011 constituted 4%, 3%, 5%, 4%, 21%, and 24% of total pigs collected, respectively.

Sixty eight percent of all pigs harvested were infested with ticks. Seventy percent of all males and 67% of all females were infested with ticks. Adult females had the highest tick infestation at 75%, followed by adult males (70%), female juveniles (62%), and male juveniles (54%). Detailed data are presented in Tables 9 and 10, respectively. The average ticks per pig were about equal for female adults and juveniles. Adult males had a higher tick load on average, with a 7:1 ratio of average ticks for adult males compared to juveniles.

The Post Oak district had the second highest number of ticks of the three areas with four species of ticks collected: *A. americanum* had the highest numbers, followed by *A. maculatum*, *I. scapularis*, and *D. variabilis*. Table 11 gives the distribution of ticks collected by season and species of ticks. Five percent of all pigs collected were infested by ticks only and 25% by both ticks and lice. Despite thorough examinations, none of the pigs had spinose ear (*Otobius megnini*) or winter (*D. albipictus*) ticks.

Table 8. Summary of seasonal distribution of arthropods collected from harvested feral pigs in the Post Oak Savannah wildlife district, Texas, 2009-2011.

Season	Total Pigs	Total Female	Total Male	Total Adults	Total Juvenile	Total Ticks	Total Lice	Total Fleas
Summer 2009	8	4	4	3	5	59	34	0
Winter 2010	6	3	3	2	4	6	103	0
Spring 2010	80	49	32	26	54	379	932	0
Summer 2010	10	5	5	1	9	14	12	0
Fall 2010	9	7	2	2	7	5	106	0
Winter 2011	42	27	15	23	19	51	890	0
Spring 2011	49	30	19	18	31	253	801	0
Composite	204	125	79	75	129	767	2878	0

Table 9. Seasonal distribution of ticks collected from harvested female feral pigs by age group in the Post Oak Savannah wildlife district, Texas, 2009-2011.

Season	Total Female	Adult Female	With Ticks	Total Ticks	AVG Ticks	Juvenile Female	With Ticks	Total Ticks	AVG Ticks
Summer 2009	4	1	0	0	0	3	3	8	3
Winter 2010	3	1	1	1	1	2	2	2	1
Spring 2010	49	20	18	115	3	29	22	85	4
Summer 2010	5	0	0	0	0	5	1	1	1
Fall 2010	7	1	1	1	1	6	0	0	0
Winter 2011	27	13	8	14	2	14	10	15	2
Spring 2011	30	12	8	21	4	18	10	51	5
Composite	125	48	36	152	4	77	48	162	3

Table 10. Seasonal distribution of ticks collected from harvested male feral pigs by age group in the Post Oak Savannah wildlife district, Texas, 2009-2011.

Season	Total Male	Adult Male	With Ticks	Total Ticks	AVG Ticks	Juvenile Male	With Ticks	Total Ticks	AVG Ticks
Summer 2009	4	2	2	40	20	2	2	11	6
Winter 2010	3	1	1	3	3	2	0	0	0
Spring 2010	31	6	6	88	15	25	15	91	6
Summer 2010	5	1	1	6	6	4	2	7	4
Fall 2010	2	1	1	4	4	1	0	0	0
Winter 2011	15	10	5	15	3	5	3	7	2
Spring 2011	19	6	3	157	53	13	6	24	4
Composite	79	27	19	313	16	52	28	140	5

Table 11. Summary of ticks by season and species collected from harvested feral pigs in the Post Oak Savannah wildlife district, Texas, 2009-2011. Numbers indicate total ticks for that species for all infested pigs for that season. Parenthesis indicates percent of pigs infested. Percent with ticks = any pig with any combination of ticks: ticks alone, ticks with fleas, ticks with lice, or ticks with fleas and lice. *A. amer* = *Amblyomma americanum*, *A. macu* = *Amblyomma maculatum*, Imm A*mb* = immature *Amblyomma* spp., *D. vari* = *Dermacentor variabilis*, Imm *Derm* = immature *Dermacentor* spp., *I. scap* = *Ixodes scapularis*, Imm *Ixodes* = immature *Ixodes* spp.

Season	Total Pigs	With Ticks	*A. amer*	*A. macu*	Imm *Amb*	*D. vari*	Imm *Derm*	*I. scap*	Imm *Ixodes*
Summer 2009	8	7 (88)	34	19	0	6	0	0	0
Winter 2010	6	4 (67)	4	2	0	0	0	0	0
Spring 2010	80	61 (76)	188	178	1	11	0	4	0
Summer 2010	10	5 (50)	6	5	3	0	0	0	0
Fall 2010	9	2 (22)	2	3	0	0	0	0	0
Winter 2011	42	26 (62)	31	0	0	0	0	19	0
Spring 2011	49	27 (55)	220	2	29	0	1	0	0
Composite	204	132(64)	485	209	33	17	1	23	0

South Texas Plains District. The South Texas Plains district (Shown as C, Figure 6) was represented by the Welder Wildlife Refuge and was sampled 6 times between the summer of 2008 and the winter 2011. Appendix A contains a satellite image of the refuge (A7). A summary of all pigs and associated arthropods collected from harvested pigs from this site is given in Table 12. This site had the lowest total of pigs (169) harvested of the three sites. Adults represented 56% of all pigs taken followed by 44%

juveniles. Of total pigs, 51% were male, of which 64% were adults and 36% were juvenile. Females were 47% adults and 53% juveniles. Of the 169 pigs collected at this site, 43% we collected in fall 2009. Pigs collected summer 2008, winter 2009, spring 2009, winter 2010, and winter 2011 constituted 21%, 8%, 8%, 10%, and 11%, respectively.

This district had the highest total number of ticks collected of the three sites with 2828. This site has a total collected tick ratio of 17:1 and 4:1 when compared to the Hill Country and Post Oak sites, respectively. Eighty six percent of all pigs collected were infested with ticks. Of the pigs infested, juvenile males were highest (90%), followed by adult females (85%). Adult males and juvenile females were equal at 80% (Tables 13, 14). This district had four species of ticks: *A. cajennense*, *A. maculatum*, *D. variabilis* and *D. halli*. Despite thorough examination, no lone star (*A. americanum*), black-legged (*I. scapularis)*, or spinose ear (*Otobius megnini*) ticks were collected at this site. Table 15 displays the distribution of ticks collected by species of tick and seasons. Nine percent of pigs collected had infestations of ticks only, 7% had infestations of lice only, and <1% with fleas only. Slightly less than twelve percent of all infested pigs had mixed populations of at least two parasite groups, <4% (ticks and lice), 5% (ticks and fleas), and <4% with all three species of parasites.

Table 12. Summary of seasonal distribution of arthropods collected from harvested feral pigs in the South Texas Plains wildlife district, Texas, 2008-2011.

Season	Total Pigs	Total Female	Total Male	Total Adult	Total Juvenile	Total Ticks	Total Lice	Total Fleas
Summer 2008	36	18	18	14	22	567	31	67
Winter 2009	13	8	5	6	7	117	6	79
Spring 2009	13	12	1	8	5	759	13	17
Fall 2009	17	7	10	7	10	991	0	10
Winter 2010	72	35	37	53	19	175	395	0
Winter 2011	18	3	15	6	12	219	594	92
Composite	167	83	86	94	75	2828	1039	265

Table 13. Seasonal distribution of ticks collected from harvested female pigs by age group in the South Texas Plains wildlife district, Texas, 2008-2011.

Season	Total Female	Adult	With Ticks	Total Ticks	AVG Ticks	Juvenile	With Ticks	Total Ticks	AVG Ticks
Summer 2008	18	6	6	125	21	12	12	168	14
Winter 2009	8	4	4	32	8	4	3	15	5
Spring 2009	12	7	3	507	169	5	3	190	63
Fall 2009	7	1	1	52	52	6	6	313	52
Winter 2010	35	20	18	68	4	15	9	17	2
Winter 2011	3	1	1	22	22	2	2	6	2
Composite	83	39	33	806	24	44	35	709	20

Table 14. Seasonal distribution of ticks collected from harvested male feral pigs by age group in the South Texas Plains wildlife district, Texas, 2008-2011.

Season	Total Male	Adult Male	With Ticks	Total Ticks	AVG Ticks	Juvenile Male	With Ticks	Total Ticks	AVG Ticks
Summer 2008	18	8	8	87	11	10	9	187	37
Winter 2009	5	2	2	25	13	3	3	45	15
Spring 2009	1	1	1	62	62	0	0	0	0
Fall 2009	10	6	6	414	69	4	4	212	53
Winter 2010	37	33	22	84	4	4	3	6	2
Winter 2011	15	5	5	106	21	10	9	85	9
Composite	86	55	44	778	18	31	28	535	19

Table 15. Summary of ticks by season and species collected from harvested feral pigs in the South Texas Plains wildlife district, Texas, 2008-2011. Numbers indicate total ticks for that species for all infested pigs for that season. Parenthesis indicates percentage of pigs infested with ticks. Percent with ticks = any pig with any combination of ticks: ticks alone, ticks with fleas, ticks with lice, or ticks with fleas and lice. *A. cajen* = *Amblyomma cajennense*, *A. macu* = *Amblyomma maculatum*, Imm *Amb* = immature *Amblyomma* spp., *D. halli* = *Dermacentor halli*, *D. vari* = *Dermacentor variabilis*, Imm *Derm* = immature *Dermacentor* spp.

Season	Total Pigs	With Ticks	*A. cajen*	*A. macu*	Imm *Amb*	*D. halli*	*D. vari*	Imm *Derm*
Summer 2008	36	35 (97)	524	32	5	0	6	0
Winter 2009	13	12 (92)	95	4	2	1	1	0
Spring 2009	13	11 (85)	708	44	5	0	2	0
Fall 2009	17	17 (100)	803	193	0	0	10	0
Winter 2010	72	52 (72)	156	18	0	0	1	0
Winter 2011	18	17 (94)	77	2	136	0	4	0
Composite	169	144(85)	2363	293	148	1	24	0

Discussion

Results of this study, combined with those of Sanders (2011), indicate that feral pigs support the maintenance of 7 species of ixodid ticks in the three Texas wildlife districts sampled from 2008-2011. One or more species of ticks infested feral pigs year round at all sites. Ticks infested all classes of gender and age, but varied with respect to site, time of year, and seasonal changes. Adults of all 7 ixodid species (*Amblyomma americanum, A. cajennense, A. maculatum, Dermacentor albipictus, D. halli*, *D. variabilis*; and *Ixodes scapularis*) were collected from study sites. Immatures of four species of three-host ticks (*A. americanum*, *A. cajennense*, *A. maculatum* and *D. variabilis*) infested all ages and sex classes of feral pigs. This indicates these ticks utilize feral pigs as hosts throughout the 3 independent blood meals needed to complete this life cycle. Evidence that one-host ticks may successfully utilize feral pigs as a host was provided by the collection of a partially engorged female winter tick, *D. albipictus*. Six of the collected tick species (*Amblyomma americanum*; *A. cajennense*; *A. maculatum*; *Dermacentor albipictus*; *D. variabilis*; and *Ixodes scapularis*) are common to a wide range of wildlife and livestock hosts (Eads et al. 1950, Samuel and Trainer 1970b, Coombs and Springer 1974). The seventh species, *D. halli*, is known from wildlife collections, predominately the collard peccary, *Tayassu tajacu* (Linnaeus). The suitability and success of feral pigs as a year-round host for ixodid ticks is high. Their relative contribution to respective tick populations on Texas landscapes is expected to continue in part because of the abundance and reproductive rate of this host. Feral pigs serve as agents for ixodid tick recruitment and dispersal by virtue of their use of landscape habitats, including movement across natural barriers such as rivers, and unnatural barriers such as fences and highways, and by human intervention. Feral pigs are widely recognized as an invasive species that cause destruction to agricultural crops as well as natural resources (Seward et al. 2004, Pimentel et al. 2005, and Chavarria et al. 2007). In addition, they also have economic value for recreational hunting, their meat, and body parts such as glands, tusks, and internal organs are in high demand. Although it is against state regulation to transport female feral pigs from their home range to be released onto another property (TAC 2011), it is not uncommon to see trapped feral pigs being transported across county (and state) lines to be released into another area. Most frequently, these releases are intended to stock recreational hunting activities. These pigs can be relocated very long distances from their original home range, resulting in the introduction of ticks into new areas.

Future studies of this type in other wildlife districts may record additional ixodid tick species on feral pigs. Potential pig-tick interactions may eventually be found with *Amblyomma inornatum* (Banks), *A. imitator* (Kohls), and from coastal and south Texas, *Haemaphysalis leporispalustrus* (Packard), and *Rhipicephalus sanguineus* Latreille. In addition, *A. triste* (Koch) was recently discovered in west Texas on white-tailed deer (Mertins et al. 2010) in the same area co-habited by feral pigs. Surveys along the Texas border with Mexico will bring into question the suitability of feral pigs as a host for two species of one-host ticks *R. annulatus* (Say), and *R. microplus* (Cannestrini). These ticks are vectors for the cattle fever pathogens *Babesia bigemina* and *B. bovis*. State and federal tick eradication programs established in 1906 eliminated these two tick species from 14 southern states and continue to manage surveillance, quarantine and eradication procedures to prevent reinfestations from Mexico (TAHC 2011). The potential for feral pigs to be a host for *R. annulatus* and/or *R. microplus* is suggested by findings of *R. microplus* on domestic pigs in Panama (Fairchild et al. 1966), and Bangladesh (Islam et al. 2006, Gosh et al. 2007) and by findings from this study of the one-host tick *Dermacentor albipictus*.

It remains of interest that *Otobius megnini* (Dugès), a soft tick (family Argasidae), was not recovered from any animals in this study as its habitats and co-habitation with cattle, horses, deer, and other known host species were common in all locations (Meleney 1975). This tick is known as the spinose ear tick and spends its life deep in the ears of its hosts. Only the adult forms of this tick intentionally detach from the host to fall to the ground, where they mate and eventual die. Absent from the feral pig collections taken in the south Texas site were *A. americanum*, and *I. scapularis*. Both of these ticks are well documented from the area and have the same hosts as *O. megnini*. Samuel and Trainer (1970b) reported both *A. americanum* and *I. scapularis* from white tailed deer, and Coombs and Springer (1974) reported *I. scapularis* from feral pigs.

Also missing from the collection is the relapsing fever tick (*Ornithodoros turicat*a Dugès). This tick is another soft tick like *O. megnini*. The relapsing fever tick is a known vector of the pathogen (*Borrelia turicatae* Brumpt) and this tick and pathogen are documented from the south Texas region (*Eads* et al. 1950). Sanders (2011) demonstrated by serologic testing that just less than half of the feral pigs sampled (44%) were exposed to three different vector-borne pathogens. These bacterial pathogens and the percent of feral pigs infected were *Borrelia* spp (2%), *Rickettsia* spp (28%), and *Ehrlichia* spp Moshchovski (13%). This study indicates that feral pigs might have a role in the maintenance and distribution of three bacterial pathogens not previously reported from this animal.

Feral pigs provide a unique opportunity to examine the role of a new tick host on landscapes dominated by traditional large animal herbivores. Feral pig characteristics of omnivory, habitat usage, and reproductive rate suggest these animals could substantially supplement the normal host community structure, and potentially increase the maintenance of tick pathogens. Daszak et al. (2000) concluded disease emergence is most frequently the result of a change in the ecology of the host, pathogen, or both.

Keesing et al. (2010) argue that biodiversity can increase or decrease pathogen transmission between species by changing either host/vector abundance, or host/parasite/vector behavior. It is unlikely that increased biodiversity as a consequence of feral pig expansion or density will decrease the incidence of zoonotic disease transmission for all pathogens. It is likely that the influence of this new host may increase transmission of some pathogens while decreasing transmission of others.

The concept of dilution by number is also known as herd immunity. If a resistant population of individuals increases within a mixed group of susceptible and resistant individuals, the disease transmission decreases because the odds of the susceptible individual coming into contact with the infected individuals decrease. The corollary could also be true and disease transmission would increase. The increase in tick hosts can be by natural reproductive means or by artificial introduction of another group of animals. An introduced host must be both as acceptable as the original host to the vector, and less accommodating to the pathogen. This would lead to inefficient effort when vectors feed on the new host and dilute the pathogen prevalence by selecting an inferior reservoir (Ostfeld and Keesing 2000).

Feral pigs could be more efficient at providing a suitable environment for both the vector and the pathogen. There is a potential risk that feral pig populations will continue to increase in spite of current feral pig control and management practices, and that the risk of disease transmission between feral pigs and domestic herds of cattle, horses, and pigs will increase (Arim et al. 2006). Feral pigs have a gestation period of 115 days, and under optimal conditions can average two litters of 7 piglets every fourteen months (Taylor et al. 1998). As the pig population increases, the contact rates between pigs and domestic/wild animals will increase and the potential for reintroduction of previously eradicated pathogens to domestic animals will increase (Cooper et al. 2010). Eppstein and Defilippo (2001) correlated periods of drought with outbreaks of West Nile Virus and St Louis Encephalitis in the United States and Europe from 1933-2001. Periods of drought have a similar effect on wildlife. When water sources dwindle, all animals begin to concentrate around existing water sources and the rate of contact between otherwise isolated species is greatly increased (Ezenwa et al. 2006, Cooper et al. 2010). Feral pigs are comingling in vertebrate and vegetational communities with endemic species of animals. These interactions provide an opportunity for the pigs to serve as bridge hosts for parasites from the indigenous/native species, as demonstrated by the collection of the one female peccary tick (*Dermacentor halli*) at the Welder Wildlife Refuge (Sanders 2011). Although the collection was one single female, and occurred one time, the implications are that it could happen more frequently. With proper surveillance there could be even more species found. Little is known about the biology and life cycles of the peccary tick in Texas other than all collections have been of adults and all collections were off of peccary. No published studies of any diseases associated with this tick and peccary or other vertebrates are available. This study represents a very small proportion of land and animals in relation to the state total acreage of 170 million acres, and 104 million estimated feral pigs. The total acres within the six counties surveyed (2.4% of 254 counties) equals approximately 3.62 million acres (NRCS 2011). This represents approximately 2% of the total 170 million acres that can be exploited by feral pigs (Mellish et al.2010).

It is unlikely that active surveillance of feral pig populations for novel pathogens will increase in the foreseeable future. Current surveillance is focused on pathogens/parasites known to affect domestic cattle, sheep, goats, and horses. Recently, the Texas Animal Health Commission announced that Texas was now *Brucella suis* free. This pathogen free status is within the domestic swine herds only. Feral hogs are potential and effective refugia for this pathogen. Texas Animal Health Commission officials also recently announced that because of budget reductions and despite the fact that two herds were diagnosed as positive earlier this year, they will no longer require brucellosis testing of adult cattle for change of ownership. It is unlikely the Texas Animal Health Commission budget will be increased significantly in the future and probable that more surveillance programs will be reduced or stopped. An introduced vector and or pathogen could be sustained for many years before being detected. By the time the new vector and or pathogen are detected, they would be very difficult to eliminate.

CHAPTER IV

SPATIAL AND TEMPORAL OCCURRENCE OF FLEAS ON FERAL PIGS IN THREE TEXAS WILDLIFE DISTRICTS

Materials and Methods

Materials and methods are as described in Chapter II. Briefly, feral pigs were trapped and harvested at specific study sites in three wildlife districts in east (Post Oak Savannah), central (Hill Country), and south Texas (South Texas Plains) from 2008 through 2011. Ticks, fleas, and lice were collected and placed into 80% ethanol until they could be returned to the TAMU Tick Laboratory for identification and storage. Blood samples were also taken from all pigs for a separate study. Ticks, fleas, and lice were identified at the TAMU Tick Laboratory to species, and sex using relevant keys.

Results

All Sites Combined. Five hundred and sixty four pigs were harvested in combination from all three sites. Feral pig collections from the Hill Country and South Texas sites were comprised of 56% and 57% adult animals, respectively. The Post Oak site had slightly fewer adults than either of the other two sites with 37%. Forty nine percent of pigs collected from all sites were adults and 51% were juveniles. Fifty two percent of pigs from all sites were female and 48% male. The Post Oak district had the highest total number of females (61%), followed by the South Texas Plains (49%) and then Hill Country (44%). The Hill Country had the highest total males (56%) followed by the South Texas Plains (51%), and finally the Post Oak site had the fewest total males

(39%). There are no published estimates of feral pig populations or herd structure at any of these sample sites.

A total of 3766 ticks, 265 fleas, and 5019 lice were taken from the 564 pigs. Ninety seven percent of all pigs were infested with one or more parasite group. Very few (3%) of the 564 harvested feral pigs were ectoparasite free. Fifty five percent of all infested pigs were infested with one parasite whether it was by ticks only, fleas only, or lice only; 38% percent were infested with two parasite groups; and, 4% were infested with all three parasite groups. The South Texas Prairie site was the only sample site for this study where fleas were collected from harvested feral pigs. Fleas were donated other counties by multiple sources and will be reported in the discussion.

<u>South Texas Plains.</u> The South Texas Plains district (Shown as C, Figure 5, Chapter II) is represented by the Welder Wildlife Refuge and, was sampled 6 times between the summer of 2008 and the winter of 2011. Appendix A contains a satellite image of the refuge (A7). A summary of all pigs and associated arthropods collected from harvested pigs for this site is given in Table 16. This district had the lowest total of pigs harvested of the three sites with 169. Adults represented 56% of all pigs taken followed by 44% juveniles. Of total pigs, 51% were male with 64% of those adults and 36% juvenile. Females were 47% adults, and 53% juveniles. Of the 167 pigs collected at this site 43% we collected in fall 2009. Pigs collected summer 2008, winter 2009, spring 2009, winter 2010, and winter 2011 comprised 21%, 8%, 8%, 10%, and 11% of the total, respectively.

Thirty percent of 169 pigs harvested at the South Texas Plains site were infested with fleas. Twenty nine percent of all females were infested with fleas, with 33% of adult females and 25% of juvenile females infested (Table 17). Thirty one percent of all males were infested with fleas, with 24% of adult males and 45% of juvenile males infested, Table 18. All fleas collected were identified as *Pulex porcinus*, commonly known as the peccary flea. Despite thorough examinations, no human fleas (*Pulex irritans*), false human fleas (*Pulex simulans*), or any other fleas were collected from harvested pigs at this site.

Table 16. Summary of seasonal distribution of fleas collected from harvested feral pigs in the South Texas Plains wildlife district, Texas, 2008-2011. Parenthesis indicate percentage of collected feral pigs in the category that were infested with fleas.

Season	Total Pigs	Female Pigs	Adult Female	Juvenile Female	Total Fleas	Male Pigs	Adult Male	Juvenile Male	Total Fleas
Summer 2008	36 (58)	18	6 (83)	12 (50)	45	18	8 (63)	10 (50)	22
Winter 2009	13 (46)	8	4 (100)	4 (50)	42	5	2 (100)	3 (100)	37
Spring 2009	13 (46)	12	7 (43)	5 (60)	17	1	1 (0)	0	0
Fall 2009	17 (6)	7	1 (0)	6 (0)	0	10	6 (17)	4 (0)	10
Winter 2010	72 (0)	35	20 (0)	15 (0)	0	37	33 (0)	4 (0)	0
Winter 2011	18 (89)	3	1 (100)	2 (0)	1	15	5 (100)	10 (60)	91

Table 17: Seasonal distribution of fleas collected from harvested female feral pigs by age group in the South Texas Plains wildlife district, Texas, 2008-2011.

Season	Total Female	Adult Female	With Fleas	Total Fleas	AVG Fleas	Juvenile Female	With Fleas	Total Fleas	AVG Fleas
Summer 2008	18	6	5	16	3	12	6	29	5
Winter 2009	8	4	4	31	8	4	2	11	6
Spring 2009	12	7	3	10	3	5	3	7	2
Fall 2009	7	1	0	0	0	6	0	0	0
Winter 2010	35	20	0	0	0	15	0	0	0
Winter 2011	3	1	1	1	1	2	0	0	0
Composite	83	39	13	58	4	44	11	47	4

Table 18: Seasonal distribution of fleas collected from harvested male feral pigs by age group in the South Texas Plains wildlife district, Texas, 2008 through 2011.

Season	Total Male	Adult Males	With Fleas	Total Fleas	AVG Fleas	Juvenile Males	With Fleas	Total Fleas	AVG Fleas
Summer 2008	18	8	5	10	2	10	5	12	2
Winter 2009	5	2	2	21	11	3	3	16	5
Spring 2009	1	1	0	0	0	0	0	0	0
Fall 2009	10	6	1	10	10	4	0	0	0
Winter 2010	37	33	0	0	0	4	0	0	0
Winter 2011	15	5	5	51	10	10	6	40	7
Composite	86	55	13	92	7	31	14	68	5

Discussion

Results of this study indicate that feral pigs support the maintenance of one species of flea in the South Texas Plains wildlife district sampled from 2008-2011. One hundred and sixty four (64%) of all fleas collected at this site were collected by Dr. David Sanders and donated to this project. An additional 92 fleas were collected in spring 2011 during the final trapping event for this project. All 256 fleas collected off of feral pigs trapped at the South Texas sample site were identified as *Pulex porcinus* (Jordan and Rothschild), commonly called the javelina flea. No javelina (*Tayassu tajacu* Linnaeus) was examined during this study to determine ectoparasite composition or densities on this host. The javelina is native to the study area (Sowls 1997 , Taylor and Synatszske 2008) and were abundant throughout the study period. This is the first record of this flea species on feral pigs. *Pulex porcinus* has previously been recorded from peccary, also known as javalina, and white tailed deer, *Odoecielus virginianus* (Zimmerman) in Texas (Irons et al. 1952, Samuel and Low 1970, Samuel and Trainer 1970a). Fleas infested all classes of feral pig genders and ages. No fleas were collected from harvested feral pigs the winter of 2010. There is no information on the prevalence of these fleas during the same time period in 2010 on their usual hosts in the same area. It would be inaccurate to say that the relationship between the fleas and feral pigs is either a casual or a permanent one. The fact that fleas were collected across several contiguous trapping events prior to the winter of 2010 and after that time period, indicates the relationship between feral pigs and javelina fleas is potentially more than a casual one at this site. There are few published studies of diseases affecting javelina

(Shender 2006) and none were found suggesting *P. porcinus* as a disease vector. A rapid javelina die-off related to environmental or pathological reasons similar to the one Shender (2006) investigated in Tucson, Arizona, would result in many javelina fleas questing for an alternate host. Surveillance of feral pig populations at the same time of the die off may support the transition of fleas from javelina to pigs. There were no documented reports of a javelina die-off during the time this study occurred. A detailed study of the weather during this study might provide additional insight.

Addition flea samples were donated from Brazos, Robertson, Bexar, Jim Hogg and Nacogdoches Counties. A veterinary student from TAMU donated two fleas (1 male, 1 female) taken from a feral pig (sex and age not available) in Hebronville, Jim Hogg County; both were identified as *P. porcinus*. Sanders (2011) collected four male, and six female fleas also identified as *P. porcinus* from one adult female feral pig captured at the Camp Bullis Military Reservation, Bexar County. Camp Bullis is approximately 15 miles west-north-west of Fort Sam Houston, San Antonio and is utilized by US military for training exercises. Camp Bullis is also a recreational site for military personnel and their families. Veterinary students from TAMU donated an additional fifteen fleas (14 males, 5 females) taken from domestic dogs the fall of 2010. All samples were taken from domestic dogs at the Brazos Valley animal shelter and were identified as *P. simulans*. One flea was taken from a neighbor's dog in College Station in May, 2011; this flea was a male *P. simulans*. Dr. Tom Craig, TAMU Veterinary College, donated 5 *P. simulans* fleas (4 male, 1 female) from domestic dogs at the Mumford, Robertson County animal shelter. In total, javelina fleas were collected from feral pigs in three counties in two different wildlife districts (A8, Appendix A). All three counties are within the historical Texas range of the collared peccary (A1, Appendix A). The fact that mixed sexes of this flea were collected simultaneously from the same host at the same time further indicates a more than casual association between feral pigs and these fleas.

The absence of two flea species expected and recorded from wildlife and domestic pigs in the same area, *Pulex irritans* and *P. simulans* (Randolph and Eads 1946, Eads 1948, Irons et al. 1952, Beard et al. 1989, Durden et al. 2005) is of interest. The human flea, *P. irritans*, has a long history of association with humans and domestic pigs. In Texas, *P. irritans* is more commonly found on members of the Canidae family such as the Swift Fox (*Vulpes velox* Say) from north west Texas, and the cosmopolitan coyote (*Canis latrans* Say) (Pence et al. 2004, McGee et al. 2006). On the other hand, *P. simulans* is reported most frequently from small rodents such as black tailed prairie dogs (*Cynomys ludovicianus* Ord) (Tripp et al. 2009), and from Swift Foxes (*Vulpes velox* Say) (McGee et al. 2006), domestic dogs (Durden et al. 2005, Mullen and Durden 2009), and captive Giant anteaters (*Myrmecophaga tridacyla* Linnaeus) (Mutlow et al. 2006). It appears *P. irritans* is on a decline among domestic animals and might be supplanted by *Pulex simulans* (Durden et al. 2005, Durden personal communication).

TAMU College of Veterinary Medicine students donated an additional 4 fleas from domestic dogs at the Brazos Valley Animal Shelter; all four were female *Echidnophaga gallinacea* (Westwood), also known as the chicken flea or sticktight flea. Most likely the two dogs with sticktight fleas acquired the fleas in the vicinity of a chicken pen. Of three male, and four female fleas collected from two male raccoons in Brazos County, all seven were *P. simulans*. At the Post Oak site we trapped two boar raccoons and combed them for fleas, lice and ticks. The two raccoons provide two female and three male *P. simulans* fleas.

The taxonomic status of *P. irritans* and *P. simulans* continues to be divisive (De la Cruz and Whiting 2003, Dittmar et al. 2003) and no studies have been conducted on *P. porcinus*. *P. irritans* and *P. simulans* were synonomized by Jordan and Rothschild from 1902 until 1958 (Smit 1958). Smit (1958) elevated *P. simulans* from a subspecies of P. irritans based on a morphological difference in terminal aedeagal sclerite and a crochet. However, even this separation is questionable as even Smit (1958) could not separate females into either species. Consequently, today, in a mixed population of males and females, the group is identified to species based on the male fleas. Dittmar et al. (2003) attempted to clarify the issue by conducting DNA studies on the two species. Her conclusion was that there was not enough genetic divergence evidence to separate the two species. To date, no taxonomist has attempted to synonymize the two again, and no new updated and comprehensive taxonomic keys have been released since 1965. Robert E. Lewis, a retired Siphonaptera taxonomist is working to produce a comprehensive updated key to the fleas of North America. He has been working on the manuscript for over fifteen years and a publication date has not yet been determined (Robert E. Lewis personal communication).

The competency of all three *Pulex* species as vectors of bubonic plague is questionable because the earlier transmission studies demonstrated large differences in transmission efficiency among species and between different studies of a single species (Eisen et al. 2009). There have been no published vector competency studies to determine which of the two *Pulex* species associated with bubonic plague transmission is the most effective vector. Recently, Eisen et al. (2009) experimentally confirmed 28 flea species as vectors for *Yersinia pestis* van Loghem. Neither *P. simulans*, nor *P. porcinus* were tested. We have been unable to find any document that illustrates the vector competency of *P. porcinus* for any pathogen before or after it was elevated from the genus *Juxtapulex* (Wagner). The general presumption in the veterinary community is that *P. simulans* and *P. porcinus* by virtue of the genus name *Pulex* are able to transmit *Y. pestis* and serve as intermediate hosts to dog tapeworms (*Dipylidium caninum*) equally as well as *P. irritans*. This cannot be stated with any certainty without supporting studies.

Several fleas are efficient vectors of murine typhus caused by infections of *Rickettsia typhi* Philip. The traditional life cycle transmission of *R. typhi* is from roof rats (*Rattus rattus* Linnaeus) or Norway rats (*Rattus norvegicus* Berkenhout) to rat fleas (*Xenopsylla cheopis* Rothschild) and back to uninfected rats (TDSHS 2011). In suburban areas, the cycle involves a different primary vector, the cat flea (*Ctenocephalides felis* Bouché) and domestic cats (*Felis catus* Linnaeus) as well as opposums (*Didelphis virginiana* Kerr) (Adams et al. 1970, Civen and Ngo 2008). Murine typhus is considered endemic in south Texas, southern California, and Hawaii. Since 1993, diagnosis of murine typhus in Texas increased with the highest increases occurring after 2003 (Adjemian et al. 2010). This is due in part to the implementation of an active surveillance program along the Texas-Mexico border (Robinson 2008). Total cases may be under reported because the disease is generally mild, physicians outside of the endemic areas don't consider murine typhus in their differential diagnosis, and the physician might have successfully treated the illness while trying to treat an unrelated malady with no confirmatory diagnostic test (Robinson 2008). Ten counties (Wichita, Fisher, Bell, Newton, San Patricio, Nueces, Kleberg, Brooks, Willacy and Hidalgo) reported murine typhus cases as of March, 2011 (TDSHS 2011).

The suitability and success of feral pigs as a year-round host for fleas is high. Their relative contribution to respective flea populations on the Texas landscapes because of the abundance and reproductive rate of this host is expected to continue. Feral pigs serve as agents of flea recruitment and dispersal by virtue of their use of landscape habitats, including movement across natural barriers such as rivers, and unnatural barriers such as fences and highways, and by human intervention. Feral pigs are widely recognized as an invasive species that cause destruction to agricultural crops as well as natural resources (Seward et al. 2004, Pimentel et al. 2005, and Chavarria et al. 2007). In addition, they also have economic value for recreational hunting, and their meat and other body parts such as tusks, glands, and internal organs are in high demand. Although it is against state regulation to transport female feral pigs from their home range to be released on another property (TAC 2011), it is not uncommon to see trapped feral pigs being transported across county (and state) lines to be released in another area. Most frequently, these releases are intended to stock recreational hunting activities. These pigs can be relocated very long distances from their original home range, resulting in the introduction of fleas into new areas.

Feral pigs provide a unique opportunity to examine the role of a new flea host on landscapes of Texas. Feral pig characteristics of omnivory, habitat usage, and reproductive rate suggest these animals could substantially supplement the normal host community structure, and potentially increase the maintenance of flea pathogens. Daszak et al. (2000) conclude that disease emergence is most frequently the result of a change in the ecology of the host, pathogen, or both. Keesing et al. (2010) argue that biodiversity can increase or decrease pathogen transmission between species by changing either host/vector abundance, or host/parasite/vector behavior. It is unlikely that increased biodiversity as a consequence of feral pig expansion or density will decrease the incidence of zoonotic disease transmission of all pathogens. It is likely that the influence of this new host may increase the transmission of some pathogens while decreasing transmission of others. The concept of dilution by number is also known as herd immunity. If a resistant population of individuals increases within a mixed group of susceptible and resistant individuals, the disease transmission decreases because the odds of the susceptible individuals coming into contact with the infected individuals declines. The corollary could also be true. The increase of flea hosts can be by natural reproductive means or by artificial introduction of another group of animals. An introduced host must be both as acceptable as the original host to the vector, and less accommodating to the pathogen. This would lead to inefficient effort when vectors feed on the new host and dilute the pathogen prevalence by selecting an inferior reservoir (Ostfeld and Keesing 2000).

Feral pigs could be more efficient at providing a suitable environment for both the vector and the pathogen. It is unlikely that the feral pig populations anywhere in the state will be significantly reduced with the use of current management practices. The real potential is for these feral pig populations to continue to increase exponentially and for the risk of disease transmission between feral pigs and domestic herds of cattle, horses, and pigs also increase (Arim 2006). Feral pigs have a gestation period of 115 days, and under optimal conditions can average two litters of 7 piglets every fourteen months (Taylor et al. 1998). As the pig population increases, the contact rates between the pigs and domestic/wild animals will increase and the potential for reintroduction of previously eradicated pathogens to domestic animals will increase (Cooper et al. 2010). Eppstein and Defilippo (2001) correlated periods of drought with outbreaks of West Nile Virus and St Louis Encephalitis in the United States and Europe from 1933-2001. Periods of drought have a similar effect on wildlife. When water sources dwindle, all animals begin to concentrate around existing water sources and the rate of contact between otherwise isolated species is greatly increased (Ezenwa et al. 2006, Cooper et al. 2010). Feral pigs are comingling in vertebrate and vegetational communities with endemic species of animals. These interactions provide an opportunity for the feral pigs to serve as bridge hosts for parasites from the indigenous/native species, as demonstrated by the collection of javelina fleas in this study. With proper surveillance, there could be even more fleas found in more areas and possibly more species. Little is known about the biology and life cycles of the javelina flea in Texas. I could find no published studies of any diseases associated with the javelina flea.

This study represents a very small proportion of land and animals in relation to the state total acreage of 170 million acres, and 1-4 million estimated feral pigs. The total acres within the six counties surveyed (2.4% of 254 counties) equals approximately 3.62 million acres (NRCS 2011). This represents approximately 2% of the total 170 million acres that can be exploited by feral pigs (Mellish et al. 2010).

It is unlikely that active surveillance of feral pig populations for novel pathogens will increase in the foreseeable future. Currently surveillance is focused on pathogens/parasites known to affect domestic cattle, sheep, goats and horses. Recently, the Texas Animal Health Commission announced that Texas was now *Brucella suis* free. This pathogen free status is within the domestic swine herds only, and feral hogs are potent and effective refugia for this pathogen. Texas Animal Health Commission officials also recently announced that because of budget reductions and despite the fact that two herds were diagnosed as positive earlier this year, they will no longer require brucellosis testing of adult cattle for change of ownership. It is unlikely the Texas Animal Health Commission budget will be increased significantly in the future and probable that more surveillance programs will be reduced or stopped. An introduced vector and or pathogen could reproduce for many years before being detected. By the time the new vector and or pathogen are detected they would be very difficult to eliminate.

CHAPTER V

SPATIAL AND TEMPORAL DISTRIBUTION OF LICE ON FERAL PIGS IN THREE TEXAS WILDLIFE DISTRICTS

Materials and Methods

Materials and methods are as described in Chapter II. Briefly, feral pigs were trapped and harvested at specific study sites in three wildlife districts in east (Post Oak Savannah), central (Hill Country), and south Texas (South Texas Plains) from 2008 through 2011. Ticks, fleas, and lice were collected and placed into 80% ethanol until they could be returned to the TAMU Tick Laboratory for identification and storage. Blood samples were also taken from all pigs for a separate study. Ticks, fleas, and lice were identified at the TAMU Tick Laboratory to species, and sex using relevant keys.

Results

All Sites Combined. Five hundred and sixty four pigs were harvested in combination from all three sites. Feral pig collections from the Hill Country and South Texas sites comprised of 56% and 57% adult animals, respectively. The Post Oak site had slightly fewer adult animals than either of the other two sites with 37%. Forty nine percent of pigs collected from all sites were adults and 51% were juveniles. Fifty two percent of pigs from all sites were female and 48% male. The Post Oak district had the highest total number of females (61%), followed by the South Texas Plains (49%) and then the Hill Country (44%). The Hill Country had the highest total males (56%), followed by the South Texas Plains (51%), and finally the Post Oak site had the fewest total males (39%). There are no published estimates of feral pig population or herd structure at any of these sample sites.

A total of 3766 ticks, 265 fleas and 5019 lice were taken from the 564 pigs. Ninety seven percent of all harvested feral pigs were infested with one or more parasite groups. Very few (3%) of all 564 harvested feral pigs were ectoparasite free. Fifty five percent of all infested pigs were infested with one parasite whether it was by ticks only, fleas only, or lice only; 38% percent were infested with two parasite groups; and, 4% were infested with all three parasite groups.

The Hill Country District. The Hill Country (Shown as A, Figure 5, Chapter II) represented by Fort Hood was sampled 5 times from winter of 2010 through winter of 2011. Appendix A has a satellite image showing general layout of the installation (A5) and a detailed map of the training areas (A6). A summary of all pigs and associated lice collected from harvested feral pigs for this site is given in Table 19. The Hill Country had the second highest total number of pigs (191) collected among the three sites. Slightly more adults (57%) than juveniles (43%) were taken overall. Of the total pigs, 44% were female of which 60% were adults and 40% juveniles. Fifty six percent of total pigs were male with 53% of these adults, and 47% juvenile. Spring 2010 was the most productive of the 6 sampling period in both numbers of pigs and arthropods collected. Of the 191 total pigs collected for this site, 55% were collected in the spring of 2010 followed by 32% in the summer of 2010. The spring 2010 pigs were comprised of a ratio of 6:1 adults to juveniles, which was reversed in a 1:6 ratio of adults to juveniles the following summer. The winter 2010, fall 2010, and winter 2011 collections constituted

6%, 3% and 4% of total pigs collected, respectively. Only juvenile pigs were harvested in the fall of 2010 and the winter of 2011.

Eighty three percent of 191 pigs harvested at this site had lice, with 96% adults infested and 66% of juveniles infested (Table 20). Adult males had the highest percentage of louse infestations with 98% (Table 21) followed by adult females with 96% and juvenile males (76%) and juvenile females (50%).

Table 19. Summary of distribution of lice collected from harvested feral pigs in the Hill Country wildlife district, Texas, 2010-2011. Parenthesis has the percentage of collected feral pigs infested with lice.

Season	Total Pigs	Female Pigs	Adult Female	Juvenile Female	Total Lice Female	Male Pigs	Male Adult	Male Juvenile	Total Lice Male
Winter 2010	11	5	2 (50)	3 (67)	64	6	6 (100)	0	42
Spring 2010	106	39	39 (97)	0	282	67	51 (98)	16(100)	539
Summer 2010	31	9	9 (100)	22 (41)	129	30	0	30 (70)	78
Fall 2010	5	0	0	3 (33)	2	2	0	2 (0)	0
Winter 2011	8	0	0	6 (83)	5	2	0	2 (50)	8

Table 20. Seasonal distribution of lice collected from harvested female feral pigs by age group in the Hill Country wildlife district, Texas, 2010-2011.

Season	Total Female	Adult Female	With Lice	Total Lice	AVG Lice	Juvenile Female	With Lice	Total Lice	AVG Lice
Winter 2010	5	2	1	8	8	3	2	56	28
Spring 2010	39	39	38	282	7	0	0	0	0
Summer 2010	31	9	9	40	4	22	9	89	10
Fall 2010	3	0	0	0	0	3	1	2	2
Winter 2011	6	0	0	0	0	6	5	5	1
Composite	84	50	48	330	7	34	17	152	9

Table 21. Seasonal distribution of lice collected from harvested male feral pigs by age group in the Hill Country wildlife district, Texas, 2010-2011.

Season	Total Male	Adult	With Lice	Total Lice	AVG Lice	Juvenile	With Lice	Total Lice	AVG Lice
Winter 2010	6	6	6	42	7	0	0	0	0
Spring 2010	67	51	50	375	12	16	16	164	10
Summer 2010	30	0	0	0	0	30	21	78	4
Fall 2010	2	0	0	0	0	2	0	0	0
Winter 2010	2	0	0	0	0	2	1	8	8
Composite	107	57	56	417	7	50	38	250	7

Post Oak Savannah District. The Post Oak district site (Shown as B, Figure 5, Chapter II) is represented by the Anderson Ranch LLC, and Beto Unit of the TDCJ. Appendix A contains a satellite map of the sites (A3 and A4, Appendix A). These sites were sampled seven times between the summer of 2009 and the spring of 2011. A summary of all pigs and associated lice collected from this site is given in Table 22. Juvenile pigs were more numerous (63%) than were adults (37%). More females were harvested (61%) with 38% being adult females and 62% being juvenile females. Thirty nine percent of all harvested feral pigs were males with 34% being adult males, and 66% being juvenile males. Of the 204 pigs collected at this site, 39% were collected in the spring of 2010. Juveniles outnumbered adults 2:1 for the same sample period. Pigs collected the summer of 2009, winter of 2009, summer of 2010, fall of 2010, winter of 2011, and the spring of 2011 constituted 4%, 3%, 5%, 4%, 21%, and 24% of total pigs collected, respectively.

Ninety four percent of 204 pigs harvested were infested with lice. Seventy percent of all males and 67% of all females were infested with lice. All sex and age groups had relatively equal infestation levels with female adults the highest at 98%, male juveniles 94%, male adults 93%, and female juveniles with 90% (Tables 23 and 24). Thirty six percent of pigs were infested with lice only, and 64% had a combination of lice and ticks. All lice collected were identified as *Haematopinus suis*, commonly known as the hog louse.

Table 22. Summary of seasonal distribution of lice collected from harvested feral pigs in the Post Oak Savannah wildlife district, Texas, 2009-2011. Parenthesis has the percentage of pigs infested with lice.

Season	Total Pigs	Female Pigs	Adult Female	Juvenile Female	Total Lice	Male Pigs	Male Adult	Male Juvenile	Total Lice
Summer 2009	8	4	1 (0)	3 (67)	11	4	2(100)	2 (100)	23
Winter 2010	6	3	1 (100)	2 (100)	42	3	1 (100)	2 (100)	61
Spring 2010	80	49	20 (100)	29 (86)	524	31	6 (100)	25(100)	408
Summer 2010	10	5	0	5 (40)	8	5	1 (0)	4 (25)	4
Fall 2010	9	7	1 (0)	6 (100)	14	2	1 (0)	1 (100)	28
Winter 2011	42	27	13 (100)	14 (100)	593	15	10(100)	5 (100)	297
Spring 2011	49	30	12 (100)	18 (100)	456	19	6 (100)	13(100)	345

Table 23. Seasonal distribution of lice collected from harvested female feral pigs by age group in the Post Oak Savannah wildlife district, Texas, 2009-2011.

Season	Total Female	Adult Female	With Lice	Total Lice	AVG Lice	Juvenile Female	With Lice	Total Lice	AVG Lice
Summer 2009	4	1	0	0	0	3	2	11	4
Winter 2010	3	1	2	14	7	2	2	28	14
Spring 2010	49	20	20	219	11	29	25	305	12
Summer 2010	5	0	0	0	0	5	2	8	4
Fall 2010	7	1	0	0	0	6	6	14	2
Winter 2011	27	13	13	316	24	14	14	277	20
Spring 2011	30	12	12	142	12	18	18	314	17
Composite	125	48	47	691	14	77	69	957	14

Table 24. Seasonal distribution of lice collected from harvested male feral pigs by age group in the Post Oak Savannah Wildlife District, Texas, 2009-2011.

Season	Total Male	Adults Male	With Lice	Total Lice	AVG Lice	Juvenile Male	With Lice	Total Lice	AVG Lice
Summer 2009	4	2	2	3	2	2	2	20	10
Winter 2010	3	1	1	28	28	2	2	33	17
Spring 2010	31	6	6	58	10	25	25	350	14
Summer 2010	5	1	0	0	0	4	1	4	4
Fall 2010	2	1	0	0	0	1	1	28	28
Winter 2011	15	10	10	154	15	5	5	143	29
Spring 2011	19	6	6	97	16	13	13	248	19
Composite	79	27	25	340	14	52	49	826	17

South Texas Plains District. The South Texas Plains district (Shown as C, Figure 5, Chapter II) is represented by the Welder Wildlife Refuge and was sampled 6 times between summer 2008 and winter 2011. Appendix A contains a satellite image of the refuge (A7). A summary of all pigs and associated lice collected from harvested pigs for this site is given in Table 16. This district had the lowest total of pigs harvested of the three sites with 169. Adults represented 56% of all pigs taken followed by 44% juveniles. Of total pigs, 51% were male with 64% of those adults and 36% juvenile. Females were 47% adults, and 53% juveniles. Of the 169 pigs collected at this site 43% we collected in the fall of 2009. Pigs collected the summer of 2008, the winter of 2009, the spring of 2009, the winter of 2010, and the winter of 2011 constituted 21%, 8%, 8%, 10%, and 11%, respectively.

The South Texas Plains site had the fewest lice (1039) of the three sites followed by the Hill Country (1102). The Post Oak Savannah site had more than two and a have times more lice than either of the other two sites (2878). Forty nine percent of 169 pigs harvested at this site were infested with lice (Table 25). Fifty one percent of all females were infested with lice, with 51% of adult females and 50% of juvenile females infested, Table 26. Forty one percent of males were infested with lice with 61% of juvenile males, and 40% of adult males infested (Table 27). Forty nine percent of infested pigs had lice alone and 51% had two or more species of parasites. Of the 51% of pigs infested with more than one species of parasite 50% were infested with lice and ticks, and the remaining 50% were infested with lice, ticks and fleas. All lice were identified as *Haematopinus suis*, the hog louse. Despite thorough examination, no other lice were collected from pigs harvested at this site.

Table 25. Summary of seasonal distribution of lice collected from harvested feral pigs in the South Texas Plains Wildlife district, Texas, 2008-2011. Parenthesis has the percentage of pigs in the category that were infested with lice.

Season	Total Pigs	Female Pigs	Adult Female	Juvenile Female	Total Lice Female	Male Pigs	Male Adult	Male Juvenile	Total Lice Male
Summer 2008	36	18	6 (0)	12 (33)	13	18	8 (0)	10 (30)	18
Winter 2009	13	8	4 (0)	4 (50)	2	5	2 (0)	3 (67)	2
Spring 2009	13	12	7 (43)	5 (20)	13	1	1 (0)	0 (0)	0
Fall 2009	17	7	1 (0)	6 (0)	0	10	6 (0)	4 (0)	0
Winter 2010	72	35	20 (80)	15 (87)	203	37	33 (58)	4 (100)	35
Winter 2011	18	3	1 (0)	2 (100)	266	15	5 (60)	10(100)	259

Table 26. Seasonal distribution of lice collected from harvested female feral pigs in the South Texas Plains wildlife district, Texas, 2008-2011.

Season	Total Female	Adult Male	With Lice	Total Lice	AVG Lice	Juvenile Male	With Lice	Total Lice	AVG Lice
Summer 2008	18	6	0	0	0	12	4	13	3
Winter 2009	8	4	0	0	0	4	2	2	1
Spring 2009	12	7	3	12	3	5	1	1	1
Fall 2009	7	1	0	0	0	6	0	0	0
Winter 2010	35	20	16	123	8	15	13	80	6
Winter 2011	3	1	1	13	13	2	2	253	127
Composite	83	39	20	148	7	44	22	349	15

Table 27. Seasonal distribution of lice collected from harvested male feral pigs in the South Texas Plains wildlife district, Texas, 2008-2011.

Season	Total Male	Adult Male	With Lice	Total Lice	AVG Lice	Juvenile Male	With Lice	Total Lice	AVG Lice
Summer 2008	18	8	0	0	0	10	3	18	6
Winter 2009	5	2	0	0	0	3	2	4	20
Spring 2009	1	1	0	0	0	0	0	0	0
Fall 2009	10	6	0	0	0	4	0	0	0
Winter 2010	37	33	19	159	8	4	4	35	9
Winter 2011	15	5	3	67	22	10	10	259	26
Composite	86	55	22	226	10	31	19	316	16

Discussion

Results of this study combined with those of Sanders (2011) indicate that feral pigs support the maintenance of one species of sucking lice (Pthiraptera: Haematopinidae) in three Texas wildlife districts sampled from 2008-2011. This species, *Haematopinus suis* (Linnaeus), known as the hog louse, infested feral pigs year round at all sites. This louse infested all classes of gender and age of feral pigs, but varied with respect to site and time of year or season. The suitability and success of feral pigs as a year-round host for lice is high based upon comparison of historical (Butler 1973, Gipson et al. 1999) and current hog louse studies (Acholonu and Epps 2009). Annex A contains a map of the counties where hog lice were collected off of feral pigs in Texas, 2008-2011 (Figure 9). Hog lice have been collected from white tailed deer (*Odocoileus virginianus* Zimmerman) in Florida (Kellogg et al. 1971) and sika deer (*Cervus nippon* Temminck) in Texas (Richardson and Demarais 1992). Our data support published population trends among domestic pigs in that summer collections consisted primarily of immature lice with few adult lice, while winter louse populations are higher and mixed numbers of all ages, but a few lice can be found year round (Campbell 2011, Williams 2011). Hog lice can be passed between pigs during daily contact between members of the herd, by grooming, or nursing. The lice can be groomed off of the pigs when the pigs are scratching themselves by rubbing against tree trunks, rocks, or stumps. The lice that are groomed off can be transferred to other animals that come into contact with the tree, stump or rock. Lice can also fall off the pigs while they are in their bedding areas and then be acquired by other animals that walk through the immediate area. The hog louse can survive for 3 days after it has been groomed off the host (Campbell 2011, Williams 2011) which allows time for them to acquire a new host. Either of the above methods potentially explains how the javelina tick, javelina flea, and hog lice might have been acquired by any or all of the alternate hosts described in this study. The relative contribution of feral pigs to respective louse populations on the Texas landscape because of the abundance and reproductive rate of this host is expected to continue. Feral pigs serve as agents of louse dispersal by virtue of their use of landscape habitats, including movement across natural barriers such as rivers, and unnatural barriers such as fences and highways, and by human intervention. Feral pigs are widely recognized as an invasive species that cause destruction to agricultural crops as well as natural resources (Seward et al. 2004, Pimentel 2005, and Chavarria et al. 2007). In addition they also have economic value for recreational hunting, their meat, and other body parts such as glands, tusks, and internal organs are in demand. Although it is against state regulation to transport female feral pigs from their home range to be released on another property (TAC 2011), it is not uncommon to see trapped feral pigs being transported across county (and state) lines to be released into another area. Most frequently, these releases are intended to stock recreational hunting activities. Pigs can be relocated very long distances from their original home range, resulting in the introduction of lice into new areas.

Future studies of this type in other wildlife districts may record additional sucking louse species on feral pigs. Sucking lice are obligate parasites and complete their entire life on their host. Lice are very host specific with most parasitizing a single host (Durden 2001). However, there is still a possibility that a novel species will be found on feral pigs. *Pecaroecus javelli* (Babcock and Ewing), the giant sucking louse, is the most commonly collected louse on Texas javelina (*Tayassu tajacu* Linnaeus) (Samuel and Low 1970, Meleney 1975). Based on the collection of the javalina flea (*P. porcinus*), and ixodid tick *Dermacentor halli* already discussed on feral pigs, it is possible that *P. javalii* (Babcock and Ewing) known as the javalina louse, could also survive on feral pigs.

Feral pigs provide a unique opportunity to examine the role of a new louse host on landscapes dominated by traditional vertebrate herbivores. Feral pig characteristics of omnivory, habitat usage, and reproductive rate seem to make these animals ideal louse hosts supplementing the normal community host structure, and their potential for maintaining louse pathogens in nature high. Daszak et al. (2000) concluded disease emergence is most frequently the result of a change in the ecology of the host, pathogen, or both. Keesing et al. (2010) argue that biodiversity can increase or decrease pathogen transmission between species by changing either: host/vector abundance; or host/parasite/vector behavior. It is unlikely that increased biodiversity will decrease the incidence of disease transmission because it would require an unrealistic high density of introduced animals.

The concept of dilution by number is also known as herd immunity. It is predicated by the principle that as the population of resistant individuals increases within a mixed group of susceptible and resistant individuals, the disease incidence decreases because the odds of the susceptible individual coming into contact with the diseased/parasitized individuals lowers. The increase can be by natural reproductive means or by artificial introduction of another group of animals. An introduced host must be both as acceptable as the original host to the vector, and less accommodating to the pathogen. This would lead to inefficient effort when vectors feed on the new host and dilute the pathogen prevalence by selecting an inferior reservoir (Ostfeld and Keesing 2000).

Feral pigs could be more efficient at providing a suitable environment for both the vector and the pathogen. There is a potential risk that these feral pig populations will continue to increase in spite of current feral pig control and management practices, and the risk of disease transmission between feral pigs and domestic herds of cattle, horses, and pigs will also increase (Arim 2006). Feral pigs have a gestation period of 115 days, and under optimal conditions can have two average litters of 7 piglets every fourteen months (Taylor et al. 1998). As the pig population increases, the contact rates between the pigs and domestic/wild animals will increase and the potential for reintroduction of previously eradicated pathogens to domestic animals will increase (Cooper et al. 2010). Eppstein and Defilippo (2001) correlated periods of drought with outbreaks of West Nile Virus and St Louis Encephalitis in the United States and Europe from 1933-2001. Periods of drought have a similar effect on wildlife. When water sources dwindle, all animals begin to concentrate around existing water sources and the rate of contact between otherwise isolated species is greatly increased (Ezenwa et al. 2006, Cooper et al. 2010). Feral pigs are comingling in vertebrate and vegetational communities with other, more endemic species of animals. These interactions provide an opportunity for the pigs to serve as bridge hosts for parasites from the indigenous/native species, as demonstrated by the collection of the one female peccary tick (*Dermacentor halli*) at the Welder Wildlife Refuge (Sanders 2011) and multiple collections of peccary fleas (*Pulex porcinus*) at the same site and across multiple years. Although the tick collection was one single female, and occurred one time, the implications are that it could happen more frequently. With proper surveillance there could be even more species found.

Hog lice are associated vectors of swinepox virus based on old literature, and have also been identified as potential vectors of hog cholera and eperythrozoonosis (Williams 2011). No published studies of this vector and swine pox have occurred since 1963. Zoonotic pathogens such as *Coxiella burnetti* Phillip (causal pathogen of Q fever), and the tularemia bacteria *Francisella tularensis* Dorofe'ev are two of the few pathogens that are known to be transmitted by lice. The majority of lice are not associated with pathogens of wild animals. This is most likely because there is a paucity of louse transmission research in the area more so than that lice are unable to transmit pathogens (Durden 2001).

This study represents a very small proportion of land and animals in relation to the state total acreage of 170 million acres and from 1-4 million feral pigs. The total acres within the six counties surveyed (2.4% of 254 counties) equals approximately 3.62 million acres (NRCS 2011). This represents approximately 2% of the total 170 million acres that can be exploited by feral pigs (Mellish et al. 2010).

It is unlikely that active surveillance of feral pig populations for novel pathogens will increase in the foreseeable future. Currently, surveillance is focused on pathogens/parasites known to affect domestic cattle, sheep, goats and horses. Recently, the Texas Animal Health Commission announced that Texas was now *Brucella suis* free. This pathogen free status is within the domestic swine herds only, and feral hogs are potent and effective refugia for this pathogen. Texas Animal Health Commission officials also recently announced that due to budget reductions and despite the fact that two herds were diagnosed as positive earlier this year, they will no longer require brucellosis testing of adult cattle for change of ownership. It is unlikely the Texas Animal Health Commission budget will be increased significantly in the future and probable that more surveillance programs will be reduced or stopped. An introduced vector and or pathogen could reproduce for many years before being detected. By the time the new vector and or pathogen are detected they would be very difficult to eliminate.

CHAPTER VI

CONCLUSIONS

A critical task for scientists is to identify areas where knowledge is lacking and where future research should be directed. It appears there is a lot of knowledge missing about the role feral pigs have in the maintenance and distribution of ticks, lice and fleas and the associated pathogens known to these arthropods. Little is known regarding the species and stages of ticks, lice, and fleas infesting feral pigs in Texas. Less is known regarding the seasonal herd dyanamics of feral pigs in relation to the movement and establishment of tick, flea, and lice populations on these animals.

This study demonstrates that feral pigs are acting as bridge hosts for two classes (three orders) of arthropod parasites that feed on native and exotic mammals in Texas, across three wildlife areas and habitats. This study indicates feral pigs potentially will have a significant role in the maintenance and distribution of arthropods and their zoonotic pathogen distribution in Texas. It is apparent that feral pig populations will continue to increase which will increase interactions with domestic stock and wildlife. This increased interaction will most likely increase vector populations, as well as potentially increase zoonotic pathogen transmission.

The taxonomic literature for the fleas of North America is substantially outdated and poorly supported. The last comprehensive keys for North America were published in two volumes, one covering the fleas of the eastern United States by Ewing (1943) and Hubbard (1947) for the western United States. The last comprehensive key for the fleas of Texas was published in 1950 by the State Health Department. The last recognized

Siphonapterist in the United States, Robert E. Lewis, has been working on a comprehensive key for the fleas of North America for 15 years. The release date for this work is yet to be announced.

The vector competency and capacity of the three *Pulex* fleas collected in this study is a subject of concern. The most recently published study of flea competency and capacity of North American fleas to transmit bubonic plague (*Yersinia pestis*) experimentally confirmed the vector efficiency of 28 species of fleas. There are 230 North American fleas that infest mammals in plague endemic areas, and only a fraction of them have been evaluated using standardize techniques for vector competence and/or efficiency (Eisen et al. 2009). Texas is a pneumonic plague endemic state, and exposure to the pathogen is documented for the collard peccary (*Tayassu tajacu*) in Texas (Gruver and Guthrie 1996), and Clark et al. (1983) identified antibodies to *Y. pestis* in feral pigs in California. The literature is replete with references of *P. simulans*' potential role in bubonic plague transmission to alternate animals after prairie dog colonies die off during a local epidemic. The presumption that all *Pulex* fleas transmit pathogens equally as well as P. irritans is irresponsible. It is imperative that studies be conducted on both *P. simulans* and *P. porcinus* to determine what their relative competencies and capacity for transmission of *Y. pestis*. Other flea borne pathogens including murine typhus (*R. typhi*) are of concern. Cases of murine typhus diagnosed along the Texas-Mexico border continue to increase since 2003.

Sanders (2011) demonstrated serologically that of the 878 feral pigs he sampled 2%, 28%, and 13% were exposed to *Borrelia spp*, *Ehrlichia* spp, and *Rickettsia* spp, respectively. Further studies will determine the particular species of these pathogen groups. Six of the ticks collected in this study are vectors of one or more of these pathogens. The lone star tick (*Amblyomma americanum*) transmits *Borrelia lonestari* (Southern Tick Associated Rash Illness), *Ehrlichia chaffeensis* (*Monocytic ehrlichiosis*), and *Francisella tularensis* (Tularemia). The black legged tick (*Ixodes scapularis*) is associated with transmission of *Borrelia burgdorferi* (Lyme disease), *Anaplasma phagocytophilum* Theiler (Human Granulocytic Anaplasmosis) and *Babesia microti* (Babesiosis). The American dog tick (*Dermacentor variabilis*) transmits *Rickettsia rickettsii* (Rocky Mountain spotted fever) and *Franciscella tularemia* (Tularemia) pathogens. The gulf coast tick (*Amblyomma maculatum*) transmits *Rickettsia parkeri* (Spotted fever) and *Hepatozoon americanum* (Canine hepatozoonosis) agents. The Cajenne tick transmits spotted fever group *Rickettsia* spp pathogens. The winter tick *Amblyomma albipictus* transmits *Anaplasma marginale* (bovine anaplasmosis) agents.

Two hard ticks that have been eradicated in Texas, but could possibly be found on feral pigs are the cattle tick (*Rhipicephalus annulatus*), and the southern cattle tick (*R. microplus*). Both of these ticks transmit *Babesia bigemina*, and *Babesia bovis* (cattle babesiosis, or Texas Cattle Fever) pathogens. One of the soft ticks anticipated but not found is the spinose ear tick, *Otobius megnini*. This tick does not transmit pathogens but causes severe damage inside the host's ears which leads to secondary infections by bacteria. Sanders (2011) seropositive results for feral pig exposure to *Borrelia* spp suggests *Ornithodoros turricata* (Relapsing fever) ticks are feeding on feral pigs. Unlike the spinose ear tick, the relapsing fever tick is an intermittent feeder that drops off its host between blood meals and finds harborage in tunnels, caves, and undercut shore lines along streams and rivers. We don't know if feral pigs are maintenance, magnifying or dead end hosts of any of these pathogens. In 2005, Lin et al. described a new *Borrelia* spp (*Candidatus Borrelia texasensis*) collected from an American dog tick (*D. variabilis*) in Webb County, Texas. This suggests there are other unidentified Borrelia spp in nature that these pigs could be exposed to and which they could then disseminate throughout the state.

A disease of interest but not studied in this research is Chagas disease. This disease is caused by infection of the protozoa *Trypanosoma cruzi*, which is transmitted by seven members of the insect family Reduviidae (Order: Hemiptera) in Texas. Transmission is via contamination of the hosts eyes, mouth or wounds with *T. cruzi* protozoa in the feces of the vector. Infection can also occur if the host ingests one of the seven triatomid insects known in Texas. Kjos (2008) conducted a state wide study and concluded canine Chagas disease is under diagnosed and therefor under reported, with 553 confirmed from 1987-1998, with cases spread across 10 of 11 ecoregions in Texas. In 2009-2010, the Texas Veterinary Diagnostics Laboratory diagnosed 148 cases of canine chagas disease from 34 counties across 9 of 10 ecoregions (A2, Appendix A). Domestic pigs are implicated in Chagas disease maintenance/transmission in studies by Diamond and Rubin (1958), USA; Marsden et al. (1970), England; Fujita et al. (1994), Paraguay; and Salazar-Schettino et al. (1997), Mexico. Herrera et al. (2008) reported detecting *T. cruzi* in feral pigs and peccary (*Tayassu tajacu* and *Tayassu pecari*) for the first time. The study was based on feral pigs and peccary blood samples taken from the

Rio Negro area of the Pantanal wetlands of Brazil. This is all further evidence that feral pigs will have a role in the maintenance and distribution of Chagas in Texas.

Feral pigs are destructive to the environment by their habit of rooting which can lead to severe erosion in erodible soil types to their omnivorous habits (Singer et al. 1984). Feral pigs are suspected of eating eggs and small birds from their nests, to small goats that have just separated from their nannies. I have yet to see any fence that can exclude a feral pig from any area.

In summary, feral pigs are hosts to 7 hard ticks, one flea, one louse and potential hosts to all the ticks, lice and fleas that infest small, medium and large mammals in the state of Texas. They will serve as maintenance and distribution hosts for these ticks, fleas and lice and the pathogens associated with the arthropods. No method so far is effective at restricting feral pig movement either by their own locomotion or with human intervention. Feral pigs could potentially be the next West Nile Virus crisis for the United States, in that they could be disseminating an unknown viral, bacterial, or protozoal pathogen for many years before the pathogen is detected, just as the *Culex* spp mosquitoes and birds did for the West Nile Virus.

REFERENCES

Acholonu, A.D.W. and C. Epps. 2009. Lice (*Haematopinus suis* (L.) (Anoplura: Haematopinidae) infestation of swine from southwestern Mississippi. J. Miss. Acad. of Sci. 54:153-156.

Adams, W.H., R.W. Emmons, and J.E. Brooks. 1970. The changing ecology of murine (endemic) typhus in southern California. Am. J. Trop. Med. & Hyg. 19:311-318.

Adjemian, J., S. Parks, K. McElroy, J. Campbell, M.E. Eremeeva, W.L. Nicholson, J. McQuiston, and J. Taylor. 2010. Murine typhus in Austin, Texas, USA, 2008. Emer. Inf. Dis. 16:412-417.

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

AMRC. 2011. American Red Cross blood testing. www.redrossblood.org.

Arim, M., S.R. Abades, P.E. Neill, M. Lima, and P.A. Marquet. 2006. Spread dynamics of invasive species. PNAS. 103:374-378.

Azad, A.F., S.R. Radulovic, J.A. Higgins, B.H. Noden, and J.M. Troyer. 1997. Flea-borne Rickettsioses: ecological considerations. Emer. Inf. Dis. 3:319-327.

Beard, C.B., J.F. Butler, and E.C. Greiner.1989. In vitro growth characterization and host-parasite relationship of *Leptomonas pulexsimulantis* N. SP., a trypanosomatid flagellate of the flea *Pulex simulans*. J. Parasit. 75:658-668.

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

Boostrom, A., M.S. Beier, J.A. Maculasu, K.R. Maculasu, D. Sprenger, J. Hayes, S. Radulovic, and A.F. Azad. 2002. Geographic association of *Rickettsia felis*-infected opossums with human murine typhus, Texas. Emerg. Infec. Dis. 8:549-554.

Butler, J.F. 1973. Rabon for hog louse control in Florida. Flor. Ent. 56:227-232.

Campbell, J.B. 2011. *Controlling external swine parasites*. NebGuide G1094. Publ., University of Nebraska, Lincoln.

CDC (Center for Disease Control and Prevention). 2011a. Bioterrorism Agents/Diseases. http://www.bt.cdc.gov/agent/agentlist-category.asp.

CDC (Center for Disease Control and Prevention). 2011b. Parasites – American Trypanosomiasis (also known as Chagas Disease). http://www.cdc.gov/parasites/chagas/.

Chavarria, P.M., R.R. Lopez, G. Bowser, and N.J. Silvy. 2007. A landscape-level survey of feral hog impacts to natural resources of the Big Bend National Preserve. Human-Wildl Confl. 1:199-204.

Civen, R., and V. Ngo. 2008. Murine Typhus: an unrecognized suburban vectorborne disease. Clinical Inf. Dis. 46:913-918.

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.

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.

Correl, D.S. and M.C. Johnston. 1970. Manual of the vascular plants of Texas. Texas Research Foundation, Renner, TX.

Davis, W.B. and D.J. Schmidly. 2011. The mammals of Texas, Online Edition. http://www.nsrl.ttu.edu/tmot1/.

Daszak, P., A.A. Cunningham, and A.D. Hyatt. 2000. Emerging infectious diseases of wildlife – threats to biodiversity and human health. Science. 287:443-449.

De la Cruz, K.D. and M.F. Whiting. 2003. Genetic and phylogeographic structure of populations of *Pulex simulans* (Siphonaptera) in Peru inferred from two genes (*Cyt*B and *CoII*). Parasitol. Res. 91:55-59.

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.

Diamond, L.S. and R. Rubin. 1958. Experimental infection of certain farm mammals with a north American strain of *Trypanosoma cruzi* from the raccoon. Exper. Parasit. 7:383-390.

Diggs, G.M., Jr., B.L. Lipscomb, and R.J. O'Kennon. 1999. *Shinner & Mahler's illustrated flora of north central Texas*. Austin College and Botanical Research Institute of Texas.

Dittmar, K., U. Mamat, M. Whiting, T. Goldmann, K. Reinhard, and S. Gullen. 2003. Techniques of DNA-studies on prehispanic ectoparasites (*Pulex* sp., Pulicidae, Siphonaptera) from animal mummies of the Chiribaya Culture, Southern Peru. Mem. Inst. Oswaldo Cruz. 98(Suppl. 1):53-58.

Durden, L.E. 2001. Lice. In: Samuel, W., Pybus M., and Kocan, A.A. (Eds.), *Parasitic diseases of wild mammals*, 2 ed. Iowa State Press, Ames.

Durden, L. A., T.N. Judy, J.E. Martin, and L.S. Spedding. 2005. Fleas parasitizing domestic dogs in Georgia, USA: species composition and seasonal abundance. Vet. Para. 130:157-162.

Eads, R.B. 1948. Ectoparasites from a series of Texas coyotes. J. Mammalogy. 29:268-271.

Eads, R.B. 1950. The fleas of Texas. In Texas State Health Bulletin, pp 86.

Eads, R.B., H.E. Henderson, T. McGregor, and J.V. Irons. 1950. Relapsing fever in Texas: distribution of laboratory confirmed cases and the arthropod reservoirs. Am. J. Trop. Med. 30:73-76.

Eads, R.B. 1951. A note on the javelina flea, *Juxtapulex procinus*. J. Para. 37:328.

Eisen, R.J., L. Eisen, and K.L. Gage. 2009. Studies of vector competency and efficiency of north American fleas for *Yersinia pestis*: state of the field and future research needs. J. Med. Entomol. 46(4):737-744.

Eppstein, P.R., and C. Defilippo. 2001. West Nile virus and drought. Global Change & Human Health. 2:2-4.

Ezenwa, V.O., M.S. Godsey, R.K. King, and S.C. Guptill. 2006. Avian diversity and West Nile virus: testing associations between biodiversity and infectious disease risk. Proc. R. Soc. R. 273:109-117.

Fairchild, G.B., G.M. Kohls, and V/J. Tipton. 1966. The ticks of Panama. In: Ectoparasites of Panama. Ed. R.L. Wenzel, and V.J. Tipton. Chicago: Field Museum of Natural History, pp. 167-220.

Foreyt, W.J. 2001. Veterinary Parasitology Reference Manual. 5th Ed. Blackwell Publishing. pp 235.

Fujita, O., L. Sanabria, A. Inchaustti, A, DeArias, Y. Tomizawa, and Y. Oku. 1994. Animal reservoirs for *Trypanosoma cruzi* infection in an endemic area in Paraguay. J. Vet. Med. Sci. 56(2):305-308.

Gillespie, J.J., N.C. Ammerman, M. Beier-Sexton, B.S. Sobral, and A.F. Azad. 2009. Louse- and flea-borne rickettsioses: biological and genomic analysis. Vet. Res. 40:1-13.

Gipson, P.S., J.K. Veatch, R.S. Matlack, and D.P. Jones. 1999. Health status of a recently discovered population of feral swine in Kansas. J. Wildl. Dis. 35:624-627.

Ghosh, S., G.C. Bansal, S.C. Gupta, D. Ray, M.Q. Khan, H. Irshad, Md. Shahiduzzaman, U. Seitzer, and J.S. Ahmed. 2007. Status of tick distribution in Bangladesh, India, and Pakistan. Parsitol. Res. 101 (Suppl. 2):S207-S216.

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.

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.

Groebel, K., K. Hoelzle, M.M. Wittenbrink, U. Ziegler, and L.E. Hoelzle. 2009. *Mycoplasma suis* invades porcine erythrocytes. Infect Immun. 77:576-584.

Gruver, K.S., and J.W. Guthrie. 1996. Parasites and selected diseases of collared peccaries (*Tayassu tajacu*) in the trans-pecos region of Texas. J. Wildl. Dis. 32:560-562.

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

Henry, V.G. and R.H. Conley. 1970. Some parasites of European wild hogs in the southern Appalachians. J. Wildl. Manage. 34:913-917.

Herrera, H.M., U.G.P. Abreu, A. Keuroghlian, T.P. Freitas, and A.M. Jansen. 2008. The role played by sympatric collared peccary (*Tayassu tajacu*), white-lipped peccary (*Tayassu pecari*) and feral pig (*Sus scrofa*) as maintenance hosts for

Trypanosoma evansi and *Trypanosoma cruzi* in a sylvatic area of Brazil. Parasitol. Res. 103:619-624.

Hoelzle, K. 2008. Haemotrophic mycoplasmas: recent advances in *Mycoplasma suis*. Vet. Microb. 130:215-226.

Holland, G.P. 1985. The fleas of Canada, Alaska and Greenland (Siphonaptera). Memoirs of the Entomological Society of Canada, No 130. Ottawa, Canada.

Hubbard, C.A. 1947. Fleas of western North America and their relation to the public health. Iowa State College Press, Ames Iowa.

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

Irons, J.V., R.B. Eads, C.W. Johnson, O.L. Walker, and M.A. Norris. 1952. Southwest Texas Q fever studies. J. Para. 38:1-5.

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

Keesing, F., L.K. Belden, P. Daszak, A. Dobson, C.D. Harvell, R.D. Holt, P. Hudson, A. Jolles, K.E. Jones, C.E. Mitchell, S.S. Myers, T. Bogich, and R.S. Ostfeld. 2010. Impacts of biodiversity on the emergence and transmission of infectious diseases. Nature. 468:647-652.

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. Ent. Sup. No. 2:1-149.

Keirans, J.E. and T.A. Litwak. 1989. Pictorial key to the adults of hard ticks, family Ixodidae (Ixodida:Ixodoidea), East of the Mississippi River. J. Med. Ent. 26:435-448.

Kellogg, F.E., T.P. Kistner, R.K. Strickland, and R.R. Gerrish. 1971. Arthropod parasites collected from white-tailed deer. J. Med. Ent. 8:495-498.

Kim, K.C., H.D. Pratt, and C.J. Stojanovich. 1986. The sucking lice of north America. The Pennsylvania State University Press.

Kjos, S.A., K.F. Snowden, T.M. Craig, B. Lewis, R. Ronald, J.K. Olson. 2008. Distribution and characterization of canine Chagas disease in Texas. Vet. Paras. 152:249-256.

Kjos, S.A., K.F. Snowden, and J.K. Olson. 2009. Biogeography and *Trypanosoma cruzi* infection prevalence of Chagas Disease vectors in Texas, USA. Vector Borne Zoonotic Dis. 9:41-50.

Layne, J.N.1971. Fleas (Siphonaptera) of Florida. The Florida Ent. 54:35-51.

Lewis, R.E. 1972. Notes on the Geographical Distribution and Host Preferences in The Order Siphonaptera Part 1 Pulicidae. J. of Med. Ent. 9:511-520.

Lin, T., L. Gao, A. Seyfang, and J.H. Oliver. 2005. '*Candidatus Borrelia texasensis*', from the American dog tick *Dermacentor variabilis*. Int. J. Sys. Evol. Microb. 55:685-693.

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

Marsden, P.D., E.J.Blackie, M.E. Rosenberg, D.S. Ridley, and J.W.C. Hagstrom. 1970. Experimental Trypanosoma cruzi infections in domestic pigs (*Sus scrofa domestica*). Trans. R. Soc. of Trop. Med. and Hyg. 64:156-158

McGee, B.K., M.J. Butler, D.B. Pence, J.L. Alexander, J.B. Nissen, W.B. Ballard, and K.L. Nicholson. 2006. Possible vector dissemination by Swift Foxes following a plague epizootic in Black-tailed prairie dogs in northwest Texas. J. Wildl. Dis. 42:415-420.

Meleney, W.P. 1975. Arthropod parasites of the collard peccary, *Tayassu tajacu* (Artiodactyla: Tayasuidae), from New Mexico. J. Para. 61:530-534.

Mellish, J.M., A. Sumrall, B. Higgenbotham, R.R. Lopez, and T.A. Campbell. 2011. Simulating feral hog population growth in Texas. Wildlife Soc. Bull. In review.

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. Ent. 47: 536-542.

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

Mutlow, A.G., M.W. Dryden, and P.A. Payne. 2006. Flea (*Pulex simulans*) infestation in captive giant anteaters (*Myrmecophaga tridactyla*). J. Zoo and Wildl. Med. 37:427-429.

NRCS. 2011. Natural Resources Conservation Service (USDA) Texas online soil survey manuscripts. soils.usda.gov/survey/online_surveys/texas.

Neal, B.J. 1959. A Contribution on the life history of the collard peccary in Arizona. American Midland Naturalist. University of Notre Dame. 61:177-190.

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-Claessens, J. Castella, I. Sanfeliu, E. Anton, and F. Segura-Porta. 2007. The Role of wild boar *(Sus scrofa)* in the eco-epidemiology of *R. slovaca* in Northeastern Spain. Vector Borne Zoon. Dis. 7:59-64.

Ostfeld, R.S., and F. Keesing. 2000. The function of biodiversity in the ecology of vector-borne zoonotic diseases. Can. J. Zool. 78:20061-2078.

Parola, P., S, Shpynov, M. Montoya, M. Lopez, P. Houpikian, Z. Zeaiter, H. Guerra, and D Raoult. 2002. First molecular evidence of new *Bartonella* spp. in fleas and ticks from Peru. Am. J. Trop. Med. Hyg. 67:135-136.

Pekins, C.E. 2006. Armored military training and endangered species restrictions at Fort Hood, Texas. Fed. Facil. Envir. J. onlinelibrary.wiley.com/doi/10.1002/ffej.20079/pdf.

Pence, D.B., J.F. Kamler, and W.B. Ballard. 2004. Ectoparasites of the Swift Fox in northwest Texas. J. Wildl. Dis. 40:543-547.

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

Ecological Economics. 52:273-288.

Presley, S.M. 2011. Focal seroprevalence of *Francisella tularensis* in feral swine in north central and northwest Texas. Diseases in Nature Conference. Corpus Christi Texas. 16 June, 2011.

Randolph, N.M. and R.B. Eads. 1946. An ectoparasite survey of mammals from Lavaca, County, Texas. Ann. Ent. Soc. Am. 39:597-601.

Richardson, M.L. and S. Demarais. 1992. Parasites and condition of coexisting populations of white-tailed and exotic deer in south-central Texas. J. Wildl. Dis. 28:485-489.

Robinson, L.E. 2008. Murine typhus in Texas. The EpiLink. 65:1-3.

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. Conflicts. 1:192-198.

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

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

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.

Salazar-Schetinno, P.M., M.I. Buchio, M. Cabrera, and J. Bautista. 1997. First case of natural infection in pigs. Review of *Trypanosoma cruzi* reservoirs in Mexico. Mem. Inst. Oswaldo Cruz, 92:499-502.

Samuel, W.M., and W.A. Low. 1970. Parasites of the collard peccary from Texas. J. Wildl. Dis. 6:16-23.

Samuel, W.M., and D.O. Trainer. 1970a. Pulex porcinus Jordan and Rothschild, 1923 (Siphonaptera: Pulicidae) an occasional parasite of white-tailed deer from the Welder Refuge in southern Texas. J. Wildl. Dis. 6:182-183.

Samuel, W.M., and D.O. Trainer. 1970b. *Amblyomma* (Acarina: Ixodidae) on white-tailed deer, *Odocoileus virginianus* (Zimmerman), from south Texas with implications for Theileriasis. J. Med. Ent. 7:567-574.

Sarkar, S., S.E. Strutz, D.M. Frank, C.L. Rivaldi, B. Sissel, and V.S. Cordero. 2010. Chagas Disease risk in Texas. PLos Negl. Trop. Dis. 4:e836. Doi: 10.1371/journal.pntd.0000836.

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.

Shender, L. 2006. Javelina mortality events and a “mystery disease” outbreak never fully explained. Ohio Vet. Med. Assoc. Proceedings, pp. 304-309.

Singer, F.J., W.T. Swank, and E.E.C. Clebsch. 1984. Effects of wild pig rooting in a deciduous forest. J. Wildl. Manage. 48:464-473.

Smit, F.G.A.M. 1958. A preliminary not on the occurrence of *Pulex irritans* L. and *Pulex simulans* B in North America. J. Para.. 44:523-526.

Smith, H.M., W.R. Davidson, V.F. Nettles, and R.R. Gerrish. 1982. Parasitisms among wild swine in southeastern United States. J. Am. Vet. Med. Assoc. 181:1281-1284.

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 Zoonotic Dis. 11:1-10.

SCWDS (Southern Cooperative Wildlife Disease Study). 2011. Wildlife distribution map. http://www.scwds.org/.

Sowls, L.K. 1997. Javelinas and other peccaries: their biology, management, and use. 2nd Ed. Texas A&M University Press, College Station.

TAC. 2011. Texas administrative code. Title 4: Agriculture, Part 2: Texas Animal Health Commission, Chapter 55: swine, Rule: §55.9 feral swine. info.sos.state.tx.us/pls/pub/readtac$ext.view TAC?tac_view=3&ti=4&pt=2

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

Taylor, R. and D.R. Synatzske. 2008. The javelina in Texas. Published by Texas Department of Wildlife, Austin. www.tpwd.state.tx.us.

TAHC (Texas Animal Health Commission). 2011. Reportable Diseases. http://www.tahc.state.tx.us/animal_health/reportable.html.

TDSHS (Texas Department of State Health Services). 2011. Notifiable Conditions. http://www.dshs.state.tx.us/idcu/investigation/conditions/.

Tripp, D.W., K.L. Gage, J.A. Montenieri, and M.F. Antolin. 2009. Flea abundance on Black-Tailed Prairie Dogs (*Cynomys ludovicianus*) increases during plague epizootics. Vector Borne Zoonotic Dis. 9:313-321.

TVMDL (Texas Veterinary Medical Diagnostic Laboratory). 2010. TVMDL Chagas positives for distribution. 27 Oct 2010.

Vincent-Johnson, N.A., D.K. Macintire, D.S. Lindsay, S.D. Lenz, G. Baneth, V. Shkap, and B.L. Blagburn. 1997. A new Hepatozoon species from dogs: description of the causative agent of canine hepatozoonosis in North America. J. Para. 83:1165-1172.

Williams, R.E. 2011. Control of swine pests. Extension Publication E-9-W. Published by Purdue University, Indiana.

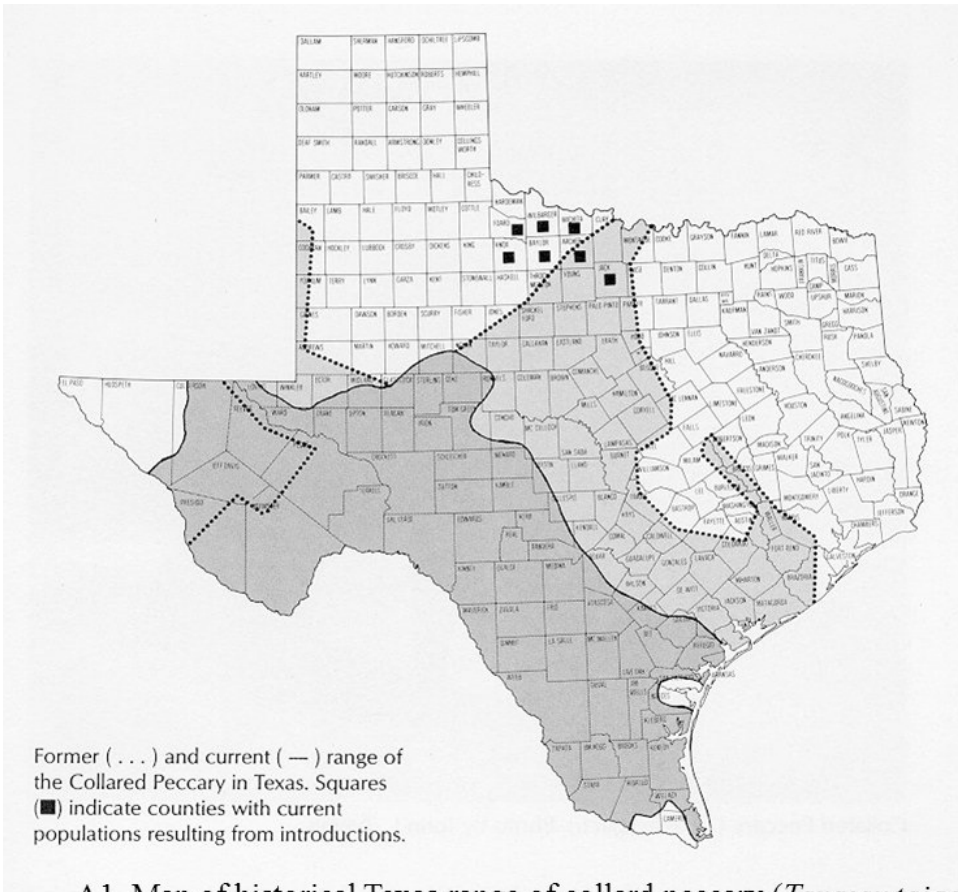
Wilson, N., and P. Bishop. 1966. A new host and range extension for *Pulex simulans* Baker with a summary of published records (Siphonaptera: Pulicidae). Am. Midland Nat. 75:245-248.

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. Of 10th Wildl. Damage Mgnt. Conf. Univ. Neb, pp 315-325.

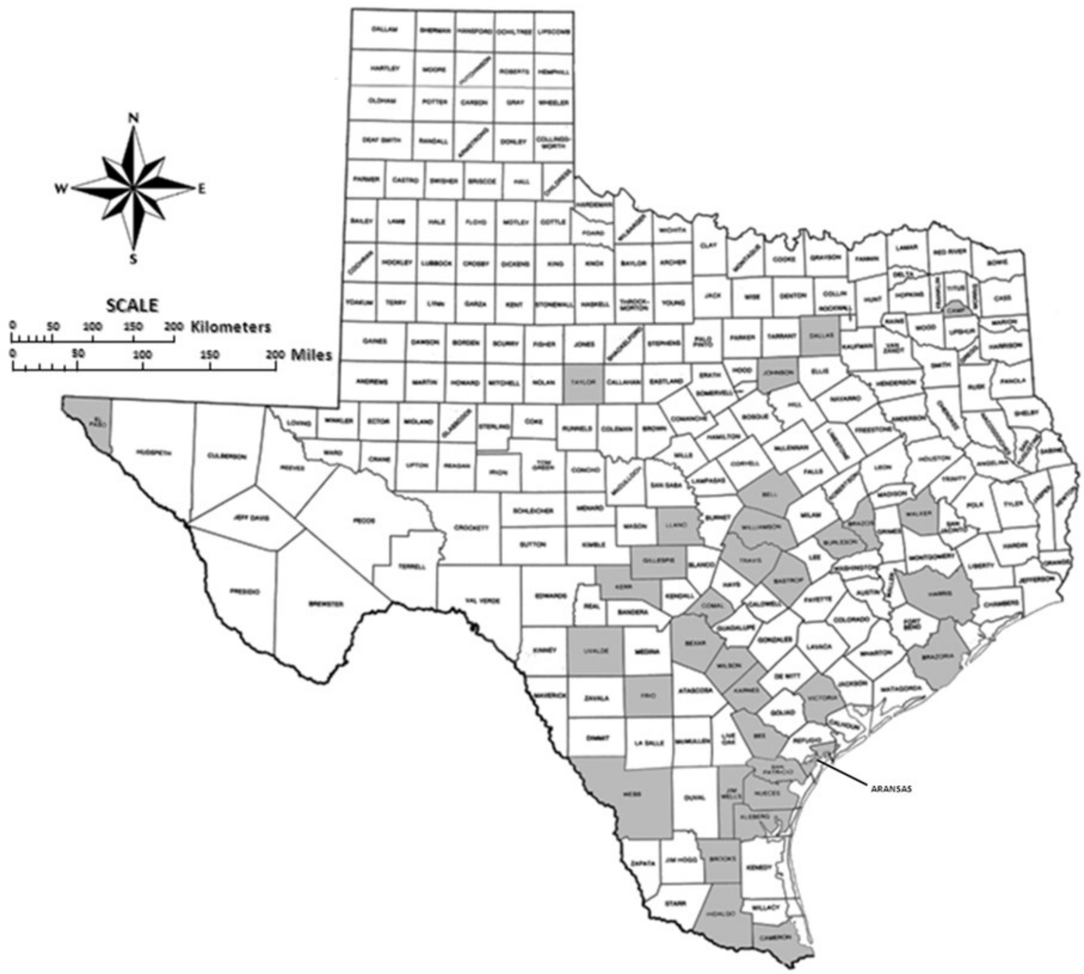
Wycoff, A.C., S.E. Henke, T.A. Campbell, D.G. Hewitt, and K.C. VerCauteren. 2009. Feral swine contact with domestic swine: a serologic survey and assessment of potential for disease transmission. J. Wildl. Dis. 45:422-429.

Yunker, C.E., J.E. Keirans, C.M. Clifford, and E.R. Easton. 1986. *Dermacento*r ticks (Acari: Ixodoidea: Ixodidae) of the new world: a scanning electron microscope atlas. Proc. Ent. Soc. Wash. 88:609-627.

APPENDIX A



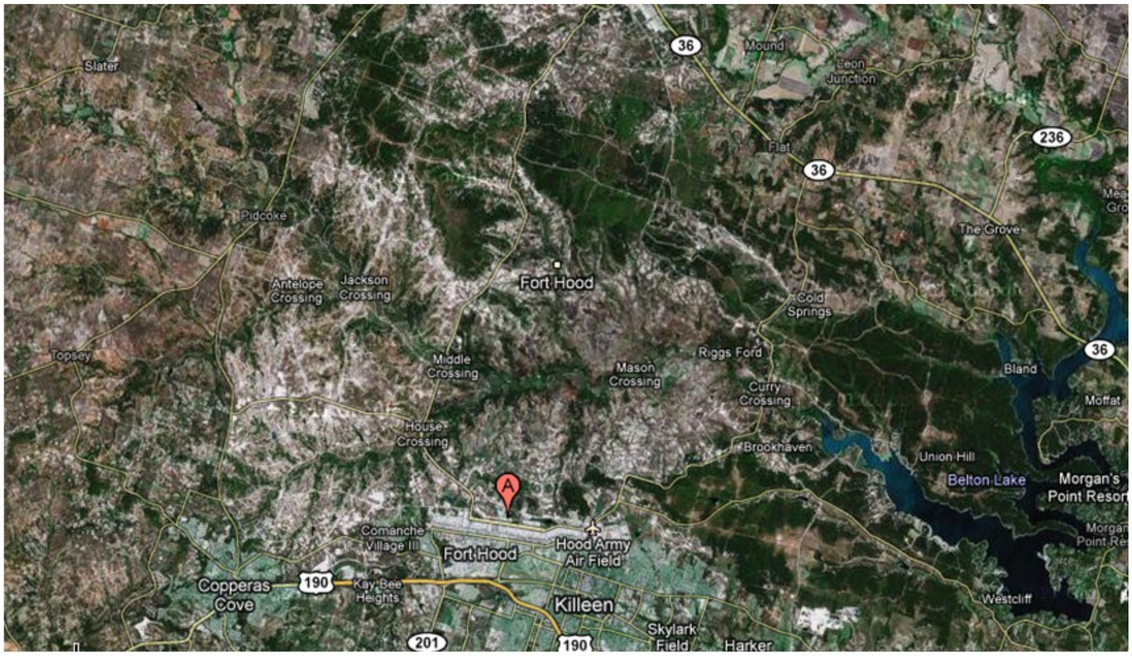
A1. Map of historical Texas range of collard peccary (*Tayassu tajacu*). From www.nsrl.ttu.edu/tmot1/tayataja.htm



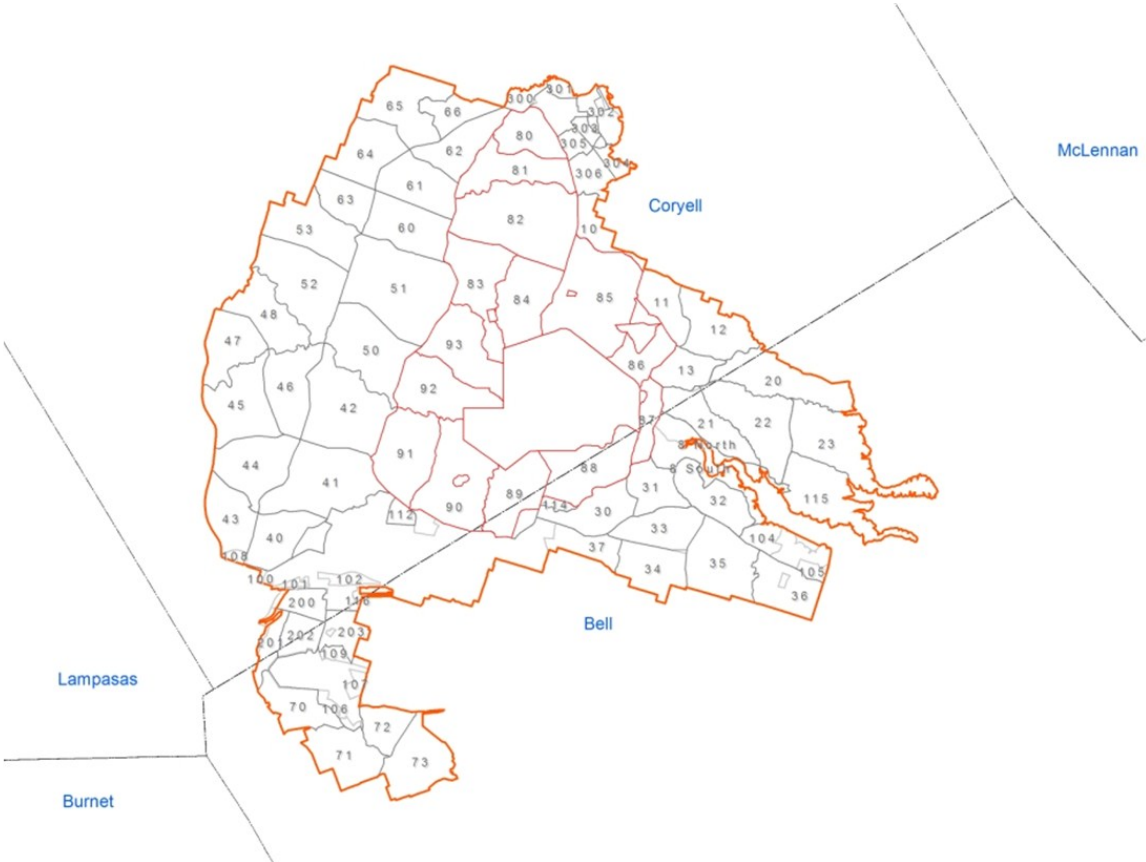
A2. Map of counties where TVMDL diagnosed canine Chagas 2009-2010.

A3. Satellite image of Beto Unit, Texas Department of Criminal Justice, Tennessee Colony, Anderson County, Texas

A4. Satellite image of Anderson Ranch, LLC, College Station, Brazos County, Texas.



A5. Satellite image of Fort Hood, Killeen, Texas



A6. Map of Fort Hood training areas, Killeen, Texas.

A7. Satellite image of Welder Wildlife Refuge, Sinton, Texas.

A8. Map of counties where javelina fleas (*Pulex* porcinus) were collected off of feral pigs, 2008-2011.

VITA

Name:	Anthony Lawrence Schuster
Address:	Texas A&M University Department of Entomology TAMU 2475 College Station, Texas 77843-2475
Email Address:	anthony.schuster@us.army.mil

Education:	B.S., Entomology, Mississippi State University, 1986 M.Agr., Texas A&M University, 1993 Ph.D.., Entomology, Texas A&M University, 2011