SPATIO-TEMPORAL RELATIONSHIPS BETWEEN FERAL HOGS AND CATTLE WITH IMPLICATIONS FOR DISEASE TRANSMISSION

A Thesis

by

AUBREY LYNN DECK

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

MASTER OF SCIENCE

May 2006

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	James C. Cathey
Committee Members,	R. Neal Wilkins
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ABSTRACT

Spatio-Temporal Relationships between Feral Hogs and
Cattle with Implications for Disease Transmission.
(May 2006)
Aubrey Lynn Deck, B.S., University of Tennessee
Chair of Advisory Committee: Dr. James C. Cathey

It is widely recognized that livestock industries are vulnerable to intentional or accidental introductions of Foreign Animal Diseases (FADs). Combating disease is difficult because of unknown wildlife-livestock interactions. Feral hogs (*Sus scrofa*) could harbor and shed disease in areas used by domestic livestock such as cattle (*Bos taurus*). Extent of risk logically depends on spatio-temporal interactions between species. I used Global Positioning System (GPS) collars on cattle and hogs in combination with a Geographic Information Systems (GIS) for detailed analysis on movement patterns of these 2 species on a ranch in southwestern Texas, USA. Motion-triggered video recorders were also utilized to determine interspecific activity patterns. I tested hypotheses that spatio-temporal distributions of domestic cattle and feral hogs on rangeland overlap and that interspecific contact occurs. If these posits are true, it is possible that introduced pathogens like foot-and-mouth disease (FMD) could be transmitted from feral hogs to cattle.

Using a rate of 1 GPS fix/15 min (96 fixes/day), I found that spatial distribution of individual hogs and cattle overlapped on both the 95% and 50% kernel area use among 4 seasons. Both cows and feral hogs used Clay Flat, Clay Loam, and Rolling Hardland more so than other range sites. During Summer 2004, riparian zones were the most used feature, identified at 14% (2,760/19,365) of cattle and 70% (445/632) of hog fixes. Other than brush strips, cattle and feral hogs primarily interacted at riparian zones, fencelines, and roads. There were no direct interspecific contacts evident from GPS data, but 3 cases were recorded from video data. Indirect interspecific contacts that may be sufficient for disease transmission occurred much more frequently (GPS = 3.35 indirect contacts/day, video = cows follow hogs: 0.69 indirect contacts/day and hogs follow cows: 0.54 indirect contacts/day). Research results suggested that both species often travel along the same roads and fencelines to water and food sources, especially during extreme heat and low-precipitation conditions. This research provides basic information needed to improve models for management of FAD outbreaks in the U.S., based on specific knowledge of landscape usage and movement patterns of feral hogs and cattle.

DEDICATION

I dedicate this to our father in heaven and my family as there is nothing more important to me in this world. I would like to recognize my daughter and father who have given me the motivation and desire to complete this challenge in life. I owe thanks to my mother for support through life's obstacles, and my step-father, brother, and my daughter's mother for being the role-models that they are to me.

ACKNOWLEDGMENTS

I would like to thank the members of my committee and the principal investigators for the opportunity to work on this research at Texas A&M University (TAMU). My committee chair, Dr. James C. Cathey, taught me life lessons, many of which had nothing to do with my research or the Texas A&M University System (TAMUS). He recognizes the importance of having a successful professional career and an even more successful family life. Despite a severe physical injury and a grueling healing process, he supervised key points of my research and was vital in the decision making process throughout my time here. Dr. Susan M. Cooper guided me in addressing unexpected data collection issues. Her expertise and diligence were vital to the success of my research. Dr. H. Morgan Scott filled in my gap of knowledge regarding epidemiology, modeling, and wildlife diseases. Dr. R. Neal Wilkins counseled me on the research process, provided office space and other logistical support. Dr. Roel R. Lopez advised me on wildlife movement analysis and telemetry problem-solving. I learned life lessons here at TAMU, many of which came from the guidance of these faculty members.

Additionally, I would like to thank research assistants Shane Sieckienus and Lang Alford, and a fellow graduate student Wally de la Garza, for their crafty problem-solving skills and diligent work in the field. Andrea Wappel entered much of the video data, and her work was important to me and greatly appreciated. Tarah Ailor assisted with data analysis. I would also like to recognize Amy Snelgrove, Amy Hayes, and Lang Alford, for GIS technical support. Lastly, I would like to thank all the staff of both the Department of Wildlife and Fisheries Sciences in College Station, Texas, and of the Texas Agricultural Research and Extension Center in Uvalde, Texas, for helping me overcome administrative hurdles.

Finally, I would like to thank the agencies that provided a platform for my research. Funding for this research was provided by the USDA-Cooperative State Research Education and Extension Service (CSREES). The private ranch where the study was conducted kindly provided property access and the staff provided helpful field support.

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INTRODUCTION

Problem and Justification

The livestock industry is an economic staple of the U.S. economy as it generates a significant portion of our agricultural gross domestic product. According to the U.S. Census Bureau (2004-2005) the livestock industry produced ~$105.47 billion in cash receipts in 2003, 43% of which was accounted for by cow/calf operations. Because there are many allied industries intertwined with the beef industry, the effects of an accidental or deliberate release of a foreign animal disease (FAD) could impact the U.S. economy as a whole. In addition to direct losses to the beef industry, Brown (2001) estimated an additional $27 billion loss to the economy. Labor, packaging, transportation, and advertising account for $0.80 of each dollar spent on food in the U.S. (FEMA 2001).

Exposure to FADs could occur through either intentional or unintentional means. Epidemics could be catalyzed by terrorist attacks with biological weapons (FADs; Bates et al. 2001, Blancou and Pearson 2003). Disease outbreaks could also be facilitated by rapid transportation of livestock among sites during commercial trade (Hutber and Kitching 2000, Bates et al. 2001, Sutmoller and Olascoaga 2002). The probability of a FAD outbreak could be heightened in areas that provide a setting with realistic vulnerability for disease introduction and transmission to occur (Pozio et al. 2001). International borders (Canada and Mexico) and seaports serve as points of entry for the importation of foreign goods and people. Legal importation undergoes a screening

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This thesis follows the style of the Journal of Wildlife Management.

process meant to reduce the potential of disease introduction. However, FAD epidemics are still possible, especially from illegal immigration of people primarily from Mexico and Central American countries, but many others, as well. According to the Center for Immigration Studies (2001), ~8 million immigrants illegally entered the U.S. via Mexico in 2000. Obviously, screening of FADs was not done for these people, their food, or supplies, which places the U.S. at risk.

Foot-and-mouth disease (FMD) is the most costly livestock disease in the world because of its deleterious effects on economically valuable animals (Meyer and Knudsen 2001). The magnitude of this threat is shown by figures of economic losses from the 2001 FMD epidemic in the United Kingdom (UK), where farming and tourism each lost ~$3 billion (Thompson et al. 2002). Australia projected that a FMD outbreak would negatively impact their economy by as much as $3.5 billion (Garner et al. 2002).

Foot-and-mouth disease is caused by a virus (FMDv) with characteristics that make eradication and control costly and nearly impossible. The viral infection is often present at undetectable levels (Thomson 1996) in much of Africa, Asia, and South America where the disease is endemic. The virus is transmitted most commonly through contact with infected animals (Donaldson and Ferris 1975, Gloster et al. 1982, Donaldson 1983). However, it can also be fomite-borne via aerosol, contaminated soil, feed, water, animal excretions, and various byproducts (Meyer and Knudsen 2001, Thomson et al. 2001). The virus is relatively resistant to environmental conditions and can survive outside the host for 3 months in excretions from infected animals (Bartley et al. 2002). It can remain viable for up to 195 days at -17°C in the soil if covered by snow and ice, but as few as 2 days at higher temperatures (≥34°C). Foot-and-mouth disease virus is capable of travel up to 50 km in the air over land by aerosol transmission (Sellers 1971) and up to 300 km over sea (Donaldson and Alexanderson 2002), especially during fall and winter in the temperate zone (Primault 1974).

Foot-and-mouth disease virus is highly contagious to most wild and domestic cloven-hoofed animals (Thomson et al. 2001). Taxonomic orders of known susceptibility to FMD include Artiodactyla, Insectivora, Xenarthra, Lagomorpha, Rodentia, Carnivora, and some groups within Monotremata and Marsupialia. Carriers are not limited to, but tend to be ruminants (Artiodactyla; Terpestra 1972).

Foot-and-mouth disease has varying effects and severity in different species (Meyer and Knudsen 2001). Generally the virus has a mortality rate of 5% in adults and 50% in juveniles. The most devastating economic impact is that pain associated with mucosal lesions such as those found in the oral cavity, nares, and even the coronary bands cause the animal to reduce food intake and become emaciated for several weeks, rendering the animal virtually worthless as an agriculture commodity. Major economic losses are related to the inability to trade internationally in animal and animal products. Biologically, most animals usually recover from the illness with time. However, the cost of the recovery makes the animals financially worthless to the producer.

Within Artiodactyla the families of Bovidae and Suidae are of major economic importance to domestic agriculture. Foot-and-mouth disease is fast acting in cattle and pigs, and they can show signs of the disease 24–48 hrs post-infection. Epidemiological studies have shown that cattle are 10,000 times more susceptible to FMD by means of oral ingestion than respiration (Burrows et al. 1981, Donaldson et al. 1987). Aerosol contamination is thought to require as little as 1 cell-culture dose to infect an animal (Thomson et al. 1984). Infected animals may carry viable infectious particles in the esophagus and pharynx for up to 2 yrs post-infection (Salt 1993, Meyer and Knudsen 2001). If FMDv were introduced into the U.S., livestock would be especially susceptible for an extended period of time, given their low immunity to a novel virus (Salt 1993, Meyer and Knudsen 2001).

Currently, FMD is not in the U.S.; therefore, the U.S. Department of Agriculture (USDA) strictly controls the importation of animals and animal products from areas with FMD (Thomson et al. 2001). Livestock in the U.S. currently holds “FMD-free” status from the International Office of Epizootics and the World Trade Organization, unlike many other countries across the world. The most recent outbreaks of FMD in North America were in 1929 in the U.S., 1952 in Canada, and 1953 in Mexico. Because this disease is widespread, animal health emergency management (AHEM) should be a collaborative effort between local, state/province, national, and international governments (Torres et al. 2002).

Wildlife plays a role in sustaining some disease outbreaks (Anderson et al. 1993, Thomson et al. 2001). However, FMDv transmission by wildlife is poorly understood. Feral hogs would be a prime example of a potentially intractable reservoir of FMD in the U.S. Feral hogs threaten the beef, dairy and hog industries in the U.S. for the following reasons: (1) feral hogs are an invasive and exotic species in the U.S. that could have negative effects on their adopted environment (Singer et al. 1984, Lacki and Lancia

1986, Kotanen 1995, and Arrington 1999), (2) hogs are especially susceptible to FMD and are an efficient reservoir for maintenance and spread of the virus (Wobeser 1994, Donaldson and Alexandersen 2002), (3) FMD is known to be density dependant in some animals (Thomson et al. 2001, Mangen et al. 2002), and for some regions of the U.S. hog numbers are thought to be high (Miller 1997, Taylor et al. 1998), (4) once FMD is observed in feral populations of a given area, eradication could be nearly impossible because feral populations are difficult to control with typical livestock fencing and are highly prolific, allowing an outbreak to become well established (Wobeser 1994), and (5) feral hogs are known to use some of the same areas as domestic livestock (Tolleson et al. 1996).

Along with the impacts on the livestock industry, feral hogs also cause damage to the environment by rooting the soil and decreasing nutrient availability through increasing erosion, altering vegetative structure and composition, decreasing resource availability for native fauna, and decreasing environmental resistance to exotic invasion (Singer et al. 1984, Lacki and Lancia 1986, Kotanen 1995, and Arrington 1999). They are opportunistic generalists that feed based on availability of various food items (Oliver et al. 1993). Feral hog diet in southern Texas encompasses grazing, similar to cattle, and rooting (Taylor and Hellgren 1997). Feral hogs feed on herbaceous forage and prickly pear cactus (*Opuntia engelmannii*) a common resource for cattle, white-tailed deer (*Odocoileus virginianus*), and collared peccaries (*Tayasu tajacu*). Feral hogs also feed on roots and tubers, which are eaten by a wide variety of wildlife.

Environmental resistance of the virus in the soil and the feeding behavior of hogs (rooting of the ground) make the feral hog a high-risk vector candidate. All suids have a high ratio of body weight to foot size and use rooting behavior for feeding. This facilitates the formation of severe sores that burst and spread the disease as they travel (Thomson et al. 2001). In addition, pigs are a likely source of airborne FMD aerosols (Sellers 1971, Wobeser 1994, Donaldson and Alexandersen 2002).

Cattle are some of the most susceptible animals to aerosol infection of FMD (Donaldson and Alexandersen 2002) and direct contact infection. Prediction of airborne transmission is especially difficult because little is understood about how relative humidity, temperature, and daylight affect this process. Feral hogs are a specific threat to the spread of FMD to cattle in the U.S. because of their foraging behavior and their observed, but unquantified, direct contact with cattle.

Feral hogs have one of the broadest geographic ranges of all terrestrial animals (Oliver et al. 1993) and the population is expanding in the U.S. (Figure 1.). They have the highest potential reproductive rate of any ungulate in the U.S. (Singer et al. 1984). A high-density population of feral hogs in the U.S. is of significant concern for livestock owners and wildlife managers (Hanson and Karstad 1959).

Feral hogs have increased their populations exponentially since they were introduced into the U.S. in 1539 as a traveling food source for the Spanish explorers of North America (Hanson and Karstad 1959). Populations in the U.S. are estimated at over 2 million animals in 23 states (Miller 1997). Texas alone has an estimated population of 1.5 million feral hogs (Burns 2004). However, the population is thought to

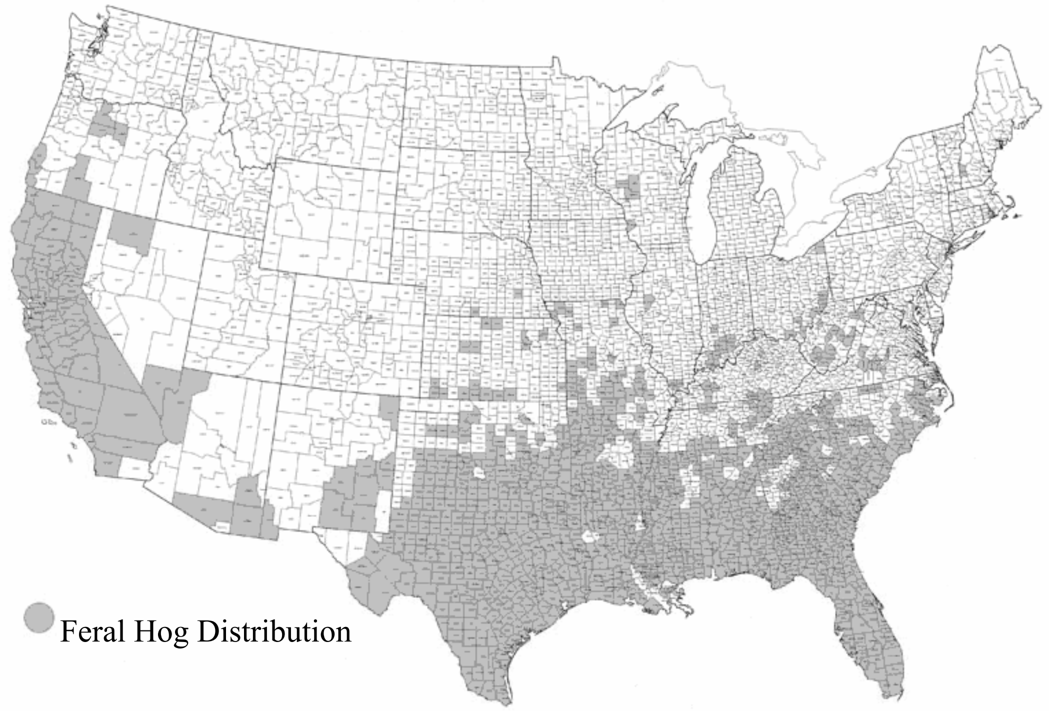


Figure 1. Range of feral hogs, USA, 2004. (modified from the Southeastern Cooperative Wildlife Disease Study, College of Veterinary Medicine, University of Georgia).

have doubled in a short period of time during the 1990s (Burns 2004). Hog presence was reported in 185 counties of Texas accounting for 73% of the state (Rollins 1997; Figure 2). Although the actual number of hogs per unit area is hard to estimate, the density differences between areas are probably representative for current distribution of feral hogs in Texas and Oklahoma (Figure 2.). As feral hog population density increases, potential for disease transmission and other associated problems also escalate.

Once FMD is observed in feral hog populations in a given area, eradication can be difficult because feral populations are difficult to control and the outbreak is often well established by the time it is diagnosed (Wobeser 1994). Foot-and-mouth disease is highly contagious and has subtle signs that cause a delay in the initial diagnosis (Bates et al. 2001). In addition, there is a latent period between infection and clinical symptoms. If there is such a delay in an area with a dense population of reservoir hosts few contacts are necessary for successful disease transmission. This could lead to rapid spread of the disease over a large geographic area. Australian researchers modeled a hypothetical FMD outbreak in the Blue Mountains near Sydney using feral hogs as a maintenance host. They predicted that 2,002 infections would likely occur among hogs over a 7-month period before diagnosis (Hone and Pech 1990). If such an outbreak were to occur in the U.S. today, the thriving feral hog population (Hone 1983*a*) might maintain the disease in feral populations.

Feral hog populations are often difficult or impossible to manage on a large scale. Since control of susceptible animal movements is the major basis of an effective disease control program (Bates et al. 2001), this is potentially problematic. Feral hog

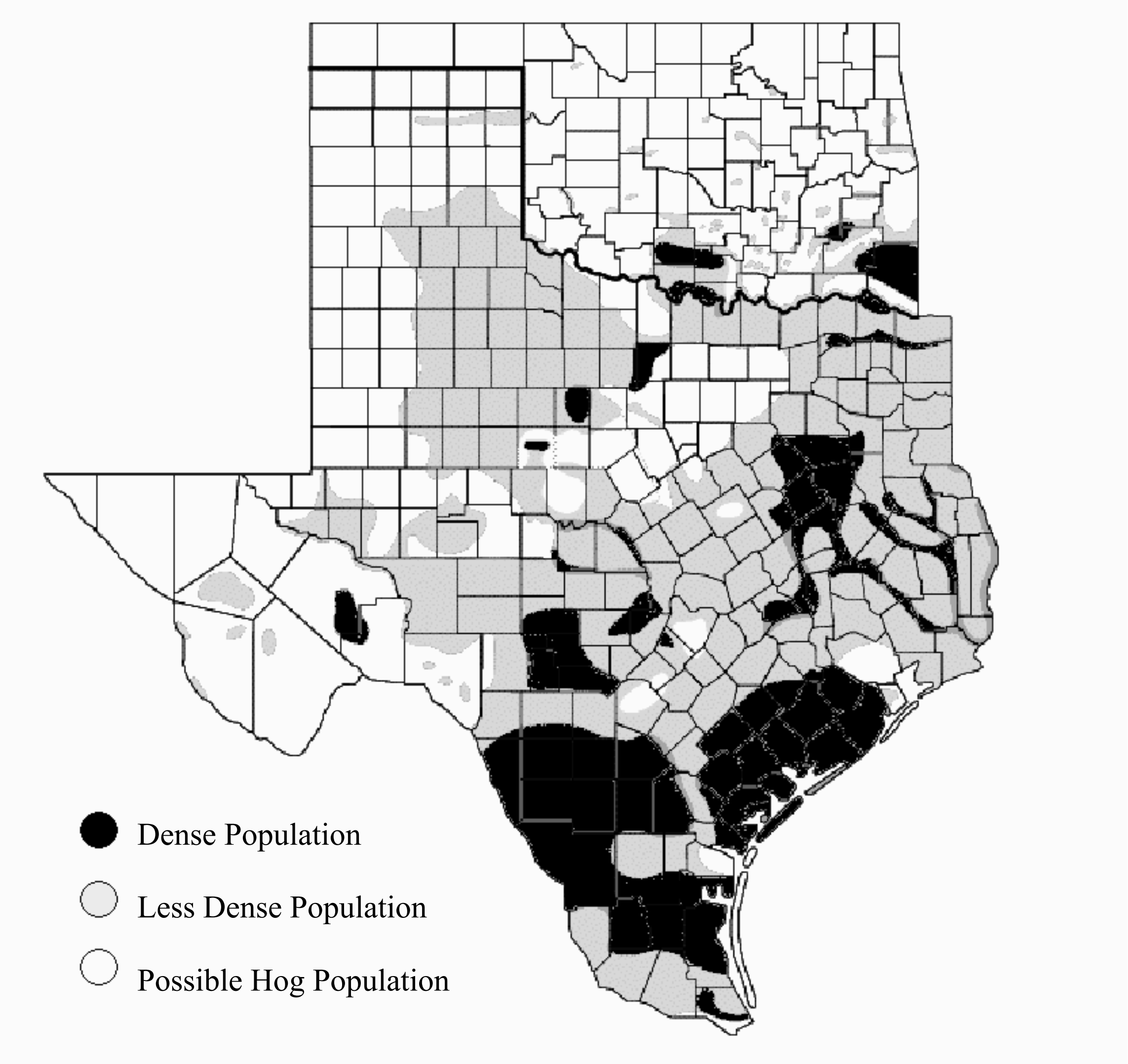


Figure 2. Feral hog density, Texas and Oklahoma, USA, 1999 (modified from the Samuel Roberts Noble Foundation, Inc.).

movements are largely driven by forage availability and climatic conditions. Groups (known as sounders) of females and young generally have common home ranges with separate movement patterns (Ilse and Hellgren 1995). Adult males (boars) are usually solitary unless they are momentarily imbedded within a sounder group for breeding purposes. Movement characteristics and the density of the population make control of feral hogs difficult because there is no single time of year or universal attractant that would consistently cause large numbers of pigs to congregate.

Feral hogs are known to use some of the same areas as domestic livestock (Tolleson et al. 1996). Feral hogs wallow in watering areas for cattle including livestock ponds and overflow areas. They feed with livestock in irrigated crop fields and hay lots. However, the frequency of interspecific overlap is unknown. Identification of overlap in movement is the initial step required to develop and refine useful and valid models of transmission (Bates et al. 2001). To model FMD, knowledge of the diffusivity of the disease (known) and contact rates of potential hosts (unknown) are needed (Pech and McIlroy 1990). In order to formulate an emergency response action plan, specific knowledge of the frequency and occurrence of feral hog and cattle interaction needs to be acquired, along with features (e.g., climate and landscape) affecting movement, land use, and interaction.

Because feral hog populations are extremely difficult to control, traditional methods of FMD outbreak management may be ineffective, unfeasible, or impossible to implement successfully. Traditional emergency action plans would incorporate separating livestock and wildlife by fencing, and/or killing all infected and susceptible livestock within a specified radius of the outbreak. Furthermore, actions like vaccination and quarantine of uninfected animals (Jansen 1969, Thomson et al. 2001) within an additional buffer zone may be warranted. These efforts are meant to eliminate all direct and indirect sources of infection (Bates et al. 2001). However, FMD has multiple serotypes (types A, O, C, Asia 1, and SAT 1-3 with 60+ subtypes) making successful immunization coverage with vaccine extremely difficult to achieve (Bates et al. 2001). Populations cannot be effectively separated if feral hog numbers are not controlled and their movements are not better understood.

Additionally, the epidemiology of FMD outbreaks is difficult to predict when wildlife is involved. Wildlife movements vary by ecosystems and climates. Ecological and economic factors also need to be considered in every region to devise an effective management response plan (Morris et al. 2002).

Parameters needed to estimate the probability of herd-to-herd transmission include but are not limited to the following: direct and indirect contact rates of potentially exposed and susceptible wild and domestic animal hosts (Bates et al. 2001), and spatio-temporal distribution of susceptible animals in varying topography and climate, for all important host species present in a region. This information is required to create a realistic model in order to predict the geographic spread of FMD effectively, and formulate subsequent emergency response protocols to minimize economic losses. This is accomplished by assigning priority areas and designing optimal surveillance and prevention strategies based on how often interspecific contact occurs.

Hypothesis and Objectives

I hypothesize that cattle and feral hogs will demonstrate spatio-temporal overlap of their distributions and interspecific contact on rangeland in southwestern Texas.

Objectives.--The following objectives produced helpful information for modeling the spread of FMD from feral hogs to cattle in southwestern Texas.

(1) Determine spatial distribution and areas of overlap between cattle and feral hog on rangeland in southwestern Texas.

(2) Determine the influence of natural land features on feral hog and cattle movement (i.e., range sites and riparian zones)

(3) Determine the influence of anthropogenic land features on feral hog and cattle movement (i.e., fences, roads, center pivot irrigation pastures, food plots, water troughs, mineral feeders, and livestock ponds) and activities (i.e., supplemental feeding of cattle and deer).

(4) Determine direct and indirect contact rates for feral hogs and cattle in relation to anthropogenic and natural features by season and time of day.

(5) Synthesize objectives 1-4 to determine the habitats, seasons, and other circumstances that may increase the likelihood of interspecific contact.

METHODS

Study Area

My research was conducted on a private ranch near La Pryor, Texas, in Zavala County in southwestern Texas (Figure 3). The ranch was chosen because it represents a typical habitat for rangeland in the South Texas Plains eco-region. The elevation is from 168–253 m above sea level (Stevens and Arriaga 1985). Topography was primarily flat with some gently rolling hills. Small drainages were interspersed throughout the landscape, although usually dry because of frequent drought. The region is subtropical with mild winters and hot summers (Stevens and Arriaga 1985). Temperature averages range from 12.8ºC (average daily minimum) in the winter to 36.1ºC (average daily maximum) in summer (Stevens and Arriaga 1985). The long term average rainfall is ~55 cm/yr with peaks in the fall and spring (Stevens and Arriaga 1985). Range sites on the ranch vary from Clay Loam to Sandy Loam soils (Stevens and Arriaga 1985). The plant community was dominated by semi-arid brush species, consisting largely of honey mesquite (*Prosopis glandulosa*), guajillo (*Acacia berlandieri*), and prickly pear cactus (*Opuntia lindheimeri*). Drainages had mixed brush species including Texas persimmon (*Diospyros texana*), live oak (*Quercus virginiana*), and whitebrush (*Aloysia gratissima*). Ruthven et al. (1993) provides a more detailed description of common vegetation in this region.

The study site provided a large (34,000 ha) landscape to conduct research and also had a beef cattle operation and a wildlife hunting enterprise. Feral hogs were

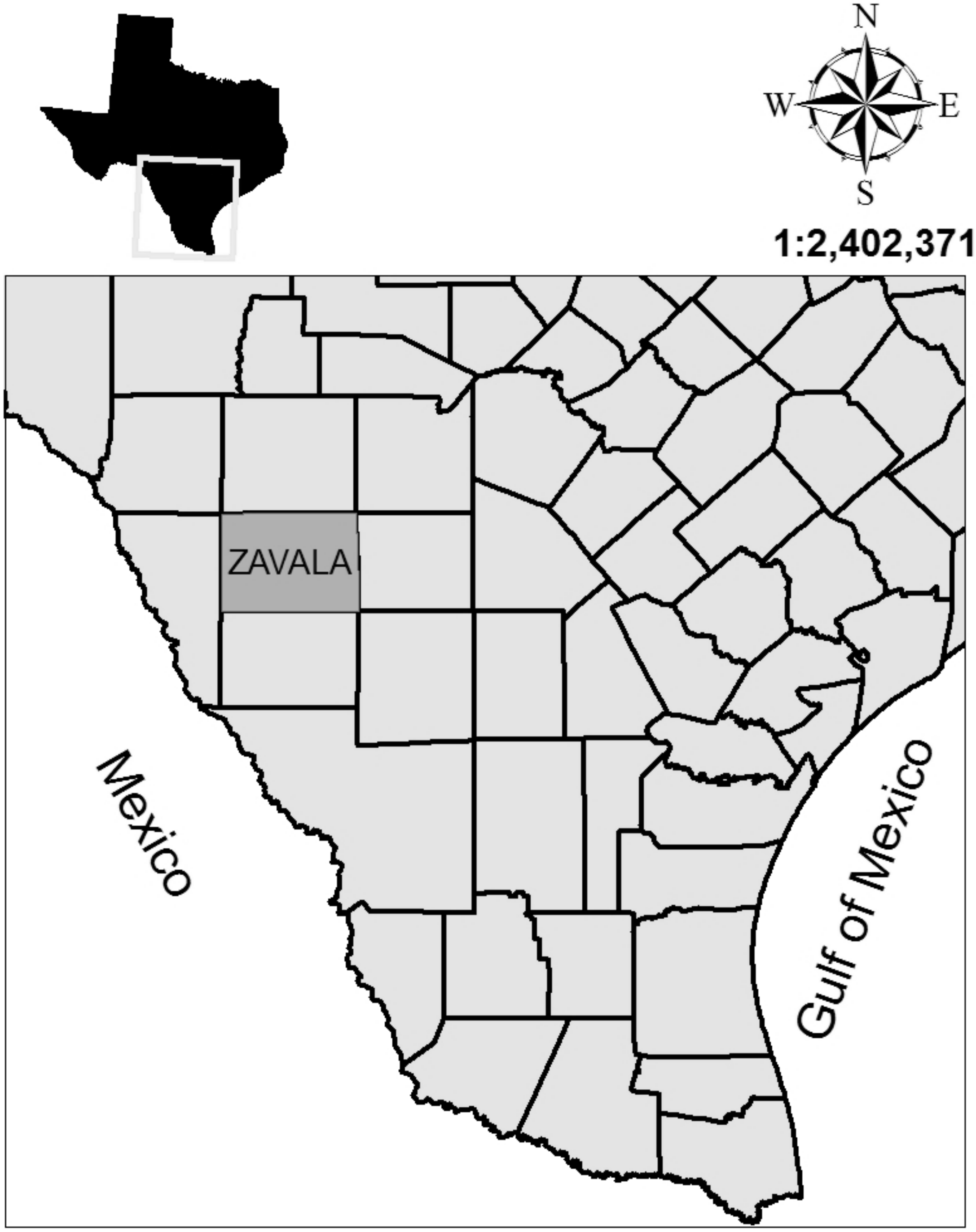


Figure 3. This investigation was conducted on a private ranch in Zavala County, Texas, USA, 2004-2005. Habitat was representative of much of the South Texas Plains eco-region.

commonly observed by ranch personnel. The ranch had 13 center pivot irrigation systems on cultivated land or improved pastures, 16 creek drainages, numerous stock ponds, deer feeders, and food plots (Figure 4). Irrigated crops were planted in October with oats, rye grass, and perennial bermuda grass; all but the perennials were disked in May. Food plots were planted with oats and triticale under the same planting timeline.

The cattle operation supported ~1,000–head cow (F1 Brahman Hereford cross-breed) herd, and 6,000-8,000 stockers. These total numbers differed among seasons and years. Stocker herds were not used in this study. Cattle were split into ~12 cow-calf or stocker herds and pastured on areas ranging from 800 acres (350 ha) to 4,800 acres (1,900 ha). Data collection took place in different pastures ranging from ~435 ha (1,074 acres) to ~1,476 ha (3,647 acres) during seasons in mid 2004–mid 2005 (Appendix A.1).

GPS and Video Equipment Description

Spatial and temporal movement data were collected to learn where and when cattle and feral hogs used the landscape and how movements could facilitate disease transmission. Most telemetry studies do not need detailed temporal data, but all seek detailed (accurate and precise) spatial data. To understand the potential of disease transfer, I used GPS-equipped collars to identify ecological landscape features (anthropogenic and natural habitat) used by these 2 species, and acquire more accurate and precise interspecific contact rates (Fancy et al. 1988, Moen et al. 1997).

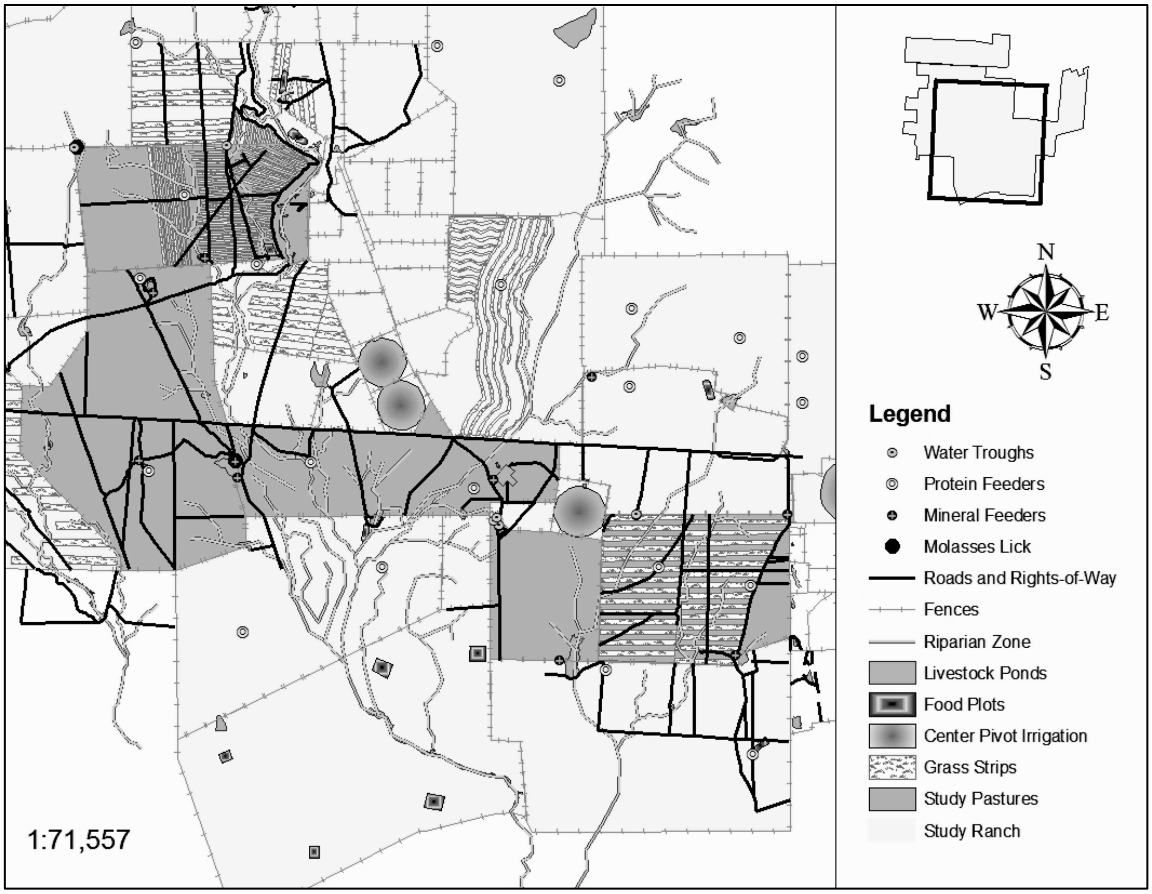


Figure 4. Study site including natural and anthropogenic land features, Zavala County, Texas, USA, 2004–2005. Habitat was representative of much of rangeland in the South Texas Plains ecoregion.

Cattle were able to carry larger collars capable of running 12 weeks on 1 set of batteries, but hogs required smaller collars and equipment because of their size. This restricted data collection deployments to ~2 weeks per hog. This equipment was used to monitor areas where feral hogs and cattle frequented, how often they were in proximity to each other sufficient for disease transfer, and where and when those contacts occurred. To accomplish this, run-time interval selected for GPS coordinate acquisition was 1 observation every 15 min. Twelve GPS collars, (8) L200 series for adult/sub-adult feral hogs and (4) L400 series for adult cows (Bluesky Telemetry™, Aberfeldy, Scotland) were used. The L200 series collars used 2 AA 1.5-volt batteries while the L400 series cattle collars used 2 AA 1.5-volt and 2 C 1.5-volt batteries to power the GPS units.

Recent advances in wildlife monitoring equipment (motion-triggered video recorders with a time/date stamp and GPS) provide an excellent platform to examine detailed spatial animal movement patterns, habitat selection, and interspecific contact. I used 3 automated motion-triggered infrared video recorders (TrophyCam ®, Springtown, Texas, USA) powered with 12-volt marine cycle batteries and recorded data on 8-hr video home system (VHS) tapes. Video recorders were placed in areas where interspecific contact between cattle and feral hogs was deemed likely to occur. When in use, the cameras were checked for battery life and remaining available tape every few days and replaced when necessary.

Capture and Handling of Animals

Pasture Selection.--Pasture selection was based on forage availability and rainfall patterns among pastures. The ranch foreman made cattle stocking decisions, thus dictating where hog trapping was done. After consulting ranch personnel, hog traps were built near locations feral hogs were known to frequent. They were also placed near prime locations (i.e., livestock ponds, food plots, and riparian drainages), as identified from aerial photography and GIS layers. Final determination to place a trap was based on fresh hog sign (i.e., scat, rooting, and tracks).

Trapping.--Feral hogs were baited and captured into box and corral traps with a spring-loaded door-mechanism (Figure 5). Several baits were used to maximize trap success including sweetened, soured, or shelled corn, and fruits and vegetables. Trap doors were rigged to allow additional pigs to push their way into the trap after the first pig tripped the mechanism. Corral traps were round or oval shaped using 2-3, 6.09 m (20 ft) X 1.22 m (4 ft) cattle panels supported by iron posts driven into the ground. There was no roof on the corral traps, giving non-target species like white-tailed deer a means of escape. Box traps had steel-welded frames in a rectangular shape with cattle-panel mesh siding. Box trap dimensions varied, but were ~1.22 m (4 ft) X 1.22 m (4 ft) X 2.44 m (8 ft).

Drug Immobilization.--When drugs were administered for immobilization, a jab-stick was used to inject a mixture of Telazol® (tilitamine and zolazepam; Wyeth Holdings Corporation, Carolina, Puerto Rico) dissolved in Rompun® (xylazine HCl; Bayer Health Care, Leverkusen, Germany; 5 mg in 5 ml). Immobilization followed the guidelines of Gabor et al. (1997) with the dosages altered for 3 mg (mixture)/kg of body weight. Authorization to use these drugs was provided by the U.S. Drug Enforcement Agency (DEA) registration number RC0297273.

Figure 5. Box (top) and corral (bottom) traps used to capture feral hogs in Zavala County, Texas, USA, during 2004-2005.

Collar Set-Up.--Initialization of the collars included battery placement, remote infrared linking of the GPS unit to a laptop computer, and downloading run-time settings for the collar (using DataTrax ™ software, Aberfeldy, Scotland). The collars were tested for accuracy prior to use and initialization was done in the field just prior to fitting the animal with the collar to maximize data collection quantity by saving battery life.

Animal Processing and Release.--Animals were ear-tagged to aid in the identification of samples in the field and to prevent collaring the same animals in subsequent seasons. However, due to limited trap success 2 and 1 pigs were recollared during the Fall 2004 and Spring 2005, respectively. Feral hogs were tagged with button-style tags to reduce the chance of the tag catching on brush and coming off of the animal.

Sex and age of the feral hogs were determined to identify trends of movement and contact rates between specific groupings of feral hogs with cattle. Generally, cattle move in herds so all cows used within a data collection season were expected to have similar movement. However, feral hog sounders (multiple females and young) generally have common home ranges with separate movement patterns than that of adult males (boars; Ilse and Hellgren 1995). Boars are usually solitary from other hogs unless breeding. Therefore, it is possible that boars would interact differently with cattle than sounders do among seasons.

Sexing and aging hogs were done by visual inspection, while chest girth and neck circumference, withers, and body length were measured and compared to approximate weights then used to assign pigs to age-class. Age-class categories were divided into juvenile, sub-adult (shoats), and adult (female sows and male boars).

Juveniles were not used in this study because the collars were too large to fit them without hampering their ability to move. Sub-adults were defined as ~23-41 kg and/or 109-119 cm long from snout to the base of the tail. Adult weights ranged from ~41-95 kg and length from 125-142 cm.

Each animal in this study was processed using the guidelines set forth in Texas A&M University Laboratory Animal Care and Use Committee animal use protocol number 2002-380. Animal behavior bias due to the collars was assumed to be eliminated because both collar models weighed < 5% of the designated animal's weight (White and Garrott 1990). Cattle were gathered by the private ranch staff and processed in a chute. Cows were fitted with a pre-initialized GPS collar and marked using ear tags.

Data Analysis

Seasons.--My primary objective was to describe trends in location where potential disease transmission might occur and the conditions that could facilitate it. Data were collected during 4 different seasons through the course of a year. I defined a season as the time between the earliest and latest animal deployments within a data collection period. The first data collection season (Summer 2004) lasted 60 days, from late-July to mid-September, 2004. The second season (Fall 2004), which lasted for 60 days was in late-September–late-November. The third season was the coolest of the 4 and had comparable rainfall to the previous season. Data were recorded for 54 days in early-February-late-April (Winter 2005). The last and fourth season was the longest (73 days) and lasted from late-April–early-July (Spring 2005).

Time of Day.--Feral hogs are known to be most active at night and/or crepuscular periods based on climate and food availability (Stevens 1996). Time of day was split into 4 categories to establish trends, including 3 night categories evenly distributed in time, with the remainder of the day defined as daytime. Categories for time of day were represented by sunset, peak of night, sunrise, and daytime. Sunset (sunset to night) began 2 hrs before official sunset. Peak of night was between the first and third night categories. The third segment (night to sunrise) ended 2 hrs after official sunrise. Daytime category was defined as the time between 2 hrs after sunrise and 2 hrs before sunset. Official sunrise and sunset times are based on data from the U.S. Naval Observatory. The latest sunrise and the earliest sunset within each data collection season was used to define these parameters. Temporal parameters were considered for habitat and anthropogenic infrastructure use and interspecific contact analysis.

Ninety-Five and 50% Kernel Area Use Analysis of GPS Data.--The goal of this analysis was to describe trends of how often feral hogs and cattle use similar areas and to identify the attractant to those locations. All 95% kernel area use analyses were calculated using the Hooge and Eichenlaub's Animal Movement Extension (USGS, Anchorage, Alaska, USA, 1999) to produce fixed kernel volume utilization distribution estimates in a GIS program (ArcView 3.3®, Redlands, California; Lawson and Rodgers 1997).

Ninety-five percent and 50% kernel area uses designate those proportions of GPS fixes for each animal's movement on the landscape. These calculations were based on algorithms that did not consider limiting variables like fencelines. Feral hogs had unimpeded travel throughout the landscape, but the cattle were limited to movement within fenceline boundaries. In addition, the battery life on cow collars generally was 6 times longer than hog collars. This was considered during interpretation of results despite the software's occasional inclusion of areas outside fencelines, and varying temporal ranges of deployments. Ninety-five percent and 50% kernel area uses were calculated for each animal such that interspecific comparisons could be made with respect to the occurrence and location of overlap and subsequent potential disease transmission.

Natural Habitat and Anthropogenic Infrastructure Use Analysis of GPS Data.--This analysis builds on the previous in that the objective was to describe trends of specific areas used within the 95% kernel area uses of feral hogs and cattle. I evaluated usage of natural habitat areas, as well as anthropogenic infrastructure.

Natural habitat areas evaluated for frequency of visitation included range sites and riparian zones. Range sites were defined by the USDA soil survey (Stevens and Arriaga 1985). Riparian zones were traced from a 2004 USDA aerial photo (1 m resolution) of the study site in GIS (ArcView 9.1 ®, Redlands, California). Identification of riparian areas on the photography was based on dense vegetation lines that connected to the creeks.

Anthropogenic infrastructure included the following: protein feeders, mineral feeders, water troughs, molasses licks, hog traps, ponds, food plots, center-pivot irrigation pastures, alternating maintained brush/grass strips, fencelines, and roads/right-of-ways. Deer protein feeders were not expected to have a high frequency of visitation because they were double fenced and checked regularly by ranch staff to ensure minimal non-target usage. Mineral feeder, water trough, molasses lick, and hog trap locations were identified using a WAAS enabled Trimble TSC1 GPS unit (+/- 1 m accuracy). Their coordinates were post-differentially corrected to maximize accuracy. Remaining infrastructure were traced similar to the riparian zones. Roads and right-of-ways that were adjacent and parallel to fencelines were not traced, as animal fixes in those vicinities were counted as fenceline use.

Geographic Information Systems were used to evaluate habitat and anthropogenic infrastructure usage. To determine range site use, ArcView 9.1 (ArcView 9.1 ®; Redlands, California) was employed to display the range site layer and count the number of GPS fixes in each range site. A similar process was applied to calculate how often animals frequented the remaining anthropogenic and natural habitat feature classes.

Anthropogenic infrastructure features were also analyzed by counting the amount of GPS fixes within (or sometimes around) their perimeter. However, because (1) the 1 m resolution of the digital photos could have resulted in human error of tracing the feature boundaries, (2) some error was possible in the GPS position fixes, and (3) observations could have been on either side of some features, a buffer was added to the features. All observations within these buffers were defined as feature usage.

Because the definition of the boundary between these features was relative to scale, buffers were set conservatively. Point-feature buffer sizes were slightly different. Protein feeder buffers were set at 25 m to extend beyond the double fence around them. Even if feral hogs and cattle could not access the feeders, they might still have attracted animals to the site. Mineral feeders and molasses licks were occasionally knocked around and subsequently moved 1–2 m at a time by cattle. Water trough and hog trap dimensions differed slightly. To account for variation in spatial dimension and potential GPS error the mineral feeder, molasses lick, water trough, and hog trap-use analysis were analyzed with a 10 m buffer.

Polygon and line feature-usage was buffered under different criteria. Center pivots, food plots, and brush/grass strip-use analysis (polygon features) were calculated with a 5 m buffer to account for some GPS position fix error, while not compromising the proper identification of the feature used. Fencelines and road right-of-ways were represented by lines in GIS because they are not wide enough throughout the study site to define all boundaries with a polygon.

Fenceline, roads and right-of-ways, and riparian zones differed in width throughout the study site. Consequently, fenceline and road right-of-way feature buffers were set at 10 m to account for GPS error (field tested to 8 m error) and feature width variation. Width of riparian zones had much more deviation of feature width among pastures and was calculated using different buffer sizes for creeks or streams for each study pasture to account for this variation (Figure 6). In Summer and Fall 2004, analyses used a riparian buffer size of 50 m, while the Winter and Spring 2005 a 100 m buffer was used. This process was repeated for each animal deployment in the study and all feature locations.

Contact Analysis of GPS Data.--I defined potential disease transmission as the occurrence of direct and indirect contact. For instance, if a feral hog fed with cattle from

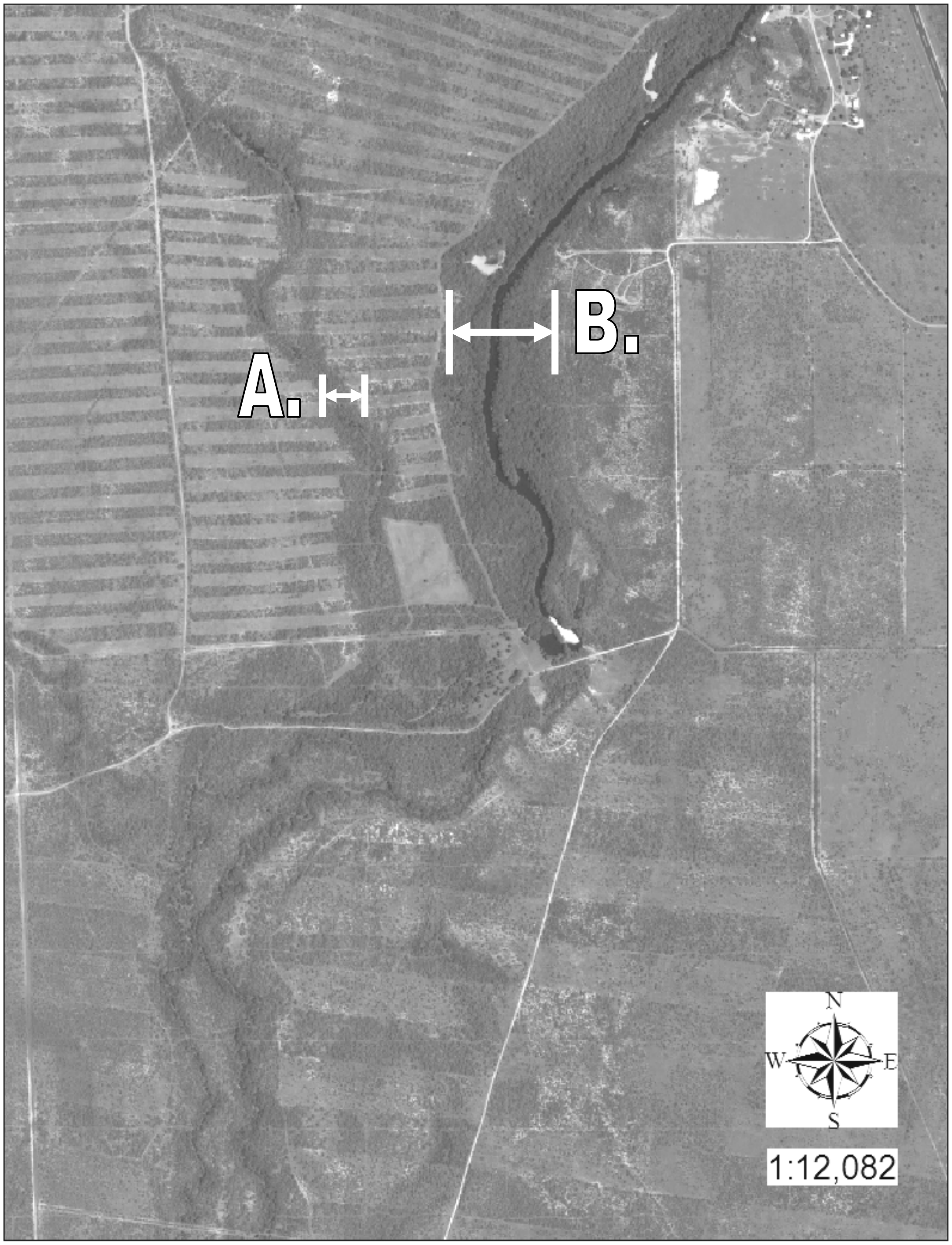


Figure 6. Riparian zones showing width differences, ranging from ~50 m (A.)-250 m (B.). This image is an infrared aerial photo of the private study ranch, Zavala County, Texas, USA, 2004.

the same trough at the same time, they had direct contact. Similarly, if a feral hog fed from a trough within a certain amount of time previous to a cow feeding at the same trough (and *vice versa*), it was defined as an indirect contact. Either case provides potential to transmit disease. Assessment of the potential for disease transmission between species (interspecific contact) was analyzed between cattle and feral hogs. However, the analysis of intraspecific contact within a feral hog population was also helpful to further our understanding of the real potential for hogs to act as a reservoir and propagating species for FMD. Intraspecific contact among cattle herds was not a primary concern, as they are managed in well defined herds. Interspecific contact was my primary focus for indirect fomite-borne transmission. However, both interspecific and intraspecific contacts were calculated for direct (nose-to-nose) transmission.

To evaluate direct contact between any 2 deployments, I accounted for animals being in the same place at the same time. Distance of 1 m could allow nose-to-nose contact that might facilitate direct disease transmission. However, a 10 m buffer was used to define this contact to allow for some GPS accuracy error. The collars were field tested *a priori* to produce GPS coordinates that were accurate to within +/- 8 m of a true geographic location. The smallest time component that observations could be compared was 15 min because of limitations of GPS equipment position fix rate. To compare direct contact at the exact same time, GPS collars would need to record observations each sec, which would exhaust the batteries in only a few hrs. Currently, collars are capable of processing and recording a GPS fix every 30 sec. Despite the argument of scale a direct spatio-temporal contact was defined as 2 animals within 10 m and 15 min of each other.

To calculate the frequency of direct interspecific contact, observation times were first aligned between deployments to within 15 min of each other in a spreadsheet. Because the time to collect a GPS fix varied among samples, I occasionally excluded points from analysis to temporally align direct contacts. The distance formula, $d=[(x_2-x_1)^2+(y_2-y_1)^2]^{1/2}$, was then used to calculate the distance between interspecific GPS fixes. Average distances were subdivided by season, time of day, and hog age-class.

Boxplots were produced using statistical software SPSS Inc. 11.5.1. (SPSS 2002) to identify patterns of close contact. The upper and lower whiskers of the box plots represent the corresponding interquartile ranges (25% of the distances measured, each). The box represents the middle 50% of data from the range of distances measured. The horizontal black line inside the box represents the median. These plots illustrate the distribution of all measured distances.

Identifying indirect interspecific contact with the GPS data required fewer steps to prepare the data for analysis. These fixes did not need to be aligned temporally to calculate contact. Indirect contacts were defined as those within 10 m (for GPS and video data) and recorded within 24 hrs (for video data) of each other during a given season. Indirect contact was assessed using Hawth's Analysis Tools version 3.21 (Beyer 2004) in GIS (ArcView 9.1 ®; Redlands, California) to measure the distance between 2 animals' GPS fixes. The output was a table of the minimum, maximum, average, and standard deviation, of the interspecific distance between those individual animal fixes. I then calculated the minimum of all the minimums to give the shortest distance and the median of the averages to report the most common average distance among all animals in the study.

Distances that met the criteria of a direct contact were reported as a rate of the number of contacts per number of days of interspecific temporally aligned data taken per season. Indirect contacts were reported as the number of contacts per total number of days data was recorded per season. The total number of data collection days for cattle, which include hog data collection days in most cases, was used as the denominator to calculate contact rates because every time a cow came into contact with an area that hogs visited (a potentially contaminated area), interspecific indirect contact may have facilitated disease transmission. This information served as a quantitative analysis of interspecific contact rates.

Activity Times and Group Size of Feral Hog Using Video Data Analysis.-- Motion-triggered infrared video recorder data were used to measure time of day that hogs were active, hog group size, age composition, and duration of stay in a given location. Video recorders were placed near prime locations like food plots, water troughs, riparian zones, livestock ponds, and protein feeders to record hog and cattle activity. When tapes were reviewed, each animal was identified if possible, as well as the time and date they came and left. Often, the same number of juvenile and adult animals would be recorded in a short period of time. When this occurred, animals within 5 min of each other were counted only once. Feral hog age was based on size similar to the methods used in the collaring protocol. In addition, the analysis of duration of stay was only completed for Winter 2005 and Spring 2005 because the time animals left the recorder view was not logged for the first 2 seasons.

Contact Analysis of Video Data.--Video recorders were used to assess the frequency of interspecific indirect and direct contact. Each time a hog or cow visited the video recorder site, the time and date were noted. The difference of time between their visits was calculated and defined as indirect contact. Occurrence of both species present in the same frame was counted as direct contact. Both direct and indirect contacts were reported as the rate of the number of contacts per number of successful days of data taped in a season (number of contacts per total days of data per season). This information served as qualitative supplemental data to the GPS contact analysis.

RESULTS

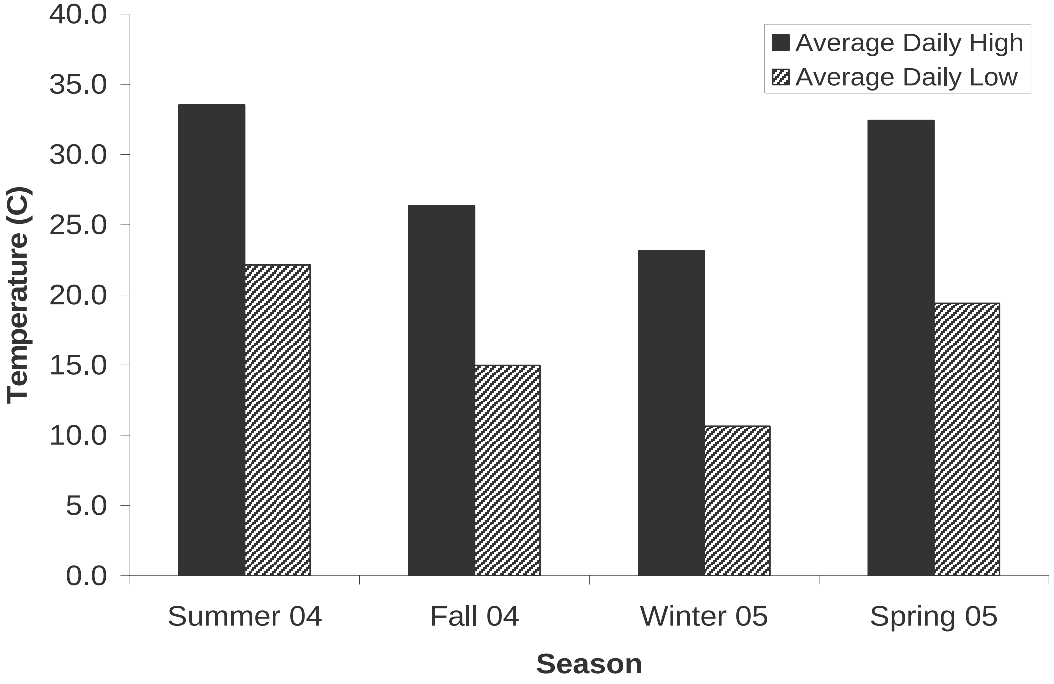
Season Description

Climatic conditions affect FMDv survival outside the host and thus the risk of disease transmission. The first data collection season (Summer 2004) lasted 60 days, from late-July to mid-September, 2004. Temperature was normally hot, with an average daily temperature range of 22 -34°C (Figure 7). Precipitation, however, was abnormally wet with a total of 10.9 cm (Figure 8). As a result, the first data collection season represented hot and wet conditions with relatively lush vegetation and ample water supply.

The second season (Fall 2004) represented cooler and wetter conditions with less abundant vegetation because of fall defoliation (late-September-late-November). Temperatures were moderate over the 60-day deployment with an average daily temperature range of 15 -26°C. Additionally, there was almost 5 cm more rainfall in the second season than the first at 15.1 cm, also representing wetter than normal conditions.

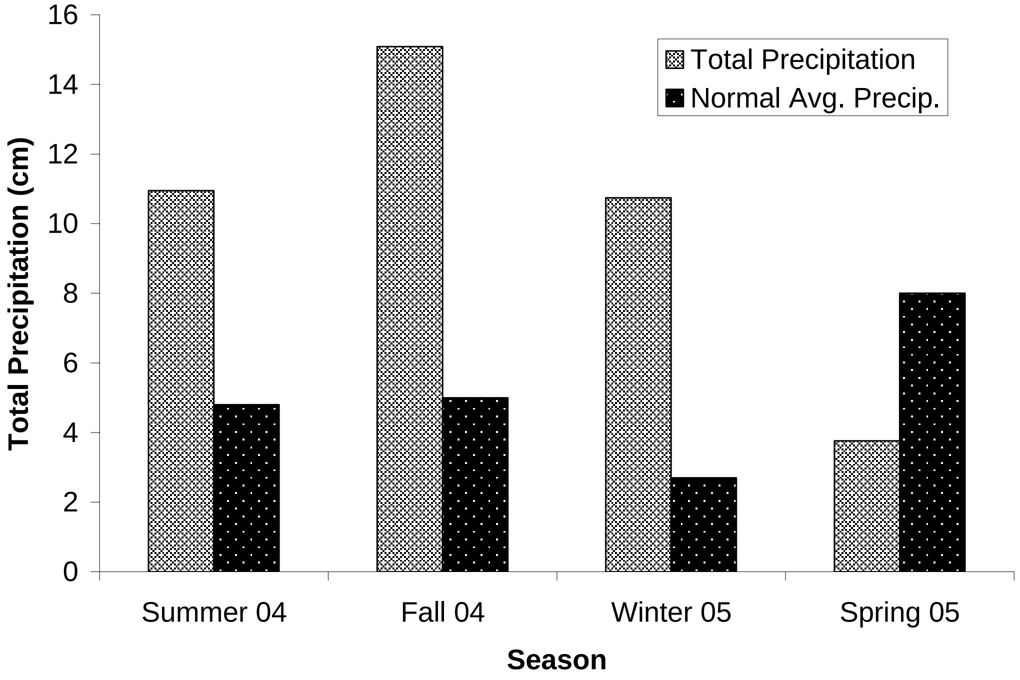
The third season (Winter 2005) was the coolest of the 4 and was wet compared to normal amounts of rainfall. Over the 54-day deployment from early-February-late-April the average daily temperature ranged from 10.7 -23°C, and the total precipitation was 11 cm. As late-winter-mid-spring months were represented, vegetation was transitioning from dormant and less forage to more productive spring growth.

The last data collection season (Spring 2005) in late-April-early-July (73 days) was hot and the daily temperature ranged from 19.4-32°C, and rainfall was lower at



Days (N) -	60	60	54	73
Dates -	22 July-19 Sept. 2004	28 Sept-26 Nov. 2004	4 Feb.-19 April 2005	20 April-2 July 2005

Figure 7. Seasonal temperatures from an on-site weather station on the host ranch in Zavala County, Texas, USA, during 2004-2005.



Days (N) -	60	60	54	73
Dates -	22 July-19 Sept. 2004	28 Sept-26 Nov. 2004	4 Feb.-19 April 2005	20 April-2 July 2005

Figure 8. Seasonal precipitation from rain gauge data on the host ranch in Zavala County, Texas during 2004-2005. The Summer 2004, Fall 2004, and Winter 2005 seasons were unusually wet, while the Spring 2005 season was unusually dry compared to normal regional climatic conditions (based on National Climatic Data Center data from 1971-2000).

3.8 cm. This climate produced less herbaceous forage and water availability compared to the first season.

GPS Data

Throughout the study the number of position fixes for individual hogs was less than that of cattle due to lesser battery capacity of the collars, greater difficulty in catching feral hogs and the lower fix rate due to hogs frequenting denser vegetation. Global Positioning System data acquisition success was not uniform across seasons. In Summer 2005, data were collected for 4 cows and 2 hogs with the number of fixes ranging from 1,912–5,831 and 287–344, respectively (Appendix A.1). Fall 2004 had better data consistency with 3 cow and 5 hog samples (7 hog deployments because 2 hog samples were used twice) with 3,853–4,277 and 164–798 observation ranges, respectively. Winter 2005 included 3 cows and 6 hogs with a range of observations from 6,545–6,946 and 142–1,154, respectively. Although Spring 2005 had the most samples (N=9), the data were the least complete. There were 10 deployments from 9 hog samples as 1 was collared twice. Observation numbers ranged from 195–5,666 and 73–541 for cows and hogs, respectively. Refer to Appendix A.1 for detailed GPS data acquisition information.

Ninety-Five and 50% Kernel Area Use Results.--In the context of this study 95% kernel area use refers to the area used by the animal while collared and should not be confused with total annual 95% kernel area use. Ninety-five percent kernel area use and 50% kernel area use size varied greatly by deployment throughout the study (Figures 9-11). Interspecific 95% kernel area use size differed the least in the Fall 2004 and

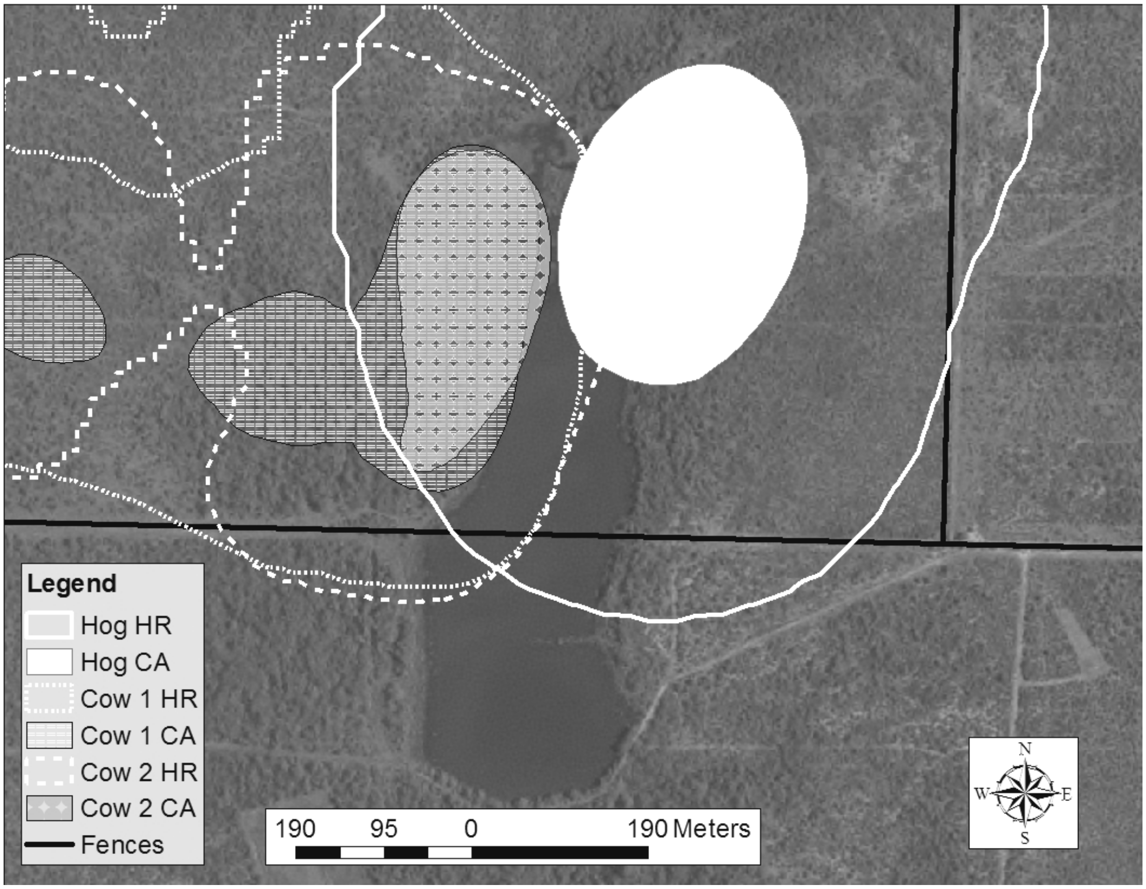


Figure 9. Interspecific spatial overlap of 2 cow (Cow 1 and 2) 95% kernel area uses with a hog's 95% and 50% kernel area use in Zavala County, Texas, USA, during Summer 2004. Cow 50% kernel area uses were within ~40 m and 70 m of the shoat 50% kernel area use. All 50% kernel area uses in this image were adjacent to a livestock pond. The 95% area use of the cows and hog are depicted by dashed lines and a solid line, respectively. Legend abbreviations are as follows: HR = 95% kernel area use and CA = 50% kernel area use.

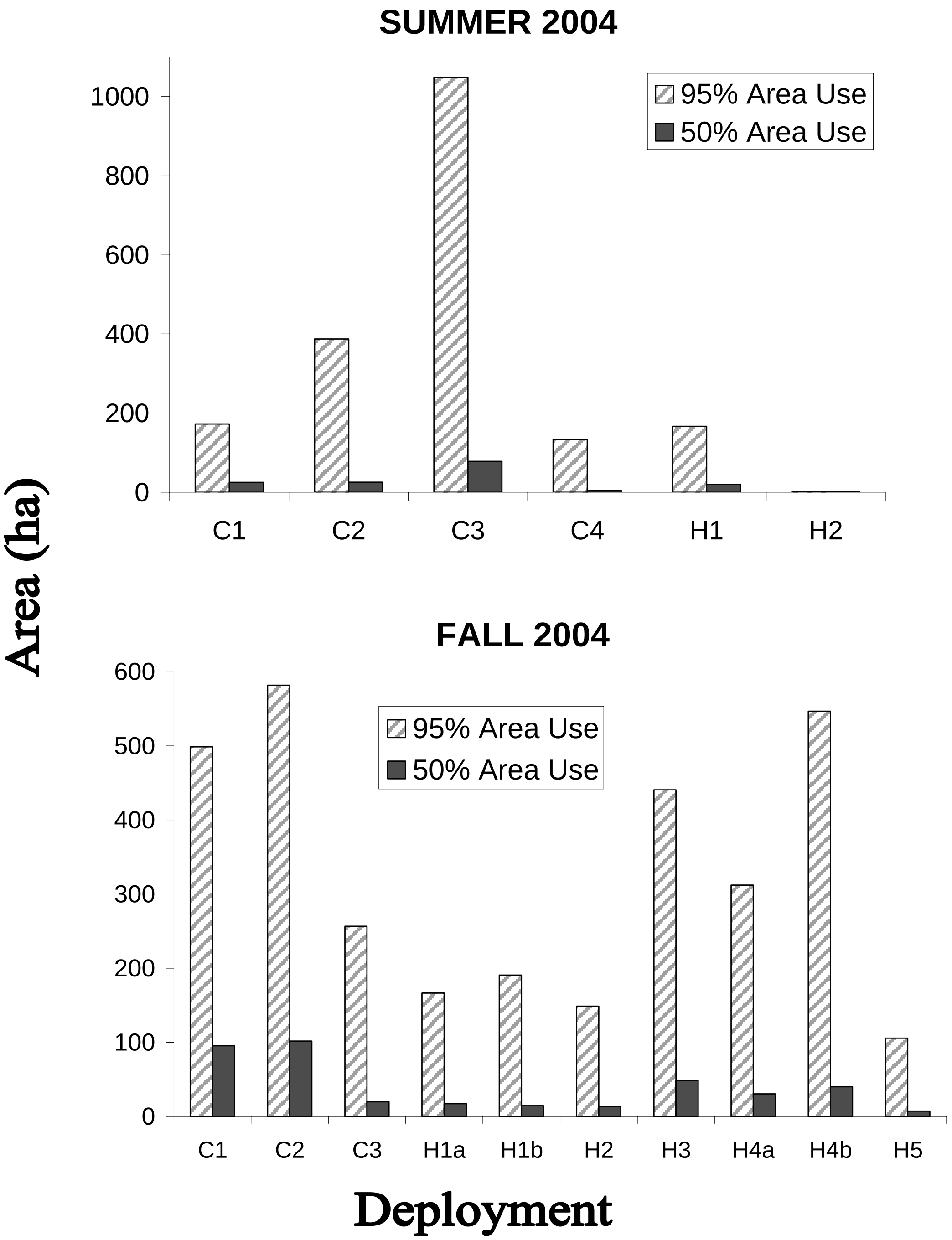


Figure 10. Seasonal 95% and 50% kernel area use size of feral hogs in Zavala County, Texas, USA, Summer and Fall, 2004. The 2 types of deployments are: C = cow, H = hog. The Fall 2004 had 2 hog samples collared for a second deployment marked by "a" for deployment 1, and "b" for deployment 2. Refer to Appendix A.1. for the number of days data were collected and the percent successful GPS fix acquisition rate for each sample. The amount of variation in area use between different hog age and sex classes was similar.

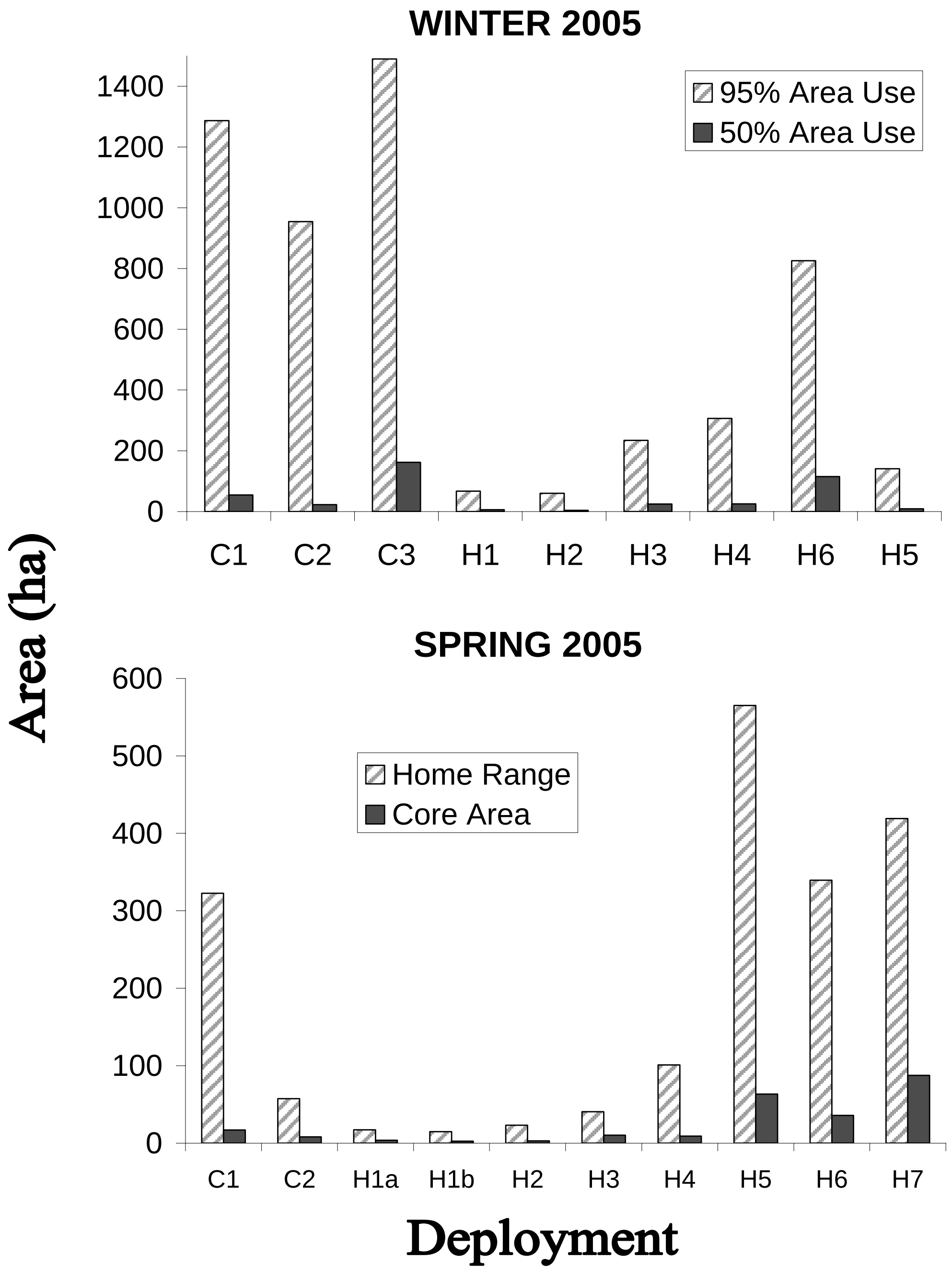


Figure 11. Seasonal 95% and 50% kernel area use size of feral hogs in Zavala County, Texas, USA, Winter and Spring, 2005. The 2 types of deployments are: C = cow, H = hog. Spring 2005 had 1 hog sample collared for a second deployment marked by "a" for deployment 1, and "b" for deployment 2. Refer to Appendix A.1. for the number of days data were collected and the percent successful GPS fix acquisition rate for each sample. The amount of variation in area use between different hog age and sex classes was similar.

Spring 2005 (Table 1). There was at least 1 case of spatial interspecific overlap between the 95% kernel area use of 1 species and the 50% kernel area use of another in each data season (Figure 8). Over the year, ~48% of the possible (N=126) indirect interspecific overlaps between 95% kernel area uses and/or 50% kernel area uses occurred at locations with unidentifiable attractants to the site. Of those contacts with seemingly identifiable attractants, 22 were near livestock ponds, 18 in riparian zones, 13 near a fencelines, 7 around roads, 5 within a center pivot irrigated pasture, 5 near a baited hog trap, 2 focused within a brush strip, and 2 on a site used for oil exploration (Figure 9; Appendix A.2).

Natural Habitat and Anthropogenic Infrastructure Results.-- Each data collection season was conducted in a different pasture. Therefore, the habitat and anthropogenic features being assessed were available in different proportions among seasons. As a result the amount of use each feature received by cattle and hogs was different (Figures 12-15). During the Summer 2004, cattle were primarily observed in Clay Flat and Clay Loam range sites (Figure 12). Feral hogs were often documented on Clay Flat sites, and had a strong presence in Claypan Prairie areas. In the Fall, a wider distribution of range site use was observed for both species. Cattle still heavily used Clay Loam sites, but also Gray Sandy Loam and Rolling Hardland range sites. Feral hogs had similar amounts of observations in 5 of the 8 range sites in the area including: Clay Flat, Clay Loam, Gray Sandy Loam, Rolling Hardland, and Saline Clay. In Winter 2005, cows primarily used Rolling Hardland, and feral hog observations were concentrated within Claypan Prairie and Rolling Hardland range sites. During Spring 2005, both species

Table 1. Average feral hog and cattle 95% and 50% kernel area use size with standard deviations across seasons, Zavala County, Texas, USA, 2004-2005. Samples with ≤ 3 days of data were excluded from averages. The maximum number of days of recorded data for cows and hogs were 73 and 16, respectively.

Season	Species (N)	Average 95% kernel area Use Size (ha)	St. Dev.	Average 50% kernel area Use Size (ha)	St. Dev.
Summer 2004	Hog (2)	84	117	10	14
	Cow (4)	436	424	33	32
Fall 2004	Hog (7)	273	166	33	15
	Cow (3)	446	169	72	46
Winter 2005	Hog (5)	272	313	35	46
	Cow (3)	1,244	270	80	73
Spring 2005	Hog (7)	136	170	22	31
	Cow (1)	323	N/A	17	N/A

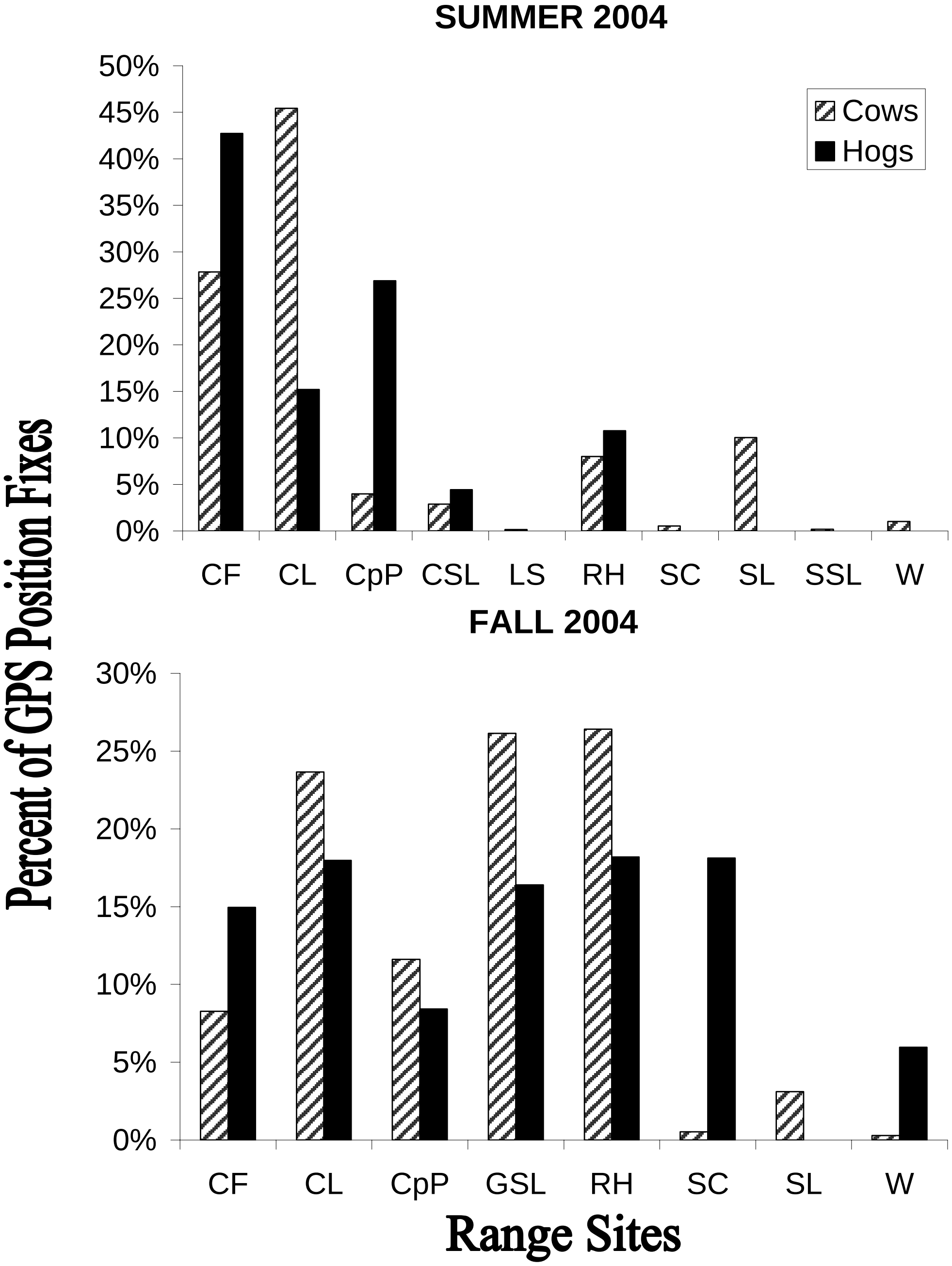


Figure 12. Seasonal range site usage of cattle and feral hogs in Zavala County, Texas, USA, Summer and Fall, 2004. Sample sizes for cattle and feral hogs were different in Summer 2004 (N = 4 cows (19,365 GPS fixes), and 2 hogs (632 GPS fixes)) and Fall 2004 (N = 3 cows (12,314 GPS fixes), and 5 hogs (5,204 GPS fixes)). Fall 2004 had 2 hog samples recollared for a second deployment each. Range site abbreviations are as follows: CF = Clay Flat, CL = Clay Loam, CpP = Claypan Prairie, CSL = Clay Sandy Loam, LS = Loamy Sand, RH = Rolling Hardland, SC = Sandy Clay, SL = Sandy Loam, SSL = Shallow Sandy Loam, GSL = Gray Sandy Loam, L = Lakebed, and W = water. See Appendix A.3. for details of the number of fixes in a site per total successful fixes for hogs and cows.

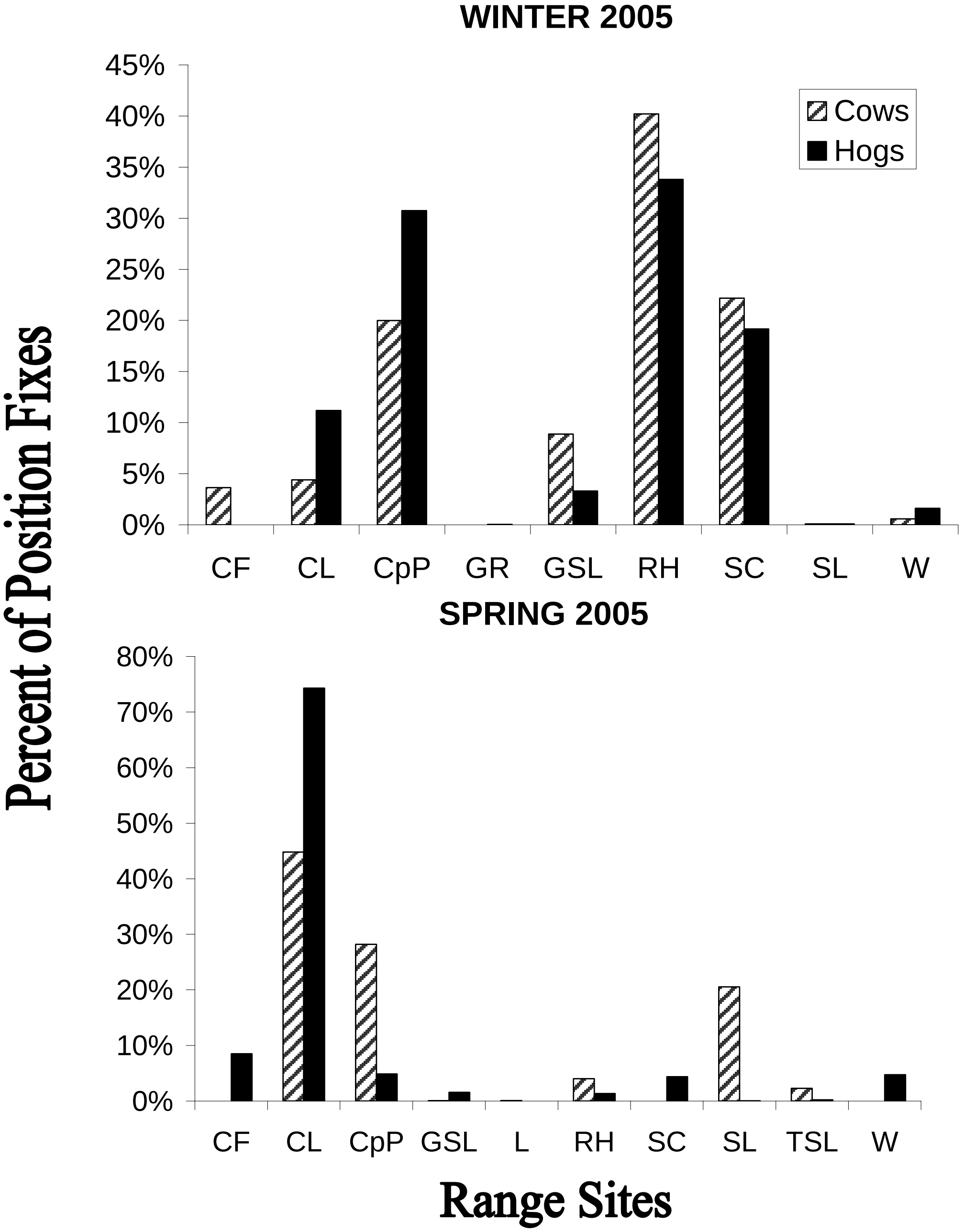


Figure 13. Seasonal range site usage of feral hogs and cattle in Zavala County, Texas, USA, Winter and Spring, 2005. Sample sizes for cattle and feral hogs were different in Winter 2005 (N = 3 cows (20,344 GPS fixes), and 6 hogs (4,121 GPS fixes) and Spring 2005 (N = 2 cows (5,861 GPS fixes), and 7 hogs (2,452 GPS fixes)). Spring 2005 had 1 hog sample recollared for a second deployment. Range site abbreviations are as follows: CF = Clay Flat, CL = Clay Loam, CpP = Claypan Prairie, Gravelly Ridge = GR, CSL = Clay Sandy Loam, LS = Loamy Sand, RH = Rolling Hardland, SC = Sandy Clay, SL = Sandy Loam, GSL = Gray Sandy Loam, L = Lakebed, and W = water. See Appendix A.3. for details of the number of fixes in a site per total successful fixes for hogs and cows.

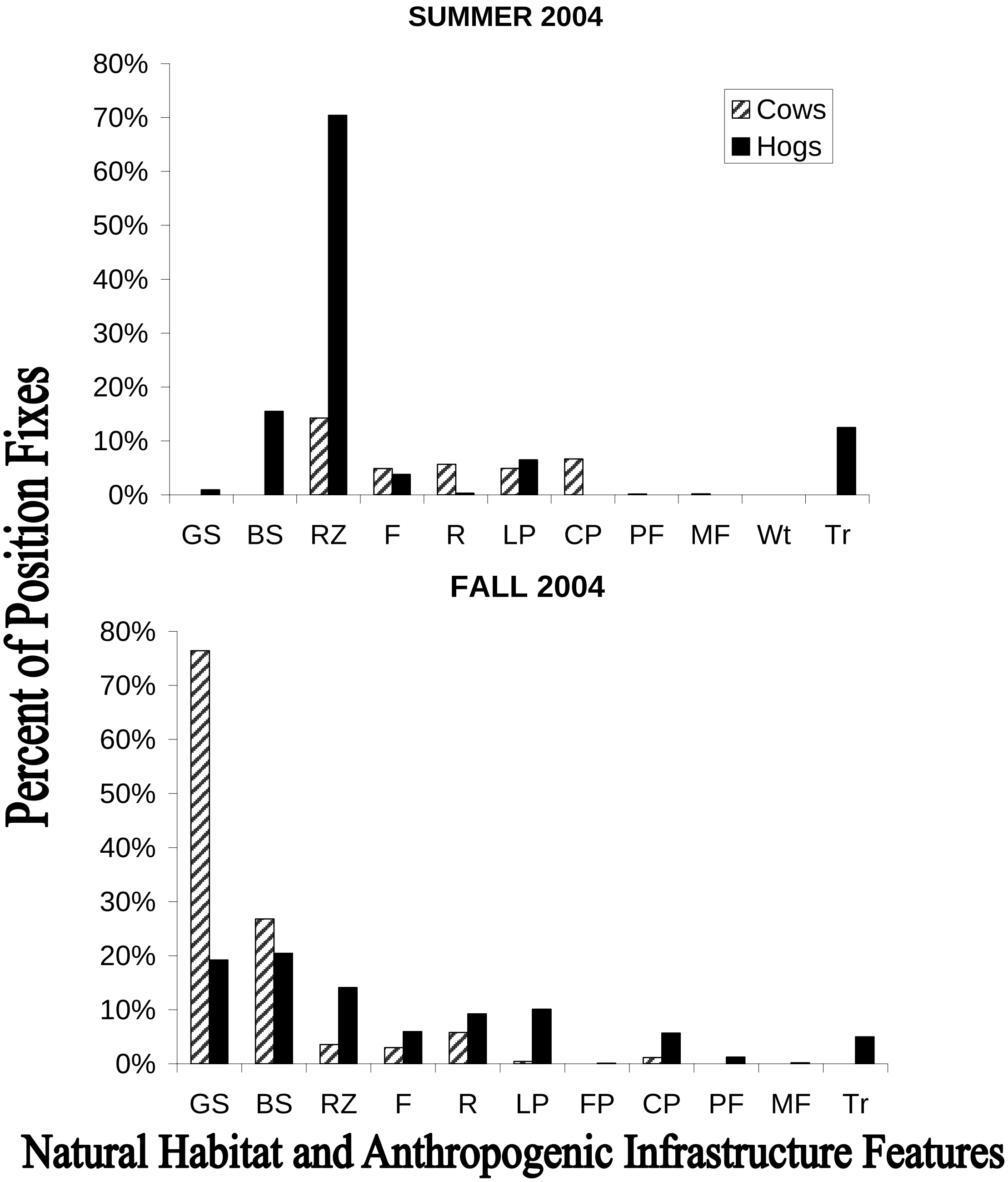


Figure 14. Seasonal natural habitat and anthropogenic infrastructure usage of feral hogs and cattle in Zavala County, Texas, USA, Summer and Fall, 2004. Sample sizes for cattle and feral hogs were different in Summer 2004 (N = 4 cows (19,365 GPS fixes), and 2 hogs (632 GPS fixes)) and Fall 2004 (N = 3 cows (12,314 GPS fixes), and 5 hogs (5,204 GPS fixes)). Fall 2004 had 2 hog samples recollared for a second deployment each. The feature abbreviations are as follows: RZ = riparian zone, F = fenceline, R = road, LP = livestock pond, FP = food plot, CP = center pivot, GS = grass strip, BS = brush strip, PF = protein feeder, MF = mineral feeder, Wt = water trough, Tr = baited traps. Percentages are not cumulative and therefore do not add up to 100% among categories. This is because the categories can overlap spatially on the landscape and animals can be in more than one land feature at a time.

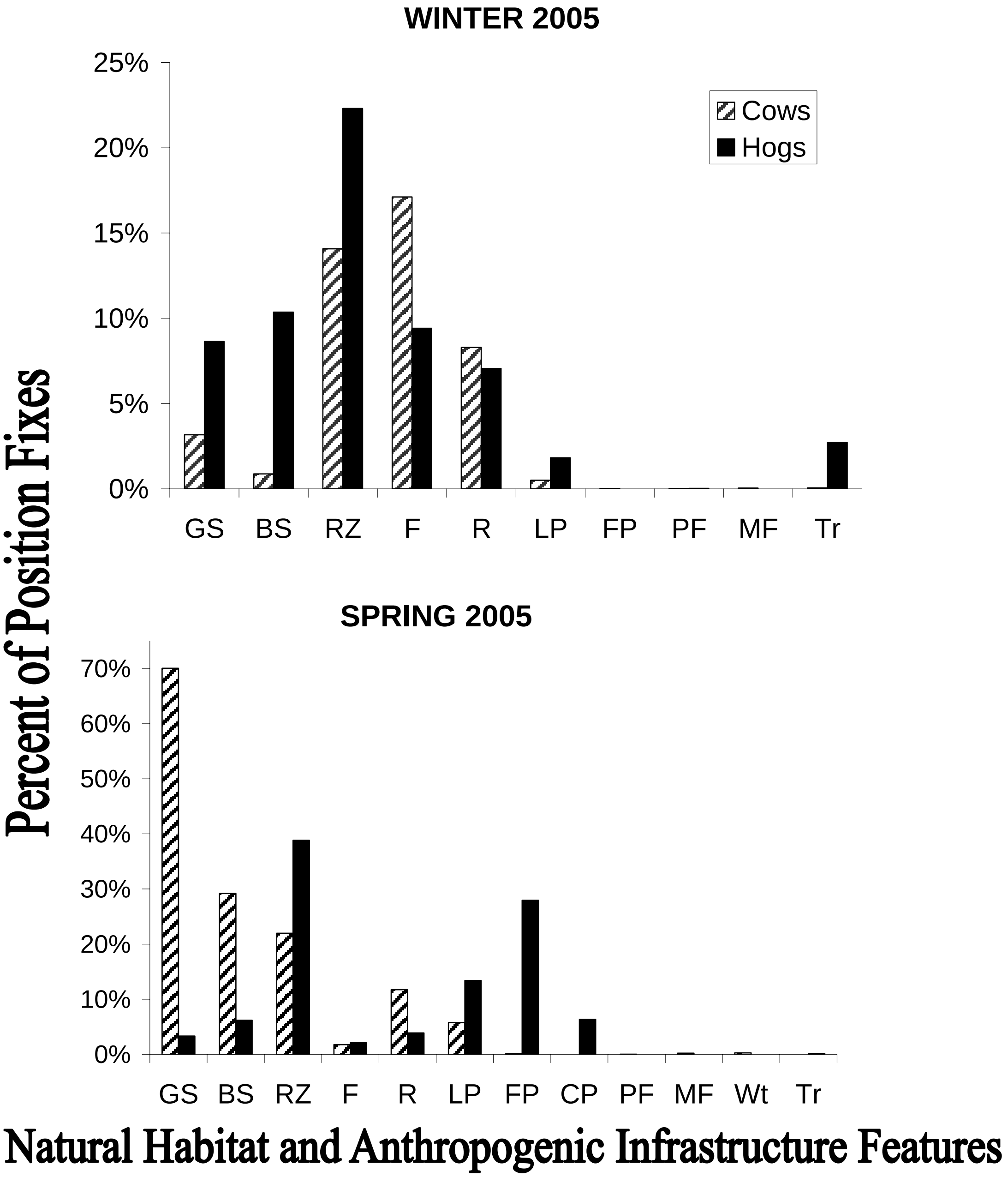


Figure 15. Seasonal natural habitat and anthropogenic infrastructure usage of feral hogs and cattle in Zavala County, Texas, USA, Winter and Spring, 2005. Sample sizes for cattle and feral hogs were different in Winter 2005 (N = 3 cows (20,344 GPS fixes), and 6 hogs (4,121 GPS fixes) and Spring 2005 (N = 2 cows (5,861 GPS fixes), and 7 hogs (2,452 GPS fixes)). Spring 2005 had 1 hog sample recollared for a second deployment. The feature abbreviations are as follows: RZ = riparian zone, F = fenceline, R = road, LP = livestock pond, FP = food plot, CP = center pivot, GS = grass strip, BS = brush strip, PF = protein feeder, MF = mineral feeder, Wt = water trough, Tr = baited traps. Percentages are not cumulative and therefore do not add up to 100% among categories. This is because the categories can overlap spatially on the landscape and animals can be in more than one land feature at a time.

seemed to concentrate more of their movements on Clay Loam sites.

Habitat and anthropogenic infrastructure feature use by cattle and feral hogs changed with seasonal pasture selection (Figures 14-15). However, riparian zones were moderately used across all seasons by cattle and feral hogs. During the Summer 2004, riparian zones were the most dominantly used feature analyzed at (2,760 of 19,365) cattle and hog (445 of 632) fixes. Both cattle and hogs used fencelines and livestock ponds. Cattle moderately used roads, and center pivot irrigation pastures; while feral hogs used brush strips, and traps.

The pasture for Fall 2004 was maintained almost entirely with brush strips, these were widely used by both cattle and hogs. Cattle were recorded in grass strips (9,411 of 12,314 fixes) nearly 3 times more often than brush strips (3,296 of 12,314 fixes; Figures 14-15). Feral hogs had high numbers of observations within grass strips (999 of 5,204 fixes) and brush strips (1,064 of 5,204 fixes). Beyond the strips, cattle primarily used riparian zones, fencelines, and roads. These features, as well as livestock ponds were the most used features for feral hogs (Figures 14-15). Center pivot pastures were used by cattle, (access controlled by ranch personnel), and by 1 sow that had ~29% of its fixes recorded within the center pivot (295 of 1,037 fixes). All 4 of the shoat deployments had at least marginal use of the trap area. One of the female shoats that was deployed twice had the highest 2 uses of trap areas with ~4% (39 of 1,055) and 17% (175 of 1,055) of their deployment fixes.

Cattle and feral hog movements in Winter 2004 followed the previous trend in that riparian zones appeared to be 1 of the most heavily used features analyzed in this study (Figures 14-15). Cattle primarily used fencelines, riparian zones, and roads. Feral hogs heavily used these features in addition to grass strips and brush strips in adjacent pastures (Figures 14-15). There were no brush strips within the study pasture, so cattle were not observed to use them except for inclusion of the grass strip buffers that are adjacent to the study pasture fencelines. These instances were minimal. However, 1 cow escaped the study pasture for about 9 days and had 554 of 6,853 fixes in grass strips to contrast the 173 of 6,853 in the brush.

Brush and grass strips were maintained in most of the study pasture during the Spring 2005 season. Cattle once again used grass strips ~ twice as often (4,105 of 5,806 fixes) as brush strips (1,710 of 5,806 fixes; Figures 14-15). Feral hogs used brush strips (152 of 2,452 fixes) almost twice more than grass (82 of 2,452 fixes). Riparian zones, roads, and livestock ponds also had observations recorded for cattle. Feral hogs had relatively large numbers of observations in riparian zones and food plots, and marginally used livestock ponds and center pivots. However, 1 male shoat did have 148 of 541 GPS fixes (~27%) recorded within center pivot boundaries.

Contact Results.--There were no direct interspecific contacts determined from GPS data analysis. However, there were 7 instances of cattle fixes within 50 m of feral hog fixes (0.06 simultaneous interactions/day; Table 2) and all were in proximity to a water source. Closest direct interspecific distance (0.03 interactions/day) was at ~17 m in the Fall 2004 season close to a water trough, another (0.03 interactions/day) was ~23 m near a livestock pond. The other 5 distances < 50 m (0.12 interactions/day) occurred

Table 2. Summary of direct and indirect contact rates for cattle and feral hogs from GPS data, Zavala County, Texas, USA, 2004-2005. Direct contact rates were calculated as the number of contacts per number of days that data was recorded for both species with temporal overlap. There were no direct contacts, but there were 7 close interactions (within 50 m) that are calculated as a rate here. Indirect contacts were calculated as the number of contacts (within 10 m to account for GPS error) per number of days GPS data were recorded. This summary includes the indirect contact rates for all data cumulative and by season.

	Direct (50 m)	Aligned Days	Direct Rate	Indirect (10 m)	Days Data	Indirect Rate
Summer 2004	0	14	0.00	19	60	0.32
Fall 2004	2	40	0.05	478	51	9.37
Winter 2005	0	31	0.00	247	74	3.34
Spring 2005	5	41	0.12	80	61	1.31
Cumulative	7	126	0.06	824	246	3.35

during Spring 2005 with interspecific distances that ranged from ~22-44 m. Four of these were consecutive observations that all centered on a livestock pond, while 1 was close to the same pond and the connecting riparian zone. Regardless of hog age class, sex, time of day, or season, the bulk of direct contact analysis distances between cattle and feral hogs were hundreds to thousands of meters apart (Figures 16-17).

When time lag (> 15 min) between interspecific visits to the same site (within 10 m) was allowed in GPS contact analysis (indirect), cattle and feral hogs frequently crossed paths in all seasons. Visual examination of indirect interspecific contacts from Summer 2004 in GIS showed that 0.32 contacts/day were primarily along riparian zones, livestock ponds, center pivot pastures, and fencelines. Fall 2004 contacts were more frequent (9.37 contacts/day) but had similar locations where they occurred (riparian zones, livestock ponds, center pivot pastures, and water troughs). The Winter 2005 data had 3.34 contacts/day at livestock ponds, fencelines, roads, and a few at mineral feeders and trap areas. In Spring 2005, contacts (1.31 contacts/day) were more concentrated on food plots, riparian zones, livestock ponds, and trap areas. Cumulative data indicates that from mid-2004 to mid-2005 there were 3.35 contacts/day from collared animals.

Indirect interspecific distances did not seem to be different by hog age-class or time of day for most of the study (Figures 18-19). Consequently, most shoat, sow, and boar samples had relatively similar distances to cattle within each season regardless of time of day. Boxplots were used to illustrate the most common distance between cattle

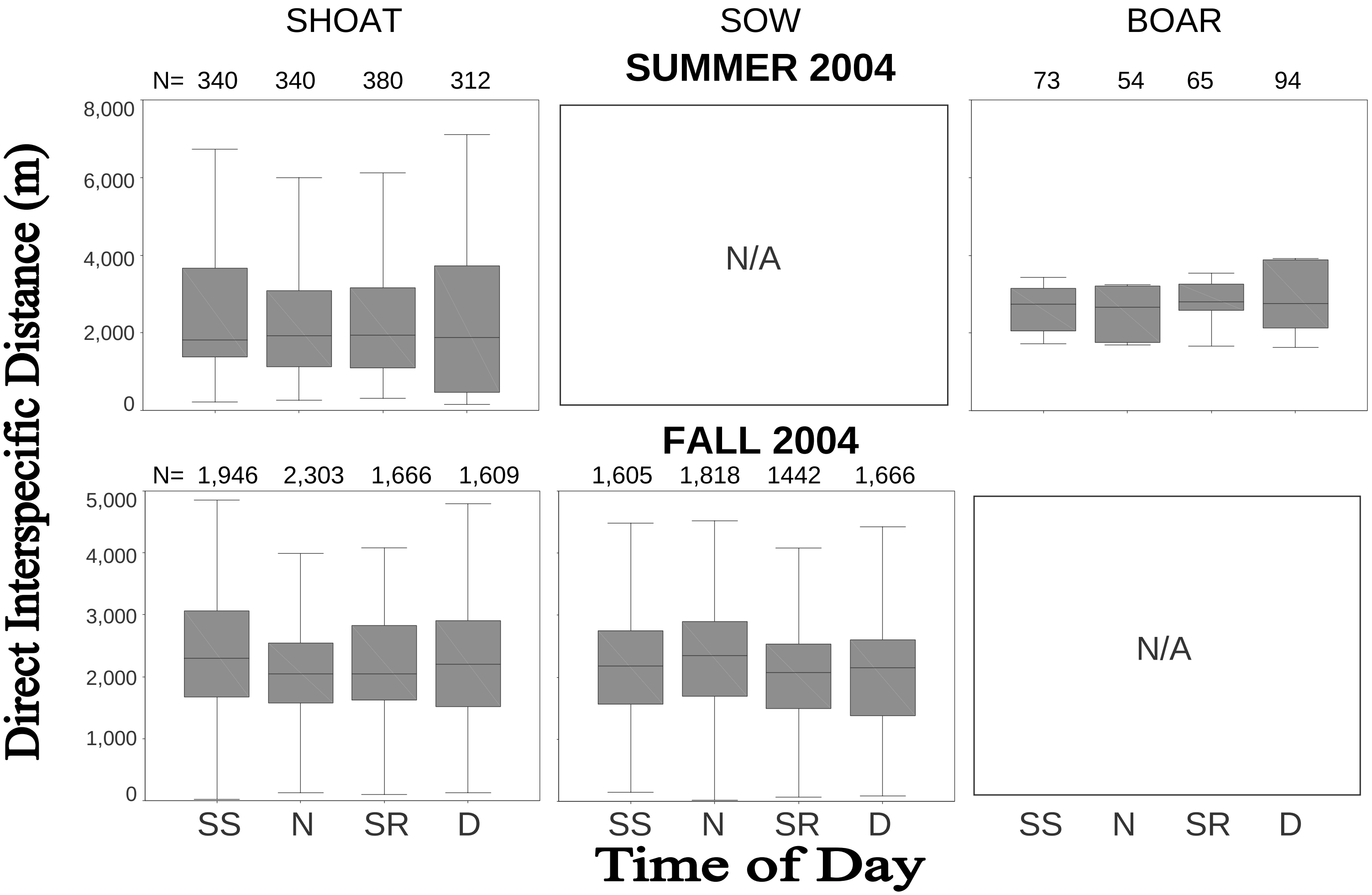


Figure 16. Seasonal direct interspecific daily contact by hog age-class, Zavala County, Texas, USA, Summer and Fall, 2004. These boxplots illustrate the distribution of the distance between cattle and feral hogs by age class and time of day under direct contact conditions. Time of day was divided into night and day conditions by season. Night time of day started 2 hrs before sunset and ended 2 hrs after sunrise. That time was divided equally into 3 categories: sunset (SS), peak of night (N), and sunrise (SR). The remaining time in the day was defined as daytime (D). There were no sow and boar samples in the summer and fall, respectively. The number of distances measured for each category is at the top of each box.

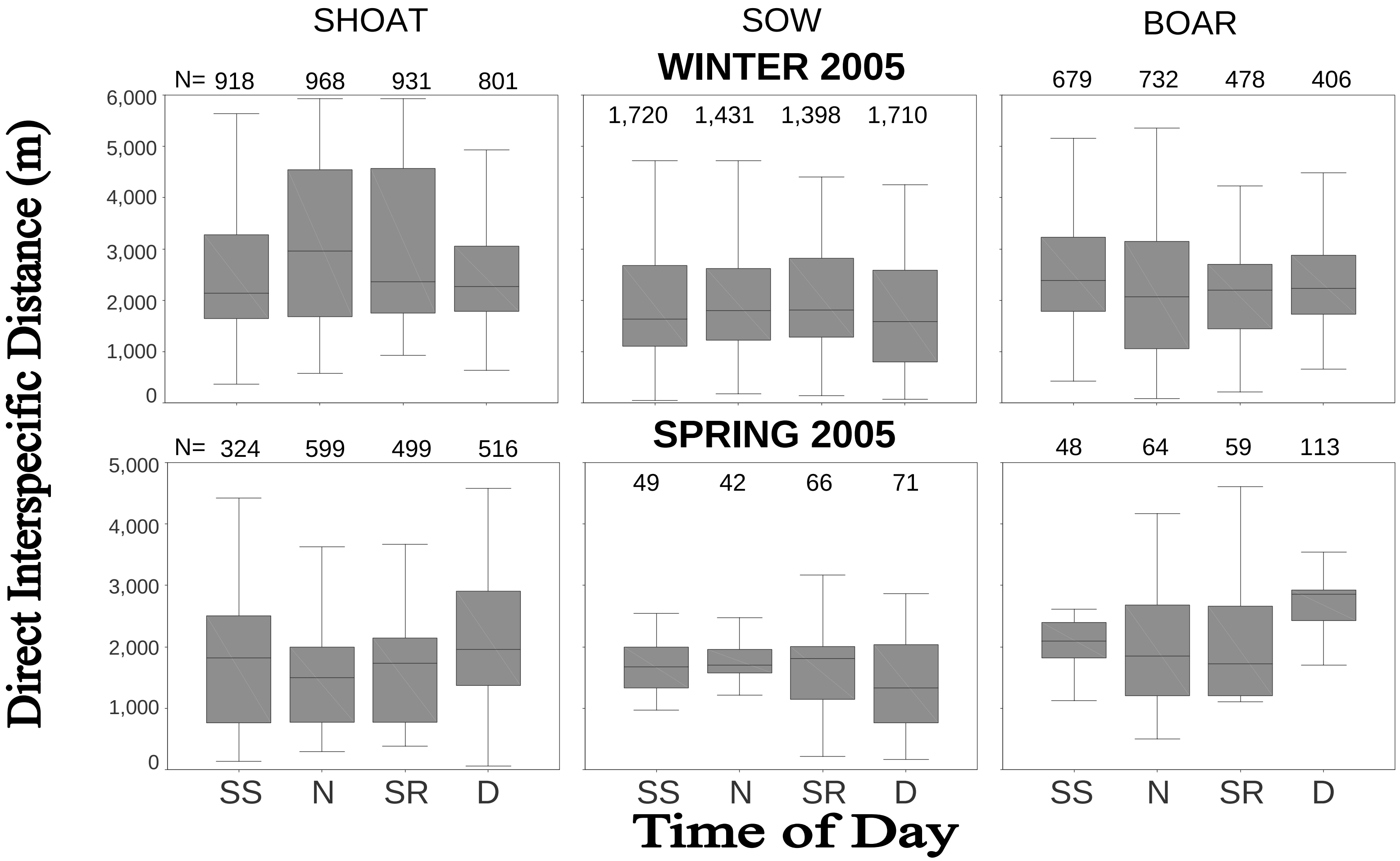


Figure 17. Seasonal direct interspecific daily contact by hog age-class, Zavala County, Texas, USA, Winter and Spring, 2005. These boxplots illustrate the distribution of the distance between cattle and feral hogs by age class and time of day under direct contact conditions. Time of day was divided into night and day conditions by season. Night time of day started 2 hrs before sunset and ended 2 hrs after sunrise. That time was divided equally into 3 categories: sunset (SS), peak of night (N), and sunrise (SR). The remaining time in the day was defined as daytime (D). There were no sow and boar samples in the summer and fall, respectively. The number of distances measured for each category is at the top of each box.

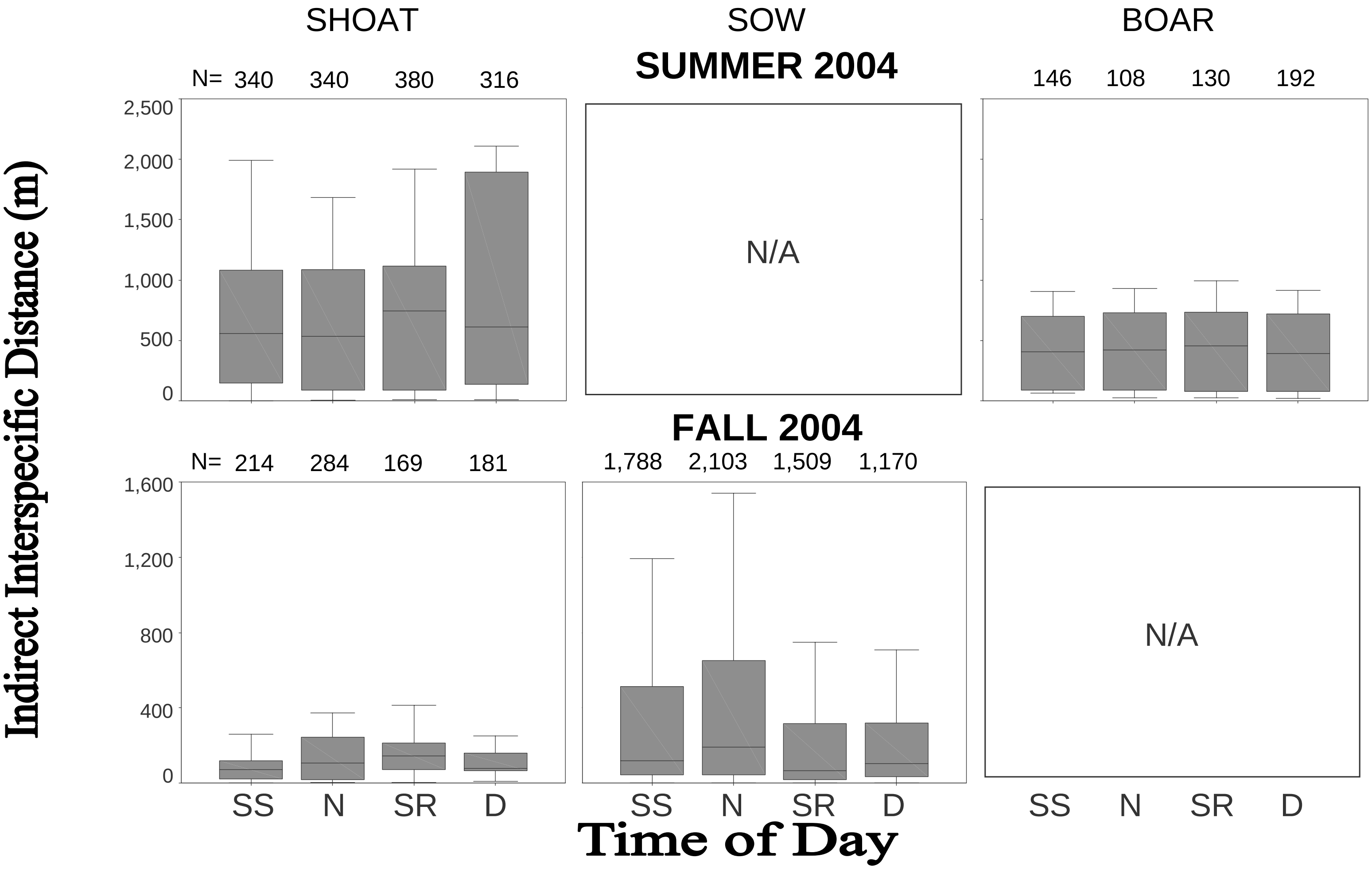


Figure 18. Seasonal indirect interspecific daily contact by hog age-class, Zavala County, Texas, USA, Summer and Fall, 2004. These boxplots illustrate the distribution of the distance between cattle and feral hogs by age class and time of day under indirect contact conditions. Time of day was divided into night and day conditions by season. Night time of day started 2 hrs before sunset and ended 2 hrs after sunrise. Night is: sunset (SS), peak of night (N), and sunrise (SR). The remaining time in the day was defined as daytime (D). There were no sow and boar samples in the summer and fall, respectively. The number of distances measured for each category is at the top of each box.

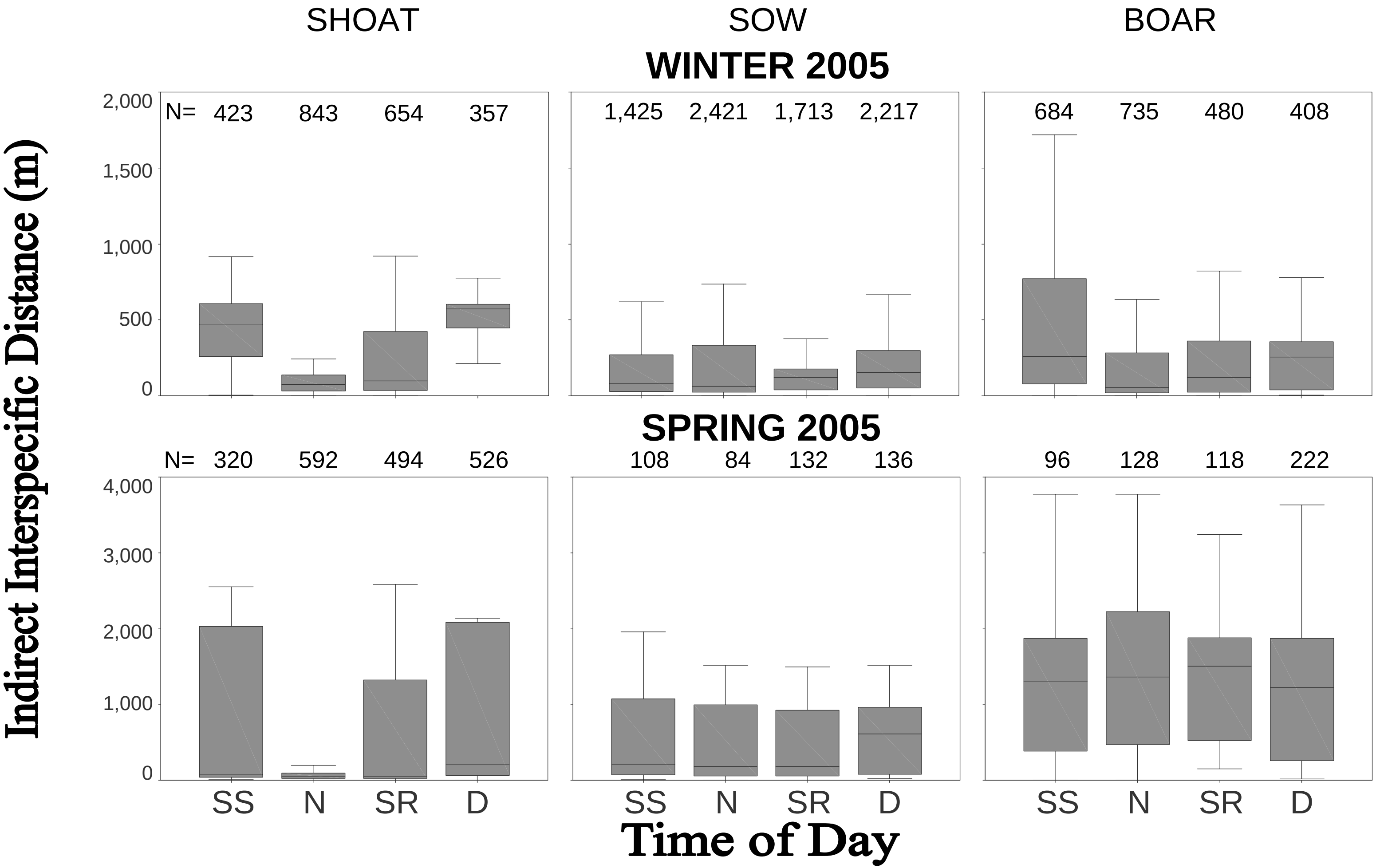


Figure 19. Seasonal indirect interspecific daily contact by hog age-class, Zavala County, Texas, Winter and Spring, 2005. These boxplots illustrate the distribution of the distance between cattle and feral hogs by age class and time of day under indirect contact conditions. Time of day was divided into night and day conditions by season. Night time of day started 2 hrs before sunset and ended 2 hrs after sunrise. Night is: sunset (SS), peak of night (N), and sunrise (SR). The remaining time in the day was defined as daytime (D). There were no sow and boar samples in the summer and fall, respectively. The number of distances measured for each category is at the top of each box.

and feral hogs, and the distribution of values for all distances measured. These distances were categorized by hog age-class and time of day.

Fall 2004 had less uniform concentrations of distances between hogs and cattle by hog age-class compared to Summer 2004. During Summer 2004, ~25% of shoat and boar GPS fixes were within ~200 m and ~100 m of cattle fixes, respectively (Figure 18). The summer season had no sow hog samples, but the data indicated hog indirect distances from cattle appeared to be similar between represented age-classes. Consequently, in Fall 2004 shoats and sows were recorded at relatively close distances to cattle (within ~200 m and ~100 m, respectively) more often as ~75% and ~25% of fixes, respectively, were within ~200 m and ~100 m, respectively, of cattle (Figure 18). There were no boar samples during Fall 2004. Of represented age-classes, shoats had a higher concentration of close distances to cattle in Fall 2004; whereas, Summer 2004 interspecific distances were more similar across age-classes.

During Winter 2005, at 25% of measured interspecific distances from shoats, sows, and boars to cattle were fairly dissimilar. Shoats had the highest concentration of close distances as 25% of distances measured were within 50 m of cattle. Twenty-five percent of sow distances to cattle were within 100 m and boars were double that at 200 m.

Spring 2005 interspecific distances were not concentrated as close as Winter 2005. Shoats and sows were within 100 m of cattle 25% of the time, but data indicated that boars only came within 600 m of cattle 25% of the time. Shoats had the highest concentration of close distances to cattle in all seasons except for Summer 2004, where hog sample size was most limited.

There were no extreme differences of distance by time of day until Winter 2005. During this season, shoats had differences in distance to cattle by time of day categories (Figure 19). Position fixes recorded at peak of night occurred more frequently (lower 25% fell between 0-50 m) than any other time of day category, meaning shoats were frequently in close proximity to cattle (Figure 19). However, regardless of time of day, the lower 25% of distances of sows and boars ranged from 0-100 m away from cows (Figure 18).

In Spring 2005, shoats had differences among time of day categories as all GPS fixes of peak of night were within 200 m of cattle (Figure 19). Sows did not have frequent close contact with cattle relative to shoats (lower 25% < 100 m). During this season, boars had the least frequent close contact with cattle (lower 25% < 500 m) for all time of day categories (Figure 19). During Winter and Spring 2005 shoats showed a difference in closeness to cattle by time of day.

In addition to direct contacts between cows and feral hogs, direct intraspecific contacts were also assessed. Contacts between cows occurred, but were not quantified because they are relatively manageable through livestock management practices. However, quantification of feral hog intraspecific direct contact was useful to assess how efficiently hogs would maintain and spread disease across the landscape. In Summer 2004, no intraspecific interaction between the 2 hog deployments was detected, but in each of the following 3 seasons feral hog intraspecific direct contact was recorded

(Figure 20). Data collected in Fall 2004 showed the highest concentration of feral hog intraspecific direct contact. In this season, the lower 25% of distances between collared hogs showed that they were < 30 m apart. Winter and Spring 2005 had the lower 25% of hog intraspecific distances at < 1,100 m and 400 m, respectively.

Video Data

Activity Times and Group Size of Feral Hog Results.--Motion-triggered infrared video recorders (video traps) were used to measure time of day that hogs were active, hog group size, age composition, and duration of stay in a given location. Most hogs were recorded during sunset hrs in Summer 2004 (0.57 hogs/trap day), Fall 2004 (0.46 hogs/trap day), and Winter 2005 (1.03 hogs/trap day); whereas, hogs in Spring 2005 (0.25 hogs/trap day) were primarily recorded during sunrise hrs (1.35 hogs/trap day; Figure 21). In Summer and Fall 2004, hogs were most commonly recorded as individuals, which occurred 45, and 15 times, respectively. In Winter 2005, hogs were only viewed on 7 occasions (less intensive sampling due to equipment failure). Of those occurrences, singles were just as common (N = 2) as a groups of 9 (N = 2). In Spring 2005, individuals were the most common, occurring 24 times.

In the Summer and Fall 2004, most activity was from the shoat age-class, which occurred near riparian zones (Figures 22-23). In the Winter 2005, all hogs of undetermined age occurred at livestock ponds. Hogs stayed in the view of the recorder for ~2 min during Winter 2005 and ~20 min in Spring 2005.

Contact Results.--Video recorders were also used to assess the frequency of interspecific direct and indirect contact by measuring the time lapse between visits by

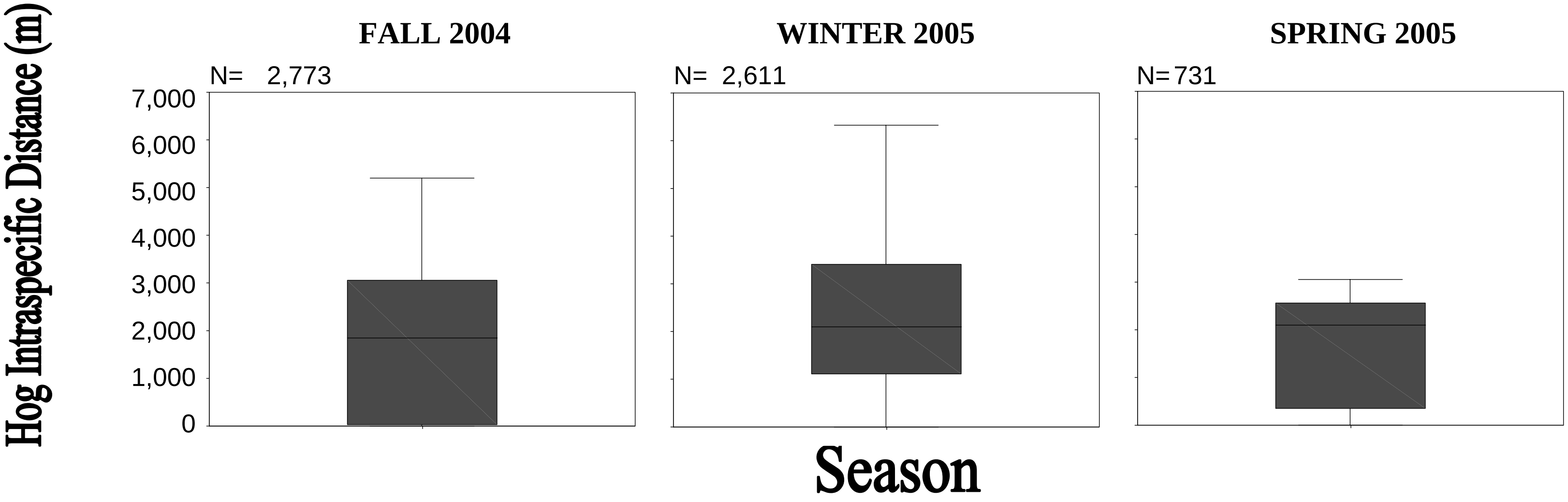


Figure 20. Box plot of seasonal direct intraspecific contact among feral hogs, Zavala County, Texas, USA, 2004-2005. There was no spatial interaction recorded from GPS fixes between hogs during the Summer 2004 season, probably because of the limited sample size (N=2). The number of distances measured for each category is at the top of each box.

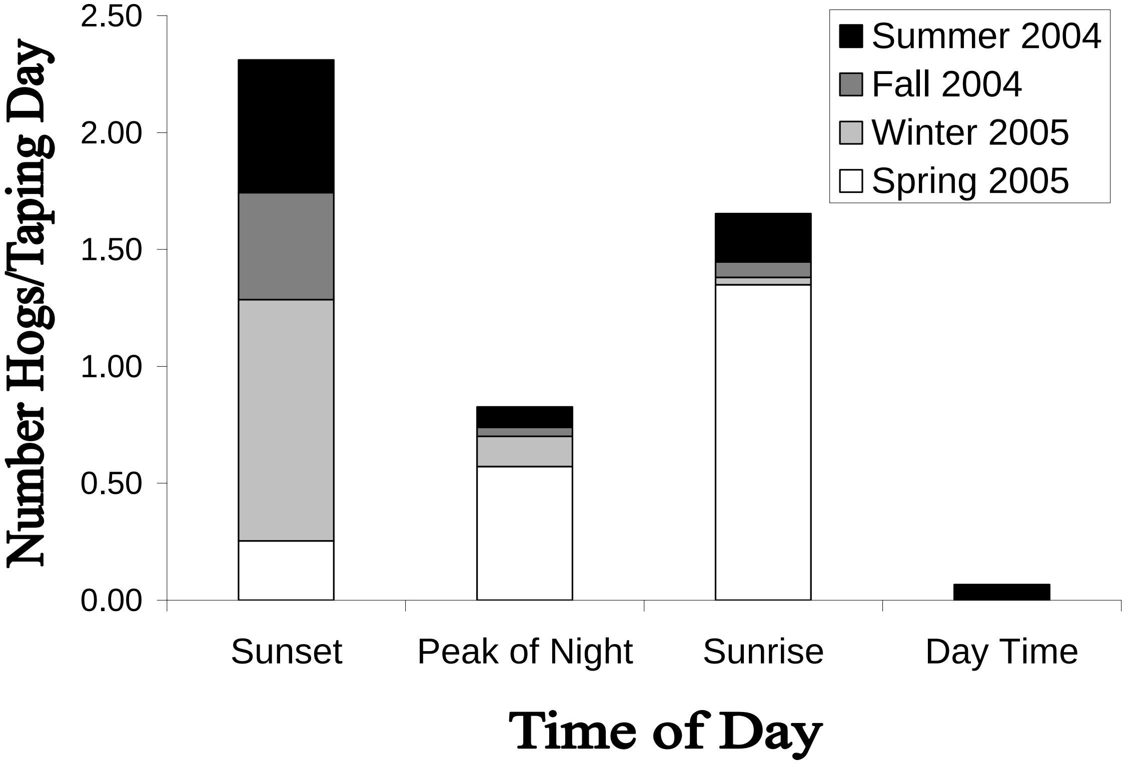


Figure 21. Seasonal motion-triggered video from 3 recorders of hog activity by time of day, Zavala County, Texas, USA, 2004-2005. Time of day was divided into night and day conditions by season. Night time of day started 2 hrs before sunset and ended 2 hrs after sunrise. That time was divided equally into 3 categories: sunset, peak of night, and sunrise. The remaining time in the day was defined as daytime. The values are cumulative and the largest number of hogs/trap day was recorded during sunset hrs at ~2.31 hogs/day for the entire study.

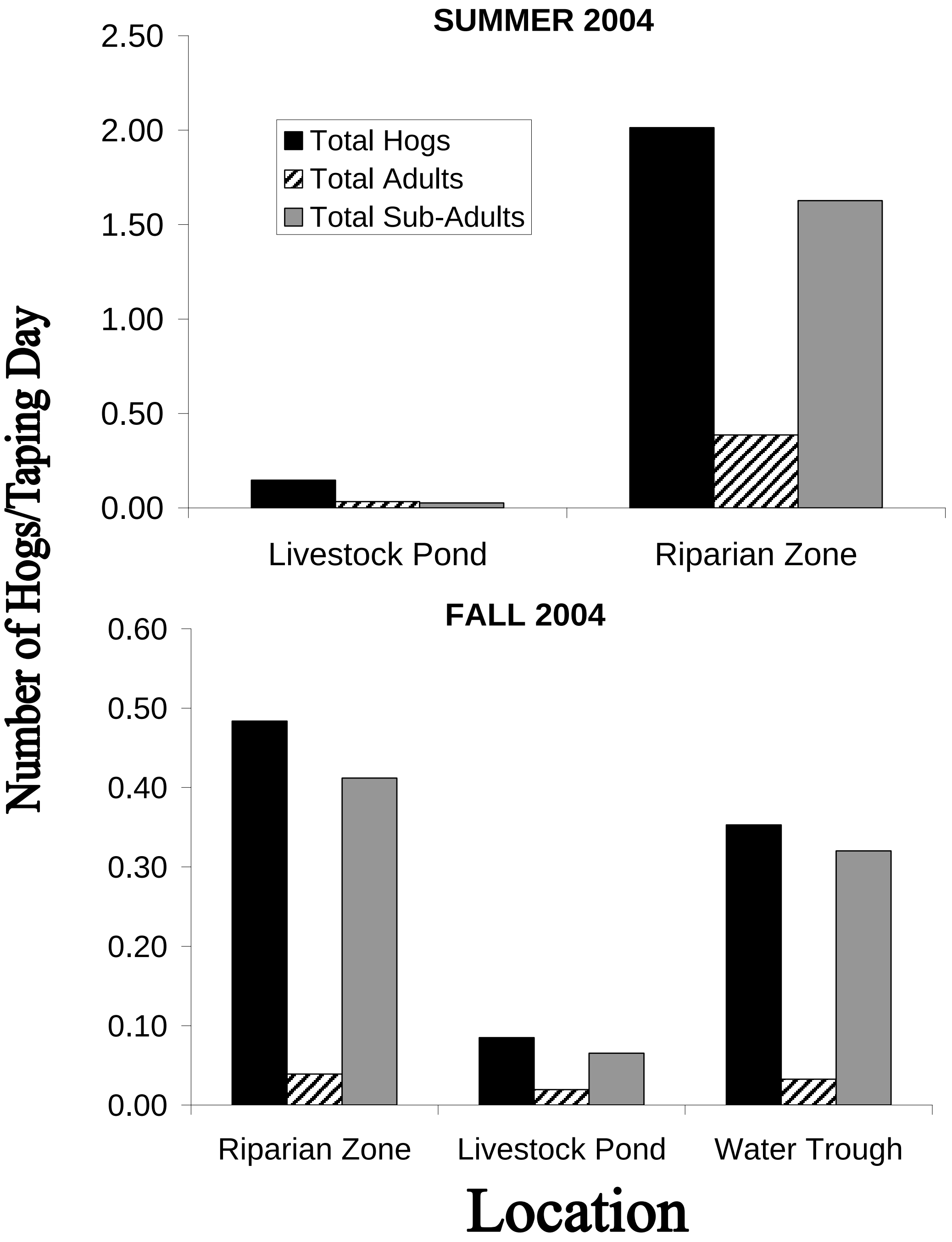


Figure 22. Seasonal number of hogs per day by age-class that visited riparian zones and anthropogenic infrastructure from video data, Zavala County, Texas, USA, Summer and Fall, 2004.

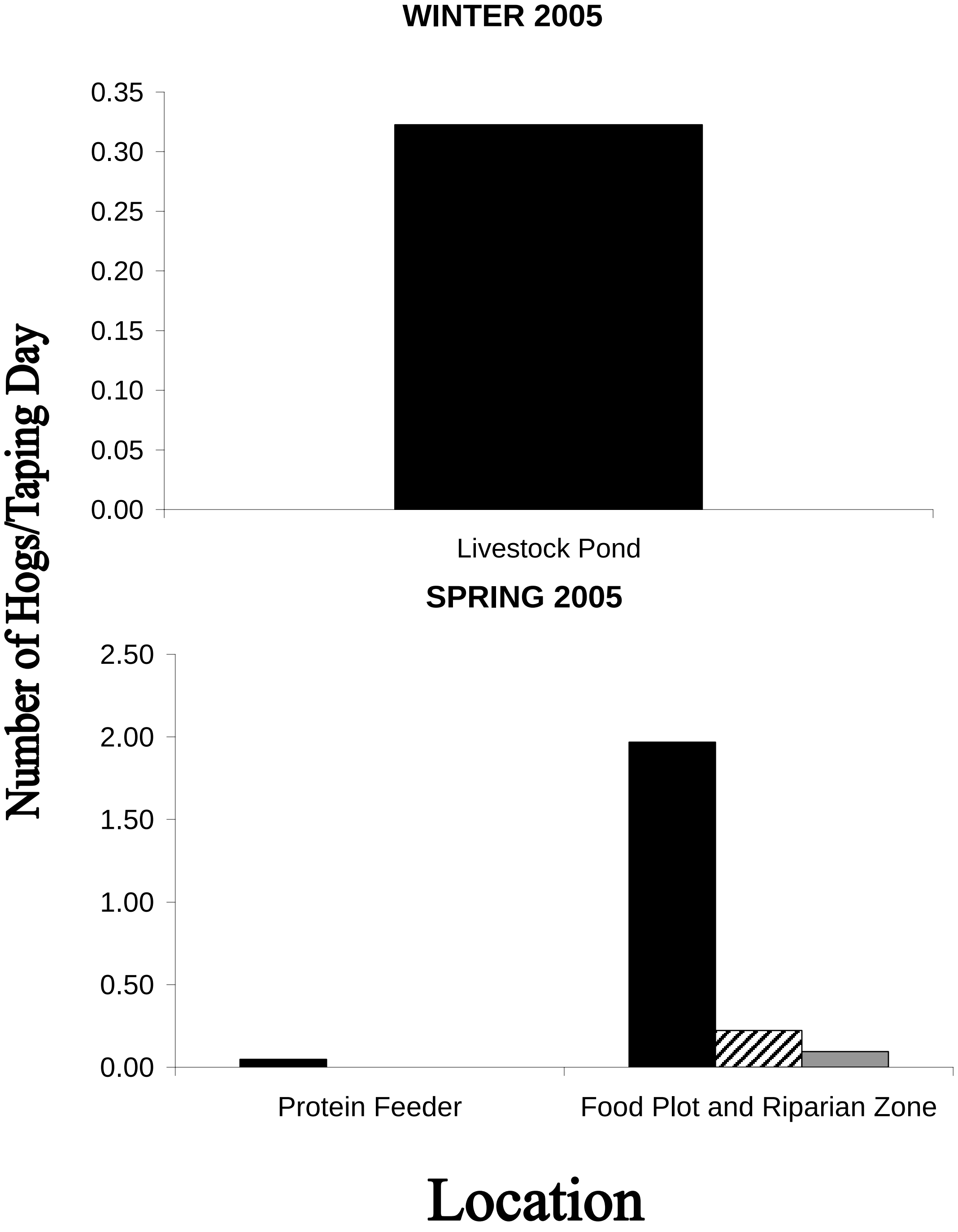


Figure 23. Seasonal number of hogs per day by age-class that visited riparian zones and anthropogenic infrastructure from video data, Zavala County, Texas, USA, Winter and Spring, 2005. The Winter 2005 data had fewer observations (N = 7) and may not represent frequency of visitation. However, it was important to note that 1 direct and 1 indirect interspecific contact did occur.

either species. Although the idea of spreading disease to the livestock would mean that cows would have to follow hogs, hogs following cows were also counted as contacts because FMD can be spread from cows to hogs and back to a different herd of cows. Contacts of cows following hogs and *vice versa* were reported separately as cumulative data throughout the study (Figure 24) and divided by season (Figures 25-27). Winter 2005 data had much less operational days of data recording (N = 31) because of increased recorder malfunctions and may not represent frequency of visitation.

Indirect contacts (limited to within 24 hrs; cow follow hog and *vice versa*) were much more common (1.21 contacts/cumulative trap days from cows follow hogs and *vice versa*; Table 3) than direct contacts (0.008 contacts/cumulative trapping days; 1 in Summer 2004 and 2 in Fall 2004) in the study. Most of the indirect contacts were from cows following hogs (0.69 contacts/cumulative trap days) versus hogs following cows (0.53 contacts/cumulative trap days; Table 3). Fall 2004 had the highest indirect contact rate at 1.61 contacts/day at riparian zones and water troughs. Summer 2004 also had an average of > 1 indirect contact per day (1.14 contacts/day) around water sources. The Winter 2005 had the least video data and the lowest indirect contact rate at 0.06 contacts/day located around livestock ponds and riparian zones. There were 0.98 contacts each day, on average, near a food plot and 2 protein feeders in Spring 2005.

Cumulative data indicated that when indirect contacts were made from cows following hogs that few occurred quickly and were more numerous as time lapse between visits increased up to 21 hrs (Figure 24). However, when hogs followed cows and had indirect contacts at video recorders, most occurred between 0-3 hrs and

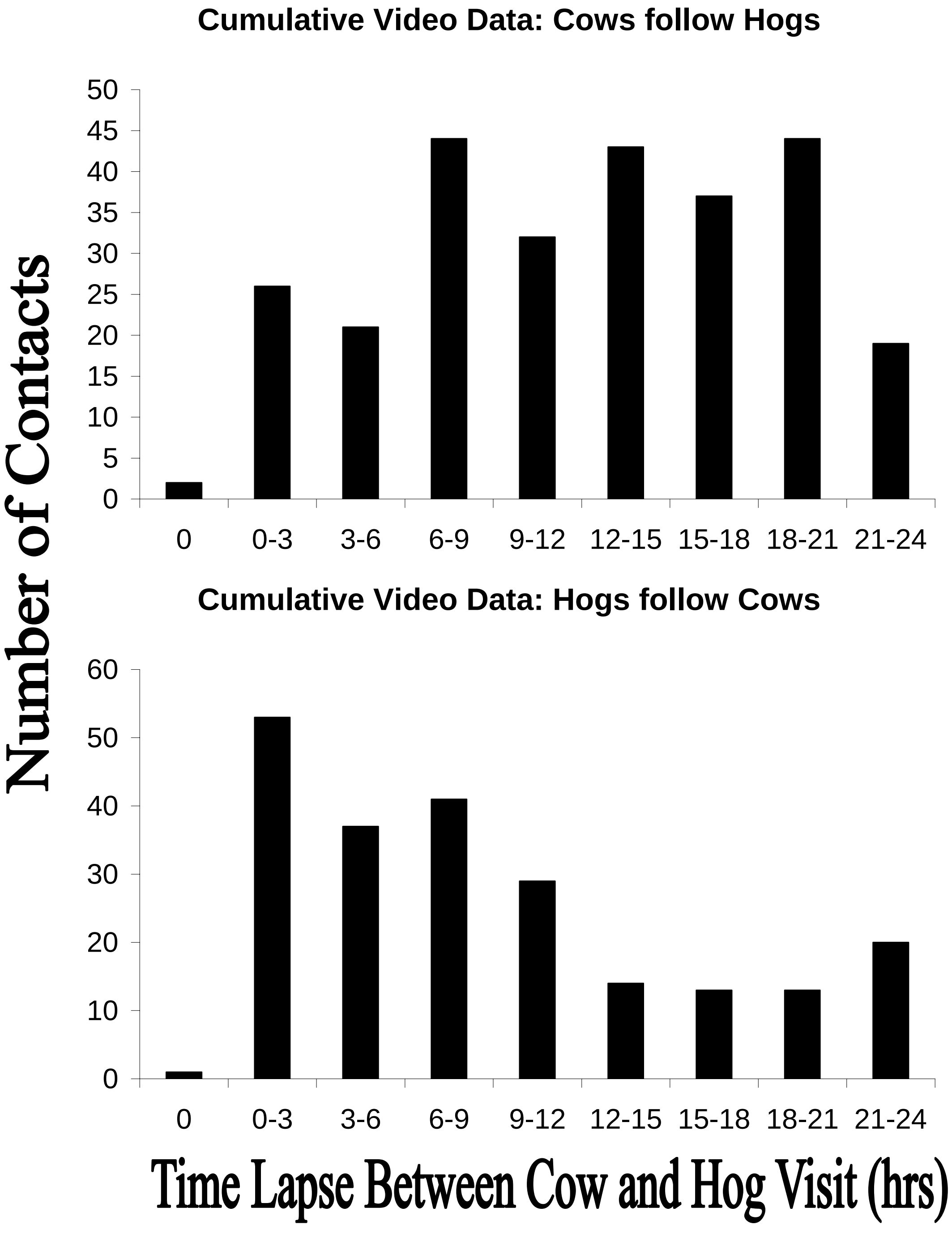


Figure 24. Cumulative time lag among visits of cattle following feral hogs and *vice versa* to the same site from video data, Zavala County, Texas, USA, 2004–2005. The Winter data had much less observations (N = 7) because of increased recorder malfunctions and may not represent frequency of visitation. There were 397 cumulative days of successful video recordings.

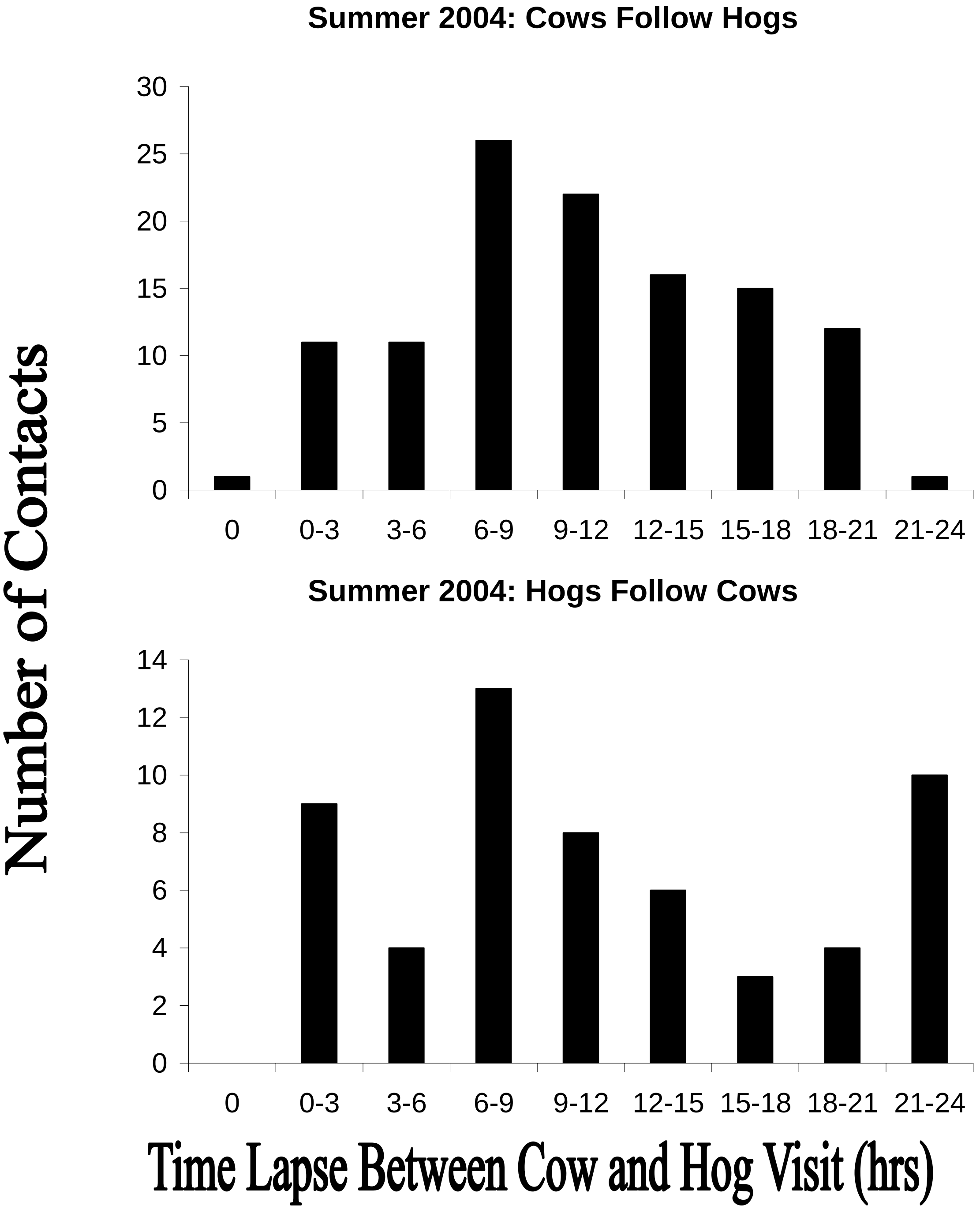


Figure 25. Summer 2004 time lag among visits of cattle following feral hogs and *vice versa* to the same site from video data, Zavala County, Texas, USA, 2004. There were 150 days that data were successfully recorded.

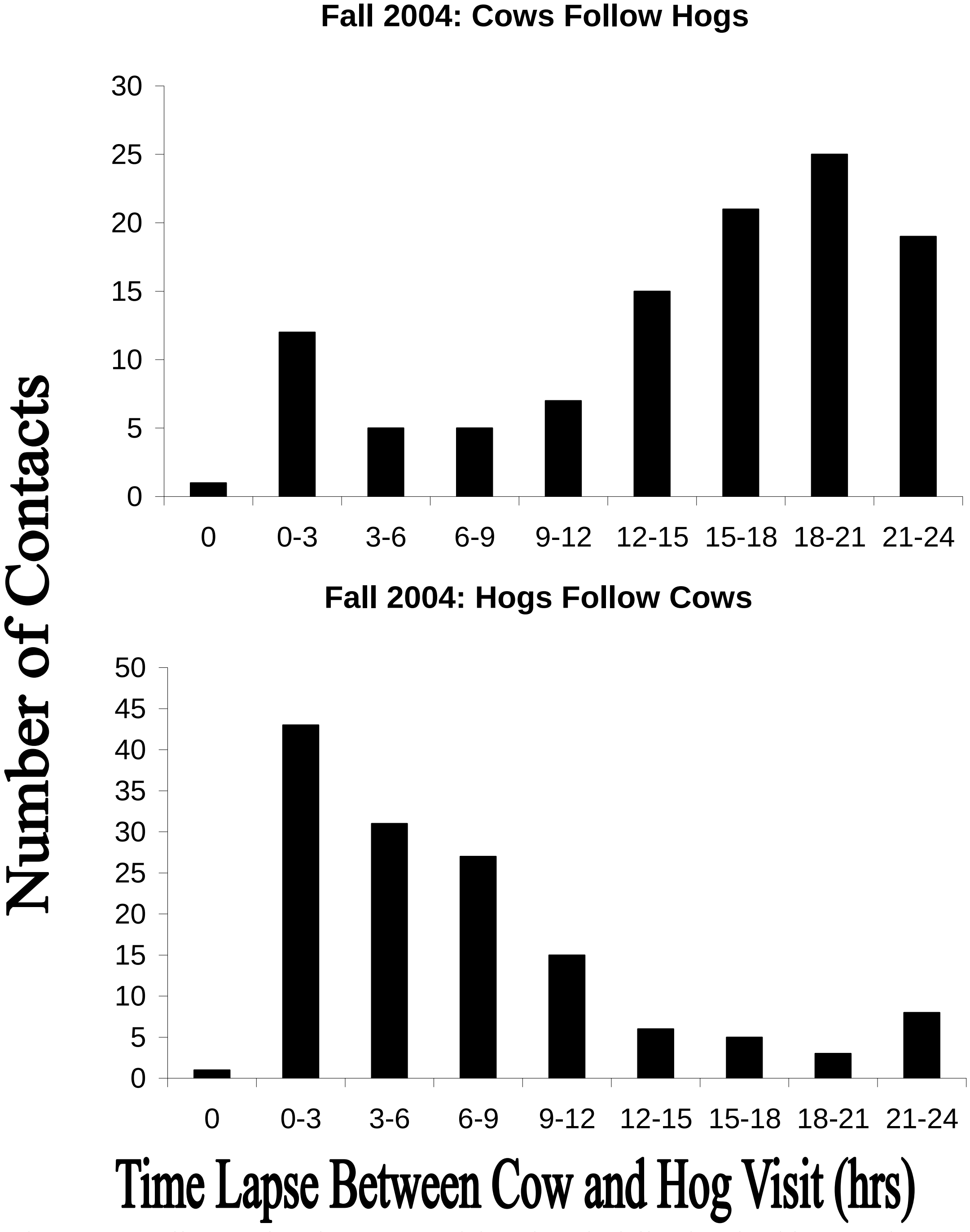


Figure 26. Fall 2004 time lag among visits of cattle following feral hogs and *vice versa* to the same site from video data, Zavala County, Texas, USA, 2004. There were 153 days in Fall 2004 that data were successfully recorded.

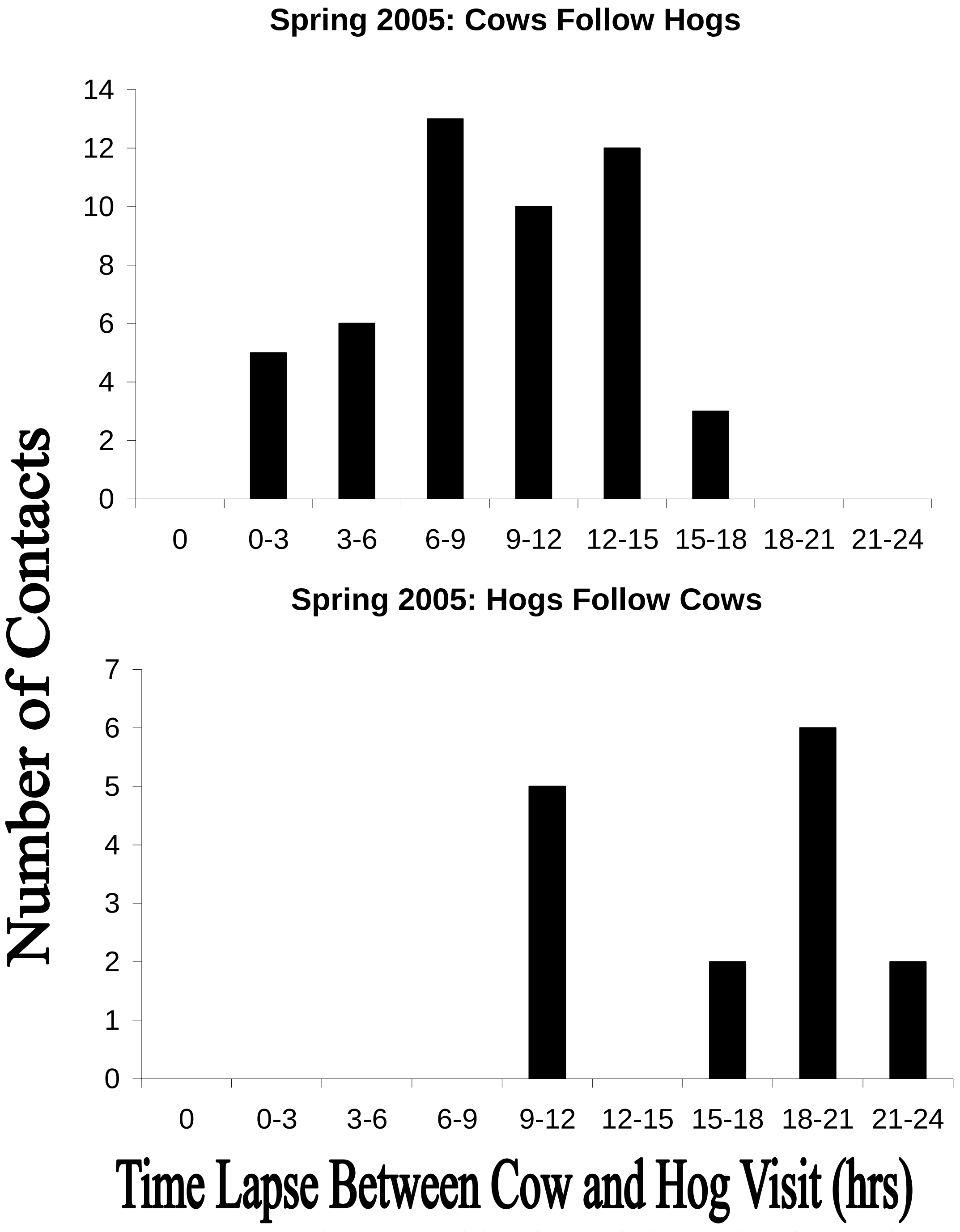


Figure 27. Spring 2005 time lag among visits of cattle following feral hogs and *vice versa* to the same site from video data, Zavala County, Texas, USA, 2005. There were 63 days in Spring 2005 that data were successfully recorded.

Table 3. Video data indirect contact rate summary, Zavala County, Texas, 2004–2005. The contact rate from video data was defined by the number of contacts divided by the number of operational contact days. This summary includes the indirect contact rates for all data cumulative and by season. Cow/hog and hog/cow headings represent cows following hogs and hogs following cows, respectively.

	Indirect Contacts (N)			Trap Days (N)	Contact Rate (Contacts/day)		
	Cow/ Hog	Hog/ Cow	Total		Cow/ Hog	Hog/ Cow	Total
Summer 2004	114	57	171	150	0.76	0.38	1.14
Fall 2004	109	138	247	153	0.71	0.90	1.61
Winter 2005	0	2	2	31	0.00	0.06	0.06
Spring 2005	49	13	62	63	0.78	0.21	0.98
Cumulative	272	210	482	397	0.69	0.53	1.21

became decreasingly frequent as time lapse increased (Figure 24). This trend was not as apparent when the data were split by season, except in Fall 2004 (Figures 25-27). The Summer 2004 had a peak of indirect contacts with 6-9 hrs time lapse between interspecific visits regardless of which animal came to the site first (Figure 25). The Spring 2005 had a peak of indirect contacts at 6-9 hrs for cows following hogs and 18-21 hrs for hogs following cows (Figure 27).

DISCUSSION

Most published studies that include models of FMD spread are conducted with a limited understanding of how wild populations of animals can harbor and transmit the virus to domesticated livestock. I measured movement parameters of feral hogs and cattle to determine if variability in habitat, anthropogenic infrastructure, time of day, or season might influence disease transmission. We determined influence, from GPS or video data, of natural and anthropogenic land features on movement and interspecific contact, though my findings are not definitive because of an inconsistent and limited dataset. Although trends of land feature use and interspecific contact locations and conditions were identified, and may gain confidence with further research.

The study site in southwestern Texas provided a setting with realistic vulnerability for disease introduction and transmission to occur (Pozio et al. 2001), as it is near points of entry of foreign goods and people. The Mexican-U.S. border and U.S. seaports are within ~42 km (27 mi) and 322 km (200 mi) from the study site, respectively (Figure 3). Furthermore, this area of Texas is more densely populated by feral hogs than most of the state (Figure 2.), which could increase the potential transmission of FMDv to other wildlife and livestock. Water in this area was a limiting resource and appears to be the most likely attractant for interspecific contact. Supplemental feed provided for wildlife and cattle has the potential to increase interspecific contact. My investigation suggests that indirect contact between feral hogs and cattle is likely to occur more often than direct contact.

Feral Hog and Cattle Overlap

Spatial overlap occurred between cattle and feral hogs in all seasons. Because feral hogs are highly mobile within their home ranges (Singer et al. 1981), this suggests that hogs are likely to encounter cattle on a frequent basis. This investigation documents the potential for interspecific contact and subsequent disease transmission between cattle and feral hogs year around. Because of limited trap success and equipment malfunctions 2 and 1 hogs were redeployed for a second time in Fall 2004 and Spring 2005 to maximize data gathered. The 95% and 50% kernel area use of feral hogs observed in ~2–12 week intervals in this study from Summer 2004 to Fall 2004 ranged from 84–273 and 10–33 ha, respectively. A separate study conducted in southwestern Texas used radiotelemetry to assess feral hog distribution reported a range of 95% minimum convex polygon and 50% harmonic mean from winter to summer of 82–233 and 12–45 ha, respectively (Ilse and Hellgren 1995). Although the definition of season and methods of analysis were slightly different in Ilse and Hellgren (1995), the findings agreed with those in this investigation, and showed that the animals traveled over much of their seasonal range in the relatively short time that they were collared.

The cattle ranch was managed primarily for herbaceous forage intended for cattle. Management practices were streamlined for beef production, although some land modifications were aimed at enhancing wildlife habitat and animals for the commercial hunting enterprise. Feral hogs also benefited from management practices intended for other animals.

I examined if range sites played a role in the distribution of livestock and feral hogs, as this information would be useful when developing prevention, surveillance, and emergency response and recovery plans. Although no single range site had the majority of use, some were more heavily used than others. I found that both cows and feral hogs used Clay Flat, Clay Loam, and Rolling Hardland more heavily than other range sites. Within study pastures, riparian zones divided some of these range sites.

According to GPS data, feral hogs used these riparian zones 70% (445 of 632 fixes), 14% (734 of 5,204 fixes), 38% (919 of 2,452 fixes), and 39% (952 of 2,452 fixes) of their time during Summer 2004, Fall 2004, Winter 2005 and Spring 2005, respectively. Although percent time use was less, it is still important that data reports cattle passed through riparian zones frequently (Summer 2004 = 14%, 2,760 of 19,365 fixes, Fall 2004 = 4%, 436 of 12,314 fixes, Winter 2005 = 14%, 2,863 of 20,344 fixes, and Spring 2005 = 22% 1,288 of 5,861 fixes) in all seasons because there are many more cattle fixes than feral hog fixes. There may be more visitations to riparian zones than thought as success of GPS fix acquisition is hampered with dense canopy cover. Riparian zones are a likely location for indirect interspecific contact as they could serve as a travel or escape corridors for feral hogs and shade water sources for both species.

Because water sources are limited in southwestern Texas, the ranch also provided water using livestock ponds and water troughs. In Summer 2004, visitation to ponds by cattle (~5% of GPS fixes, 950 of 19,365) and hogs (~6% of GPS fixes, 41 of 632) were lower than hypothesized. Rainfall during the study was > normal in Summer 2004. These unusually wet conditions and the additional availability of natural water holes may have influenced visitation to livestock ponds by cattle and feral hogs. Livestock ponds and water troughs would likely have greater importance to cattle and feral hogs as focal points for disease transmission during drought periods.

Center pivot irrigation pastures were planted with grasses to supply additional forage for cattle and wildlife. These sites also attracted hogs as shown by the spatial distribution of 1 sow and 1 male shoat who had ~29% (295 of 1,037) and ~27% (148 of 541) of their GPS fixes occurred in a center pivot pasture during Fall 2004 and Spring 2005, respectively. These sites offer forage when the surrounding land may not be as productive because of drought conditions, making them attractions for both species and a site for interaction to occur.

The ranch maintains brush-grass strip patterns in many pastures. The grass strips serve as both forage for cattle and escape cover for wildlife. These strips were available to cattle during the Fall 2004 and Spring 2005. Cattle used grass strips during these seasons ~76% (9,411 of 12,314) and ~70% (4,105 of 5,861) GPS fixes, respectively. Feral hogs used grass (~19%, 999 of 5,204 GPS fixes) and brush strips (~20%, 1,064 of 5,204 GPS fixes) more evenly during the Fall 2004. Brush strips may serve as travel corridors for feral hogs, giving the access to the same grass strips used by foraging cattle. This information may be important when formulating best management options for reducing feral hog numbers, brush management patterns, and emergency response protocols.

Ranch strategies for enhancing wildlife habitat are also important to consider. For instance, this ranch, like many in the area, implemented a supplemental feeding program for deer and cattle. Mineral feeders and molasses licks were not used often by either species. Protein feeders for deer were double fenced from hogs and cattle. On ranches without exclusion fencing around feeders, hogs are known to utilize feed provided for other species. Even when the feeders are fenced, their presence may be an attraction (i.e., scent of feed, site for scent marking, or scratching etc.). The management practice of spreading shelled corn on the road to attracted deer for hunting purposes also clearly attracted hogs (Figure 28).

Frequency and Conditions of Contact

Intraspecific disease transmission within cattle herds is likely, but it is unknown how feral hogs will factor in to the FMD outbreak or maintenance of the disease on rangeland. This study found no direct interspecific contacts from GPS data probably because of the use of large study pastures and relatively low number of collared animals. However, 3 cases were recorded on video where the number of collared animals did not matter. Indirect interspecific contacts that may be sufficient for disease transmission occurred much more frequently (GPS = 3.35 indirect contacts/day, video = cows follow hogs - 0.69 indirect contacts/day and hogs follow cows - 0.54 indirect contacts/day). The closest direct recorded distance between a hog and a cow from GPS data was 17 m within a 15 min time frame. At other times the 2 species came within 50 m of each other within 15 min near a water source in Fall 2004 (0.05 direct interactions/day) and Spring 2005 (0.12 direct interactions/day). Given the mobility of aerosol FMD, these short distances would not provide much protection against contracting the disease. When distance between all cattle and feral hog observations, regardless of timing, were

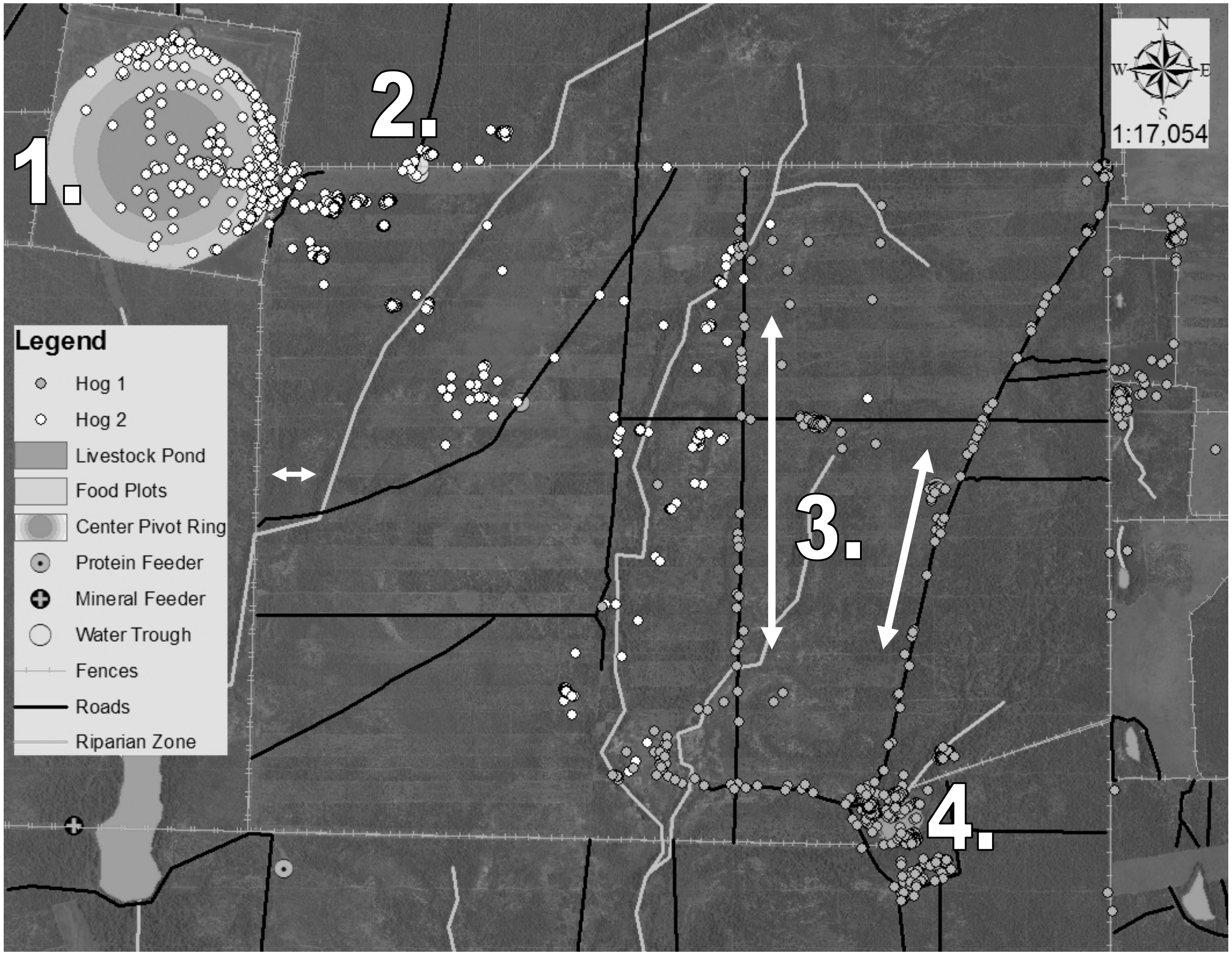


Figure 28. Feral hog GPS position fixes on roads and center pivot pastures, Zavala County, Texas, USA, Fall 2004. This GIS image shows the use of a (1) center pivot irrigated pasture, (2) water troughs, (3) roads baited with corn, and a (4) livestock pond by 2 hogs in the Fall 2004 season.

examined, there were many times when the 2 species were a short distance apart. Because of the persistence of FMD through time (Bartley et al. 2002), there was ample opportunity to contract the disease as animals moved about the pasture, foraging over much of the same ground.

Interspecific indirect contacts occurred during each season, but were most numerous in the Fall 2004 (GPS = 9.37 indirect contacts/day, video = 1.61 indirect contacts/day) and Winter 2005 (GPS = 3.34 indirect contacts/day). These seasons had the highest concentration of relatively small distances between feral hogs and cattle (Figures 18–19). These are the times of year when the risk of infection would be greatest because relatively mild ambient temperatures facilitate longer viral viability (Bartley et al. 2002). Contact rates during these seasons may be in part due to lower forage availability and increased supplement feeding and baiting of white-tailed deer. To minimize risk at this time, a reduction of grazing time in a single pasture and a decrease of stocking rates could maintain higher levels of available forage. This would decrease the need for supplemental feed for cattle and wildlife. Halting supplemental feeding of deer and baiting of roads would lessen the chance of concentrating cows, hogs and deer to the same site, thus reducing the chance of contamination and subsequent spread of virus.

In Summer and Fall 2004 and Winter 2005, video indicated that the shoat age-class was most active during sunset-sunrise at riparian zones and verified that direct contacts occur (Figure 29). Interspecific interaction occurred (N = 49) most often during 0-3 hrs time lapse between animal visits. Because FMDv stays viable in the soil for < 2

Figure 29. Image of video with cattle foraging next to a cattle guard with feral hogs traveling in the background, Zavala County, Texas, USA, Fall 2004.

hrs at 34°C and ≥ 38 hrs at 3°C (Bartley et al. 2002), cattle may contract FMDv in normal southwestern Texas climatic conditions should it be introduced.

Most interspecific contact occurred between cattle and shoats, rather than with adult hogs, especially in Winter 2005 and Spring 2005. This could be due to a higher number of shoats in the local hog population. Contacts between shoats and cattle were most frequent in the peak of night. This may lead to greater risk of disease transmission due to lower ambient temperatures at night allowing longer viral survival (Bartley et al. 2002).

Frequency of feral hog intraspecific contact would be useful for modeling an epidemic to estimate how effectively hogs would maintain and propagate FMD in the population. Similar to interspecific contact, hog intraspecific contact was greatest in the Fall 2004 season, coinciding with increased baiting for white-tailed deer.

Future Research

This investigation provides a starting point and data source to improve current models of the spread of an FMD epidemic. Continuation of GPS data collection at multiple sites and among years would increase sample size and ensure replication. Remote sensing software could be used to classify habitat and anthropogenic infrastructure features on satellite imagery. This may enhance the detail of feature borders making the assessment of GPS fix location more accurate. Algorithms could be written to interpolate where animals traveled between GPS observations to add to the area use analysis. Environmental factors of disease agent resistance such as the length of time the virus is viable under different conditions should be incorporated into the indirect contact analysis to help define effective contact for disease transmission. Although I documented many indirect contacts, knowing the viability of FMD particles could be used to understand risk of animals using the same location or resources at varying periods < 24 hrs. Land owner and rural population surveys could be used to document feral hog regional population size in order to better model an epidemic. Once we know how FMD would spread across the landscape further research on control and prevention methods could be conducted to streamline an emergency response plan and minimize economic loss.

GPS Technology Challenges

Global positioning system collars were used to track concurrent movements and usage patterns of cattle and feral hogs. The advantages of GPS collars over conventional radiotelemetry are that GPS collars provide accurate and precise position fixes at frequent intervals throughout the day and night regardless of weather and the behavior of the animals (Springer 1979, Fancy et al. 1988, Beyer and Haufler 1994, and Moen et al. 1997). The high cost of these GPS units limits the number of animals that can be collared. Thus, it is essential that the animals be valid seasonal samples from the population, rather than considered as individuals. Deploying the collars for short periods on numerous different animals during the course of the study alleviated the problem of small sample size to some degree.

The only way potential direct contact could be realistically represented in the data was to collect data on a relatively short time interval. One observation every 15 min is a much finer temporal scale of data collection than traditional wildlife telemetry studies. However, my objectives were different than traditional telemetry studies, calling for an alternative study design. Many wildlife telemetry studies often explore species movement in general (i.e., habitat selection or home range estimation). My objectives, however, were to collect data that represented frequency of contact between species. If a traditionally large time interval were used such as 1 GPS fix each day or even 1 GPS fix every hr, direct interspecific contact could have occurred several times without being recorded. Chances of recording direct or indirect contact are greatly increased and only realistic if a short time interval is used for data collection.

Some would argue that short temporal data observation intervals cause bias in data analysis. Swihart and Slade (1985) suggested that animal movement observations at small temporal scale violate the basic assumption of independence of successive animal fixes for many statistical tests. Violation of this assumption (temporal autocorrelation) refers to the idea that the animal did not have enough time to move far enough before it was located again and that the resulting analysis would underestimate true 95% kernel area use size.

Fixed kernel methods estimate the complete utilization distribution of the animal and are not sensitive to the independence of GPS fixes or outlying points (Kie et al. 1996, Kernohan et al. 1998). Fixed kernel utilization distribution estimates were used to calculate the size of each animal’s 95% and 50% kernel area use based on GPS fixes (Seaman et al. 1998, Worton 1989, Seaman et al. 1999). This method excludes outlier fixes (95%) unlike the 100% minimum convex polygon that can use locations that were traveled to, but were not representative of the normal range of animal movement on the landscape.

Otis and White (1999) maintained that a statistical translation of 95% kernel area use was that the movement trajectory generated by the animal can be modeled as a 2-dimensional, continuous, stationary, stochastic process. By definition this process generates an associated autocorrelation function. In addition, autocorrelation is not a relevant concern because my sampling design was a representation of an unbiased sample of the animal's continuous trajectory in the landscape during the study interval without regard to external factors. Regardless of autocorrelation, my objectives define my sampling design. To assess contact rates between species, small temporal interval between successive observations was needed. As a result, temporal autocorrelation is not a limiting concern to this study.

Collars used in this study incorporated innovative features designed for more efficient telemetry data collection. Commonly found AA 1.5-volt and C 1.5-volt batteries allowed for less costly and more efficient battery replacement than with other models. At the rate of 4 GPS fixes per hr, the hog and cow collars had the capacity to record data over 15 days and 3 months, respectively. Potentially, this would mean that 4 cow and 48 hog deployments of data would be recorded in a 3-month season. However, hog deployments were often limited by the number of hogs that could be trapped within each season. Number of collars was weighted toward feral hogs because cattle movements are better understood and feral hog behavior was expected to damage collars. Increasing the potential feral hog sample size was intended to mitigate for these possibilities. In addition, 2 and 1 feral hogs were recollared for a second deployment in Fall 2004 and Spring 2005, respectively. During those periods, trap success was relatively low and redeployment was used to assure proper data collection quantity. The hogs used as redeployments are not believed to bias the sample because they were of the shoat age-class, the most represented class used in the study.

The need for post-processing of data was investigated once data were retrieved. Even though GPS technology is more accurate than traditional telemetry, there is still concern with reliable GPS data because of interference and error caused by canopy cover and dynamic satellite availability (Rempel and Rodgers1997). Differential correction is used to ground truth GPS data with known locations on the earth and correct for these errors. Collars used in this study were enabled with the differential correction program Wide Area Augmentation System (WAAS) yielding differentially corrected data.

I verified the minimization of bias by testing a dataset from my study with additional post-differential correction software (P4, Institute of Engineering Surveying & Space Geodesy, Nottingham, United Kingdom, 2002). Average correction distance for that deployment was 2.7 m. Accuracy of the collars was tested *a priori* to be 8 m. Some undetected variation exists in the natural landscape boundaries, such as water sources drying up, cows moving feeders around, vegetation growing and dying. Consequently, data improvement after post-correction was not detected, making post-differential correction unnecessary.

The GPS collars had deficiencies that decreased the quantity of data and complicated the analysis process. Once released, animals were supposed to be tracked periodically by radio-telemetry to maintain a known general proximity of the collar. However, the integral ultra high frequency (UHF) beacons only transmitted a signal ~100 m. This distance was far less than promoted by the manufacturer and made tracking the animals and retrieval of the collars extremely difficult. This problem was solved by attachment of a very high frequency (VHF) beacon (Advanced Telemetry Systems, Isanti, Minnesota) which increased the tracking distance up to ~0.8 km (0.5 mi).

In addition, the remote drop-off mechanism did not perform according to design. This necessitated re-trapping or harvesting the hogs to retrieve the collars and data stored within them. It was thought that harvesting would have little effect on the hog population since they are a hunted population and the deployments were conducted in a different pasture each season. However, this method of collar retrieval was much more time intensive and ultimately slowed the data collection process and reduced the number of samples collected in the study.

Portions of downloaded data were incomplete and/or inconsistent. Some collars collected < 24 hrs worth of data and stopped working. Others collected a few points every few days or never started collecting data despite verified successful deployment. Deployments with extremely large temporal gaps between observations or other unidentified malfunctions were excluded from analysis. In the last season, ambient temperatures over 40^{o}C caused the batteries to burst in 2 of the cow collars halting data collection. One of the cows was excluded from analysis because the collar quit working before the animal was in the study pasture.

Other data inconsistencies were not attributed to technical malfunctions. During the last season the cows were moved into the designated study site pasture 2 weeks later than intended (a ranch decision). As a result 1/6 of the cow data were of no use. Some pig collars inadvertently came off the animal resulting in a mortality radio beacon. One cow slipped her collar off and the beacon failed so it was never recovered from the pasture. This reduced the cow samples to 3 for Fall 2004, Winter 2005, and Summer 2005.

Some data deficiencies were inherent in the technology. The collars attempted to take an observation for a defined period of time. If the GPS unit was unable to communicate with passing satellites during a specified time, due to interference from thick brush, cloud cover, or the lack of enough orbiting satellites, the unit recorded "No Position" for that time stamp. As a result, the percent successful fixes varied between deployments (Appendix A.1). If a collared feral hog spent most of its time under thick brush in a riparian zone the amount of data recorded were decreased up to 93%. Data from the cow collars were much more complete than data from the hog collars, probably because they spent less time in thick brush and had much greater battery power. Compounding the problems, some of the "No Position's" were recorded as blank and others as "GPS malfunction" for unknown reasons. The blank recordings were confusing to identify and delayed the analysis process.

Other data biases were expected and corrected before analysis. Short-term bias affecting hog movements was expected, depending on the length of time that traps remain pre-baited before capture (Mansouri 1986). In such cases, post-data processing was completed to exclude fixes within 15 m of the trap from analysis. In most cases, the trapping and collaring process was assumed to be a negative experience because the data reflected that hogs left the trap and did not return.

Video Technology Challenges

Motion-triggered infrared video recorder also collected animal-use data with minimal human bias. Animals showed no fear of the video recorder and were assumed to travel their normal routes. Occasionally, cows did investigate the units and knocked them over, while hogs sometimes sniffed the video recorder momentarily. However, the equipment was not perceived as an attractant for either species to the area, nor did either spend much time at the video recorder.

There were technical malfunctions with the video units that reduced the data quality and quantity. At times, the video data were inconsistent. Some of the data recordings were of poor quality, to the point that animal identification and date/time stamps could not be determined. Often, the video recorder would mangle the tape. Other times, the date/time stamp was not recorded onto the video for unknown reasons. The unpredictable nature of this equipment reduced the amount of data to be analyzed.

MANAGEMENT IMPLICATIONS AND SUMMARY

This investigation provides a first attempt to qualitatively and quantitatively assess the interaction of feral hogs with cattle, as well as the use of many man-made features and natural habitat components. It illustrates the potential for disease transmission if FMDv was introduced into the U.S. and stresses the importance for cattle managers to minimize feral hog and cattle focus points of contact. These recommendations are only suggestions that could be implemented in the face of an epidemic.

Exclusion to Interspecific Focal Points

Excluding Feral Hogs.--Excluding feral hogs from cattle would probably require considerable expense and intensive planning (Stevens 1996). Feral hogs find their way through or under traditional fencing. Alternative fencing like chain link buried at least 30 cm underground, mesh wire fences, or electric fences could be used to prevent hog access to an area (Hone 1983*b*), but this is an expensive alternative. Rough terrain, creeks, and ditches would require fence modifications, as these areas are likely points of entry. The cost of fencing is high and may not be option for all land owners. Because feral hogs are highly prolific and difficult to control, excluding hogs from cattle might be unreasonable. However, excluding cows from feral hogs may be an effective alternative to lower risks of interspecific contact and possible disease transmission.

Excluding Cattle.--Preventing cattle access to areas feral hogs frequently use may be the best management strategy for reducing risks if FMDv was in the U.S. Study results indicate that Clay Flat, Clay Loam, Rolling Hardland, and Gray Sandy Loam range sites on the study ranch should be avoided for livestock grazing or at least have reduced stocking rates in dormant seasons when FMDv viability is most resistant to the environment. Restricting access to or filling in livestock ponds and strategically placing water troughs on those sites could reduce interspecific contact also.

Cattle should preferably drink from troughs which could be disinfected rather than from livestock ponds and riparian zones which serve as an attractant for rooting and wallowing. Data indicated that feral hogs frequented riparian zones often, ~14% (734 of 5,204 fixes) and ~70% (445 of 632 fixes) of their GPS fixes. During drought months (summer and spring) when feral hogs visited riparian zones the most, cattle could be fenced off from riparian zones all together. Cattle rely on other water sources at those times and could seek loafing cover under brush mottes. Water troughs could be located on upland sites by trucking in water, thereby drawing cattle away from riparian zones. Burning and/or brush control techniques could also be used on upland sites to promote grass growth for forage in these areas.

These results indicated feral hogs on this ranch used (up to ~27% (148 of 541 fixes) center pivot irrigation pastures meant for supplemental forage for cattle during the dormant season. Feral hog exclusion around these pastures, as mentioned above, could be effective in reducing interspecific contact and is probably worth the cost as FMD transmission risk is higher in cold temperatures when livestock need supplemental feeding.

When available in this study, maintained brush strips intended for grass growth stimulation were heavily used (~70% [4,105 of 5,861] – ~76% [9,411 of 12,314] of fixes) by cattle. Managers should avoid stocking cattle in pastures with brush strips during the dormant growing season as these areas are generally much larger and more costly to fence. Because disturbance of the soil could attract feral hogs to feed on plant tubers and insects, maintenance of these strips could be scheduled around the growing season when higher temperatures reduce the longevity of FMDv viability.

A quantitative analysis of GPS data in GIS depicted daily routines of feral hogs and cattle traveling to watering points, and foraging and loafing areas along fencelines and roads, especially in Fall 2004 when roads were baited. Using GPS collars, Depew (2001) determined that roads and water were some of the most used infrastructure sources by cattle. Owens et al. (1991) found that cattle avoided dense brush; consequently, it was not surprising to find them using roadways as path of least resistance when traveling in search of pasture resources. It was unlikely that travel along these routes would stop, but eliminating the practice of supplying corn on roads should reduce the number of animals attracted to roads and from this reduce the probability of FMD transmission from feral hogs to cattle.

Although supplemental feeding and watering is perceived to be needed in this region, this study suggests it could also be a likely focal point for disease transmission to livestock during those seasons (primarily fall and winter) in which supplemental feeding occurs. In the event of a disease outbreak baiting roadways with corn and supplemental feeding deer should cease or cattle could be separated from those baited locations or sold.

Feral Hog Population Reduction

Implementing a feral hog reduction strategy with the aim being to depopulate hogs from the property could also reduce interspecific contact risks. Hunting hogs could be very effective in this region because many ranches are already equipped with hunting blinds and have established clientele. This could be a viable option for ranchers to reduce hog populations with minimal expenditures or departure from fall hunting practices. However, an eradication program could be used as feral hog harvest is legal year around because of their exotic pest classification.

In southern Texas, aerial gunning of hogs from helicopters is one of the most efficient methods of removing hogs from dense brush with limited road access. Although costly for private ranchers, this is a suitable method for state and federal agencies (U.S. Department of Agriculture-Animal and Plant Health Inspection Service-Wildlife Services). Managers may also consider snaring, but this technique runs the risk of capturing non-target species. Toxicants, birth control, or repellants are not viable options, as none are currently registered for control on feral hogs (Stevens 1996).

Trapping may be the most effective way to reduce hog populations (Stevens 1996, Richardson et al. 1997). Because feral hogs tend to move about in search of resources, traps could be designed to be easily transported among pastures and designed to capture many hogs at once. Evidence from this investigation showed that shoats may be the most likely to spread the disease and during night hrs. Coincidentally, the naivety of shoats makes them easiest to trap. Once traps are built and in place, this control method is the least labor intensive and could be the most effective.

Other options to reduce feral hog numbers could be to secure a radiotelemetry collar on a sow, who would serve as a Judas pig (McIlroy and Gifford 1997). By homing in on the radiosignal of the telemetered Judas pigs, the location of sounder members could be ascertained. The USDA – Animal and Plant Health Inspection Service (APHIS) – Wildlife Services or local hog hunters with dogs could be contracted to reduce feral hog populations. Dogs could be used to harass hogs from the area or bay them until harvested. Ultimately, the best feral hog control strategy would be to implement a combination of several techniques prescribed to each area (Richardson et al. 1997).

There needs to be a concerted effort between land owners in the form of wildlife associations, in addition to lessees and government entities to reduce feral hog numbers through like minded techniques. Some land owners desire the importation of feral hogs to their land for hunting purposes. Many of these people may be unaware of the risks they are placing on their ranching operation and their neighbors. Collaborative agreements between local, state and federal government agencies, and land owners, to apply 1 or more of the techniques mentioned above could lead to regional control and extirpation of feral hogs.

Summary

Cattle managers should think about biological and anthropogenic influences on interspecific disease transmission from feral hogs to cattle. Water sources are one of the most limiting resources in southwestern Texas and in turn may decrease natural forage availability. During drought conditions cattle and wildlife often focus on supplemental food and water sources. However, the longevity of FMDv viability is at its shortest in high temperatures. Therefore, viral particles will remain a risk to cattle longer in the dormant growing season. Management to protect livestock from FMDv transmission is important year around, but especially in the fall, when this study recorded the most interspecific contacts (GPS = 9.37 interspecific indirect contacts/day, video = 1.61 interspecific indirect contacts/day). These contact rates may have been influenced by road baiting for deer, increased plant defoliation, and lower temperatures (which increases the longevity of disease particle viability) The best management strategy is a combination of cattle exclusion to interspecific focal points and feral hog population reduction.

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APPENDICES

Appendix A.1. Usable animal sample GPS fix successful acquisition rate summary in Zavala County, Texas, USA, 2004–2005. The 5 types of deployments used are as follows: C = cow, FS = female shoat, MS = male shoat, S = sow, and B = boar. The Fall 2004 and Spring 2005 seasons had 2 and 1 hog samples recollared for a second deployment marked by "a" for deployment 1, and "b" for deployment 2.

Season	Animal	Collar Number	Date	Total Days	Total Attempts for GPS Fixes	% Success
Summer 2004	C1	38	7/21-9/19	60	5,856	99.57%
Summer 2004	C2	41	7/21-9/19	60	5,856	99.13%
Summer 2004	C3	42	7/21-8/10	20	1,932	98.96%
Summer 2004	C4	43	7/21-9/19	60	5,856	99.33%
Summer 2004	FS	34	7/30-8/5	7	565	60.88%
Summer 2004	B	32	8/25-8/30	6	507	59.20%
Fall 2004	C1	41	9/28-11/18	51	4,303	99.40%
Fall 2004	C2	42	9/28-11/14	47	3,901	99.69%
Fall 2004	C3	43	9/28-11/17	50	4,197	98.77%
Fall 2004	MS1	30a	10/5-10/21	16	1,524	55.64%
Fall 2004	MS2	30b	11/11-11/26	15	1,449	86.34%
Fall 2004	FS1a	35	10/5-10/15	10	841	54.70%
Fall 2004	FS1b	32	10/21-11/5	15	1,442	73.16%
Fall 2004	S1a	37a	10/7-10/15	8	744	58.60%
Fall 2004	S1b	37b	10/21-11/5	15	1,455	55.64%
Fall 2004	S2	31	10/8-10/20	12	1,201	86.34%

Appendix A.1. Continued.

Season	Animal	Collar Number	Date	Total Days	Total Attempts	% Success
Winter 2005	C1	41	2/4-4/18	73	6,985	99.44%
Winter 2005	C2	42	2/4-4/14	69	6,580	99.47%
Winter 2005	C3	43	2/4-4/19	74	7,102	96.49%
Winter 2005	FS	30	2/23-3/10	16	1,388	55.33%
Winter 2005	S1	33	2/15-2/22	8	649	70.72%
Winter 2005	S2	34	2/8-2/23	16	1,435	80.42%
Winter 2005	S3	35	2/16-2/28	13	1,181	70.87%
Winter 2005	S4	37b	2/18-3/3	14	1,251	61.47%
Winter 2005	B	37a	2/8-2/9	2	145	64.68%
Spring 2005	C1	42	5/03-7/2	59	5,738	98.71%
Spring 2005	C2	43	5/03-5/5	3	196	98.48%
Spring 2005	FS1a	30	5/27-6/2	7	562	27.92%
Spring 2005	FS1b	37a	5/13-5/25	12	1,130	27.88%
Spring 2005	FS2	35a	5/15-5/24	9	875	83.88%
Spring 2005	FS3	36	6/1-6/14	14	1,167	39.25%
Spring 2005	MS1	33a	5/19-5/26	7	645	83.88%
Spring 2005	MS2	34	5/19-5/20	2	92	44.91%

Appendix A.1. Continued.

Season	Animal	Collar Number	Date	Total Days	Total Attempts	% Success
Spring 2005	S	37b	6/9-6/22	14	1,272	18.08%
Spring 2005	B	35b	6/10-6/14	5	409	68.95%

Appendix A.2. Seasonal locations of interspecific 95% kernel area use (HR) and 50% kernel area use (CA) overlap in Zavala County, Texas, USA, 2004–2005. The 5 types of deployments are: C = cow, FS = female shoat, MS = male shoat, S = sow, and B = boar. Fall 2004 and Spring 2005 had hog samples recollared for a second deployment marked by “a” for deployment 1, and “b” for deployment 2. Sample labels represent different animals seasonally. The locations of overlap are identified by habitat features and anthropogenic infrastructure: RZ = riparian zone, LP = livestock pond, CP = center pivot irrigated pasture, Tr = baited trap area, R = road, F = fenceline, OP = old oil pad, and BS = brush strip. The symbol “†” denotes that an overlap existed but no specific habitat feature or anthropogenic infrastructure was identified. “## m” denotes the distance between 50% kernel area uses and/or 95% kernel area uses when they are in close proximity with no overlap.

			C1		C2		C3		C4	
Season	Animal Deployment		HR	CA	HR	CA	HR	CA	HR	CA
Summer 2004	B	HR					†			
Summer 2004	B	CA					RZ			
Summer 2004	FS	HR	†	LP/Tr	†		†	CP	†	LP
Summer 2004	FS	CA	LP	70m					†	40m
Fall 2004	FS1.a.	HR	†		†	3m	†	RZ	n/a	n/a
Fall 2004	FS1.a.	CA			LP		LP		n/a	n/a
Fall 2004	FS1.b.	HR	†		†		†	RZ	n/a	n/a
Fall 2004	FS1.b.	CA	LP		LP		LP		n/a	n/a

Appendix A.2. Continued.

			C1		C2		C3		C4	
Season	Animal Deployment		HR	CA	HR	CA	HR	CA	HR	CA
Fall 2004	MS1	HR	†		†	BS	†		n/a	n/a
Fall 2004	MS1	CA			LP		LP		n/a	n/a
Fall 2004	MS2	HR	†		†	RZ	†		n/a	n/a
Fall 2004	MS2	CA			LP		LP		n/a	n/a
Fall 2004	S1.a.	HR	†		†	R	†	RZ	n/a	n/a
Fall 2004	S1.a.	CA			LP/R		LP		n/a	n/a
Fall 2004	S1.b.	HR	†		†		†	RZ	n/a	n/a
Fall 2004	S1.b.	CA	LP		LP		LP		n/a	n/a
Fall 2004	S2	HR	†	BS	†	BS	†	RZ	n/a	n/a
Fall 2004	S2	CA	LP/CP	LP/CP	LP/CP		LP/CP		n/a	n/a
Winter 2005	FS	HR	†		†		†	R/F	n/a	n/a
Winter 2005	FS	CA	F/RZ		F		F	10m	n/a	n/a

Appendix A.2. Continued.

Season	Animal Deployment		C1		C2		C3		C4	
			HR	CA	HR	CA	HR	CA	HR	CA
Winter 2005	S1	HR	F/RZ/Tr		F/RZ/Tr		F/RZ/Tr		n/a	n/a
Winter 2005	S1	CA							n/a	n/a
Winter 2005	S2	HR	†	R	†		†		n/a	n/a
Winter 2005	S2	CA	†	†	R		R/Tr		n/a	n/a
Winter 2005	S3	HR	†	OP	†		†	F	n/a	n/a
Winter 2005	S3	CA	F	OP	F		†	F	n/a	n/a
Winter 2005	S4	HR	†		†	†	†	F	n/a	n/a
Winter 2005	S4	CA	LP/F/RZ		†		†	R/RZ/F	n/a	n/a
Winter 2005	B	HR	†	†	†		†	†	n/a	n/a
Winter 2005	B	CA	†	5m	R		†		n/a	n/a
Spring 2005	FS1.a.	HR	RZ				n/a	n/a	n/a	n/a
Spring 2005	FS1.a.	CA					n/a	n/a	n/a	n/a

Appendix A.2. Continued.

			C1		C2		C3		C4	
Season	Animal Deployment		HR	CA	HR	CA	HR	CA	HR	CA
Spring 2005	FS1.b.	HR	RZ				n/a	n/a	n/a	n/a
Spring 2005	FS1.b.	CA					n/a	n/a	n/a	n/a
Spring 2005	FS2	HR	RZ				n/a	n/a	n/a	n/a
Spring 2005	FS2	CA					n/a	n/a	n/a	n/a
Spring 2005	FS3	HR	RZ/R				n/a	n/a	n/a	n/a
Spring 2005	FS3	CA	RZ/R				n/a	n/a	n/a	n/a
Spring 2005	MS1	HR					n/a	n/a	n/a	n/a
Spring 2005	MS1	CA					n/a	n/a	n/a	n/a
Spring 2005	MS2	HR	†	†			n/a	n/a	n/a	n/a
Spring 2005	MS2	CA	†	†			n/a	n/a	n/a	n/a
Spring 2005	S	HR	†	R	†		n/a	n/a	n/a	n/a
Spring 2005	S	CA	†	RZ			n/a	n/a	n/a	n/a

Appendix A.2. Continued.

			C1		C2		C3		C4	
Season	Animal Deployment		HR	CA	HR	CA	HR	CA	HR	CA
Spring 2005	B	HR	†	LP/RZ			n/a	n/a	n/a	n/a
Spring 2005	B	CA					n/a	n/a	n/a	n/a

Appendix A.3. Seasonal interspecific range site usage in Zavala County, Texas, USA, 2004–2005. Percent site-use is the amount of fixes located spatially within the range site divided by the total number of successful fixes acquired for hogs or cows in each season.

		Number Site-Use Fixes		Total Fixes		Percent Site-Use	
Season	Range Site	Hogs	Cows	Hogs	Cows	Hogs	Cows
Summer 2004	Clay Flat	270	5,388	632	19,365	43%	28%
Summer 2004	Clay Loam	96	8796	632	19,365	15%	45%
Summer 2004	Claypan Prairie	170	772	632	19,365	27%	4%
Summer 2004	Clay Sandy Loam	28	560	632	19,365	4%	3%
Summer 2004	Loamy Sand	0	28	632	19,365	0%	0%
Summer 2004	Rolling Hardlands	68	1,550	632	19,365	11%	8%
Summer 2004	Sandy Clay	0	101	632	19,365	0%	1%
Summer 2004	Sandy Loam	0	1,940	632	19,365	0%	10%
Summer 2004	Shallow Sandy Loam	0	35	632	19,365	0%	0%
Summer 2004	Water	0	195	632	19,365	0%	1%
Fall 2004	Clay Flat	778	1,018	5,204	12,314	15%	8%

Appendix A.3. Continued.

		Number Site-Use Fixes		Total Fixes		Percent Site-Use	
Season	Range Site	Hogs	Cows	Hogs	Cows	Hogs	Cows
Fall 2004	Clay Loam	935	2,914	5,204	12,314	18%	24%
Fall 2004	Claypan Prairie	438	1,430	5,204	12,314	8%	12%
Fall 2004	Gray Sandy Loam	853	3,219	5,204	12,314	16%	26%
Fall 2004	Rolling Hardland	947	3,252	5,204	12,314	18%	26%
Fall 2004	Saline Clay	943	65	5,204	12,314	18%	1%
Fall 2004	Sandy Loam	0	382	5,204	12,314	0%	3%
Winter 2005	Clay Flat	0	741	4,121	20,344	0%	4%
Winter 2005	Clay Loam	461	896	4,121	20,344	11%	4%
Winter 2005	Claypan Prairie	1,267	4,068	4,121	20,344	31%	20%
Winter 2005	Gravelly Ridge	2	0	4,121	20,344	0%	0%
Winter 2005	Gray Sandy Loam	136	1809	4,121	20,344	3%	9%
Winter 2005	Rolling Hardland	1,393	8,179	4,121	20,344	34%	40%

Appendix A.3. Continued.

		Number Site-Use Fixes		Total Fixes		Percent Site-Use	
Season	Range Site	Hogs	Cows	Hogs	Cows	Hogs	Cows
Winter 2005	Saline Clay	790	4,511	4,121	20,344	19%	22%
Winter 2005	Sandy Loam	4	19	4,121	20,344	0%	0%
Winter 2005	Water	67	118	4,121	20,344	2%	1%
Spring 2005	Clay Flat	209	0	2,452	5,861	9%	0%
Spring 2005	Clay Loam	1,822	2,627	2,452	5,861	74%	45%
Spring 2005	Claypan Prairie	120	1,652	2,452	5,861	5%	28%
Spring 2005	Gray Sandy Loam	39	3	2,452	5,861	2%	0%
Spring 2005	Lakebed	0	5	2,452	5,861	0%	0%
Spring 2005	Rolling Hardland	33	235	2,452	5,861	1%	4%
Spring 2005	Saline Clay	107	0	2,452	5,861	4%	0%
Spring 2005	Sandy Loam	1	1,204	2,452	5,861	0%	21%
Spring 2005	Tight Sandy Loam	5	135	2,452	5,861	0%	2%

Appendix A.3. Continued.

		Number Site-Use Fixes		Total Fixes		Percent Site-Use	
Season	Range Site	Hogs	Cows	Hogs	Cows	Hogs	Cows
Spring 2005	Water	116	0	2,452	5,861	5%	0%

Appendix A.4. Seasonal interspecific natural and anthropogenic feature usage in Zavala County, Texas, USA, 2004-2005. Percent site-use is the amount of fixes located in proximity of the feature divided by the total number of successful fixes acquired for hogs or cows in each season, accordingly. Proximity to a feature is defined in the methods section and is variable by feature type.

		Number Site-Use Fixes		Total Fixes Acquired		Percent Site-Use	
Season	Natural and Anthropogenic land Features	Hogs	Cows	Hogs	Cows	Hogs	Cows
Summer 2004	Grass Strips (5m)	6	0	632	19,365	1%	0%
Summer 2004	Brush Strips (5m)	98	0	632	19,365	16%	0%
Summer 2004	Riparian Area (50m)	445	2,760	632	19,365	70%	14%
Summer 2004	Fences (10m)	24	944	632	19,365	4%	5%
Summer 2004	Roads and Rights of Way (10m)	2	1,100	632	19,365	0%	6%
Summer 2004	Livestock Pond (10m)	41	950	632	19,365	6%	5%
Summer 2004	Food Plots (5m)	0	0	632	19,365	0%	0%
Summer 2004	Center Pivots (5m)	0	1,290	632	19,365	0%	7%
Summer 2004	Protein Feeders (25m)	0	27	632	19,365	0%	0%
Summer 2004	Mineral Feeders (10m)	0	34	632	19,365	0%	0%

Appendix A.4. Continued.

		Number Site-Use Fixes		Total Fixes Acquired		Percent Site-Use	
Season	Natural and Anthropogenic land Features	Hogs	Cows	Hogs	Cows	Hogs	Cows
Summer 2004	Water Troughs (10m)	0	1	632	19,365	0%	0%
Summer 2004	Molasses Lick (10m)	0	0	632	19,365	0%	0%
Summer 2004	Traps (10m)	79	2	632	19,365	13%	0%
Fall 2004	Grass Strips (5m)	999	9,411	5,204	12,314	19%	76%
Fall 2004	Brush Strips (5m)	1,064	3,296	5,204	12,314	20%	27%
Fall 2004	Riparian Area (50m)	734	436	5,204	12,314	14%	4%
Fall 2004	Fences (10m)	310	367	5,204	12,314	6%	3%
Fall 2004	Roads and Rights of Way (10m)	481	714	5,204	12,314	9%	6%
Fall 2004	Livestock Pond (10m)	526	53	5,204	12,314	10%	0%
Fall 2004	Food Plots (5m)	6	0	5,204	12,314	0%	0%
Fall 2004	Grass Strips (5m)	999	9,411	5,204	12,314	19%	76%
Fall 2004	Brush Strips (5m)	1,064	3,296	5,204	12,314	20%	27%

Appendix A.4. Continued.

		Number Site-Use Fixes		Total Fixes Acquired		Percent Site-Use	
Season	Natural and Anthropogenic land Features	Hogs	Cows	Hogs	Cows	Hogs	Cows
Fall 2004	Center Pivots (5m)	296	143	5,204	12,314	6%	1%
Fall 2004	Protein Feeders (25m)	65	0	5,204	12,314	1%	0%
Fall 2004	Mineral Feeders (10m)	11	0	5,204	12,314	0%	0%
Fall 2004	Water Troughs (10m)	0	0	5,204	12,314	0%	0%
Fall 2004	Molasses Lick (10m)	0	0	5,204	12,314	0%	0%
Fall 2004	Traps (10m)	260	0	5,204	12,314	5%	0%
Winter 2005	Grass Strips (5m)	356	645	4,121	20,344	9%	3%
Winter 2005	Brush Strips (5m)	427	178	4,121	20,344	10%	1%
Winter 2005	Riparian Area (100m)	919	2,863	4,121	20,344	22%	14%
Winter 2005	Fences (10m)	388	3,483	4,121	20,344	9%	17%
Winter 2005	Roads and Rights of Way (10m)	291	1,687	4,121	20,344	7%	8%
Winter 2005	Water Bodies (10m)	75	102	4,121	20,344	2%	1%

Appendix A.4. Continued.

Season	Natural and Anthropogenic land Features	Number Site-Use Fixes Hogs	Number Site-Use Fixes Cows	Total Fixes Acquired Hogs	Total Fixes Acquired Cows	Percent Site-Use Hogs	Percent Site-Use Cows
Winter 2005	Food Plots (5m)	0	3	4,121	20,344	0%	0%
Winter 2005	Protein Feeders (25m)	1	1	4,121	20,344	0%	0%
Winter 2005	Mineral Feeders (10m)	0	9	4,121	20,344	0%	0%
Winter 2005	Water Troughs (10m)	0	0	4,121	20,344	0%	0%
Winter 2005	Molasses Lick (10m)	0	0	4,121	20,344	0%	0%
Winter 2005	Traps (10m)	112	10	4,121	20,344	3%	0%
Spring 2005	Grass Strips (5m)	82	4,105	2,452	5,861	3%	70%
Spring 2005	Brush Strips (5m)	152	1,710	2,452	5,861	6%	29%
Spring 2005	Riparian Area (100m)	952	1,288	2,452	5,861	39%	22%
Spring 2005	Fences (10m)	51	104	2,452	5,861	2%	2%
Spring 2005	Roads and Rights of Way (10m)	95	687	2,452	5,861	4%	12%
Spring 2005	Water Bodies (10m)	329	338	2,452	5,861	13%	6%

Appendix A.4. Continued.

Season	Natural and Anthropogenic land Features	Number Site-Use Fixes		Total Fixes Acquired		Percent Site-Use	
		Hogs	Cows	Hogs	Cows	Hogs	Cows
Spring 2005	Food Plots (5m)	685	8	2,452	5,861	28%	0%
Spring 2005	Center Pivots (5m)	156	0	2,452	5,861	6%	0%
Spring 2005	Protein Feeders (25m)	0	2	2,452	5,861	0%	0%
Spring 2005	Mineral Feeders (10m)	0	13	2,452	5,861	0%	0%
Spring 2005	Water Troughs (10m)	0	16	2,452	5,861	0%	0%
Spring 2005	Traps (10m)	4	0	2,452	5,861	0%	0%

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