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# DISTRIBUTION AND INTERSPECIES CONTACT OF FERAL SWINE AND CATTLE ON RANGELAND IN SOUTH TEXAS: IMPLICATIONS FOR DISEASE TRANSMISSION

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ABSTRACT: The last outbreak of foot-and-mouth disease (FMD) in the United States occurred in 1929. Since that time, numbers and distribution of feral swine (*Sus scrofa*) have increased greatly, especially in the southern states. This creates a potential risk to livestock production because swine are susceptible to, and can be carriers of, several economically harmful diseases of livestock. Most importantly, swine are potent amplifiers of FMD virus. In this study, global positioning system (GPS) collars were placed on rangeland cattle (*Bos indicus* × *taurus*) and feral swine to determine shared habitat use by these species on a large ranch in south Texas from 2004 to 2006. The aim was to identify locations and rates of interspecies contact that may result in effective transfer of FMD virus, should an outbreak occur. In shrubland and riparian areas, animals were dispersed, so contacts within and between species were relatively infrequent. Indirect contacts, whereby cattle and feral swine used the same location (within 20 m) within a 360-min period, occurred primarily at water sources, and seasonally in irrigated forage fields and along ranch roads. Direct contacts between species (animals $<20$ m apart and within 15 min) were rare and occurred primarily at water sources. Changes in ranch management practices are suggested to reduce interspecies contact should an FMD disease outbreak occur. This information can also be used to improve current epidemiologic models to better fit free-ranging animal populations.

*Key words:* Epidemiology, foot-and-mouth disease, GPS, habitat selection, *Sus scrofa*.

## INTRODUCTION

Feral swine (*Sus scrofa*) in the United States are undergoing rapid population expansion. In 2000, feral swine were present in 30 US states (Bergman et al., 2002), and the population was estimated at 4 million animals (Pimentel et al., 2000). The population has now expanded into 44 states (Hutton et al., 2006), with a concomitant increase in numbers. Population densities are highest in the southern states, especially in Texas, California, and Florida, USA. The Texas, USA, population is estimated to be $>2$ million animals (Mapston, 2004). This expansion of feral swine populations is of concern, not only because of damage caused to ecologic and agricultural systems but also because of the potential for transmission of diseases to livestock by free ranging swine (Seward et al., 2004). Texas, USA, agencies have reported annual damage to agriculture at $51.8 million (Adams et al., 2005), whereas total damage caused by feral swine in the United States was last estimated to be more than $800 million annually (Pimentel et al. 2000). Costs and risks of disease transmission remain unknown. Feral swine can be infected with at least 18 viral diseases, 10 bacterial diseases (Davidson and Nettles, 1997; Samuel et al., 2001; Williams and Barker, 2001), and 37 parasites (Forrester, 1991) that can affect livestock. Diseases of most concern to the US livestock industry are pseudorabies, leptospirosis, swine brucellosis, bovine tuberculosis, and vesicular stomatitis

(Seward et al., 2004). Several of these diseases have been eradicated from commercial livestock, but a potential reservoir of reinfection still resides in feral swine populations (Hutton et al., 2006). In addition, feral swine are susceptible to several foreign animal diseases, such as foot-and-mouth disease virus (FMDv; Dudley and Woodford, 2002), which devastated the livestock industries of the United Kingdom in 2001.

The United States has been FMDv-free since foot-and-mouth disease (FMD) was eradicated following the last recorded incursion in 1929; however, FMD is the most costly livestock disease in the world (Meyer and Knudsen, 2001), and a risk of reintroduction remains. The financial loss attributed to the FMD outbreak in the United Kingdom in 2001 was estimated at more than $12 billion (Pearson et al., 2005). A similar outbreak in the United States has been predicted to decrease US farm income by at least $14 billion (Paarlberg et al., 2002), with associated social disruption through loss of jobs and businesses in the agricultural sectors (Blancou and Pearson, 2003).

Foot-and-mouth disease is the most contagious disease of cloven-hoofed animals. Transmission occurs mainly through contact with infected animals (Samuel and Knowles, 2001); however, the virus can be transmitted indirectly via aerosols; contaminated soil, feed, and water; animal excretions; and animal by-products (Meyer and Knudsen, 2001; Sellers, 1971; Thomson et al., 2001). Although swine do not become long-term carriers of FMDv (Pinto, 2004), they are highly susceptible to infection and, once infected, become potent amplifiers of the virus (Durand and Mahul, 2000), shedding up to 1,000 times more virus than ruminants (Donaldson et al., 2001). In addition to aerosol shedding of virus, swine may distribute virus in the soil when they root for food. These factors, combined with the high susceptibility of cattle to infection (Donaldson et al., 1987, 2001; Donaldson and Alexandersen, 2002), could lead to rapid spread of a multispecies epidemic. In farming situations with small, fenced pastures, the movements of domestic animals can be controlled, but in more extensive ranching operations, there is less control over animal movements and greater potential for contact between livestock and wild or feral animals (Bates et al., 2001). In sparsely populated rangeland, disease could spread within feral swine populations for an extended period before being detected. This would allow the disease to become well established before detection (Hone and Pech, 1990), by which time eradication would be nearly impossible (Pech and McIlroy, 1990). Several aspects of feral swine behavior make population control difficult: They breed prolifically, their ability to dig under fences makes containment virtually impossible, and their nocturnal behavior and use of dense or inaccessible habitats makes hunting and trapping inefficient means of population control (Gabor et al., 1999; Graves, 1984).

In this study, we examine the seasonal habitat selection of feral swine and cattle on rangeland in relation to key features of the landscape, such as water sources, riparian zones offering shade and cover, and roads, to identify areas of spatial and temporal overlap between feral swine and cattle. Areas favored by both species will be the primary zones of animal contact and potential pathogen transmission. We also examine rates of direct and indirect contact between animals in each landscape feature. Knowledge of primary areas of interspecies contact and the favored habitats of feral swine will assist in the prevention and control of diseases shared by rangeland livestock and feral swine populations. The role of nondomestic animals in sustaining disease outbreaks is relatively unknown (Anderson et al., 1993; Thomson et al., 2003). Information on the distribution and seasonal dynamics of livestock and wild and feral animals is needed to advance current epidemiologic models, such as geographic-automata models (Ward et al., 2007) and cellular automata models (Doran and Laffan, 2005) to predict the course of disease spread in free-ranging animal populations to facilitate the prevention, control, and mitigation of disease outbreaks.

## MATERIALS AND METHODS

The South Texas Plains ecologic region (Griffith, 2004) was selected as the study region because of the international border with Mexico and proximity to international seaports, which could facilitate entry of foreign animal diseases. Extensive cattle-ranching operations and large wildlife populations in south Texas, USA, could facilitate spread of incoming disease organisms. The study was conducted on a 35,000-ha ranch in Zavala County (28°56′N, 99°51′W). The climate was semiarid, with mean annual precipitation of 55 cm (National Weather Service, 2005). The amount of precipitation received annually is typically erratic: In 2004, the ranch received 74 cm of rainfall, but the following 2 yr were relatively dry, with only 35 cm of rainfall per year (Texas Evapotranspiration Network, 2007). Temperatures are subtropic with mean upper and lower temperatures of 18.7 C and 6.1 C in January and 31.4 C and 22.0 C in July, respectively (Stevens and Arriaga, 1985).

Topography is primarily flat with some gently rolling hills. Two creeks and several small, ephemeral drainages run through the area. Major soil types are clay loam and sandy loam (Stevens and Arriaga, 1985). Vegetation is predominantly a mixed, semiarid, shrub community with native and introduced grasses and taller woody species along the riparian areas. Common shrubs include blackbrush (*Acacia rigidula*), guajillo (*Acacia berlandieri*), and guayacan (*Guaiacum angustifolium*) mixed with cacti (*Opuntia* spp.). Riparian areas include thickets of granjeno (*Celtis pallida*) and whitebrush (*Aloysia gratissima*) with Texas persimmon (*Diospyros texana*) and trees of honey mesquite (*Prosopis glandulosa*) and live oak (*Quercus virginiana*). Typical of many ranches in the region, much of the rangeland had been overseeded with common buffelgrass (*Cenchrus ciliaris*) to provide cattle fodder.

The economy of the region is based on cattle ranching and hunting. During the study, the ranch ran 12 cattle herds (approximately 1,000 cows and 7,000 stocker cattle) in a rotational grazing system. Grazing pressure was light because of an emphasis on hunting and optimizing wildlife habitat. Game species included white-tailed deer (*Odocoileus virginianus*), collared peccary (*Tayassu tajacu*), wild turkey (*Meleagris gallopavo*), and quail (*Colinus virginianus* and *Callipepla squamata*). The recent increase in feral swine abundance in this region was of concern (Texas Parks and Wildlife, 2006). Density of feral swine on the study site was unknown, but at the nearby Chaparral Wildlife Management Area, which consists of similar rangeland, but without such extensive distribution of water points and irrigated fields, densities were estimated at 0.038 feral swine/ha (Gabor et al., 1999).

Eight contiguous pastures in the center of the ranch were used for the study. Pasture size varied from 948 ha to 3,882 ha, with a mean of 1,900±1,964 ha. Within all but one pasture, there was a fenced area for irrigated cultivation of hay grazer (*Sorghum album*). Animals had access to at least six water points (mainly earthen stock ponds) in each pasture. Approximately half the ponds were in riparian areas and half in open rangeland.

Distribution of domestic cattle and feral swine and rates of contact between animals were determined through use of Global Positioning System (GPS) collars. Field trials were conducted during four seasons (winter: December–February; spring: March–May; summer: June–August; fall: September–November,) for 2 yr, giving a total of eight trials between July 2004 through July 2006. In each trial, the goal was to obtain data from four cows, four sows, and four boars. A different pasture was used in each trial, and none of the animals were used more than once. All trapping and handling of animals followed guidelines established in an approved animal use protocol (Texas A&M University Laboratory Animal Care and Use Committee Animal Use Protocol 2002-380/2005-281).

To collar the cattle, ranch personnel held back four Brahman-Hereford cross-cows, belonging to different herd subgroups, in the squeeze chute when transferring a herd to a new pasture. These animals were fitted with the GPS collars (BlueSky$^{TM}$, BlueSky Telemetry Ltd, Aberfeldy, Scotland; or Lotek$^{TM}$ GPS 3300LR, Lotek Wireless Inc, Newmarket, Ontario, Canada) and immediately transported to their destination pasture. After the trial, cattle collars were removed by ranch staff when the animals were rotated to a fresh pasture.

Two weeks before each trial, six feral swine traps were placed in suitable areas by water bodies or riparian areas that contained recent sign of use by swine (e.g., tracks, scat, rooting, or visual observation). Originally, both corral traps and box traps were used, but after the first trial, only box traps were used because they provided easier handing of animals and less risk of injury to the animals. Traps were baited with shelled corn, fruits and vegetables, and soured corn. Trapping was continued until an adequate sample size of swine had been captured, thus trapping time overlapped with GPS data collection periods. Manageable, trapped animals were restrained with a cable noose on a catchpole, then blindfolded, and hogtied. Feral swine were very sensitive to thermal stress when sedated, as noted by Ilse and Hellgren (1995a), so only large and potentially dangerous boars were chemically immobilized. A pole syringe was used to inject Telazol® (tiletamine hydrochloride and zolazepam hydrochloride; A. H. Robins Company, Richmond, Virginia, USA) intramuscularly at a dosage of 1 mg/kg. This low dosage was enough to briefly sedate the animals for collaring. Mixing Telazol® with xylazine hydrochloride, as recommended by Gabor et al. (1997), resulted in higher incidences of heat stress than using Telazol® alone. To lower body temperature when heat stress was a risk, Banamine® (flunixin meglumine, Schering Plough Animal Health, Kenilworth, New Jersey, USA) was administered intramuscularly at a dosage of 1 mg/kg before release. Sex was determined for each animal; age, weight, standard morphometric measurements and distinguishing characteristics were recorded. Subadults were defined as weighing from 20 kg to 40 kg and/or from 109 cm to 119 cm long from snout to the base of the tail. Adult weights ranged from 41 kg to 95 kg and length from 125 cm to 142 cm. Each animal was fitted with a GPS collar and ear-tagged to ensure that it would not be recollared in subsequent trials. A preprogrammed automatic drop-off unit made by Lotek was incorporated into each of the swine collars to aid retrieval of the collars.

The GPS collars were set to record one location every 15 min to determine rates of contact between animals. Initially, BlueSky collars were used, which featured internal differential correction to an accuracy of ± 5 m (Hulbert and French, 2001). Cow collars ran for 10 wk, and the swine collars ran for 2 wk; however, these collars were not robust enough to withstand deployment on wild animals or in the high ambient temperatures encountered during the study. After the first five trials, the swine collars were replaced with new and improved BlueSky collars and two Lotek GPS 3300S collars. This change increased data collection abilities from 2 wk/battery life to 4 wk. Two of the cattle collars were also replaced with Lotek GPS 3300LR collars. Postprocessing differential correction of data from Lotek collars, using the program N4 (Lotek Wireless Incorporated, Newmarket, Ontario, Canada), corrected position fixes to an accuracy of ±5 m (Moen et al., 1997).

Landscape features of the ranch were digitized using 2004 color infrared digital orthorectifed quarter quadrants (DOQQ) at 1 m resolution (Texas Natural Resources Information System [TNRIS], 2006). Four classes of landscape features were included: 1) roads (all were dirt ranch roads), 2) riparian zones, 3) water bodies (stock ponds), and 4) cultivated fields (irrigated and nonirrigated). Deer feeders were fenced to keep out swine and cattle and were, therefore, not included in the analysis. Riparian areas and the boundaries of the water areas were buffered at 50 m to account for seasonal variation in extent. Roads were buffered at 20 m from the center line to account for locational error. Cultivated fields, which were defined by fence lines, were not buffered. All areas of rangeland not included in one of the four categories above were classified as shrubland.

Feral swine distribution was not restricted by fences as were cattle; therefore, their use of landscape often extended outside the study pasture. Area use by each animal was calculated by creating a 90% minimum convex polygon (MCP) for each animal using ArcGIS 9 (ESRI, Redlands, California, USA) and Hawth's Tools (Beyer, 2004). Area use derived using MCP method (Ilse and Hellgren, 1995b) included all potential area traveled while collared and provided maximum potential for interaction as opposed to a reduced normal home range derived by other methods (Girard et al., 2002).

Differential land use (percentage of GPS fixes in a given landscape) by species, relative to the four buffered-landscape types and shrubland, was calculated using the seasonal MCP for both species. Because of the variation in data collection period for individual animals, including a few very short trials for swine, data for each season were pooled for each species. Preferred habitats were defined as those used in greater proportion than their availability; conversely, nonfavored habitats were those used in lower proportion than their availability. Differences were tested with the chi-squared ($\chi^2$) statistic and accepted at $\alpha<0.05$. Gaps in GPS data coverage of less than 8 hr were examined visually using animal movements tracking analyst (Hooge and Eichenlaub, 1999) overlaid on DOQQ. When the locations just before and after the data gap were very close and within the same habitat type, the animal was presumed to have remained within that habitat type, and the number of missing locations was calculated. This information was used to detect bias in interpretation of habitat selection patterns because poor GPS coverage in dense vegetation, but because differences proved to be minimal, these inferred data were not used in the statistical comparisons of resource use.

To estimate inter- and intraspecies contact rates, Euclidian distances were measured between nearest GPS locations of pairs of individuals for 0 to 360 min. Data were then corrected for known population densities and relative rates of contact were estimated in STATA version 9.2 (de la Garza, 2007; StataCorp LP, College Station, Texas, USA). Based on GPS location accuracy, FMDv survival characteristics (Bartley et al. 2002; Cottral 1969) and regional climate averages, direct contacts were defined as occurring <20 m and within 15 min, and indirect contacts were defined as occurring <20 m and within 360 min. Cattle densities were calculated from known herd and pasture sizes, and swine densities were estimated at 0.038 feral swine/ha (Gabor et al., 1999).

Three automated, motion-triggered, infrared video recorders (TrophyCam, Springtown, Texas, USA) were also placed in areas where contact between cattle and feral hogs was thought likely to occur, such as beside water. These cameras were used mainly to confirm incidents of contact because repeated damage and disturbance by the animals limited the consistency of data collection by these cameras.

## RESULTS

The aim was to place GPS collars on four cows and eight feral swine for each of eight trials from July 2004 to July 2006; however, because of a combination of collar malfunctions and variability of trapping success for feral swine, sample sizes varied from season to season. Reliable GPS data were obtained from 3.1±0.8 (mean±SE) cows and 5.0±2.7 swine per season, which provided 99±45 days of data for cattle and 94±58 days of data for swine per trial.

For the entire study, location data were obtained from 25 cows and 40 feral swine. Demography of the collared swine was 25 subadults (shoats) of mixed age and sex caught in all seasons, six adult sows caught in fall 2004 through spring 2005, and nine adult boars, with at least one boar collared per season in all but fall 2004. Sows and subadults live together in social groups, whereas boars were generally solitary. The proportion of successful GPS fixes for cattle was 99%, with equal distribution of fixes between day and night. The proportion of swine GPS fixes obtained in the first five trials was 70%, with slightly more fixes recorded during the night (60.2%) than during the day. Examination of animal placement immediately before and after each data gap showed that missing locations were equally likely to occur in riparian zones (31.5±5.85%) and shrub dominated rangeland (22.7±2.21%; $t=1.49$, df=8, $P>0.10$); thus, these missing points will not greatly affect estimations of proportional habitat use by the animals. The discrepancy between day and night was resolved once the improved-model collars were used and the proportion of successful swine GPS fixes rose to 98%.

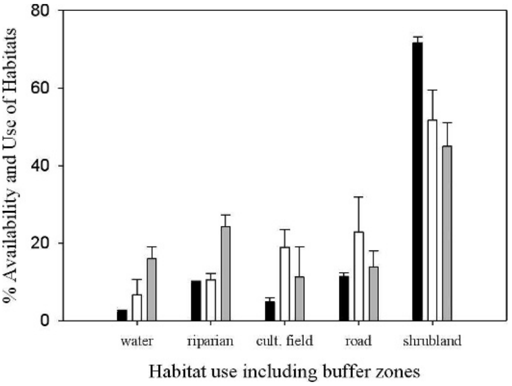

FIGURE 1. Proportional distribution of habitat features and mean use, with error bars by cattle and feral swine, in south Texas rangeland, 2004–2006. Water and riparian zones buffered at 50 m, roads buffered to 20 m. Habitat availability=black, habitat use by cattle=white, habitat use by swine=grey.

### Animal distributions

Most habitat on the ranch consisted of shrub-dominated rangeland (71.7±4.3%). Riparian zones including the buffer constituted 9.8±3.4% of the habitat, and surface water and surrounding buffer constituted 2.4±1.0% of the area. Cultivated fields were incorporated into all but one pasture and accounted for 4.8±2.6 % of the habitat. Roads with buffers constituted 11.4±0.8 % of the landscape (Fig. 1).

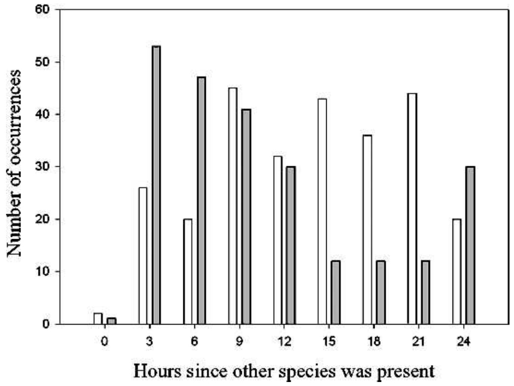

FIGURE 2. Sequence of animal visitations recorded by motion-activated video cameras south Texas rangeland, 2004–2005. Cattle follow swine=white, swine follow cattle=grey.

During the 2-yr period, cattle and swine spent approximately half their time in shrubland (i.e., area not included in buffered features: cattle 51.67±21.9%, swine 45.0±17.4 %). Proportionate use of this habitat type was less than its availability (cattle: $\chi^2=5.60$, df=1, $P<0.05$; swine: $\chi^2=9.94$, df=1, $P<0.01$); thus, shrubland is not considered to be a focal point of animal distribution. Distribution of cattle and feral swine in this habitat was further divided by their different responses to rangeland improvement practices to reduce shrub cover. In pastures configured in alternating strips of unimproved shrubland and grassy strips cleared of shrubs, the distribution of GPS locations in the grassy strips was 74.0±2.8% for cattle but only 41.7±9.5% for feral swine.

Cattle used riparian areas in proportion to availability, and they preferentially selected cultivated fields and areas near water and roads (fields: $\chi^2=41.74$, df=1, $P<0.001$; water: $\chi^2=7.73$, df=1, $P<0.01$; roads: $\chi^2=11.60$, df=1, $P<0.001$). Feral swine favored water areas, riparian areas, and cultivated fields (water: $\chi^2=78.14$, df=1, $P<0.001$; riparian: $\chi^2 = 21.05$, df=1, $P<0.001$; fields: $\chi^2=8.85$, df=1, $P<0.01$), and they used roads in proportion to their availability.

Habitat use varied seasonally (Table 1). Cattle favored areas near surface water in summer 2004 then again from summer 2005 through the next three seasons. Cattle generally used riparian areas in proportion to their availability but showed a negative association with these areas in fall 2005 and summer 2006. When given access to cultivated fields of hay-grazer (*Sorghum* spp.) from summer 2005 through to summer 2006, cattle showed strong selection for this resource. Cattle tended to use roads in all seasons except summer and fall 2004 and fall 2005.

Feral swine favored areas near water in all seasons and riparian areas in all seasons except winter. They showed strong selection for cultivated fields (weedy plots of oats [*Avena Sativa*]) in spring 2005 and for hay-grazer fields from fall 2005 through the rest of the study. Swine only used roads extensively in the fall and winter of 2004.

### Contacts between animals

Direct contact between feral swine and cattle was rare and occurred only 12 times during the study. Within each species, direct contact was much more common. We recorded 5,915 direct contacts among cows and 1,530 direct contacts among swine. Indirect contacts (animals passing the same location within 6 hr) were naturally more common; cattle followed swine to a location on 140 occasions, and swine followed cattle on 144 occasions. Again intraspecies contacts were most common; we recorded 17,481 indirect contacts among cows and 5,642 indirect contacts among swine.

Direct interspecies contact between cattle and feral swine occurred mainly near water sources and in cultivated fields (Table 2). Indirect contacts, where a cow went to a site previously occupied by a swine, were highest in cultivated fields (sixfold increase) and near water (fourfold increase). Swine were most likely to follow cattle at water (sixfold increase) and on roads (twofold increase). The least contact between and within species occurred in riparian and shrubland areas (relative rate

TABLE 1. Seasonal usage of landscape features by global positioning system (GPS)-collared cattle and feral swine (% GPS locations) and proportional area (%) of landscape features, south Texas rangeland, 2004–2006.

| Landscape feature | Summer 2004 | Fall 2004 | Winter 2004–05 | Spring 2005 | Summer 2005 | Fall 2005 | Winter 2005–06 | Summer 2006 |
|---|---|---|---|---|---|---|---|---|
| Landscape | | | | | | | | |
| Pasture size (ha) | 1,383 | 2,418 | 2,556 | 994 | 1,958 | 1,059 | 3,882 | 948 |
| Aggregate minimum convex polygon (ha) | 1,405 | 1,812 | 3,225 | 2,154 | 2,400 | 2,136 | 5,275 | 5,546 |
| % area road | 12.24 | 12.42 | 11.81 | 10.86 | 10.83 | 11.99 | 10.39 | 10.35 |
| % area riparian | 15.94 | 7.51 | 10.29 | 11.28 | 5.29 | 9.08 | 6.67 | 12.44 |
| % area water | 3.49 | 2.15 | 2.23 | 4.13 | 1.92 | 1.08 | 1.91 | 1.97 |
| % area cultivated | 6.26 | 3.97 | 0.09 | 2.41 | 7.96 | 7.07 | 5.97 | 4.40 |
| % range outside focal areas (shrubland)[a] | 62.07 | 73.95 | 75.58 | 71.32 | 74.00 | 70.78 | 75.06 | 70.84 |
| Cattle % use[b] | | | | | | | | |
| Road with 20-m buffer | 14.73 | 14.61 | 36.16 s | 21.47 s | 42.51 s | 10.30 | 25.97 s | 16.93 s |
| Riparian with 50-m buffer | 14.25 s | 3.47 | 6.88 | 11.21 | 3.77 | 2.93 r | 10.66 | 3.73 r |
| Water with 50-m buffer | 12.82 s | 1.42 | 1.88 | 8.07 | 5.72 s | 3.76 s | 13.76 s | 5.57 s |
| Cultivated field | 10.04 | 1.25 | 0.01 | 0.05 | 31.03 s | 38.53 s | 0.45 r | 69.64 s |
| Shrubland | 60.23 | 80.29 | 57.78 r | 67.37 | 26.89 | 48.25 r | 59.58 | 12.95 r |
| Swine % use[b] | | | | | | | | |
| Road with 20-m buffer | 14.42 | 31.47 s | 21.69 s | 9.01 | 10.94 | 6.95 | 8.71 | 7.68 |
| Riparian with 50-m buffer | 71.78 s | 14.10 s | 8.85 | 17.89 s | 29.28 s | 10.58 | 4.27 | 36.67 s |
| Water with 50-m buffer | 10.70 s | 25.87 s | 5.97 s | 18.09 s | 23.98 s | 2.19 | 23.01 s | 17.71 s |
| Cultivated field | 0.00 r | 6.17 | 0.00 | 33.09 s | 2.54 | 20.76 s | 15.95 s | 11.31 s |
| Shrubland | 19.38 r | 40.70 r | 70.00 | 28.39 r | 50.83 s | 62.37 | 54.01 r | 34.30 r |

[a] Buffered areas may overlap.

[b] s = selected habitat; r = low-use habitat.

TABLE 2. Relative rates[a] of direct and indirect contact between cattle and feral swine relative to habitat, south Texas, 2004–2006.

| | Swine to cow | | Cow to swine | | Swine to swine | | Cow to cow | |
|---|---|---|---|---|---|---|---|---|
| Landscape feature | Direct | Indirect | Direct | Indirect | Direct | Indirect | Direct | Indirect |
| Road | 1.6 | 2.3 | 0.3 | 0.6 | 2.2 | 1.8 | 1.9 | 1.6 |
| Riparian | 2.2 | 0.6 | 0 | 0.8 | 0.7 | 0.6 | 1.1 | 1.0 |
| Water | 8.9 | 5.8 | 11.8 | 3.9 | 1.5 | 1.2 | 0.7 | 0.2 |
| Cultivated field | 2.1 | 0.8 | 3.3 | 6.5 | 0.9 | 1.4 | 0.4 | 0.9 |
| Shrubland | 0 | 0.4 | 0.1 | 0.2 | 0.8 | 0.9 | 0.9 | 0.8 |

[a] Relative rates are indexed to 1 so, <1 means a relatively less-contact effect by feature, and >1 means relatively more contact effect by feature, relative to all other features listed (after de la Garza, 2007).

of contact <1). Within-species contact occurred most often on roads (twofold increase) for both cattle and swine.

Automated cameras were only active for year 1 and were damaged repeatedly by the animals; however, they did provide confirmation of direct contact between cattle and feral swine near water. Frequency of visitation by swine was 0.25 visits/day in spring, 0.57 visits/day in summer, 0.46 visits/day in fall, and 1.03 visits/day in winter. In spring, most activity occurred at dawn, but for the rest of the year, swine activity peaked at dusk. Swine were most frequently recorded as individuals, and the ratio of adults to shoats seen was 1:3. Simultaneous photography of cattle and swine was rare, only three incidents were recorded. Cattle were recorded at water during all times of day and were recorded at the camera sites within 6 hr of the presence of swine on 17.0% of records. Swine were recorded at the camera sites within 6 hr of the presence of cattle on 43.4% of records (Fig. 2).

## DISCUSSION

Animals were not randomly distributed throughout the landscape but concentrated their activities in resource-rich areas. Shrub-dominated rangeland was not a preferred habitat for either cattle or feral swine. Both species spent about half their time in shrubland, which covered 72% of the landscape; however, individuals were widely distributed so interspecies contacts were relatively few. The species were further separated by differential use of improved rangeland, which had been cleared of shrubs and planted in forage grasses, mainly buffelgrass. Cattle tend to graze in areas that allow them to maximize food intake (Senft et al., 1985) and to avoid thick shrub, which offers low biomass of herbaceous forage and forms a physical impediment to movement (Owens et al., 1991); hence, cattle were located predominantly in the cleared grassy strips. On the other hand, feral swine require areas of dense vegetation for thermal and protective cover (Graves, 1984; Mapston, 2004). Feral swine used both shrubby and open areas in proportion to their availability on the landscape. Because dry heat and desiccation affect survival of FMDv adversely; the probability of indirect transfer of FMDv on open range remote from water sources is probably low.

Habitat selection of swine was affected by their need for thermoregulation (Isle and Hellgren, 1995a). In rangeland, feral swine favored the shade and dense cover of riparian habitats especially in the warmer months from spring through fall (Ilse and Hellgren, 1995a; Gabor et al., 1999). Cattle generally used riparian areas in proportion to availability in the pasture. Use of riparian strips by cattle was very low in fall 2005 and summer 2006 because, at that time, cattle had access to cultivated fields, which were highly favored, so proportional use of other habitat types was reduced. Because only swine favored the riparian habitat, it was not a zone of interspecies contact. Surprisingly, intraspecies contact between swine was also low in riparian areas. Initially, we thought that use of the riparian areas by the swine may have been underrecorded because GPS signals were blocked by dense vegetation (Rempel and Rodgers, 1997); however, further investigation showed that missing GPS locations occurred at similar frequency in riparian areas and the more open, shrub-dominated rangeland. The low rate of intraspecies contact of swine in these areas may be because swine were using riparian areas for resting rather than for foraging and travel, so they did not make much contact with animals outside their own social group. Many of the riparian areas were narrow and thickly vegetated with shrubs and, consequently, did not make easy travel corridors. Many of the smaller riparian strips were dry for most of the year; thus. often soil moisture conditions would not be favorable for survival of FMDv for extended periods.

Surface water and areas that remain moist throughout the year are major habitat requirements for feral swine (Graves, 1984). Historically, these resources were scarce in semiarid rangeland, but the recent improved distribution of water on rangeland brought about by construction of additional water points for cattle and wildlife, especially white-tailed deer, is likely to be a major contributor to the expansion of feral swine populations into rangeland (Mapston, 2004). Moist soils near stock ponds favor the survival of FMDv outside the host and the potential for indirect transfer to a susceptible host. Swine were particularly attracted to earthen stock ponds for watering and for wallowing and rooting in the damp soil. The same areas were also focal points for cattle, especially during the hot summer months when water was needed for both hydration and cooling. Cattle also stayed near water during dry times, such as those experienced in the second year of the study. Cattle are dependent on surface water, and most studies of free-ranging cattle report that grazing pressure varies inversely with distance from water, often with intense grazing around water sources (Roath and Krueger, 1982). However, the distribution of artificial water points in many south Texas, USA, ranches, the study ranch included, is such that animals are rarely more than 1.6 km (1 mile) from water (Holechek et al., 1989). In this environment, Owens et al. (1991) found that cattle are more likely to stay close to water at times when forage availability is low; but, when green forage is readily available, water distribution has less effect on cattle distributions. Water points were the primary location of contact between cattle and feral swine, including some instances of direct contact. Thus, water points (especially stock ponds) are a prime point for disease transfer, direct contacts being the most dangerous because of the high potency of aerosol disease transmission of FMDv (Donaldson et al., 1987, 2001).

Irrigated and cultivated fields also provide resource-rich patches within rangeland. Access by cattle was controlled by the ranch management, and in summer, when the cattle had open access to cultivated hay grazer (*Sorghum album*) fields, these areas were intensively used. Swine also favored cultivated fields, particularly in the dry year from fall 2005 through summer 2006, when the availability of natural food was low. Because swine used these fields along with the cattle, both direct and indirect interspecific contacts were relatively common. Swine could also access fields through or under the fences at times when cattle were excluded. It was surprising that not more swine activity was seen in the irrigated fields before the crops matured, but possibly the openness of the fields was a deterrent. Swine also spent much time in a weedy oat field used in the previous winter (before the study) as a food plot for white-tailed deer, indicating that food plots may be a potential contact point for swine and deer.

In shrub-dominated rangeland, cattle use roads as travel corridors (Depew, 2005; Cooper et al., 2008). Roads offer accessible energy-efficient travel corridors compared with traveling through dense, and often thorny, shrubland. However, wild animals, particularly those in hunted populations, may be less likely to use roads. Feral swine only used roads intensively in fall and winter of 2004. During this time, the ranch management was spreading shelled corn on the roads each day to increase the visibility of deer for survey and harvest. Although within-species contact for both cattle and swine was high near roads, interspecies contact between cattle and feral swine was low on roads, possibly because cattle tend to reduce their use of roads in the fall (which happened to be the time of greatest swine activity on the roads). The risk of contact between feral swine and white-tailed deer, which were the target of the baiting of the roads, is probably high. White-tailed deer, like cattle, do make extensive use of ranch roads for travel through shrubby areas (Cooper et al., 2008).

Direct contact (same place same time) between species occurred extremely rarely. This fits with the biologic principle that different species inhabit a unique ecologic niche, and although integrated locally, do not tend to interact readily with one another. Indirect contacts (same place within 6 hr) were greatest within species, as expected for gregarious species. Collared cattle were selected from different herd subgroups, and effort was made to collar swine from different sounders, but without prior study, there was no way to know the relationship between animals. However, contact is expected between members of different feral swine sounders because individuals are highly mobile (Singer et al. 1981) and the home ranges of these social groups overlap (Isle and Hellgren, 1995b).

Reduction of contact rates between animals is paramount to limiting the spread of disease. At low population density, disease tends to die out (Durand and Mahul, 2000; Ward, 2007); however, at high density, as is the current situation with feral swine in Texas, USA, disease may become endemic (Pech and MacIlroy, 1990). Eradication of feral swine is not possible, nor would it be popular with sport hunters (Degner et al., 1983), but reduction in numbers may limit disease incursions.

This study identified water and cultivated fields as high risk areas for disease transfer between feral swine and cattle. Water was the primary zone of contact both within and between species, and shared use of this resource was particularly high in drought conditions and during the hot summers. The wallowing and rooting behavior of swine at earthen stock ponds intensifies the risk of transfer of a disease, such as FMD, where virus could survive in moist soil where high temperatures are ameliorated (Bartley el al. 2002). Stock ponds tend to provide water, moist soil, and cover and may represent areas where a sick animal may linger. Fencing of stock tanks and watering cattle at elevated concrete troughs would reduce the extent of indirect contact between cattle and swine. Cattle are more likely to be distributed close to water at times when forage availability is low (Owens et al., 1991; Cooper et al., 2008). Although it is often convenient to provide cattle with mineral and feed supplements at water points, doing so increases the animals' attraction to high-risk areas. An alternative plan would be to move the supplements to the more open areas of the rangeland or to ranch roads, which are extensively used by cattle but generally are not favored by feral swine.

Concentrated food resources are another strong attractant for livestock and wild animals. Cultivated food plots were zones of high contact between animals. Feral swine seemed to be most attracted to the hay grazer fields when the crop was mature, the very time when cattle were also concentrated in the fields. Swine grazed the crop (Taylor and Hellgren, 1997) and rooted in the moist, tilled earth, and in doing so, they could shed the virus in an area where cattle were highly likely to feed. Cultivated fields under irrigation provide both food resources to attract and to concentrate animals, and moist soils favor the survival of FMDv outside the host. The only way to reduce interspecies contact in cultivated fields would be by securing the fences against entry by swine. Feral swine also use food plots grown for deer, and readily eat from unfenced deer feeders (Cooper, 2006). A sturdy, low, mesh fence easily deters feral swine from accessing these feeders but still allows deer to have access to the supplemental feed. Deer are not considered to be high-risk transmitters of FMDv (Gibbs et al., 1975; Rhyan et al. 2008), but they are susceptible to FMD and are abundant on rangeland. On many ranches, in fall and winter, shelled corn is used to bait deer into open areas for survey and harvest. One practice is "corning the roads," whereby shelled corn is trickled along ranch roads to lure deer out of the brush for better viewing. Even though feral swine did not normally use roads for travel as cattle did, they congregated on the roads to feed on the corn. Contacts with other animals were high at that time. Although only a seasonal practice, attracting deer with corn does increase risk of spreading disease from swine to deer and livestock. In the event of a disease outbreak, this practice should be curtailed.

Although this study focused on FMDv transmission between feral swine and cattle, the information on comparative habitat use and interspecies contact zones can be used in predicting rates of transmission of other diseases and parasite infections between these species. Incorporation of this information into current epidemiologic models of livestock and wildlife or feral species interaction, such as the geographic-automata model described in Ward (2007), will allow better prediction of the course disease outbreaks may take; thereafter, improving response measures to limit potential disease incursions and help safeguard agricultural, ranching, and wildlife industries both domestic and abroad.

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