Wildlife-Cattle Interactions in Northern Michigan: Implications for the Transmission of Bovine Tuberculosis

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Utah State University, 2005

WILDLIFE-CATTLE INTERACTIONS IN NORTHERN MICHIGAN:

IMPLICATIONS FOR THE TRANSMISSION

OF BOVINE TUBERCULOSIS

By

Jerry Alan Hill

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ABSTRACT

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Bovine tuberculosis (*Mycobacterium bovis*) was discovered in northern Michigan white-tailed deer (*Odocoileus virginianus*) in 1994, and has been known to exist in Michigan cattle herds since 1998. Despite efforts to eradicate the disease in cattle, infection and re-infection of farms continues to occur, suggesting transmission among cattle, deer, or other wildlife reservoirs. The goals of this study were to document wildlife activity on farms and evaluate the possible role wildlife play in the ecology of bovine tuberculosis (TB) in Michigan. Visual observations were conducted on farms in a 5-county area of northern Michigan to document direct wildlife-cattle interactions (i.e., ≤5 m between individuals) and indirect interactions (e.g., wildlife visitations to food stores and areas accessible to cattle). Observations were conducted primarily during evening and early morning hours between January and August, 2002, and on a 24-hour schedule between January and August, 2003. Total observation time accumulated through the duration of the study was 1,780 hours. Results indicated that direct interaction between deer and cattle was a rare event; no direct interactions were observed during the first year, and only one direct interaction was observed during the second year. However, through the duration of the study 21 direct interactions were documented between cattle and turkey, and 11 direct interactions were documented between cattle and mammals other than deer. In total, 273 indirect interactions by deer, 112 indirect interactions by turkeys, and 248 indirect interactions by mammals other than deer were observed during the 2 field seasons combined. These data supported the hypothesis that indirect interactions among wildlife and cattle are a potential mechanism for the transmission of TB in Michigan. If direct interactions were important mechanisms of TB transmission to cattle in northern Michigan, my data suggested that feral cats were the species of most concern, even though there were more observations between turkey and cattle. Unlike cats, which can become infected with and transmit TB, there is no evidence for such pathogenesis in turkey.

(58 pages)

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INTRODUCTION

Bovine tuberculosis (TB) is an infectious disease caused by a bacterium, *Mycobacterium bovis (M. bovis)*, affecting both domestic and wild animals worldwide. In most species the disease causes a slow debilitation of health that may not become apparent until it has reached an advanced stage (Witmer et al. 2003). The risk of contracting the disease for humans is very low in most developed countries due the introduction of milk pasteurization (Witmer et al. 2003). TB poses a greater threat to the livestock industry as well as wildlife with their many social, ecological, and economic values than it does to human health.

TB was discovered in Michigan's white-tailed deer (*Odocoileus virginianus*) herd following the 1994 firearm deer season (Schmitt et al. 1997). The first TB positive deer was harvested in northeastern Michigan, in an area now referred to as the TB core area, covering portions of Alpena, Alcona, Oscoda, and Montmorency counties. As of March 6, 2005, 509 deer have tested positive in 11 different counties. Other TB positive wildlife found in Michigan include elk (*Cervus canadensis*), coyote (*Canis latrans*), raccoon (*Procyon lotor*), black bear (*Ursus americanus*), bobcat (*Lynx rufus*), opossum (*Didelphis virginianus*), red fox (*Vulpes fulva*), and domestic cat (*Felis catus*) (Payeur et al. 2002). Between 1994 and 2003, 33 cattle (*Bos taurus*) farms have tested positive for TB in 7 counties, with 26 of the herds being beef and 7 being dairy.

The presence of TB in Michigan wildlife and livestock has raised concerns about potential economic and health consequences in the state (Schmitt et al. 2002). Whitcomb (1999) estimated that the loss of Michigan's TB Accredited-Free State status could cost the state up to $16 million a year. As a way to control the spread of infection in the state, there was increased testing of cattle herds, destruction of infected cattle herds, a ban on supplemental feeding in 1998 to prevent deer-to-deer interactions, and increased harvests on deer to reduce the population density.

Results of DNA analysis on *M. bovis* isolates from Michigan white-tailed deer indicated that the majority of deer were infected with a single strain of *M. bovis* identical to the strain isolated from cattle (Palmer et al. 2001). This information suggests that there is a single source of infection, and cattle became infected through contact with free-ranging white-tailed deer (Palmer et al. 2001). These findings give strong evidence that infection of wildlife with *M. bovis* represents a serious risk to domestic livestock and the bio-security of farms in northern Michigan.

Wildlife Disease Reservoirs

In some circumstances wildlife can provide a potential reservoir for TB (Delahay et al. 2001). Wildlife disease reservoirs are predominantly associated with situations where infection in wildlife is a threat to domestic animals or humans. A species is considered a reservoir host for TB when the disease can persist within the species without an external source of reinfection (Palmer et al. 2001). Wildlife reservoir hosts include the brushtail possum (*Trichosurus vulpecula*) in New Zealand, badgers (*Meles meles*) in the United Kingdom, and white-tailed deer in the United States (Palmer et al. 2001). Species that can become infected, but the disease cannot persist within the species without an external source of reinfection are referred to as spillover hosts (Palmer et al. 2001). These species often become infected by interaction with reservoir hosts or by scavenging infected carcasses.

Intraspecific interaction helps to explain why the disease is able to persist within reservoir host species. Most experts agree that the disease has persisted in Michigan's deer herd due to the large population size and the large scale supplemental feeding that had been taking place, creating a situation where deer were congregating in large numbers (O'Brien et al. 2002; Miller et al. 2003). This is important since *M. bovis* can be transmitted between wildlife and livestock through respiratory pathways and through the ingestion of contaminated materials (Thoen and Bloom 1995; Schmitt et al. 1997; Palmer et al. 2001; Bengis et al. 2002). Close, face-to-face contacts were documented at bait and feeding stations in northeastern Michigan, artificially increasing the transmission rate among deer. Furthermore, deer were shown to frequent more than one bait site, creating the potential to further spread the disease (Garner 2001).

It is thought that high population densities and the simultaneous sharing of dens contribute to the persistence of TB in brushtail possums in New Zealand (Caley et al. 1998; Ramsey et al. 2002). In the United Kingdom it has been found that high population densities and the fact that badgers live in large social groups has contributed to the maintenance of the disease within the species. However, the organization of the population into social groups, each with an exclusive territory, helps to limit the spread of the disease (Delahay et al. 2001). Inter-group transmission may occur, but it appears that interactions within a family group are responsible for the disease persisting in localized areas (Delahay et al. 2001).

Wildlife-Cattle Interactions

The importance of interactions between individuals in spreading and maintaining the disease within wildlife reservoir hosts has been documented. Direct (e.g., aerosol transmission) and indirect interactions (e.g., ingestion of contaminated materials) between wildlife and cattle present viable risks of infection to cattle herds located in areas where wildlife reservoirs have been identified. Such interactions between wildlife and cattle have not been documented in the infected area of northern Michigan.

Documentation of wildlife-cattle interactions may be lacking in Michigan, but it has been demonstrated that *M. bovis* can be transmitted to livestock through direct interaction with brushtail opossums in New Zealand (Paterson and Morris 1995; Sauter and Morris 1995; Black et al. 1999) and European badgers in Great Britain (Benham and Broom 1989; Gavier-Widen et al. 2001). Previous research has described direct interaction as being nose-to-nose contact between individuals or a maximum distance of two meters between individuals with no physical contact (Benham and Broom 1989; Paterson and Morris 1995; Sauter and Morris 1995; Black et al. 1999). Studies have shown that sedated opossums behave in a way that simulates the behavior of terminally ill tuberculous animals (Paterson and Morris 1995; Sauter and Morris 1995). The abnormal behavior of sedated opossums attracts the attention of cattle resulting in direct interaction, which clearly demonstrates the feasibility of a direct mechanism for the transmission of tuberculosis between opossums and cattle (Paterson and Morris 1995).

Similar results were found with badgers in Great Britain, although the potential for interaction appeared to be much lower than that for possums in New Zealand. There are documented cases of cattle investigating the rapid and relatively noisy activities of badgers such as digging holes (Benham and Broom 1989). Badgers, unlike opossums, tend to show a flight response when approached by cattle, but badgers will often allow cattle to approach within 2-3 meters providing for the potential direct transmission (Benham and Broom 1989).

Contaminated feed or infected carrion create a viable mode of transmission to wildlife and livestock when ingested. Survival of *M. bovis* outside of the host is highly variable and dependent on environmental conditions, especially exposure to sunlight (Jackson et al. 1995*a*; Williams and Barker 2001). *M. bovis* survival time is greatest when there are low temperatures, absence of ultra-violet radiation, and high humidity (Jackson et al. 1995*a*; Tanner et al. 1999; Scanlon and Quinn 2000; Williams and Barker 2001; Moore and Roper 2003). *M. bovis* is known to survive 5 to 14 days in infected tissues during seasons other than winter, 7 days on hay at room temperature, up to 6 weeks in infected tissues outside during winter, and on feedstuffs at 0°C for up to 16 weeks (Jackson et al. 1995*a*; Tanner et al. 1999; Palmer and Whipple 2000*a*). The ability of *M. bovis* to survive on substrates for extended periods of time increases the risk of ingestion by wildlife or livestock.

It has been documented that *M. bovis* can be transmitted to cattle through indirect interactions with brushtail possums in New Zealand (Paterson and Morris 1995; Sauter and Morris 1995) and badgers in the United Kingdom (Hutchings and Harris 1997; Garnett et al. 2002; Garnett et al. 2003). Both species have been observed in direct interactions with cattle, an indication that they were utilizing a common space. It has been documented that brushtail possums are capable of shedding *M. bovis* through respiration, urination, and defecation (Jackson et al. 1995*b*). Badgers have been documented using cowsheds, feed sheds, barns, haystacks, slurry pits, cattle troughs, and pastures (Hutchings and Harris 1997; Garnett et al. 2002; Garnett et al. 2003). Badgers also can shed M. bovis through their urine, feces, and sputum, creating a potential route of transmission (Hutchings and Harris 1997).

Importance of Wildlife-Cattle Interactions in Michigan

Observations of wildlife-cattle interactions may be absent in Michigan, but studies have demonstrated the ability of several wildlife species that inhabit the state to develop disseminated TB. Experimentally infected white-tailed deer have been documented shedding *M. bovis* (Palmer et al. 1999, 2001; Palmer and Whipple 2000*b*). Lesions found in the pulmonary airways, trachea, and kidneys of infected deer indicated that coughing, exhalation, and urination all provided likely means of excretion of *M. bovis*. Palmer et al. (2001) also demonstrated that feces from infected deer can infect foodstuffs and provide a means by which tuberculosis may be transmitted indirectly to other wildlife and livestock. Palmer et al. (2004) have recently demonstrated that shared feed was a viable mode of deer-to-deer transmission of *M. bovis*. This data suggests that feed sharing between infected, free-ranging deer and cattle can create a viable route of transmission.

Palmer et al. (2002) have documented raccoons shedding *M. bovis* through nasal secretions and saliva, although it required large, multiple doses of TB to become infected. Opossums are able to become infected and can transmit TB through respiratory pathways and through their feces (Diegel et al. 2002; Fitzgerald et al. 2003*d*). Pigeons (*Columba* *livia*) are susceptible to TB infection with high dose inoculations, and once infected they have the capacity to shed the bacteria through fecal waste (Fizgerald et al. 2003*a*, 2003*c*).

The information describing the pathways in which Michigan wildlife can shed *M. bovis* is valuable information. However, the relative importance of these pathways in the ecology of *M. bovis* in infected areas of Michigan has not been fully elucidated. Documentation of wildlife activity on farms will help to develop more effective management plans to prevent further spread of the disease.

The goals of this study were to document wildlife activity on farms and evaluate the possible role wildlife play in the ecology of bovine tuberculosis (TB) in Michigan. This was done by documenting both direct and indirect interactions between wildlife and cattle. I have defined direct interactions as a distance of less than or equal to five meters between individuals. Indirect interactions are defined as the sharing of common resources, creating the potential for disease transmission through ingestion or inhalation of contaminated materials. Documentation of these interactions will further our understanding about potential pathways for TB transmission in northern Michigan.

STUDY OBJECTIVES

Objective 1: To determine if interaction (i.e. $\leq$ 5 m) between wildlife and cattle occurs in the northeastern portion of Michigan's Lower Peninsula.

Objective 2: To determine if interaction (i.e. $\leq$ 5 m) between wildlife and cattle occurs more frequently in areas with high TB prevalence in deer than in those with low TB prevalence in deer.

Objective 3: To determine if wildlife visit areas commonly used by cattle when the cattle are absent.

METHODS

Study Area

Fieldwork was conducted on farms located in a five county area (Alcona, Alpena, Montmorency, Oscoda, and Presque Isle) in northern Michigan. Major habitat types located in northern Michigan included upland hardwood stands (*Quercus rubrus, Quercus alba, Acer rubrum, and Acer saccharum*), aspen stands (*Populus tremuloides and Populus gramdidentata*), hardwood/aspen mixed stands, upland conifer stands (*Pinus strobus, Pinus banksiana, and Pinus resinosa*), hardwood/conifer mixed stands, and lowland conifer forests/swamps (*Picea glauca, Picea mariana, Thuja occidentalis, Abies balsamea, and Latrix laricinea).* Elevation ranged from 150m to 390m above sea level (Williams 1992; Hughey 2003). The mean annual temperature is 6.6˚C, the mean rainfall is 72.5 cm, and the mean snowfall is 175cm (Sitar 1996; Hughey 2003).

The study site incorporated the entire TB core area, also known as Deer Management Unit 452 (DMU 452), which is approximately 1,550 km², covering portions of Alpena, Alcona, Montmorency, and Oscoda Counties (Figure 1). The study area was divided into 2 primary zones, based on the known TB prevalence rates for deer, the primary reservoir species for TB in Michigan. High TB prevalence areas included the entire TB core area along with TB positive farms located outside of the core area. Low TB prevalence areas were defined as areas outside of the TB core area consisting of farms with no known occurrence of TB.

TB prevalence rates for deer in townships located inside the core area were generally higher than in townships located outside of the core area. The core area had a number of large privately owned properties, many of which were used as sportsmen clubs, or hunt clubs, where deer densities were often very high. This often created tension between hunters and farmers in this area. Farmers were upset with hunt clubs that were unwilling to address the potential for deer to cattle transmission of TB by reducing deer numbers on their properties. Alternately, hunt club owners did not view TB as a problem for deer, and were interested in managing for higher deer densities in order to assure better annual harvests. Land outside of the core area consisted of small properties owned by individuals interspersed with large tracts of state land that experience greater hunting pressure than most land located inside the core area boundary.

It was important that farms located inside and outside of the core area represented a variety of different physical characteristics. Both dairy and beef operations were targeted, with more beef operations being observed due to the low number of dairy operations in the study area. I observed farms with a variety of different types of stored feed (i.e., hay, silage, grain), as well as a variety of ways in which the feed was stored. Pasture size and distance from cover (i.e., woodlots, brush, and swamps) were considered important characteristics that can affect wildlife activity and behavior on farms. Farms representing different combinations of these variables were observed to determine if they affected wildlife activity.

Year One

Two field seasons were completed, running from January through August, 2002 and January through August, 2003. Five high prevalence farms and 6 low prevalence farms were sampled during the first year (Figure A.1). Of the 5 high prevalence farms,

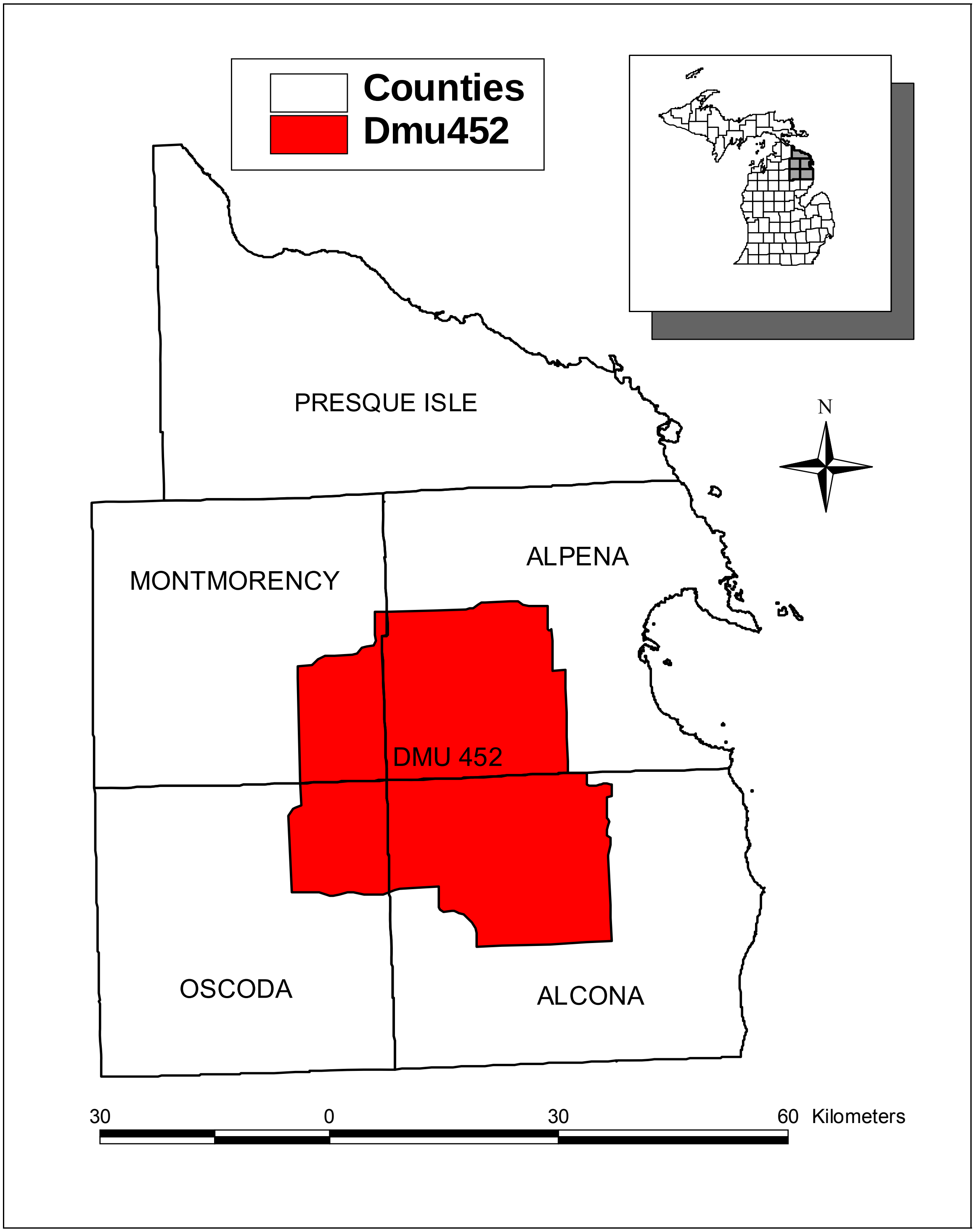


Figure 1: Map depicting 5-county study area observed during each year of observations, including DMU 452 (TB core area).

2 had beef cattle and 3 had dairy cattle. Of the 6 low prevalence farms, five had beef cattle and one had dairy cattle. These farms were located in areas that are known to hold large numbers of wintering deer; of these were 7 beef operations and 4 dairy operations in areas of high and low TB prevalence. A farm was considered an acceptable observation site if pastures, holding pens, water sources, feed sites, and stored feed locations could all be observed from a single location on the farm. A series of 2-3 nights of observations were conducted using spotlights to help assess wildlife activity on farms that were considered acceptable observation sites. I conducted observations in areas where wildlife activity appeared to be highest, giving me the best opportunity to document wildlife behavior on cattle farms.

Visual observations were conducted at each farm located in areas with high and low TB prevalence. Observers positioned their vehicle on the farm so that the pasture, holding pens, water sources, and feed sites could be observed from the vehicle.

At the beginning of the field season, observers followed an observation schedule where the day was split into 4, 6-hour time periods (i.e., 12 a.m.-6 a.m., 6 a.m.-12 p.m., 12 p.m.-6 p.m., and 6 p.m.-12 a.m.). Initially, one 24-hour observation period was completed for each farm per week. However, due to the lack of wildlife activity during daylight hours, the observation period was reduced to 6-hour time blocks in the morning hours and evening hours from February to April, 2002. From May through August, the morning and evening observations were reduced to 4-hour time blocks and random 2-hour daytime observations were conducted each week (2-4/wk).

Prior to initiating observations, and periodically during the study, observers practiced judging distances to help assure consistency when conducting observations.

This was done by using fixed objects located on the farm that were measured prior to the start of observations.

When light levels dropped below those necessary for accurate observations, PVS-7B Night Vision Goggles (Nightline, Inc., Florida) were utilized. Weather conditions, temperature, time, wildlife species, age of the deer (adult or juvenile), type of cow, age of the cow (adult or juvenile), defecation (wildlife), urination (wildlife), estimated distance between wildlife and cattle, distance from a known structure, and duration of the event were recorded whenever an animal was observed visiting an area or interacting with cattle. When a direct interaction was observed general comments were recorded addressing the behavior of the wildlife and the behavior of the cow (i.e., aggression, tolerance, etc.).

Year Two

The second year of observations ran from January through August, 2003. As in Year One, fieldwork was conducted in areas of high and low TB prevalence. The sample size was increased from eleven to 201 farms. This allowed us to move away from the intensive sampling of a small number of farms and increase the size of our study site, creating a more diverse group of observation sites. Of the 201 farms observed during Year Two, 52 were high prevalence farms and 149 were low prevalence farms (Table 1). Of the 52 high prevalence farms, 34 had beef cattle and 18 had dairy cattle. Of the 149 low prevalence farms, 96 had beef cattle and 53 had dairy cattle.

The study area was subdivided into 6 distinct units. The units covered farms inside of the core area and farms within a 20-mile radius of the core area boundary. Each unit was comprised of 5-7 townships (Figure A.2). Individual units covered farms inside and outside of the core area boundary. There were between 30-35 farms observed in each of the 6 sub-areas.

Like the schedule initially developed for observations during Year One, the day was broken into 4, 6-hour time periods (i.e., 12-6 a.m., 6 a.m. -12 p.m., etc.). Each sub-area was observed once a week, with all 6 sub-areas being sampled during the same observation period. The observation period was adjusted each week until all 4 time periods were completed for each sub-area. This was done to assure that a full 24-hour period was completed for each route once a month. Each sub-area was composed of several different townships. To assure that individual farms within a sub-area were being observed at different times during each observation time block we started in a different township (within the sub-area) during each observation period.

The use of Forward Looking Infrared technology (FLIR) was the primary tool used to gather information during this year. Forward Looking Infrared technology detects an animal's (or target's) presence based on its radiant heat signature, which is much higher than the ambient temperature (Belant and Seamans 2000). This technology offers several advantages over the alternative methods of animal detection such as spotlighting and night vision equipment. One advantage of using FLIR is the ability to detect animals that are partially concealed by vegetation or animals that are difficult to detect due to cryptic coloration (Bontaites et al. 2000). Second, FLIR allows the identification of individual species based on morphological characteristics (Bontaites et al. 2000). Third, FLIR allows for minimal disturbance of target animals due to the lack of projected light (Belant and Seamans 2000). Finally, FLIR allows the observer to record information on video for future analysis, something that is not easily accomplished using other techniques.

All observations were conducted from the vehicle using the FLIR scope. The observer positioned the truck so the farm was located on the driver's side of the vehicle, and the FLIR scope could be held outside of the driver-side window. Observations on each farm lasted a minimum of 5 minutes. If an animal was spotted on the property the observer stayed on-site to record the duration of the visit, for up to fifteen minutes. For each observation period the observer recorded the weather conditions, temperature, time, species observed, number of individuals, indirect and direct interactions, duration of interactions, distance between animals, type/age of cattle, and the behavior of both the cattle and the wildlife (if a direct interaction was observed).

Much of the information gathered was highly descriptive in nature. Descriptive statistics (i.e., frequency of visit, duration of visit) were used to quantify observations during Years One and Two. For all of the farms observed I recorded physical characteristics, which included presence/absence of silage, presence/absence of hay, distance to cattle, number of cattle, type of cattle, and size of pasture. Hay and silage were considered present when they were located on the main farm or within 100 m of the pasture and were accessible to wildlife.

Chi-square analysis (exact test) was run for each species group (i.e., deer, turkey, and other mammals) against several different farm characteristics (i.e., silage, hay, cover, cattle type, TB prevalence) to determine if there was any correlation between wildlife presence and the respective physical variable, during Year Two. Statistical significance was defined as, $\acute{\alpha} \leq 0.05$.

RESULTS

Year One

Observations

In total, 260 observations were completed during Year One, equaling 1,157 hours of observation time (Tables 1 & A.1). Eleven farms were observed during the first year (Table 1). Some farms were not observed during the entire field season due to logistic constraints, poor visibility, and limited wildlife activity. Of the farms observed, 7 farms were beef operations, 4 were dairy operations, 5 were considered to be farms in an area with high TB prevalence, and 6 were considered to be in an area with low TB prevalence (Table 1).

Table 1
Information describing observation time, number of farms, and types of farms observed during Year One and Year Two

Characteristic	Year One	YearTwo
Duration	January-August, 2002	January-August, 2003
Total Observations	260	211
Observation Time (hrs.)	1157	622
Total No. of Farms Observed	11	201
No. of Beef Farms Observed	7	130
No. of Dairy Farms Observed	4	71
No. of High Prevalence farms Observed	5	52
No. of Low Prevalence farms Observed	6	149

<u>Direct Interactions</u>

No direct interactions between deer and cattle were observed (Table 2). Eastern wild turkeys (*Meleagris gallopavo*) were documented within five meters of cattle on eighteen separate occasions (Table 2). Mean duration of these interactions was sixteen minutes, with turkeys being documented within 0.3m of feeding cattle. Cattle and turkey seemed to be tolerant of one another with no aggressive behavior being documented. One raccoon and one coyote were observed within 5 m of cattle, with the duration of both interactions lasting ≤ 1 minute (Table 2).

<u>Indirect Interactions</u>

White-tailed deer were the species with the highest number of observed indirect interactions on farms during Year One, with 140 recorded (Table 3). The next most common species observed was wild turkey with 44 observed indirect interactions, followed by raccoon, rabbit, coyote, and opossum (Tables 3 & A.3). The average duration of visit by white-tailed deer on a farm was 31 minutes, while the average duration of visit for turkeys was 21.5 minutes (Table 3).

Deer were seen visiting pasture and silage storage areas more often than any other area on the farm, with visitations to each respective area being relatively equal (Figure 2*a*). Observed visits to stored hay were about one-third of the observed visits to both pasture and stored silage combined. Deer were only observed feeding out of hay racks or silage troughs on one occasion. Observed visits to cattle feed sources occurred almost exclusively on stored feed to which cattle did not have immediate access. Turkeys and mammals other than deer were primarily observed in pasture, with a small number of

Table 2
Number and duration of direct interactions (i.e., ≤ 5 m) between cattle and various wildlife species during Year One and Year Two

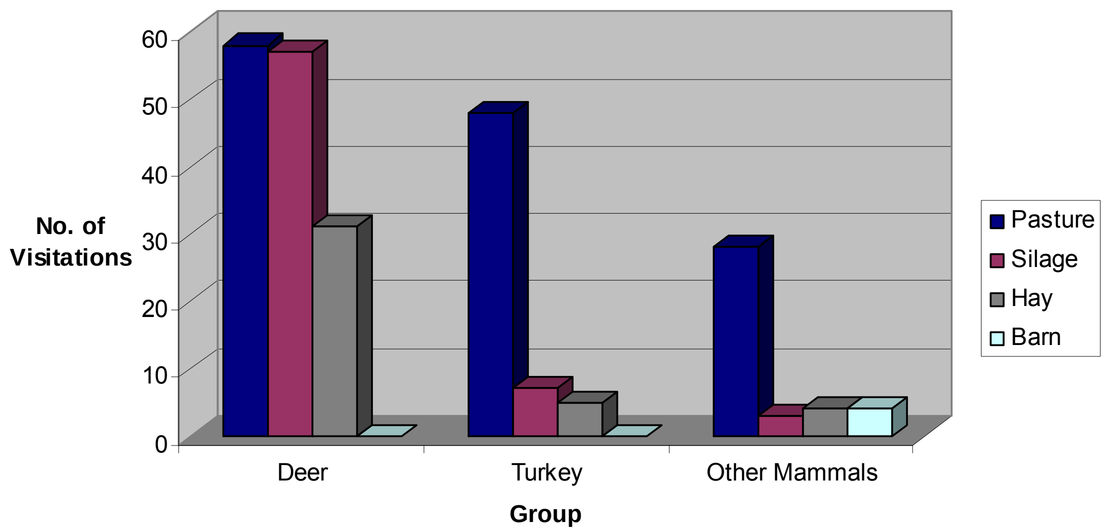
Species	Observed Interactions	Individuals/ Interaction	Range of Duration (min.)	Mean Duration (min.)
Year One				
Turkey	18	1-50	1-37	16
Raccoon	1	1	1	1
Coyote	1	1	1	1
Deer	0	0	0	0
Year Two				
Deer	1	3	<1	<1
Turkey	3	4-8	2-15	10
Feral Cat	6	1-2	1-15	4
Rabbit (*Sylvilagus floridanus*)	1	1	1	1
Skunk (*Mephitis mephitis*)	1	1	1	1
Fox	1	1	1	1

Table 3
Number and duration of indirect interactions for individual wildlife species during Year One and Year Two

Species	Observed Interactions	Individuals/ Interaction	Range of Duration (min.)	Mean Duration (min.)
Year One				
Deer	140	1-25	<1-127	31
Wild Turkey	44	1-85	<1-50	21.5
Raccoon	19	1-3	NA[a]	NA
Rabbit	8	1	NA	NA
Coyote	4	1-3	NA	NA
Opossum	3	1	NA	NA
Year Two				
Deer	133	1-19	1-15	10
Rabbit	61	1-4	1-15	7
Turkey	56	1-30	1-15	10
Raccoon	50	1-5	1-15	8
Feral Cat	33	1-4	1-15	4.5
Opossum	31	1-5	1-15	6.7
Skunk	24	1-2	1-15	8
Coyote	5	1	3-7	3.6
Fox	2	1	1-3	2
USM[b]	5	1-2	1-15	5

[a] - NA= Not Available, data was not recorded
[b] - USM= unidentified small mammals (i.e., raccoons, opossums, and skunks)

(a).



(b).

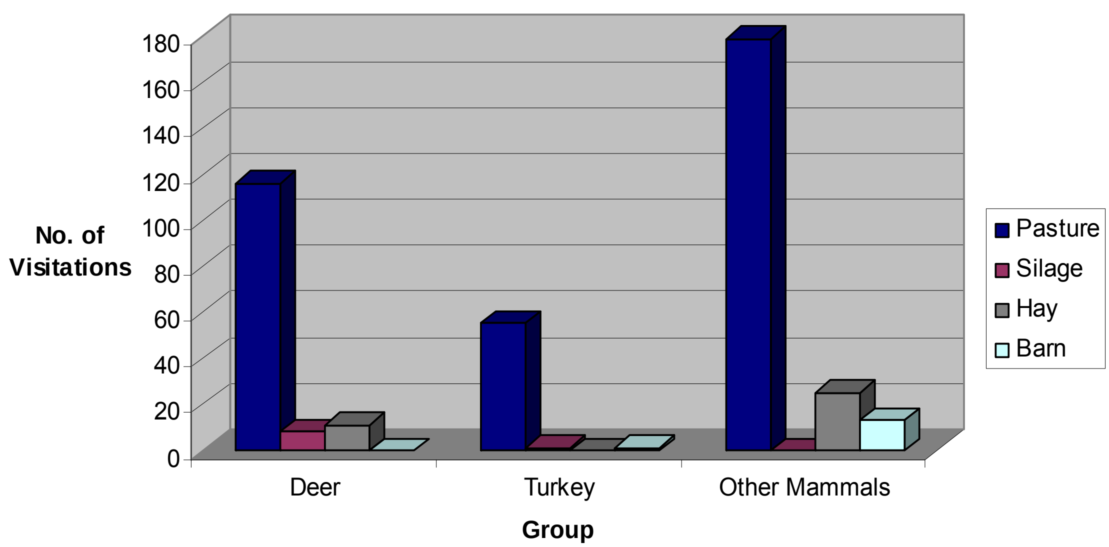


Figure 2: (a) Number of observed visitations by species, or groups of species, to pastures and stored feed sites on farms observed during Year One, (b) Number of observed visitations by species, or groups of species, to pastures and stored feed sites on farms observed during Year Two.

observed visits to stored feed and farm structures (Figure 2*a*). Turkeys were often documented feeding on food particles (i.e., loose grain) in areas where cattle were being fed. Most small mammals (i.e., raccoons, opossums, skunks, feral cats, rabbits) and mid-sized mammals (i.e., coyote and fox) were observed passing through the pasture without visiting cattle feeding areas.

Year Two

Observations

Two Hundred and eleven observations were completed during the second year, equaling 622 hours of observation time (Tables 1 & A.2). Two hundred and one farms were observed throughout the duration of Year Two. These farms included 130 beef operations and 71 dairy operations. Fifty-two farms were considered to be in an area with high TB prevalence and 149 farms were considered to be in an area with low TB prevalence (Table 1).

Direct Interactions

One direct interaction was observed between deer and cattle during the second year (Table 2). The direct interaction involved 1 doe and 2 fawns that ran past a cow at the edge of the pasture, near a woodland. The deer came within 5 m of the cow, turned, and ran another direction; the event lasted only a few seconds. Turkeys were observed within 5 m of cattle on 3 separate occasions, lasting an average of 10 minutes per interaction (Table 2). Feral cats also were observed within 5 m of cattle on 6 occasions, with an average duration of visit equaling 4 minutes (Table 2). Cattle were documented making direct physical contact with feral cats on 2 separate occasions, an occurrence not documented between cattle and any other species. One rabbit, 1 skunk, and 1 fox were observed within 5 m of cattle, with an average duration of visit equaling 1 minute (Table 2).

Indirect Interactions

White-tailed deer was again the species with the most observed indirect interactions, totaling 133, with an average duration of 10 minutes/visit (Table 3). Other wildlife observed on farms includes rabbit, turkey, raccoon, domestic cat, opossum, skunk, coyote, fox, and small mammals that were not identified by species (Tables 3 & A.4).

All species observed visiting farms were primarily observed in pasture (Figure 2*b*). Deer were not observed feeding out of hay racks or silage troughs at any time during the second year. Deer visitations to stored silage were almost nonexistent during the second year, which was opposite of what was seen during the first year. Turkey behavior mirrored the data from the first year with most turkeys observed in pasture, often in cattle feeding areas. Small and mid-sized mammals were primarily seen in pasture, with relatively few seen in, on, or around stored feed or farm structures.

Chi-square analysis was run pairing individual variables with species presence. There was no detected relationship between deer presence and any of the 5 physical characteristics of farms tested (Tables 4, 5, & 6). The only relationships detected were between turkey presence and available cover (p=0.006) and the presence of mammals other than deer and available cover (p=0.033) (Table 4). Available cover was defined as any wooded area within 100 m of the pasture fence line.

Table 4
Chi-square analysis of farms with (Available) and without (Unavailable) silage, hay, and cover[a] during Year Two, testing to determine if physical characteristics can be used to predict wildlife activity[b] on farms

Group/Variable	Available (n)	Wildlife Activity	Unavailable (n)	Wildlife Activity	P-value
Deer					
Silage	37	35.14	164	39.63	0.612
Hay	171	36.84	30	50.00	0.177
Cover	168	41.07	33	27.27	0.137
Turkey					
Silage	37	13.51	164	17.07	0.598
Hay	173	16.18	28	17.86	0.825
Cover	168	19.64	33	0.00	0.006
Other Mammals					
Silage	37	51.35	164	50.00	0.882
Hay	173	49.71	28	53.57	0.705
Cover	168	53.57	33	33.33	0.033

[a] - Cover was defined as woodlands within 100 meters of the pasture
[b] - Wildlife activity is measured as the percentage of farms that experienced at least one direct or indirect wildlife encounter

Table 5
Chi-square analysis of farms in areas of High TB Prevalence and in areas of Low TB Prevalence observed during Year Two, testing to determine if farms in high TB prevalence areas are at greater risk of experiencing wildlife activity[a]

Group	Wildlife Activity/ High Prevalence (n=52)	Wildlife Activity/ Low Prevalence (n=149)	P-value
Deer	48.08	35.57	0.111
Turkey	17.31	16.11	0.841
Other Mammals	48.08	51.01	0.716

[a] - Wildlife activity is measured as the percentage of farms that experienced at least one direct or indirect wildlife encounter

Table 6
Chi-square analysis of Beef farms and Dairy farms observed during Year Two to determine if cattle type affects a farm's risk of experiencing wildlife activity[a]

Group	Wildlife Activity/ Beef (n=130)	Wildlife Activity/ Dairy (n=71)	P-value
Deer	40.00	36.62	0.638
Turkey	15.38	18.31	0.593
Other Mammals	50.00	50.70	0.924

[a] - Wildlife activity is measured as the percentage of farms that experienced at least one direct or indirect wildlife encounter

Additional Observations

There were many recorded observations of wildlife visiting areas on farms that were inaccessible to cattle. These data were recorded from the same locations where the pastures and stored feed sites were being observed. The most notable of these observations is the 2,005 deer that were observed on the perimeter of the observed properties, 294 of the deer observed during the first field season and 1,711 observed during the second field season (Table 7). Only wildlife seen from observation points were recorded, many more individuals (especially deer) were observed in fields and woodlots as the observer left the observation site.

Table 7
Number of wildlife observed greater than 5 meters from pasture, fence lines, or stored feed without being observed in an indirect interaction during Year One and Year Two

Species	No. of Individuals (Year One)	No. of Individuals (Year Two)	Total
Deer	294	1711	2005
Turkey	89	193	286
Cat	1	33	34
Raccoon	2	25	27
Opossum	0	19	19
Rabbit	0	13	13
Skunk	1	6	7
Bear	0	6	6
Coyote	9	3	12
Unidentified[a]	0	4	4

[a] - Unidentified=any animal observed that was not able to be identified by species

DISCUSSION

White-tailed deer are considered to be the reservoir host for bovine TB in northern Michigan and, consequently, may serve as the primary source of infection for livestock and other wildlife species. Other wildlife species may become infected through contact with infected deer, consequently, they also pose a risk of spreading the disease to cattle and other wildlife. It is important to understand which wildlife species are more likely to transmit TB through direct pathways and which are more likely to transmit TB through indirect pathways. This information will help in developing more effective management practices, for both livestock and wildlife, aimed at eradicating the disease.

There is very little known regarding interactions between cattle and white-tailed deer with no conclusive studies to provide proof that interactions occur. I failed to discover any scientific data that would imply that direct interaction is taking place between deer and cattle. Most studies of interaction between deer and cattle deal with competition for mutual food sources. Studies show that wild ungulates and cattle tend to select different vegetation types, topographic positions, and different slopes (Lonner and Mackie 1983; Telfer 1994; Solanki and Naik 1998). Documentation of spatial tolerance between deer and cattle is an important component in understanding the risk of TB transmission that deer pose to cattle.

Aerosol transmission is thought to be the primary mode of transmission for TB (Thoen and Bloom 1995). My data suggested that direct interaction (i.e. ≤ 5 m, aerosol transmission) between deer and cattle in northern Michigan is a rare event and is probably not a significant route of transmission of TB to cattle. It appeared, based on observed deer behavior, that deer were not tolerant of cattle at a distance less than 30 meters apart. On 8 separate occasions, cattle were documented approaching deer that were either feeding in the pasture or along a pasture fence line. Seven of the eight deer ran before the cattle approached within 30 m of the deer's location, while 1 deer allowed the cattle to approach to about 8 m of its location before fleeing.

Only one direct interaction was documented between deer and cattle. The interaction involved three deer and one cow. The deer were fleeing from a woodlot and appeared to inadvertently approach a single cow within 5 m. The deer immediately fled from the cow with the interaction lasting only seconds, making the probability of direct aerosol transmission unlikely, even if the deer were shedding *M. bovis* in respiratory secretions. These data supported the hypothesis that deer and cattle are behaviorally intolerant of each other, rarely occupying space within 5 m, suggesting that direct interaction between the two is not a significant route for TB transmission to cattle.

All species observed in this study were documented more often visiting pastures or stored feed sites than approaching cattle within 5 m. My data indicates that indirect interactions may therefore pose a greater risk to cattle in northern Michigan than direct interactions. Many of the species observed (e.g. deer, raccoon, opossum, and feral cats) are capable of shedding the bacteria through means other than respiratory secretions, although some shed it more efficiently than others (Diegel et al. 2002; Palmer et al. 2002; Fitzgerald et al. 2003*b*). As long as a species has demonstrated the capacity to become TB infectious it should be considered a risk to cattle, regardless of how difficult it is for them to shed the bacteria.

Of the species observed in indirect interaction the white-tailed deer was by far the most common with 273 visitations, totaling 949 individuals (Table 3). Deer were usually observed feeding on the side of the pasture opposite cattle. This does not indicate that cattle did not use the areas of pasture that the deer were observed using; cattle were often observed using the same areas during other observation periods. There were instances where deer were seen feeding in the same area of an individual pasture on multiple occasions. It is possible that deer feeding in similar areas on multiple occasions could create foci of contaminated respiratory secretions and waste products, increasing the risk of TB transmission to cattle using these foci. The ability of *M. bovis* to survive on substrates for extended periods of time, combined with areas that experience multiple visits by deer, further increases the risk of cattle ingesting contaminated materials.

Deer were also observed feeding on or around stored feed during each field season (Figure 2). During the first year, there was nearly an equal number of deer observed feeding on stored silage as there was deer observed feeding in, or passing through pastures. However, during Year Two, observed visits to pasture were more than 14 times greater than observed visits to stored feed (Figure 2*b*). This was primarily attributed to large numbers of deer being observed feeding on silage pits located on 2 farms during Year One and very few deer seen in pastures on any of the farms observed.

Another possible reason for the observed annual variation in deer use of pastures and silage was the use of FLIR technology during Year Two. The use of FLIR increased the sightability of deer in pastures and fields. Also, the increase in farms revealed that there were relatively few farms that had as many deer on silage as two of the farms that were observed during Year One. However, deer that were documented feeding on stored feed (silage or hay) were often observed feeding at the same location on multiple occasions. This was particularly true of the 2 farms that had accessible silage during the first year of observations. Deer routinely fed off of one side of the silage pit or the open end of silage bags. This created repeat exposures to a confined area, likely increasing the chances of cattle ingesting particles contaminated by deer.

Mean duration of visits by deer dropped from Year One to Year Two. This was primarily attributed to the change in methods. Year One had a minimum observation time of 2 hours (range, 2-12hrs.), while Year Two had a maximum observation time of 15 minutes. With visitations by deer lasting up to 127 minutes during Year One, the mean duration is much higher than the mean duration during Year Two. This also explains the difference in mean duration of visits by turkeys between Year One and Year Two. Deer and turkey were the only 2 species with data on duration of visits during each year of observations.

Deer observed feeding on stored hay was relatively low through the duration of the study. Deer feeding out of hay racks where cattle were actively feeding was almost nonexistent. A deer was documented feeding out of a hay rack or silage trough that was being used to feed cattle only once. On that occasion, cattle were bedded 70 m away at the time of the visit. When deer visited stored feed sites they would seldom cross through a pasture or holding pen that was being used by cattle. If they did, they were not observed any closer than 50 m from the cattle. Deer often had trails along the outside of the pasture fence line to access the feed storage sites (if they were not entering from a road).

Given that deer did not seem to cross pastures to access feed, did not feed out of hay racks being used by cattle, ran from approaching cattle, and fed on opposite ends of pasture from cattle, I concluded that deer actively avoid cattle. This conclusion is reinforced by the fact that 557 deer were observed in pastures through the duration of the study (Table 3), while 2,005 deer were documented standing greater than 5 m outside of a pasture fence line during the same time period (Table 7). Additionally, if I counted deer that were in the immediate areas surrounding farms and pastures while driving away from farms the number of deer seen would have more than doubled.

Although, direct interaction between cattle and deer were rarely observed, they were much more common among cattle, turkeys, and feral cats. These were the only 2 species observed within five meters of cattle on multiple occasions. Turkeys were observed in direct interaction with cattle on 21 separate occasions (Table 2)

Turkeys were documented on several occasions feeding within 0.33 m of cattle. Cattle appeared to have little to no observable reaction to the presence of turkeys, while turkeys exhibited no hesitations about walking and feeding amongst cattle. Turkey/cattle interactions were observed on multiple farms, suggesting that the interspecific tolerance was not specific to individual turkey flocks or cattle herds.

This spatial tolerance of cattle and turkey could be considered a potential threat for direct, interspecific transmission of TB. However, currently there is no evidence that turkeys can develop TB or shed *M. bovis* through respiratory or fecal routes (Fitzgerald et al. 2003*a*).

Turkeys, like deer, were primarily seen in pasture, either feeding or passing through (Figure 2). A large number of turkeys were observed feeding off of stored silage on one particular farm during Year One, while another farm experienced large numbers of turkey feeding out of grain troughs being used by cattle.

It is plausible that turkeys could indirectly transmit TB to cattle by serving as a mechanical vector. If contaminated feed particles became attached to the feet of a turkey it might be possible for the bird to contaminate a previously uncontaminated farm. However, observational data from the first year suggested that turkeys did not travel great distances from the property in which they were observed. Turkeys were documented visiting individual farms during the same time periods on consecutive days. Based on these data and the study showing that they are not good hosts for TB it is unlikely that turkeys pose a serious threat to cattle.

Mammals other than deer were documented on and around farms quite frequently, these included raccoon, rabbit, opossum, feral cats, skunk, fox, and coyote. There was a noticeable increase in observed visitations by these species from Year One to Year Two. This was almost entirely attributable to the use of the FLIR unit, which allowed us to detect small to mid-sized animals that were difficult or impossible to see with the Night-Vision Goggles (NVG) used during Year One.

Feral cats were observed within 5 m of cattle on 6 separate occasions (Table 2). Given that I did not conduct observations in barns and other farm structures, I was unable to evaluate many of the interactions that may have been taking place between cattle and feral cats. Based on the interactions that I did observe, cats were tolerant of cattle with no aggressive or nervous behavior observed. Cattle were documented as being either intolerant of cats, curious towards their presence, or indifferent to their presence. Two of the observed direct interactions documented physical contact between a cow and a cat, where the cow was the one to initiate contact.

Feral cats have the capacity to disseminate TB (Hoise et al. 1989; Monies et al. 2000) and should be considered a risk for transmitting the disease to cattle through direct interaction. It is plausible that feral cats may be a source of reinfection for individual farms, since they are not removed after a farm becomes infected. However, there is no scientific data documenting TB positive cats or prevalence rates in the infected area. A surveillance program for feral cats in the infected area is needed to better understand the risk they pose to cattle.

Direct interaction between cattle and fox, raccoon, rabbit, skunk, and coyote were observed on one occasion for each respective species (Table 2). Due to the fact that there was only one direct interaction with cattle documented for each species it is not possible to draw any strong conclusions about the risk they pose to cattle through direct interaction. Like the deer, direct interaction between coyote and cattle, and fox and cattle appeared to be rare events. It is difficult to accurately address the frequency of direct interactions between cattle and the other small to mid-sized mammals because I did not conduct observations inside of barns where direct interactions, if they occur, would be more likely. Direct interaction in open pasture between cattle and raccoon, rabbit, opossum, or skunk also appeared to be a rare event.

Like deer and turkey, small to mid-sized mammals were primarily observed in pasture (Figure 2), and tended to utilize areas of pasture that were not being used by cattle. It is likely that small mammal visits to farms take place inside barns and enclosed feed storage areas as often as they do in pastures and holding pens. Due to the design of this study we were unable to view the interiors of these types of structures. Raccoons and opossums are 2 of the species most likely to visit enclosed areas such as barns and feed storage buildings in search of food and shelter. Studies have been done that documented the ability of raccoons and opossums to shed *M. bovis* (Diegel et al. 2002; Palmer et al. 2002; Fitzgerald et al. 2003*d*). Therefore, studies designed to increase understanding of the movements of these small to mid-sized mammals in and around farm buildings are necessary.

In evaluating the computations I ran, pairing farm characteristics with wildlife activity, few relationships were observed. The only relationships observed were turkey presence and available cover, and the presence of mammals other than deer and available cover (α=0.006 and 0.033, respectively) (Table 4). I hypothesized at the beginning of this study that farms with beef herds were at greater risk of experiencing wildlife/cattle interactions than farms with dairy herds. This was due to the fact that beef herds in northern Michigan are generally left in pasture or in holding pens year around, increasing their exposure to species such as deer. The chi-square results indicated that there is no significant difference between beef and dairy operations and wildlife activity.

One of the objectives of this study was to determine if interactions between wildlife and cattle occurred more frequently in areas with high TB prevalence in deer than in areas with low TB prevalence in deer. The high TB prevalence areas (e.g., the core area) have higher deer densities, which is the primary reason for higher TB prevalence rates. Deer density remains high because of the large tracts of privately owned land that are used for hunt clubs. Hunt club owners have a greater interest in managing for higher deer densities in order to assure better annual harvests than they do in eradicating the disease. With higher deer densities it is reasonable to hypothesize that the probability of interactions are higher in the TB core area. My analysis showed that there was no detectable difference between areas of high and low TB prevalence when it comes to wildlife/cattle interactions (direct or indirect). However, even though there were no detectable difference in interactions between high and low prevalence areas, the probability of TB positive wildlife interacting with cattle remains higher in the high TB prevalence areas.

Although observed indirect interactions significantly outnumbered direct interactions for all species, the total number of interactions, especially by deer was much less than expected. With the emphasis placed on the deer by the public and the agencies involved in the Michigan bovine TB issue, I had expected to find deer on farms with much greater frequency. The winters were mild through both of the field seasons, which may have minimized the need for deer to use farm pastures and feed storage areas. Regardless of the weather conditions, my data demonstrated a definite avoidance of cattle by deer whenever possible. This information, paired with only one observed direct interaction suggested that direct interaction between deer and cattle is a rare event. However, if TB is transmitted through indirect pathways, my data suggested that deer were the species most likely to transmit the disease.

Deer, considered the reservoir host for TB in Michigan, are likely the primary source of reinfection for other species. It is important to address the risks that spillover hosts pose to cattle. Trapping and removing small to mid-sized mammals can be used to reduce the risk of TB transmission to cattle. However, efforts aimed at controlling TB in spillover hosts will do little to help eradicate the disease. If management efforts are successful at reducing or eradicating TB in the deer herd the disease is not likely to persist in other species. Prevalence rates for deer have declined since management efforts have been implemented, but the drop in the prevalence rate has slowed. The annual deer harvest has slowed in recent years, primarily because hunters are unwilling to accept deer densities in the infected area lower than current levels (Elaine Carlson, personal communication, 2004). Future management practices should continue to try and reduce the TB prevalence rate in deer. Regardless of whether cattle herds have become positive from sources other than deer, eradication of the disease in the deer herd is an important step towards Michigan becoming TB free.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Based on the data that I have collected, it appears that direct interaction between white-tailed deer and cattle is a rare event and probably does not play a significant role in TB transmission to cattle in northern Michigan. My data indicates a clear spatial intolerance of cattle by deer. If direct interaction between wildlife and cattle does play a role in TB transmission, my data suggested that it would most likely involve feral cats. TB prevalence rates are not known for cats in Michigan, a TB surveillance program is needed to gain a better understanding of the threat cats may pose to cattle.

Indirect interaction seems to be a more viable avenue for the transmission of bovine tuberculosis from wildlife to cattle in northern Michigan. White-tailed deer was the species most frequently documented on and around farms. Deer were observed feeding in the same areas (pasture and stored feed) on individual farms on several occasions, possibly creating foci of contaminated secretion and waste products. This was not observed with the same frequency for other species. If bovine tuberculosis is being transmitted through indirect pathways deer are the species most likely to do so, based on my observational data and their known ability to shed *M. bovis*.

Movement patterns of small mammals (i.e. raccoons, opossums, skunks, feral cats) in and around farm buildings needs to be better understood. This project was not designed to view activity inside barns and other farm structures where interactions are likely to take place.

There was no detectable difference in wildlife activity on farms in areas of high TB prevalence and areas of low TB prevalence. However, the probability of TB positive wildlife interacting with cattle remains higher in the high TB prevalence areas.

There was no significant difference in wildlife activity on farms that run a beef operation compared to farms that run a dairy operation. Farms with exposed silage, exposed hay, or that have pasture within 100m of cover did not show a greater risk of experiencing wildlife activity. This data suggested that wildlife activity on farms cannot be accurately predicted based on individual, or combinations of physical variables commonly found on farms (i.e., silage, hay, available cover).

Guard dogs trained to protect cattle and cattle pastures from intruding wildlife would be an effective tool to limit wildlife visitations to large open pastures where fencing would be expensive and impractical. A study conducted in northern Michigan has demonstrated that guard dogs can be an effective tool in preventing wildlife-cattle interactions (Kurt Vercauteren, personal communication, 2003). Various forms of fencing are an excellent tool to protect stored feed from deer, and may have some success keeping out turkeys and small mammals. Live trapping and removing raccoons, opossums, skunks, and other small mammals would help to reduce risk of direct and indirect interactions with cattle.

A combination of these management tools can be implemented to help reduce the risk of TB transmission between wildlife and cattle. Future management goals, regarding wildlife, should continue to focus on eradicating the disease in the deer her. Without TB in the deer the disease is not likely to persist in other wildlife species.

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APPENDIX

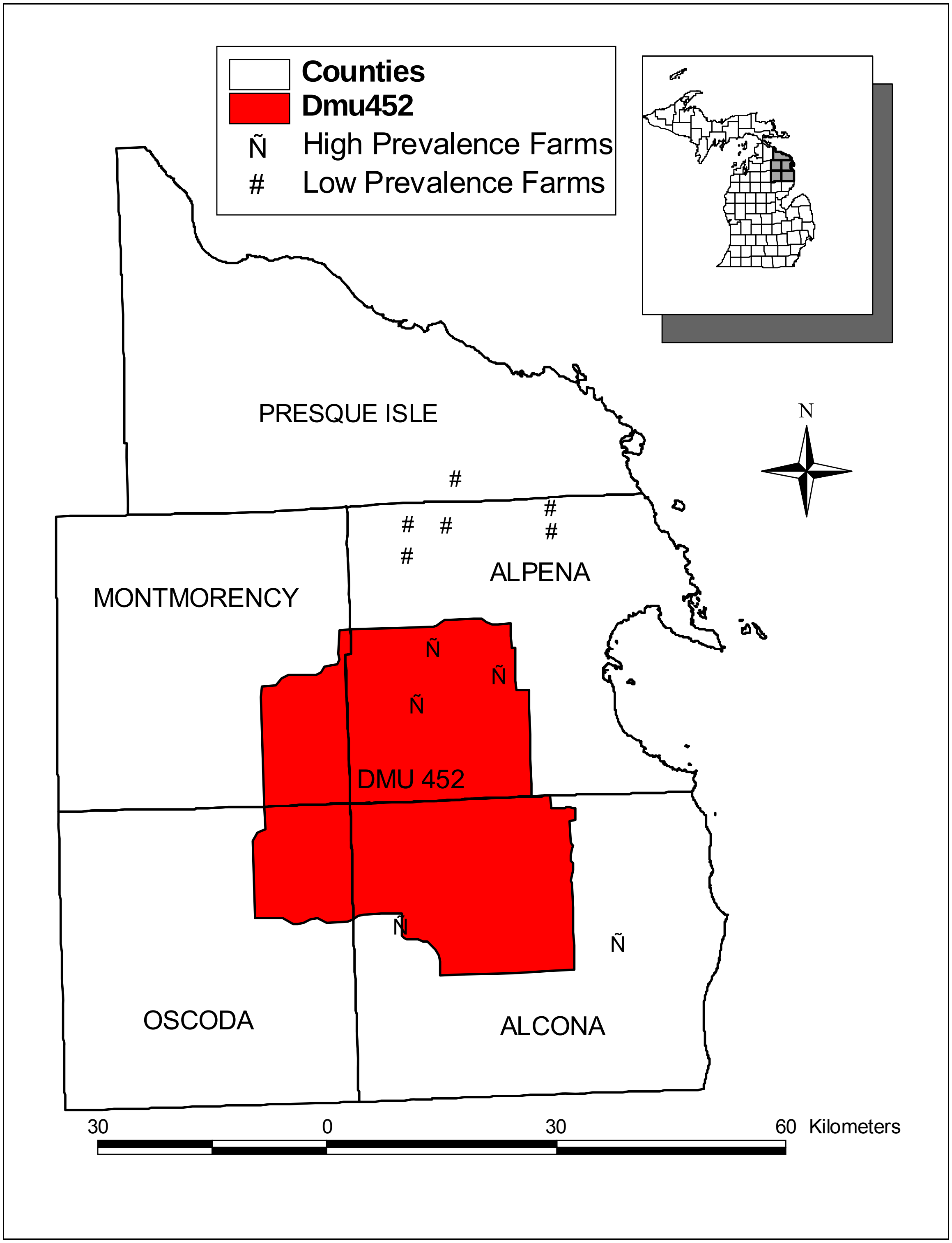

Figure A.1: Map of the study area depicting the location and the prevalence area of each farm observed during Year One.

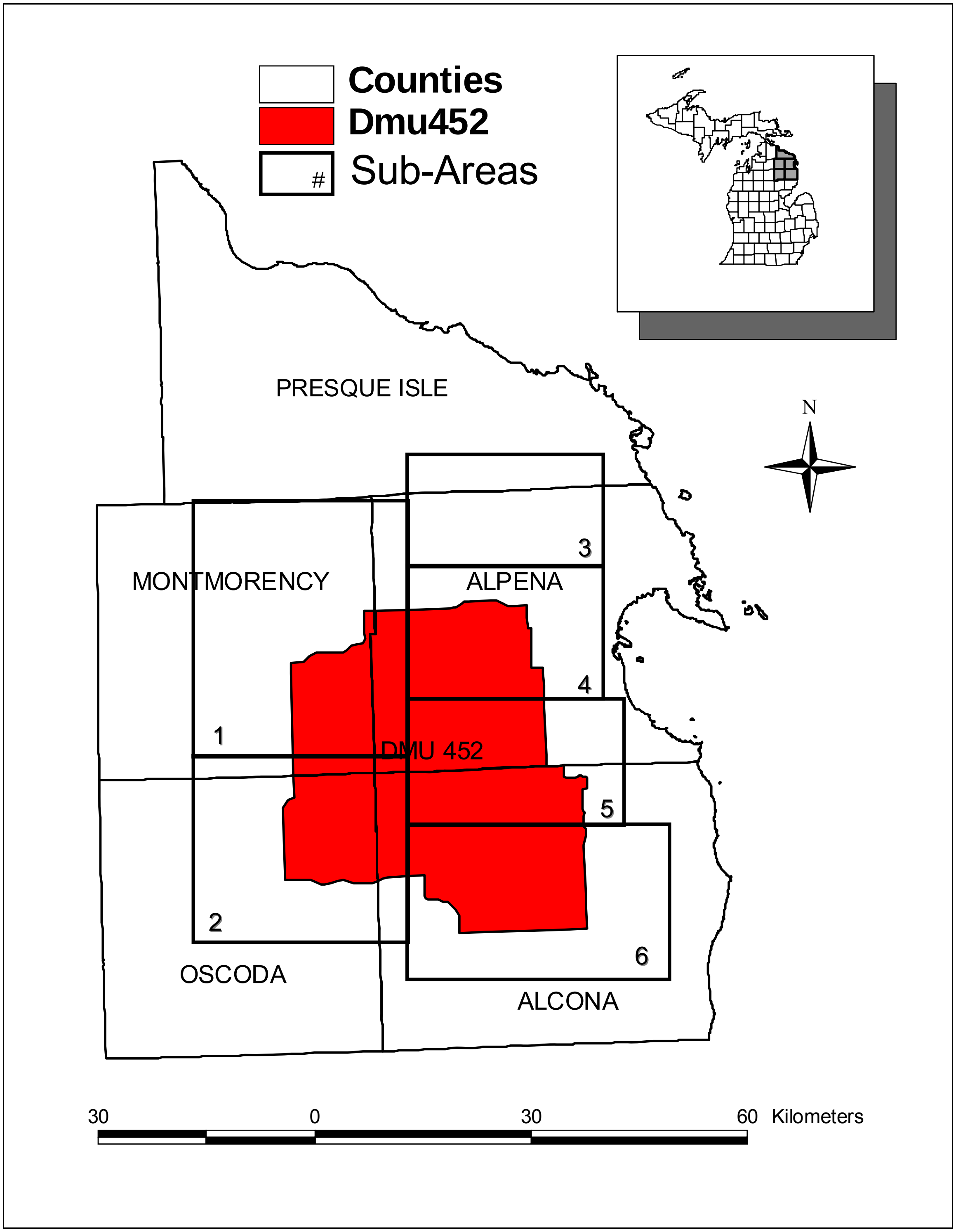

Figure A.2: Map of the study area, defining the 6 individual sub-areas observed during Year Two.

Table A.1
Number of observations completed during each observation period on farms observed during Year One[a]

Farm	Morning	Daytime	Evening
A	5	2	7
B	15	7	14
C	9	3	9
D	7	0	6
E	2	2	2
F	15	6	14
G	10	4	8
H	3	3	3
I	16	3	15
J	14	8	16
K	16	0	16
Total	112	38	110

[a] - Farm names are anonymous, so they are substituted with letters. Observation periods varied by time of year. The morning observation periods is defined as two hours before sunrise and two hours after sunrise. The evening observation period is defined as two hours before sunset to two hours after sunset. The daytime observation period is all time between two hours after sunrise and two hours before sunset.

Table A.2
Number of observations completed during each observation period for each sub-area during Year Two

Sub-Area[a]	0-6:00	6-12:00	12:00-18:00	18:00-24:00
1	9	9	9	9
2	9	9	9	9
3	8	9	9	9
4	9	9	8	9
5	9	9	9	8
6	8	8	9	9
Total	52	53	53	53

[a] - See Figure A.2 for location of each sub-area.

Table A.3
Number of visits by species during 3 time periods during Year One

Species	0000-0800	0800-1600	1600-2400
Deer	61	1	78
Turkey	21	18	17
Raccoon	5	0	12
Rabbit	4	0	4
Coyote	0	1	3
Opossum	2	0	1
Skunk	0	0	1

Table A.4
Number of visits by species during each observation period during Year Two

Species	0000-0600	0600-1200	1200-1800	1800-2400
Deer	73	11	18	31
Rabbit	33	9	4	14
Turkey	1	31	15	9
Raccoon	42	2	1	5
Domestic Cat	11	8	6	8
Opossum	17	0	1	13
Skunk	18	2	0	4
Coyote	3	0	2	0
Fox	1	0	1	0
Unidentified[a]	3	1	1	0

[a] - Unidentified= Unable to identify the animal by species