12-19-2008

Reducing the Public Health Impact of Bovine Tuberculosis by Controlling Disease Transmission Between Cattle and White-Tailed Deer in Northwestern Minnesota

Barbara Knust

Reducing the public health impact of bovine tuberculosis by controlling disease transmission between cattle and white-tailed deer in northwestern Minnesota

Barbara Knust, DVM
Master's Project

In partial fulfillment of the requirements for Master's Degree in Public Health,
Executive Program at the School of Public Health,
University of Minnesota

December 19, 2008

Table of Contents

I.   Abstract

Bovine tuberculosis, caused by infection with *Mycobacterium bovis,* is a re-emerging zoonotic disease. It has staged a comeback by establishing infections in wildlife and cattle, creating the potential for human disease in locations where it was thought to be under control. In northwestern Minnesota, infected cattle and white-tailed deer were first discovered in 2005. A major bovine tuberculosis eradication campaign is underway in the state, with multiple efforts employed to control *M. bovis* infection in both cattle and deer populations. In order to effectively eradicate bovine tuberculosis in Minnesota, there is a need for better understanding of the factors that increase the risk of deer and cattle interacting in a way that facilitates tuberculosis transmission. By reducing the risk of disease transmission within the animal populations, we will also reduce the risk that bovine tuberculosis will again become a common disease in human populations.

The purpose of this study is to characterize the risk of interactions between cattle and white-tailed deer in northern Minnesota in order to prevent *M. bovis* transmission. A survey originally developed to assess deer-cattle interactions in Michigan was modified for use in Minnesota, introducing a scoring method to evaluate the areas of highest priority at risk of potential deer-cattle interaction. The resulting semi-quantitative deer-cattle interaction risk assessment was used at 53 cattle herds located in the region adjacent to the bovine tuberculosis "Core Area". Two evaluators each scored the farm separately, and then created a management plan for the farm that prioritized the areas of greatest risk for deer-cattle interactions. Herds located within the "Management Zone" were evaluated by Minnesota Board of Animal Health staff, and results from these surveys were used as a point of comparison.

Half the herds visited by the University of Minnesota group had experienced deer damage to stored feeds within the past year. Only 11% of herds reported that deer were most frequently seen in the winter, while spring, summer, or fall were more common times for 50% of the herds. A strong association was found between increasing percentage of land that would serve as deer cover and the presence of deer damage to stored feeds on the farm. Farms most often had deer damage to stored hay, although the feed with highest proportion of damage by deer was silage. Cattle feeding practices were also found to have increased risk for deer-cattle interactions, with average scores for location of feeding site and the rate at which feed was consumed worth >50% of the maximum possible score.

Comparison of risk scores assigned by U of M observers at the same farms revealed that the two evaluators had a high level of agreement for many of the management areas. However, some risk areas had inconsistencies between evaluators, and the risk assessment's repeatability can be improved with some revisions to simplify the scoring system. In spite of these issues, the total risk score was significantly associated with the probability of a farm having deer damage. The total risk score and % deer cover land around the farm were used to create a logistic regression model that accurately predicted the presence of deer damage to stored feeds.

 The recommendations made most often were to fence or otherwise protect hay storage, move the feeding location for cattle, move a feed storage site, reduce the amounts of feed fed at a time, or fence beet pulp storage. As described earlier, the risks of management factors varied, but the process of on-farm risk assessment ensured that all potential risk areas were evaluated in order to determine which risks were of greatest importance for the farm.

Management practices in many herds in northwest Minnesota were such that risk of deer-cattle interactions were present and significant. In order to prevent potential transmission of

bovine tuberculosis between deer and cattle, continued development of biosecurity practices is needed. The on-farm risk assessment evaluated in this study serves as a valuable tool in prioritizing a farm's specific needs. Continued vigilance is necessary to maintain this zoonotic pathogen as a potential rather than a realized public health threat.

II.   Introduction

a. Background and Public Health Significance of Bovine Tuberculosis

Mycobacterium bovis, the causative agent of bovine tuberculosis, was an important cause of human illness in the United States until the first part of the 20th century. Tuberculosis was the leading cause of human deaths in 1900; an estimated 10-20% of cases were caused by *M. bovis*.[1] Similar to *Mycobacterium tuberculosis*, *M. bovis* is an acid-fast bacteria that evades the host's immune defenses, killing macrophages and causing the formation of granulomas and cellular necrosis. [2] The routes of transmission for *M. bovis* to infect humans are through gastrointestinal, respiratory, and direct contact with broken skin. Historically, humans were thought to be infected mainly through ingestion of unpasteurized milk, and the resulting lesions were typically extrapulmonary. Granulomatous infection of the cervical lymph nodes was known as "scrofula", while skin infection from direct contact of the bacteria with an open cut was termed "butcher's wart". Tuberculosis of the intestinal tract, meninges, and joints were also reported. [3]

Scientists strengthened their associations between the wasting granulomatous disease of cattle and cases of human tuberculosis in the early 1900s, and concluded that humans could become infected with *M. bovis*. A series of public health measures were enacted to prevent human infections, including the Meat Inspection Act of 1906 and routine adoption of milk pasteurization. The combination of these measures caused a dramatic decrease in the incidence of zoonotic bovine tuberculosis, particularly extrapulmonary cases, and is considered a tremendous public health success story.[4] In 1917, the United States introduced a cooperative state-federal program to eradicate bovine tuberculosis from cattle through a test-and-cull strategy.[1] By the 1970s, bovine tuberculosis was uncommonly reported in much of the U.S. cattle population, and every state in the Union had achieved tuberculosis-free status by the 1990s. Similar programs were introduced in many other countries, making bovine tuberculosis a rare disease in many developed parts of the world, both for humans and cattle.

However, it would be a mistake to assume that *M. bovis* is no longer a pathogen of concern to public health. In developing nations, humans continue to become infected through ingestion of unpasteurized milk and contact with infected animals. Few countries in Africa have control programs for bovine tuberculosis, and it is likely *M. bovis* infections comprise a large number of human tuberculosis cases.[5] Additionally, HIV co-infection has been found to increase the severity of bovine tuberculosis, potentiating human-to-human transmission.[2] This presents a problem for countries where there is a large burden of bovine tuberculosis and HIV. In the United Kingdom, a cluster of six bovine tuberculosis cases occurred in 2004-05. Only one person in the cluster was confirmed to have consumed unpasteurized dairy contacts, and had occupational exposure to cattle. The remaining cases had social contacts with one another. This cluster makes a convincing case for human-to-human transmission of bovine tuberculosis, and highlights the importance of immunocompromise, as four of the six people involved had predisposing conditions such as HIV infection, drug abuse, and diabetes.[6]

As globalization increases, so does the migration of infected individuals and potentially contaminated dairy products. Mexico has a bovine tuberculosis eradication program, but the dairy sector still has endemic tuberculosis in many Mexican states.[7] In San Diego County, California, epidemiologists recently reported 45% of children with tuberculosis were infected with *M. bovis*, and *M. bovis* cases were more than twice as likely to die before treatment was

completed than were cases infected with *M. tuberculosis*.[8] In this study, nearly every case of *M. bovis* occurred in persons of Hispanic ethnicity. The close contact between the Hispanic community in San Diego and bordering Tijuana, Mexico was hypothesized to be an important factor in the occurrence of bovine tuberculosis.

M. bovis has staged a comeback by establishing infections in wildlife and cattle, thereby creating the potential for human disease in several locations around the world where it was thought to be under control. In each country, the disease epidemiology differs, demonstrating the utility of *M. bovis* to survive and cause infection in a variety of different species. The routes of bovine tuberculosis transmission will be reviewed, followed by a discussion of ongoing bovine tuberculosis situations in the United Kingdom, New Zealand, and the United States (including Michigan and Minnesota). These three countries serve as prime examples to highlight the importance of human disease prevention by disease control at the wildlife-domestic animal interface.

b. Cattle Infection & Epidemiology

Cattle are highly susceptible to infection with *M. bovis*; a sufficient infectious dose can be as small as one organism through respiratory route of infection.[9] Virulence of the organism, dose, route, and host's susceptibility are all important determinants of whether an infection will be sustained.[10] Respiratory introduction is thought to be the most effective means of transmission in cattle, typical lesions being enlarged granulomatous lymph nodes in the head or thorax. The retropharyngeal lymph nodes are most commonly affected. However, absence of visual lesions does not guarantee absence of the organism, or the animal's ability to be infective. [11] Cattle may also be infected by ingestion of the organism, although it is a less efficient route. Heavily infected cattle can shed *M. bovis* through respiratory droplet nuclei, sputum, milk, and manure. Similar to humans, bovine tuberculosis can have a long latent period before clinically evident signs are seen.[12] Whole-herd tuberculin tests are therefore particularly helpful in detecting early stages of infection.

Epidemiologists tend to categorize *M. bovis* transmission in cattle by direct and indirect routes. Direct transmission routes for cattle are considered to occur either by nose-to-nose contact, or by ingestion of contaminated milk from an infected animal. Direct transmission is a major source of spread in cattle, most commonly occurring by respiratory contact within herds. Federal regulations for bovine tuberculosis seek to control direct contacts by requiring testing of animals before their movement and potential commingling with other cattle in a location that is of tuberculosis-free status.[13]

Indirect transmission can occur due to the organism's ability to persist in the environment. Experimental studies found that the organism can successfully survive suspended in manure for 1-7 months in a variety of environmental conditions, although persistence increases when the bacilli are protected from sunlight and kept at lower temperatures.[14, 15] In New Zealand, a field experiment was carried out where an inoculum of *M. bovis* was placed on cotton strips, and the bacteria only survived in the environment for three weeks or less, suggesting an important role of organic material for long-term environmental persistence.[16] Several types of feed stuffs (apples, corn, carrots, sugar beets, potatoes, and hay) were able to harbor viable bacteria for up to 112 days; bacteria stored in colder temperatures had the longest survival times.[17] Although water sources have not been implicated in bovine tuberculosis

outbreaks, other *Mycobacteria* can survive long-term in water, so this potential source should not be overlooked.[18]

Experimental infections of animals by exposure to pasture inoculated with *M. bovis* have been successful, although it does not appear to occur easily. In the 1930s, Maddock[19, 20] was able to infect calves through grazing exposure only when the pasture had been repeatedly inoculated with a large number of bacilli. Later studies of pasture inoculation showed similar results.[11] Exposure to feedstuffs contaminated by infected white-tailed deer was sufficient to establish an infection in cattle under experimental conditions, as 4 of 9 cattle exposed to feedstuffs alone developed lymph node lesions.[21] In the same experiment, all 9 cattle exposed to both feedstuffs and unclean housing areas that held infected deer developed detectable infections with *M. bovis*.

c. Importance of wildlife in bovine tuberculosis transmission-- examples
i. United Kingdom

The United Kingdom has had a long battle with bovine tuberculosis, never having successfully eradicated the disease from cattle. The badger (*Meles meles*) was recognized as a maintenance host for *M. bovis*, and there are several factors that create adequate conditions for disease transmission between badgers and cattle. Badgers live in close association with cattle herds, often having communal setts in pasture hedgerows. They can be infected over the course of years, shedding bacteria by respiratory, renal, and gastrointestinal routes. It is postulated that cattle contacting badger excreta in the pasture is an important means of transmission between species. Studies have found that badger latrines had *M. bovis* DNA detected by PCR,[22] and cattle will graze areas of badger latrines when pasture grass levels are low.[23] Badgers have also been observed eating from stored feed on cattle farms and entering farm buildings, which may result in disease transmission by either direct contact with cattle, or by indirect transmission through feed.[24] Case-control studies carried out in Northern Ireland found that the presence of badgers was associated with herd breakdowns with tuberculosis.[25]

However, the role the badger plays in tuberculosis transmission in the UK is controversial, and cattle sources are still thought to be the most important means of infection. A case-control study of cattle herds in England found that herd size, multiple premise operations, and cattle purchasing sources were significant risk factors, rather than proximity to badger setts.[26] Spatial models predicting cattle movements were shown to retrospectively predict the locations in southeast England with bovine tuberculosis-positive cattle herds, implying the importance of cattle-to-cattle disease transmission.[27] Badger culling was employed as a control measure that was met with public opposition, and the results of the most recent randomized badger culling trial were found to increase the prevalence of bovine tuberculosis in cattle herds that were located on the periphery of control zones. The failure of badger culling has been linked to perturbation of the social structure of the surviving badgers, causing increased migration and subsequent cattle exposure.[28] During the Foot and Mouth Disease outbreak of 2001, cattle testing and culling was discontinued due to movement restrictions, and a logistic regression was used to demonstrate that suspension of this program contributed to increased rates of badger infection.[29]

Indeed, the extensive research that has been carried out on bovine tuberculosis in the UK has painted a complicated picture of disease transmission, where *M. bovis* infection circulates within cattle and badger populations, with interchange across species at an unknown rate. Human exposure and infections continue to occur as well. Molecular typing of 50 human *M. bovis* cases

in the UK found that 35 of the spoligotypes isolated were related to cattle strains currently found in the country.[30] A retrospective comparison of human infections with *M. bovis* to cattle breakdowns found the incidence of cattle cases increased by more than five times during the 1990s, but there was no increase in human cases during the same time period.[31] Of the cases reported, 83% occurred in people born before 1960, when pasteurization of dairy products became widespread. Of the few *M. bovis* cases born more recently, occupational exposure to cattle was the prominent risk factor, with pulmonary lesions occurring more commonly.

ii. New Zealand

In New Zealand, bovine tuberculosis eradication efforts began to lose ground in the 1970s, as some cattle operations persistently had herd breakdowns. Several wild animals were found to be infected with *M. bovis*, including the brushtail possum (*Trichosurus vulpecula*), deer, and ferrets, along with 9 other potential species.[32] Researchers used pathologic findings, wildlife-cattle interactions, and geographic overlap of infected wildlife with infected cattle to determine the role that each species could potentially play in transmission.[33] It was concluded that brush-tailed possums were the most important species to maintain the infection and serve as a reservoir of infection to cattle, due to the high level of bacterial shedding and spatial association between areas of infected possums and cattle.[34] Control efforts in New Zealand are based on the spatial relationships between possum habitat and cattle populations, with designated Vector Risk Areas that have increased cattle testing and movement controls.[35] Both cattle test-and-remove strategies, along with culling of possums are employed in the eradication efforts. Although culling of possums is associated with decreased TB prevalence in cattle in some areas, farms located adjacent to possum habitat continue to have an increased risk of infection.[36, 37]

iii. Michigan

Unlike the situation in the United Kingdom and New Zealand, Michigan achieved free status for bovine tuberculosis in the state's cattle herd for approximately two decades. The disease re-emerged in cattle in 1995, and immediately it was found that white-tailed deer (*Odocoileus virginianus*) were also infected in the same geographic region. A leading theory proposes deer became infected prior to tuberculosis eradication and served as a maintenance host to reestablish infection in cattle. Epidemiologic investigation of the area has found a specific "core area" of infected deer, with decreasing prevalence as distance increases from the center.[38] A historical analysis found that the geographic area in which bovine tuberculosis re-emerged in deer had a high incidence of cattle herds with the disease in the 1920-30s, and habitat loss along with harsh winter weather may have potentiated the initial transmission from cattle to deer.[38, 39] Hunt clubs in the area began feeding deer to increase the population in the 1960s, resulting in an increase in deer density from 9 to 23 deer/km^2.

It was hypothesized that supplemental feeding and increased deer densities contributed to the spread of infection through the deer population, and infection studies have demonstrated deer can effectively transmit *M. bovis* through shared feeds.[17] *M. bovis* has been isolated from oral, nasal, tonsillar, and rectal secretions of deer; animals with disseminated disease from experimental infection have had *M. bovis* isolated from virtually every part of the lymphatic system.[40] Under natural infection conditions, *M. bovis* is most commonly isolated from the medial retropharyngeal lymph nodes.[41, 42]

Adult bucks were more likely to be infected than adult does in hunter harvest surveys. A two-phase transmission cycle of bovine tuberculosis in the deer population has been proposed, with bucks playing an important role in bovine tuberculosis transmission as they disperse over longer distances and interact with different groups of deer over time. Female deer tend to live in smaller family groups with other related females and their fawns, promoting transmission to successive generations within these groups.[38] The movement patterns of white-tailed deer are seasonal, with deer dispersing in spring and fall most commonly. [43] In northern Minnesota, deer were found to migrate in winter to areas that have adequate shelter and browse, and this behavior appeared to be learned from their dam.[44, 45] A simple deterministic model of tuberculosis transmission in deer was created using Michigan's infection parameters and estimated the conditions that would lead to a reduction in the prevalence of infected individuals in the population. The most effective reduction of prevalence occurred when the survival of infected individuals decreased (achieved through population control methods such as increased hunting), and the transmission rate between deer was reduced (achieved by enacting measures such as a feeding ban).[46]

Disease control efforts within Michigan's deer population have consisted of several methods, including enacting a ban on feeding or baiting deer and expanding hunting seasons to reduce the deer population. Several studies have demonstrated the importance of reducing access to common feeding sources to control *M. bovis* transmission. In a study that evaluated the genetic relatedness of hunter-harvested deer before and after the ban on artificial feeding, there was evidence of increased deer segregation once the ban was introduced.[47] A radio-collar study of deer movement patterns when baiting was used demonstrated the presence and frequency of deer interactions at bait piles.[48] Such increased deer interactions and overlap likely increases the transmission of bovine tuberculosis among deer. A retrospective survey within the tuberculosis-affected area found associations with large feeding sites in suitable deer habitat and higher prevalence of *M. bovis*-infected deer.[49]

However, regulators also speak of the importance that hunters and landowners in the area accept regulations and participate willingly in control efforts. Hunter surveys revealed a perception that baiting bans and extended hunting seasons made hunting more difficult. As regulations become more extensive to decrease biological risk, political risk increases, with a resulting reduced public acceptance of control measures. Regulators must therefore find a balance where biological risk and political risk are both minimized.[48] Nevertheless, the prevalence of *M. bovis*-infected deer has reduced over the course of 10 years, from an apparent prevalence of 4.9% in 1995 to 1.7% in 2004.[50]

Spatial data has been employed to describe the risks of infected deer and cattle herds. Areas with land types that form suitable deer habitat (deciduous forest & forested swampland) were associated with increased risk of both tuberculosis-positive deer and cattle herds.[51, 52] A case-control of positive cattle herds found that case herds had significantly higher prevalence of tuberculosis-positive deer within the area and higher numbers of adjacent positive herds than did controls. On-farm measures to exclude deer from feed and water sources were strongly associated with decreased risk of the cattle herd testing positive.[52]

Measures to control the disease in Michigan cattle have therefore focused on both testing and removal of infected herds, along with reducing deer-cattle interactions. In 2005, a wildlife risk survey was used to better understand management practices on farms that would increase deer-cattle interaction risks, and to develop herd plans for deer mitigations. [53] Such mitigations have included erecting fencing and using dogs that chase deer from cattle housing & feed storage

areas.[54] New cattle herd infections continue to occur in the area of bovine tuberculosis-infected deer, with 44 positive herds diagnosed since 1998. Five herds that were diagnosed, depopulated, and subsequently repopulated had repeated outbreaks of bovine tuberculosis, suggesting a need for continued work to manage the wildlife reservoir of infection.[55]

In consideration of the potential for zoonotic infections, public health campaigns in Michigan have targeted hunters and wildlife biologists. A survey of hunter safety practices carried out in the field found that only 44% of hunters within or adjacent to the TB control zone used gloves when field-dressing deer. Five percent of survey respondents cut themselves while field dressing deer, and the study authors estimated that approximately 140 positive deer were field dressed without the hunter wearing gloves.[56] Educational campaigns were launched to inform hunters of the clinical signs of bovine tuberculosis in deer, and promote using protective equipment during field dressing. An occupational safety program was developed to protect the persons taking part in the deer surveillance operations.[57] Two human cases of *M. bovis* infection have been reported with deer contact as the likely exposure. The first case developed a pulmonary infection who was potentially exposued to *M. bovis* through deer hunting and had concomitant immunocompromise. The second case had cut himself while field dressing an infected deer and developed a cutaneous infection that was refractory to conventional antibiotic treatment. This patient recognized the clinical signs in the deer carcass, and made health care professionals aware of the possibility of *M. bovis* infection.[58]

iv. Minnesota

In 2005, tuberculous lesions were identified in a Minnesota cow at slaughter. The subsequent epidemiologic investigation has resulted in depopulation of 12 infected herds to date, all located in northwestern Minnesota. The *M. bovis* strain has similarity to strains circulating in the southwestern US and Mexico, but the exact source of the infection has not yet been identified.[59] Epidemiologic investigations of cattle movements has identified at least one bovine moving between farms in most of the infected herds, although two herds have not been connected by documented movements of cattle. Infected deer have been found within 2 miles of both these farms.[60] To date, no human cases of *M. bovis* associated with this outbreak have been reported.

At the same time, surveillance in free ranging white-tailed deer populations in the area of the infected cattle herds has identified test-positive deer, with a recent estimate of 0.3% apparent prevalence in a small clustered area around the infected herd locations.[61] One hypothesis is that cattle were the initial source of infection in this Minnesota outbreak, cattle movement has led to spread of infection to other herds, and the disease has spilled over into a small percentage of the free-ranging deer population which may have led to infection in one or more cattle herds.

A bovine tuberculosis eradication program in both cattle and deer populations is underway in Minnesota. Eradication in identified infected cattle populations has been rapid and aggressive, with removal of cattle on all of the infected cattle herds. However, eradication of *M. bovis* from the white-tailed deer poses a greater challenge, as efforts in wild populations have not been successful to date in any location around the world. The implied risk of inter-species disease transmission has warranted creation of a disease management plan for ongoing bovine tuberculosis control in Minnesota deer.

When a positive case of bovine tuberculosis was first detected in Minnesota, a ban on deer and elk feeding was enacted within Minnesota's Roseau, Lake of the Woods, Marshall,

Pennington, and Beltrami counties.[62] This step was considered an important disease mitigation measure to reduce the unnatural congregation of white-tailed deer. Additionally, white-tailed deer commonly will eat feeds that are stored or made available to cattle, and can use these feed sources extensively during conditions of low forage availability such as in winter.[63] In order to effectively control bovine tuberculosis in Minnesota, there is a need for better understanding of the factors that increase the risk of deer and cattle interacting in a way that facilitates tuberculosis transmission.

Interaction between cattle and white-tailed deer occurs frequently on Minnesota cattle operations. In a survey to estimate possible *Mycobacterium avium* ssp. *paratuberculosis* transmission between cattle and wildlife, 87% of Minnesota dairy producers observed deer on their farms, with 49% reporting at least weekly sightings.[64] In addition, over 50% of study dairy cattle producers reported the possibility of physical contact between species or their feces and 32% reported this physical contact on at least a weekly basis. While feces is not considered a critical vehicle of transmission for *M. bovis*, this evidence of interaction indicates the possibility of transmission between cattle and deer through direct and indirect transmission routes. Deer interaction with feedstuffs has not been evaluated in Minnesota, although the presence of deer on farms may be linked to deer depredation of stored feeds.

d. Purpose of the study

Assuming that all tuberculosis-infected cattle have been removed from Minnesota, cattle movement and testing regulations are effective, and no other animals serve as a significant source of infection, the most likely way that a new infection in cattle would arise is through exposure to tuberculosis-infected deer. According to Corner, the transmission rate from an infected wildlife species to a susceptible domestic species depends on the spatial and temporal distance between the two populations, along with population densities, prevalence of disease, and factors that affect the survival of the bacterium outside the host.[33] As demonstrated within this overview, the bovine tuberculosis situation in Minnesota is such that *M. bovis* transmission between deer and cattle is possible. *M. bovis* is persistent in the environment, both cattle and deer are highly susceptible, and there is evidence to believe that deer and cattle interact both directly and indirectly.

Although the potential for deer-cattle interactions sufficient for bovine tuberculosis transmission seems likely, there has not been any research done to characterize these risks. Specifically in the area of interest (northwestern Minnesota), the following points are unkown: 1. Herds located in deer-friendly habitat, 2. Herds with feed storage that is unprotected, 3. Herds with deer damage to stored feeds, 4. Time of year that deer are most commonly present on the farm.

When considering means to control bovine tuberculosis in humans, public health measures such as slaughter surveillance and pasteurization of milk have effectively reduced the number of people affected. In order to maintain the prevalence of zoonotic bovine tuberculosis at a low level, the disease must continue to be controlled in the cattle population and in wildlife that can become reservoir species. By reducing the risk of disease transmission within the animal populations, we will also reduce the risk that bovine tuberculosis will again become a common disease in human populations.

A strategy to minimize contact between cattle and deer to eliminate potential transmission of *M. bovis* between species is an important component to disease control measures.

This strategy is dependent upon an understanding of transmission pathways between affected species and by identification of high risk interspecies interactions on cattle farms.

The purpose of this study is to characterize the risk of interactions between cattle and white-tailed deer in northern Minnesota in order to prevent *M. bovis* transmission. We hypothesize that a high risk for interactions occurs during the winter months, when food and water are in short supply. We also hypothesize that the burden of deer-cattle interactions are not evenly dispersed between cattle farms. This may be due to a number of factors including feed management, cattle housing, land type around main farm operation, presence of lethal deer control in the farm vicinity, and fencing.

III. Materials & Methods

a. Creation of a "Minnesota Wildlife Interface Risk Assessment"

A qualitative survey was previously developed by USDA-APHIS-WS personnel in Michigan to evaluate feed storage, feeding practices, and deer characteristics for the premise. This survey was modified for use in Minnesota by introducing a scoring method to evaluate the areas of highest priority at risk of potential deer-cattle interaction. This kind of quantitative on-farm risk assessment has been used extensively to evaluate cattle herds for transmission risk of Johne's disease, caused by *Mycobacterium avium* ssp. *paratuberculosis*. In the case of Johne's disease, the bacteria are excreted into the environment by mature cattle, and immature cattle are susceptible to infection. The Johne's disease risk assessment therefore evaluates the major management areas of the farm and each area receives a score based on the potential risk of within-farm *M. avium paratuberculosis* transmission.[65]

To assign a score for a herd's potential deer-cattle interaction, the herd management was split into four areas for evaluation: Feed Storage, Feeding Practices, Cattle Housing, and Water. The Feed Storage category took all the different types of feed stored on the farm into account, and assigned a score for each item based on the type of storage used and ease of access for deer. Hay was given a separate score depending on relative content of alfalfa (2nd or 3rd cutting) or grass (1st cutting). For Feeding Practices, Cattle Housing, and Water a separate score was assigned for each housing group that would be present on the farm—adult cattle, yearlings, and calves. Scores were assigned based on the location of the feeding site, housing, or water source and accessibility for deer. Additionally, scores were assigned based on how quickly feed was consumed by the animals and the location of any mineral supplements.

Once the management areas and items to receive risk scores were identified, available literature and bovine tuberculosis & wildlife experts were consulted to determine the maximum score that each item could receive. The greater risk a particular item had for potential deer-cattle interaction, the higher the "maximum risk" score. Similarly, scoring guidelines were created to give the evaluator a range of points for a particular management practice. The risk assessment was written and scored with the intent to evaluate the herd in winter time, when producers typically use stored feeds and house cattle more intensively.

As a result, 18 different items were included in the risk scoring system (see appendix). The total possible risk score for a herd was 180, with Feed Storage accounting for 75 possible points, Feeding Practices 75, Cattle Housing 15, and Water 15. In addition to the scoring, there were 17 qualitative questions regarding herd demographics and deer presence on the farm. Once the risk assessment scoring was completed, the resulting scores would indicate the areas of greatest risk for deer-cattle interaction on the farm. This information could be used to draft a herd management plan that addresses these priorities.

In April of 2007, the Minnesota Board of Animal Health used the original version of the "Minnesota Wildlife Interface Risk Assessment" in 21 cattle herds in the Bovine Tuberculosis Core Area in northern Minnesota (see appendix). After these initial assessments were completed, the on-farm assessors gave the authors comments on the utility of the product, and subsequent

revisions were made. The revised survey was piloted at a 500-cow herd located in southern Minnesota.

b. Herd Recruitment & Selection

Herd selection criteria for receiving an on-farm risk assessment were as follows. Farms had a minimum of 20 cattle, and were located in the area of northwestern Minnesota proximate to the Core Area. A random sample of 60 eligible herds would be selected from those interested in study participation. The sample size was estimated based on a 20% prevalence of risk +/- 10% with 95% confidence. Databases of dairy and beef cattle herds from the University of Minnesota Extension Service and the Minnesota BAH were queried to create a mailing list for recruitment letters. A mapping program (Social Explorer®) was used to determine the town zip codes that were applicable. The study was determined by the Institutional Review Board of the University of Minnesota to not be research involving human subjects.

The study was first presented at three public producer meetings in cooperation with the University of Minnesota Extension and the Minnesota Board of Animal Health. An initial mailing sent to 174 herds in a 100 mi^2 area included the following towns: Roseau, Badger, Wannaska, Gatzke, Grygla, Middle River, & Strathcona. Due to low response rates, second and third mailings were sent for a total of 857 herds contacted. In addition to the above towns, the additional mailings also included the towns of Warroad, Lancaster, Lake Bronson, Halma, Hallock, Karlstad, Salol, Strandquist, Viking, Thief River, and Goodridge. A recruitment letter was sent to the herds informing producers about the study and requesting that they return a postage-paid card expressing their interest in participation. Responding herds that fit the inclusion criteria had a herd visit scheduled.

c. On-Farm Risk Assessment

The same two evaluators carried out every on-farm deer-cattle risk assessment. Evaluator A, the author of this study, is a veterinarian employed by the University of Minnesota with mixed animal practice experience and epidemiological training. Evaluator B is a wildlife disease biologist employed by the USDA-APHIS-Wildlife Services with a BS in Fisheries and Wildlife and extensive work with wildlife damage control. Each enrolled herd was visited once during the months of January or March 2008.

When visiting the farm, each evaluator performed a risk assessment, assigning scores independently after reviewing all management areas on the farm. As much as possible, all sources of feed and all cattle groups on the farm were directly observed by the evaluators. Special attention was paid to the visible presence of deer activity around the management areas, and characteristic signs (hair, hoof prints, urine and/or fecal material) were recorded. Management areas were scored by potential for deer-cattle interaction, based on the criteria described in section A. Once the herd risk scores were recorded, the evaluators shared their scores and together devised a herd management plan based on the management areas that scored highest and had greatest risk priority for the herd. Risk assessment outcomes were explained to the producer during the visit, and a written copy of the risk assessment scores and herd management plan was mailed afterward.

In April of 2008, Minnesota Board of Animal Health (BAH) representatives visited herds within the Bovine TB Management zone (see map) and administered the same risk assessment to cattle herds. Score results will be provided in summary form as a means of comparison.

d. Data Analysis

Risk assessment data was recorded into computerized spreadsheet software (Excel®) and tests for significance were performed with commercial statistical programs (SAS, inc., Chicago, Ill). Qualitative questions, quantitative scores, and herd management recommendations were summarized with descriptive analysis and reported as simple frequencies. Between-observer variability on risk assessment scores was evaluated using Spearman correlation. Question responses and risk scores were compared between herds that had experienced deer damage to stored feeds and herds that had not with the use of t-tests for continuous variables, and chi-square analysis for binomial variables. Statistical significance level for tests was $p=0.05$.

A multivariable logistic regression model was created to predict the probability of a farm experiencing deer damage to stored feeds. Risk assessment variables that were found to be significantly associated with the presence of deer damage were retained in the logistic regression model.

Question responses and risk assessment scores carried out by the BAH were compared with the University of Minnesota (U of M) results. Question responses and risk scores were compared with the use of t-tests for continuous variables, and chi-square analysis for binomial variables.

IV. Results

a. **University of Minnesota study**
   i. **Descriptive Results**

Of 857 total farms contacted by recruitment letter, 23 (2.6%) letters were returned to sender due to incorrect address. From the 834 recruitment letters that were presumably received by producers, 191 (23%) responses were received. Sixty-four (7.7%) cattle producers indicated interest in participation, and 127 (15.2%) declined participation in the study. Of the 64 farms, 9 were omitted from the study for having fewer than 20 cattle or because the herd was located within the Core Area and had already received a risk assessment. Therefore, 55 herds had an evaluation scheduled. Two farms did not complete a risk assessment due to a scheduling conflict and a decline of interest, so 53 risk assessments were completed (6.4% of herds successfully contacted).

Risk assessments were carried out during Jan 9-12, 24-26, and March 11-14, 2008. The study area was approximately 70 miles north-south by 40 miles east-west, with the TB Core Area situated in the central-east portion of the area. Twenty-eight herds were located within the current Modified Accredited zone, 5 of which were located within the TB Management zone. Twenty-five herds were located outside the Modified Accredited zone. Fifty-one herds visited were beef cow-calf operations, one was a dairy, and one was a dairy calf raiser. Of the herds with adult cattle, mean herd size was 73 adult cattle, with a range between 20 and 250. Eleven producers had more than 100 cows on the farm. Average number of young stock was 34.

Twenty-one farms had horses, 3 had swine, 3 had sheep, and 1 farm had a goat in addition to cattle.

Fourteen farms (26%) had fence line contact with another herd, and the average number of herds contacted was 1.3. Five farms had not introduced any cattle in the last 36 months. Of herds that had introduced cattle, a combination of known and unknown sources was used, with 17 herds (32%) using unknown sources (auctions, sales barns) and 36 (68%) using known sources. Twenty-four percent of the adult herd on average was introduced in the past 36 months.

Producers were asked to describe the land types around the main farm operation in an approximately 1 mile radius. Twenty percent of farms had less than 20% of the land surrounding the farm composed of woods, swamp, or Conservation Reserve Program land (hereafter referred to as "deer cover"); 42% of farms had between 20 and 50%; 38% of farms had greater than 50% of such land. Deer-related survey questions are summarized in **Table 1.** Of the 27 herds that had experienced deer damage within the past 12 months, 11 herds (40%) classified the damage as severe, 8 (30%) classified the damage as mild-moderate, and 8 herds (30%) classified it as mild. Twenty-one percent of herds reported seeing deer year-round, while half reported seeing deer between spring and fall. Eleven percent of producers reported that they saw deer most frequently in the winter.

All herds visited fed either alfalfa ($2^{nd}/3^{rd}$ cutting), grass (1st cutting), or mixed hay to cattle. Thirty-eight farms(74%) fed grain, while 9 (21%) fed beet pulp, and 7 (13%) fed silage. No farms visited fed high moisture corn. The types of feed available on farms and numbers of farms that had deer damage directly observed by the evaluators is summarized in **Figure 1**. Silage had the highest proportion of damage, where 71% (5 out of 7) herds feeding it had evidence of deer feeding at the time of the risk assessment. Herds feeding 2nd or 3rd cutting hay and beet pulp also had high proportions of deer damage, accounting for 34% and 38% of herds that fed each type of feed, respectively. First cutting hay and silage had the lowest proportions of deer damage, with apparent damage on only 2% and 10% of farms, respectively.

ii. Risk Assessment scores

Risk assessment scores are summarized in **Table 2**. Of the risk scores, silage storage had the highest score relative to total points available (8.5/10). The risk assessment was originally organized so that the evaluator would calculate a separate score for each housing group present on the farm (adult cattle, yearlings, and calves prior to breeding). However, because co-housing of different cattle groups was commonly practiced, these groups were not consistently scored separately. Therefore, the scores across the three different housing groups were averaged together for feeding site, cattle housing, and water source.

Spearman correlation coefficients are summarized in **Table 2**. Twelve out of twenty-one risk scores had correlation coefficients that were >0.7. Coefficients that had the highest level of agreement included scores for Total Feed Storage, Total Feeding Practices, Total Cattle Housing, and Total Risk. Five scores had correlation coefficients that were <0.5. Coefficients that had the lowest level of agreement included scores for Silage, Beet Pulp, and the rate at which feed was consumed.

iii. Recommendations given

Recommendations given to producers at the herd visit are summarized in **Figure 2**. Feed storage was the most consistently mentioned risk area, with 34 farms receiving recommendations to fence stored hay to exclude deer. Alteration of feeding practices were frequently recommended. Approximately twenty herds were recommended to move feeding locations, or reduce the amount of feed given to minimize left over residues that attract deer. On eight farms where deer damage was sustained and severe, the recommendation was made to seek a depredation permit to remove deer from the premises. On two farms, it was recommended to discontinue deer feeding adjacent to cattle housing or stored feeds.

b. Statistical tests
i. Land cover & Deer damage association

T-tests were used to compare the means between farms that had deer damage and farms that did not for several variables, summarized in **Table 3**. There was no association between herd size (measured by number of adult cattle) and probability of deer damage. Farms with deer damage had a significantly higher percentage of wood/swamp/CRP land surrounding the farm (t-test statistic = 2.6, p= 0.01) and a higher total risk score (t-test statistic = 2.61, p= 0.01). The risk assessment sub-score for total feeding practices was also significantly associated with the presence of deer damage (t-test statistic = 2.5, p= 0.02), and total feed storage score showed a trend toward association (t-test statistic = 1.84, p= 0.07).

ii. Logistic regression predicting deer damage

A logistic regression predicting the presence or absence of deer damage to stored feeds was based on parameters from risk assessments. Total risk score and percentage of deer cover were included as continuous variables. Although the risk score subcategories of total feeding practices and total feed storage could have been entered into the regression, the scores were represented within the total risk score variable and therefore not included in the model.

Fifty herds had complete data for inclusion in the logistic regression model. The results of the model are summarized in **Table 4**. Total risk score and percentage of deer cover were evaluated by logistic regression separately, and then both variables were combined. Out of all the comparisons performed, percentage of deer cover alone had the highest test score result and lowest p-value (-2 LL x^2 = 5.63, 1 df, p = 0.018). However, the model where both total risk score and % deer cover were included also fit the data significantly (-2 Log Likelihood x^2 = 7.58, 2 df, p = 0.023). Hosmer-Lemeshow goodness-of-fit test indicated that the data points observed were not significantly different from the model predictions, indicating a good fit (p = 0.43). A test for interaction between total risk score and % deer cover was not statistically significant (-2 Log Likelihood x^2 =7.58, 3 df, p = 0.054).

c. BAH risk assessment scores

Forty-five risk assessments were carried out during April 15-25, 2008. Two different evaluators carried out the risk assessments, one evaluator at each farm. Both evaluators were employees of the Minnesota Board of Animal Health (BAH). All herds were located within the management area or core area. Only risk assessments for premises that actively had cattle present

on the farm were used for analysis, as other risk assessments evaluated pasture sites or hay storage sites.

Sixteen herds (36%) had risk assessments performed previously, according to the written report that accompanied each assessment. Seven herds were noted to have a 10-foot fence protecting some portion of the operation from deer when the BAH risk assessment was carried out. Forty-one herds were either a beef cow-calf or feeder operation, and two herds were dairies. Four herds had not introduced any cattle within the past 36 months. Incomplete information was available for the sources of cattle purchased for the herds that had additions.

Of the herds visited by the BAH, 14 farms(31%) had less than 20% of the land surrounding the farm composed of deer cover; 40% of farms had between 20 and 50%; 30% of farms had greater than 50% of such land. Deer-related survey questions are summarized in **Table 1.** Chi-square values are reported for the difference in responses between the risk assessments carried out by the University of Minnesota (U of M) team as compared to the BAH team. Significant differences were found between the two groups in the number of herds reporting deer damage, presence of adequate deer cover around the farm, seeing congregations of more than 10 deer, neighbors leaving feed for deer, and deer being hunted on farm property. In all cases, a higher proportion of herds visited by the U of M team responded in the affirmative to these questions. Seven percent of herds within the management zone or core area reported seeing deer year-round, while 63% reported seeing deer most often in spring, summer, or fall. Nine percent of producers reported that they saw deer most frequently in the winter. All herds but one (98%) were scored for alfalfa hay, but only 26 herds (58%) had a separate score for grass hay. Twenty-eight herds (62%) fed grain, and 9 herds (20%) fed beet pulp. No herds were reported to feed silage or high moisture corn.

Risk assessment scores for the herds visited by the BAH are summarized in **Table 2**. T-tests were performed to compare mean risk assessment scores between herds visited by U of M and BAH groups. Number of adult cattle on the farm, percent of herd that had been introduced, and percent of land with deer cover was not significantly different between herd groups. Mean scores evaluated between the two different groups that were significantly different include Alfalfa hay storage, Total Feed Storage, Feeding Site location, how quickly feed was consumed, Minerals, Total Feeding Practices, Cattle Housing, and Water Source.

Four herds were evaluated by both U of M and BAH groups. These herds were all located outside of the bovine TB core area but within the management zone. U of M visited these herds in the winter months, while BAH visited in April. Three out of the four herds had total risk scores that differed by more than 15 points between the U of M and BAH risk assessments. In three herds, the U of M team scored alfalfa hay and grass hay separately where the BAH team gave a single score for hay. Also in three herds, adult and yearling cattle were the only animals present on the farm in the winter when the U of M team visited, whereas calves were present during the spring, creating a third housing group to score and hence more total risk points. In one farm, beet pulp was being fed during the BAH visit but was not fed when the U of M evaluators were visiting.

V. Discussion

The majority of farms visited by the U of M researchers had notable interactions with white-tailed deer. Half the herds visited had deer damage to stored feeds within the past 12 months, and nearly two-thirds had seen more than 10 deer at a time on the farm. Although the majority of herds reported mild or moderate deer damage, more than one-third of herds reported the damage to their feeds as severe. One study performed to quantify the amount of feed eaten by deer at a crop storage site estimated that an individual deer only consumed approximately 163g of feed per visit,[66] but numerous anecdotal reports of substantial damage have demonstrated that deer are likely capable of eating far larger quantities of stored feeds. Stored feed can also be lost due to spoilage from contamination with feces and urine, and from deer tearing holes or walking over the outer covering of ensiled feeds.

Half the herds visited reported knowledge of neighbors within the area feeding deer, either through use of feed plots or by bringing in feed. Because some herds were visited within the feeding ban area, this question did not ask to specify the type of deer feeding being done. There are several types of deer feeding practices, which ranged from use of bait for hunting purposes, to supplemental feeding, to full feeding in a yarding situation. Supplemental feeding, defined as making feeds available to improve nutrition, has been linked to increased reproductive carrying capacity for does and improved survival of fawns through the winter months.[67] Feed plots are generally small areas that have been planted with a forage that is left for deer to consume, and generally is considered a feed supplement. The use of feed plots has not been directly linked to bovine tuberculosis transmission, as the area is generally large enough to prevent close congregation of deer over shared feeds. Feed plots are not included in the feed ban legislation, and are therefore legal to use.

In contrast to feed plots, deer feeding areas are designated sites where feed stuffs are brought in and made available, usually in concentrated piles. Such feeing areas have been found to contribute to the transmission of bovine tuberculosis in Michigan. Feeding sites that were large-scale, both in attracting larger numbers of deer and in the amount of feed made available to deer, were both associated with increased prevalence of infected deer.[49] The increased congregation of deer that occurs with feeding, along with the shared feedstuffs, serves as a sufficient means for *M. bovis* transmission by both direct and indirect contact. No studies have been done in Minnesota to quantify the extent of deer feeding, although the practice is thought to be widespread. Even if deer feeding is not extensive, deer can become more accustomed to approaching buildings to search for forage items. This may contribute to increased deer depredation on stored feeds, as deer learn that such places can be sources for feed during scarce times.

Only 11% of herds reported that deer were most frequently seen in the winter, while spring, summer, and fall were the most common times that deer were seen in 50% of herds visited. In preliminary results of a Michigan telemetry study, deer were found to visit farms most frequently in the spring and fall months.[68] However, it was not known whether deer also commonly eat feed stores at this time. The risk assessment used in this study did not quantify which time of year deer most commonly ate stored feeds, although it is the impression of the author that for farms visited, winter was the season with the most feed depredation.

In the herds that were visited, the land type surrounding the farm was evaluated in order to determine if there was adjacent deer habitat. The most common land types were estimated by the evaluators with the landowner's input, although this information was not verified by use of objective data, such as satellite imagery. Nevertheless, a strong association was found between

increasing percentage of land that would serve as deer cover and the presence of deer damage to stored feeds on the farm. In Michigan, landsat data was used to characterize the predominant land types surrounding case and control farms, and this was associated with a herd's likelihood of having bovine tuberculosis. A higher percentage of open land present around the farm had a protective effect.[52] Similarly, land type in Michigan was associated with infected deer, with forested areas having a higher deer prevalence of bovine tuberculosis, and open areas having a lower prevalence. Spatial factors were stronger indicators of deer infection than were supplemental feeding factors.[51]

Because the herds who were recruited and visited by the U of M researchers volunteered to have risk assessments performed, the results of the study have the potential for volunteer bias. Such a bias can mean that the herds evaluated may not necessarily be representative of the entire population in the region. Particular herd tendencies that would cause them to willingly have a risk assessment carried out may include a pre-existing problem with deer depredation of stored feeds, proximity to positive herds, or greater value of cattle. Although the average herd size for the counties included in the study has not been reported, there were 11 herds that had more than 100 adult cattle, and we eliminated herds that had fewer than 20 cattle. Larger herds may have more extensive operations, with larger volumes of stored feeds that would attract deer. Regardless of the potential bias in the herds evaluated, the results of the study demonstrate that deer depredation of stored feeds is occurring in the region, and many herds' management practices are such that they are at risk for interspecies interactions.

When the scores from the risk assessment were created, the maximum point values were assigned to 2nd/3rd cutting hay and beet pulp, as they were known to commonly be depredated by deer. Other high-quality forages such as grain and silage were assigned middle-value risk scores. Lower-quality forage (grass hay) was assigned the smallest maximum point value. Feeding trials support the hypothesis that in the winter deer tend to prefer high-energy feed sources.[69] However, deer will eat lower quality feeds if they are the only thing available-- essentially, there is no stored feed that has zero risk for deer feeding. This was the case with the herds visited; every type of stored feed evaluated was consumed by deer on at least one farm.

The feed with highest proportion of damage by deer was silage. Silage was only present on 7 farms, but 5 of these farms (71%) had damage from deer. In all of these 5 herds with deer damage, an open silage pile was the method of storage. Beet pulp was also stored in an open pile on the ground, and deer accessed it at 9 of 21 farms (38%) using this feed. Both silage and beet pulp had potential to attract large numbers of deer to cattle operations, likely due to the high nutritional value of such feeds. Considering how commonly deer were observed to eat silage, it would be appropriate to increase the risk points available for this feed relative to other types of feed. Grain was more commonly stored in covered bins, with only two farms keeping grain in open piles. The more common biosecurity issue with grain storage was the presence of spill residues that could attract deer.

Bales of hay were also commonly stored in open areas that were unprotected. As a result, 17 of 50 herds (33%) visited had evident damage to their 2nd or 3rd cutting hay. In Michigan, storing hay outdoors, or leaving hay bales in fields or fence rows was associated with tuberculosis-positive herds, while protecting hay by bagging, wrapping, or storing indoors was associated with tuberculosis-negative herds.[52]

Because it was anticipated that deer would more readily eat higher-quality alfalfa hay than grass hay, more risk points were assigned to alfalfa hay. However, the separation of these two forage types presented problems for the evaluators. On many farms, all hay was a mix of

both alfalfa and grass, with increasing quality of alfalfa by cutting. Therefore, we adapted and adjusted the scoring to reflect the storage for 1st cutting (scored as grass hay) and 2nd-3rd cutting (scored as alfalfa hay). Other types of forage, such as oat hay, were also observed on farms. As long as the forage had a higher energy value (e.g., oat heads present), it was scored in the same category as alfalfa hay. If the forage was primarily fiber (e.g., stemmy wheat stubble or straw), it was scored in the same category as grass hay. This alteration of scoring seemed to accommodate the different types of hay available, but was not apparently consistent when comparing scores between the University of Minnesota and BAH evaluators. Only 60% of the BAH risk assessments evaluated both grass hay and alfalfa hay, which likely resulted in significantly different Total Feed Storage scores between the two groups.

Scoring risk by cattle housing group did not fit well with the types of herds that were present in the winter time in northwestern Minnesota. Most herds visited were beef operations, with several age groups of cattle housed together. Moreover, since beef herds tend to calve seasonally, the population make-up fluctuates throughout the year. This can become difficult in terms of evaluating the transmission risk of a chronic disease such as bovine tuberculosis, because the way that a herd is housed can change drastically depending on the week the risk assessment is carried out. Thus, when we visited some herds in January the calves from the previous year were present in addition to the adults and yearlings, so three housing groups were scored. A few weeks later, only the cows and yearling heifers were on the farm, so two housing groups would be scored. Two months later in March, the cows were calving and increasing number of calves were present. In some herds, bulls were housed separately from the cows, and their housing could have very different risks for deer-cattle interactions. As a result of these complicating factors, it became difficult to easily separate and score the risks for these overlapping housing groups. An improvement may be to evaluate the groups separately but then assign a single score that reflects the average risk across all housing groups.

Cattle feeding practices were also found to have risk for deer-cattle interactions, with average scores for location of feeding site and the rate at which feed was consumed worth >50% of the maximum possible score. Often, the location that cattle were housed could easily be entered by deer. To save time, many producers placed several round bales of hay in the winter feeding area, so that cattle only needed to be fed a few times a week. This practice increased the chance that hay would be left over after the cattle have finished feeding, and the remaining hay attract deer to eat. With large quantities of hay, cattle may again return to the hay source later and become exposed to any potential secretions that may have been left by deer. In Michigan, herds that had been diagnosed with tuberculosis were significantly more likely to feed loose hay and less likely to be housed in a barn, feedlot, or barnyard. Feeding hay on the ground had a non-significant association with case herds.[52]

Bulk or *ad libitum* feeding of items other than hay was not frequently observed, although there was evidence of deer feeding on silage, beet pulp, or grain residues from feeding tubs at a few different farms. In most cases, these higher-quality feeds were fed once or twice daily, and cattle usually would readily eat these feeds within hours of their being made available. However, creep feeders were in used on a few farms to supplement the diets of calves that were nursing. Creep feeders are self-feeding grain hoppers filled with either corn or another grain, and available for calves to eat on an *ad libitum* basis. Generally, creeps were used more commonly in the fall months. On a few farms, the feeders were in use at the time of the visit, and there was evidence of deer accessing them and potentially interacting with the cattle.

Although minerals are a potential item that may attract deer, the average risk scores assigned to this category were <50% of the maximum. In general, minerals were often made available in covered feeders or adjacent to farm buildings. Similarly, water sources may attract deer, but most types of waterers used in the winter months were located adjacent to barn buildings or otherwise protected from freezing and less likely to be accessed by deer. Evaluation of the management practices used in the summer months may find that water sources may be of higher risk—such as stock ponds or open troughs. The presence of ponds or creeks in cattle areas was associated with tuberculosis-positive herds in Michigan.[52]

Comparison of the risk scores between U of M observers revealed that for many of the management areas, the two evaluators had a high level of agreement. However, the Spearman rank score was <0.5 for 7/21 different scores assigned on farms. The risk score that had the lowest level of agreement was silage (coefficient = 0.29). Interesting to note in the scoring guidelines, use of bunk silage storage (which was used on most herds with this feed type) was to receive the maximum number of points. This suggests the evaluators may not have been consistently following the guidelines when scoring silage storage. Similarly, beet pulp storage also had relatively low agreement (coefficient = 0.44), although the storage method seen most commonly was an open pile, and such storage was suggested to receive the maximum number of points. For both these risk areas, the scoring guidelines were less prescriptive than what was given for the different types of hay, which had higher interobserver agreement. A potential improvement is to create more detailed guidelines. Low agreement was also observed between the location of mineral feeders and the measure of how quickly feed was consumed, along with evaluation of housing for Group B cattle, and evaluation of water source for Group C cattle. With the latter two scores, the maximum point values were small (5 points each), meaning that a difference between evaluators of only one point may have contributed to discrepant scores. However, the scores for mineral feeders and feed consumption had higher maximum point values (15 points possible).

Another potential influence on interobserver agreement is a particular evaluator's tendency to score farms higher or lower. If an evaluator scored a particular risk item consistently higher or lower than the other, the agreement would be low between observers even if they tended to give proportionally similar scores. The correlation between scores for an individual observer, or the intraobserver agreement, was not evaluated for this project. However, it will be evaluated for future publication.

The difference in scoring between groups became especially evident when scores were compared between U of M & BAH risk assessments. Although the herds assessed by each group did not differ in numbers of adult cattle, % cattle introduced to the herd, or % land surrounding the farm that was deer cover, average scores differed significantly between groups for alfalfa hay storage, feeding site location, feed consumption, minerals, cattle housing, and water scores. Many differences existed between the herds visited by U of M and BAH that may have confounded the scores. The BAH had previously performed risk assessments in the core area, and seven herds (16%) already had 10-foot deer fences in place on the property. The differing times of year between the two risk assessments also likely affected the scores assigned. Interestingly, the total risk scores between U of M and BAH groups did not differ significantly.

The four herds that were evaluated by U of M and BAH groups was a small but illuminating sample to demonstrate differences in how feed was scored (e.g. one score for all hay as compared to two separate scores for alfalfa and grass hay) and how cattle groups were scored (e.g. two groups vs. three groups evaluated due to absence/presence of calves) could change the

total score by several points. However, the desired outcome of the risk assessment—prioritization of the risks for deer-cattle interactions—was still consistent between the two different groups using the tool. On all four farms, the recommendations made by both U of M and BAH were very similar, with the same priorities highlighted. The only notable exception was the single herd that was not feeding beet pulp at the time of the U of M risk assessment, but had begun feeding it when the BAH visited. For that herd, the beet pulp storage was the highest priority recommendation for the BAH evaluator.

Other important differences were noted between the risk assessments that were carried out by the two groups in terms of herds' exposure to deer. Fewer herds within the management area scored by BAH had deer damage, adequate cover for deer around the farm, congregations of greater than 10 deer, neighbors leaving feed for deer, and deer hunted on the farm property. When the BAH risk assessments were carried out in April 2008, the core area and adjacent management area were in the midst of a wide-ranging campaign to reduce deer populations that had been underway for the past two years. During that time, extended hunting seasons, sharpshooting, and aerial shooting of deer had all been employed, and the deer population was very low. Additionally, farms that had a 10-foot fence in place likely had prevented deer from damaging stored feed.

As a result of these differences, the risk assessments for the herds within the management zone evaluated by the BAH and the herds in the greater region evaluated by the U of M are difficult to directly compare. It would appear the herds at greatest risk for deer-cattle interaction are those located outside of the management zone because the deer population density is higher (no depopulation efforts have been attempted), and herds have not received fencing or developed other measures to protect their operations from deer.

Logistic regression models successfully predicted the presence of deer damage to stored feed on farms by using total risk scores and % deer cover as variables. Both these variables were significant predictors of deer damage alone, and also worked well in combination. Although the variable % deer cover alone had the lowest p-value and therefore the best mathematical fit to the available data, the model that included both variables was also highly significant. The multivariate model also took into account two important determinants of a farm's risk: the surrounding land type, and the calculated risk from the on-farm assessment.

The resulting logistic regression equation is as follows:

Log (odds of damage) = $\beta_0 + \beta_1 x_a + \beta_2 x_b$, where β represents the estimated slope for the equation and x_i is the variable value. β_0 = intercept, β_1= total risk, and β_2= % deer cover. This equation can be used to predict the likelihood of deer damage with some example variables. A demonstration of the resulting probability of deer damage for various given values of risk score and deer cover is depicted in **Table 5**. Interesting to note is the similarity in slope of both Total Risk score and % Deer Cover (~0.03-0.04), meaning the rate of change for these variables was similar. There is a possibility the Total Risk score and % Deer Cover variables are confounded, considering proximity to adequate deer cover was taken into account in the scoring process. However, in the logistic regression models the odds ratio predicting deer damage by total risk score was not remarkably different when it was adjusted for % deer cover (1.039 vs. 1.035), indicating that the two variables may not have much effect on one another. Further, there was not a significant interaction between the two variables in the logistic regression analysis.

Combinations of eleven different recommendations were made by the U of M team, using the result of the risk assessment to prioritize and tailor the recommendations to the farm. The recommendations made most often were to fence or otherwise protect hay storage, move the

feeding location for cattle, move a feed storage site, reduce the amounts of feed fed at a time, or to fence beet pulp storage. As described earlier, the risks of management factors varied, but the process of on-farm risk assessment ensured that all potential risk areas were evaluated in order to determine which risks were of greatest importance for the farm.

VI. Recommendations

a. Changes to Risk Assessment tool

The assessment's evaluation point to some areas in need of improvement. Notably, the risk scores appear to have some inconsistencies between evaluators, and may be subjective as a result. The scoring system may be improved by developing more prescriptive guidelines for assigning points, or by reducing the point system to a categorical classification of "High/Medium/Low" risk for various parameters. The potential disadvantage to the latter system is that the relative weight of the risk areas, measured as maximum points, is lost. For example, a high risk alfalfa hay storage would be classified the same as a high risk water source, although hay storage is considered to be more important to potential deer-cattle interactions. Perhaps a balance could be struck between the two systems, where the low/med/high scores are given a specific point value (ex: 5, 10, 15, 20 points). This method may provide both a simplified judgment process for the evaluator, along with a semi-quantitative result that takes the relative importance of each risk area into account.

At this time, the amount of deer habitat adjacent to the farm and the farm's history of deer damaging stored feeds is not included in the risk assessment. These factors are very important to determine the farm's overall risk for deer-cattle interactions, although they do not focus on any specific areas of risky management factors. Perhaps they can be accounted for as a value that is multiplied by the subtotal, increasing the farm's overall risk score. Other improvements to the risk assessment include increasing the importance of silage as a feed that attracts deer and adjusting the evaluation process for cattle housing groups. A suggestion for this area would be to have the evaluator consider the risks of the various housing groups on the farm separately, but only assign one score that represents the average between all groups. In order to ensure that all the cattle housing groups are evaluated, it may be best to retain space on the assessment to make notes for each group or even assign a score for each group that serves as a subtotal.

b. Utility of the Risk Assessment Tool

Regardless of the methods that may be employed to improve the on-farm risk assessment, the process of developing recommendations that look at the individual characteristics and risk areas of the farm is valuable. The management areas that are taken into account give a complete picture and help to prioritize the risks that are present. The on-farm recommendations therefore were often specific to the farm, and reflected differing biosecurity needs. Enticott describes the need for biosecurity measures against bovine tuberculosis as "a multiple and ultimately nonuniform practice" [70] due to the disease ecology for that particular farm. Such variables that affect a farm's need for biosecurity include the very things that are evaluated in the risk assessment—proximity to deer habitat, known presence of deer on the farm, and management factors that can contribute to deer-cattle interactions.

In general, the risk assessment served as an important tool to take into account all potential risk areas of the farm. Some areas of scoring did not have high reliability between evaluators, although many areas did have high reliability. Additionally, the categorization of risk items (alfalfa/grass hay, separate housing groups) caused inconsistencies in the way that these items were scored. Despite these inconsistencies, the prioritization of risks was clarified by the

process, and resulted in generation of farm -specific recommendations. The results of the logistic regression analysis also indicate that a farm's total risk score does have value in estimating the probability of deer damage to stored feed.

VII. Conclusion

Management practices in many herds in northwest Minnesota were such that risk of deer-cattle interactions were present and significant. Half the herds visited by the U of M group had deer damage to stored feed within the past year. Farms that had higher percentage of deer cover-type land and higher total risk scores had a greater probability of deer damage to stored feeds on the farm. Winter was not the time of year that deer were most frequently seen on the farm, although it seemed to be the season where deer most frequently damaged stored feed.

The results of the assessments found that herds were not all equal in their relative risks of deer-cattle interactions. Management practices that placed farms at higher risk of deer-cattle interactions included feed storage that was not protected from deer, and feeding practices that made cattle feed or feed residues easily available to deer. Additionally, deer reduction efforts and the presence of fencing on farms that were within the bovine TB core area modified the farms' risks of deer-cattle interactions.

Successful oral transmission of tuberculosis via feed is dependent on 1) the infected animal shedding a sufficient amount of bacteria through bodily secretions (respiratory, feces, or urine) and 2) the organism's ability to survive in the environment long enough for a susceptible animal to eat the feedstuff and become infected.[12] *M. bovis* has proven capable to survive for weeks to months in a variety of environmental conditions, although it has the longest persistence in cold temperatures when protected from sunlight. Ambient winter conditions in northwestern Minnesota are such that long-term survival of *M. bovis* is likely.

Although the presence of deer on a farm does not imply that deer are infected with a disease transmissible to cattle, it does increase the risk of sufficient contacts between species. The flow of infectious disease can proceed either direction through shared feed; white-tailed deer in Minnesota likely became initially infected with *M. bovis* by direct or indirect contact with one of the original infected cattle herds within the core area and may pass infection back to cattle.

It was outside of this project's scope to determine the likelihood of a cattle producer following the biosecurity recommendations, but there are several factors that can influence whether a new management practice will be adopted. Social behavioral theory describes six main constructs that influence a person's belief about performing a specific behavior. Among these constructs are perceived susceptibility, perceived severity, perceived benefits, barriers, cues to action, and self-efficacy.[71]A survey of livestock owners in the area of Canada adjacent to Riding Mountain National Park found that concern about bovine tuberculosis in wildlife (predominantly elk) increased with decreasing distance to the national park.[72] It is likely that a farm's proximity to tuberculosis-affected farms in Minnesota or infected deer influences the perceived susceptibility. Because the outcome of finding a bovine tuberculosis-positive herd is usually depopulation, perceived severity is high. However, the barriers to employing increased biosecurity to exclude deer from the property are high as well—for example, fencing is expensive and requires daily attention to ensure that the gate is closed. A survey of United Kingdom producers who previously had a TB breakdown in their herds ranked biosecurity low as a measure they preferred to use, and few farms actually undertook increased biosecurity measures.[73]

Methods that can be employed to improve producer compliance with farm biosecurity measures include finding ways to reduce the overall costs associated with some measures and increase producer knowledge about bovine tuberculosis transmission risks through effective risk communication. In developing plans to prevent bovine tuberculosis transmission at the livestock-

wildlife interface, there is a great need to consider not only the epidemiologic factors, but also the socio-economic, ecological, and political implications.[74] Because of the chronic nature of bovine tuberculosis infection, the plans for eradication are necessarily long-term. A strategic vision that incorporates the needs and concerns of livestock owners, wildlife enthusiasts, the local economy, and public health will improve stakeholder buy-in. Successful plan implementation depends on the long-term commitment of these various groups, as each will be asked to do its part. The success or failure of bovine tuberculosis management efforts in Michigan have been mainly determined by stakeholder acceptance.[50]

Tremendous challenges exist in eradication of a complicated disease such as bovine tuberculosis. Wildlife-cattle interactions are only a small component of the multiple factors that must be considered; improved cattle herd biosecurity is one dimension of the numerous controls that all must be effectively implemented. The on-farm risk assessment evaluated in this study has many advantages for use in determining potential biosecurity or management practices that can be used in preventing bovine tuberculosis transmission. Namely, it is a relatively simple tool that can quickly take several risk areas into account and help prioritize the most important risks for the farm. Minor improvements can help this tool become even more helpful for the evaluator and the producer as they consider the farm's specific needs.

Continued vigilance is necessary to maintain this zoonotic pathogen as a potential rather than a realized public health threat. As discussed previously, the overlapping controls of meat inspection and milk pasteurization have effectively controlled the food borne pathways of human infection with *M. bovis*, but the people working in close contact with infected cattle or wildlife remain at risk of exposure. The only way to eliminate the potential for zoonotic disease with bovine tuberculosis is to eliminate the disease from the animals that can be infected. With wildlife species serving as potential reservoirs, we must work to control disease within the affected populations, and to control the transmission between populations.

VIII. **References**

1. Olmstead AL, Rhode PW. An Impossible Undertaking: The Eradication of Bovine Tuberculosis in the United States. *The Journal of Economic History* 2004;64(03):734-772.

2. Thoen CO, Steele JH, Gilsdorf MJ. *Mycobacterium bovis infection in animals and humans.* 2nd ed. Iowa: Blackwell Pub; 2006.

3. Grange JM. Human aspects of Mycobacterium bovis infection. In: Thoen CO, Steele JH, eds. *Mycobacterium bovis infection in animals and humans.* 1st ed. Iowa: Iowa State University Press, 1995; 29–46.

4. Fairchild AL, Oppenheimer GM. Public health nihilism vs pragmatism: history, politics, and the control of tuberculosis. *Am J Public Health* 1998;88(7):1105-1117.

5. Etter E, Donado P, Jori F, et al. Risk Analysis and Bovine Tuberculosis, a Re-emerging Zoonosis. *Ann N Y Acad Sci* 2006; 1081:61-73.

6. Evans JT, Smith EG, Banerjee A, et al. Cluster of human tuberculosis caused by Mycobacterium bovis: evidence for person-to-person transmission in the UK. *Lancet* 2007;369(9569):1270-1276.

7. de Kantor IN, Ritacco V. An update on bovine tuberculosis programmes in Latin American and Caribbean countries. *Veterinary Microbiology* 2006;112(2-4):111-118.

8. Rodwell TC, Moore M, Moser KS, et al. *Mycobacterium bovis* tuberculosis in binational communities. *Emerging Infectious Diseases* 2008;14(6).

9. Menzies FD, Neill SD. Cattle-to-cattle transmission of bovine tuberculosis. *Veterinary Journal* 2000;160(2):92-106.

10. Hancox M. A critical reappraisal of transmission routes for bovine TB in cattle. *Respiratory Medicine* 1999;93(3):220-222.

11. Morris RS, Pfeiffer DU, Jackson R. The epidemiology of Mycobacterium bovis infections. *Veterinary Microbiology* 1994;40(1-2):153-177.

12. Kaneene JB, Thoen CO. Tuberculosis. *J Am Vet Med Assoc* 2004;224(5):685-691.

13. United States Department of Agriculture, Animal and Plant Health Inspection Service. Bovine Tuberculosis Eradication Uniform Methods and Rules. 2005.

14. Duffield BJ, Young DA. Survival of Mycobacterium bovis in defined environmental conditions. *Vet Microbiol* 1985;10(2):193-197.

15. Williams RS, Hoy WA. The viability of *B. tuberculosis* (Bovinus) on pasture land, in stored faeces and in liquid manure. *Journal of Hygiene* 1930;30:413-419.

16. Jackson R, de Lisle GW, Morris RS. A study of the environmental survival of Mycobacterium bovis on a farm in New Zealand. *N Z Vet J* 1995;43(7):346-352.

17. Palmer MV, Waters WR, Whipple DL. Shared feed as a means of deer-to-deer transmission of Mycobacterium bovis. *J Wildl Dis* 2004;40(1):87-91.

18. Vaerewijck MJM, Huys G, Palomino JC, et al. Mycobacteria in drinking water distribution systems: ecology and significance for human health. *FEMS Microbiol Rev* 2005;29(5):911-934.

19. Maddock, E. Experiments on the infectivity for healthy calves of bovine tubercle bacilli discharged in dung upon pasture. *J Hyg* 1936;36(4):594-601.

20. Maddock E. Further Studies on the Survival Time of the Bovine Tubercle Bacillus in Soil, Soil and Dung, in Dung and on Grass, with Experiments on Feeding Guinea-Pigs and Calves on Grass Artificially Infected with Bovine Tubercle Bacilli. *J Hyg* 1934;34(3):372-379.

21. Palmer MV, Waters WR, Whipple DL. Investigation of the transmission of Mycobacterium bovis from deer to cattle through indirect contact. *Am J Vet Res* 2004;65(11):1483-1489.

22. Courtenay O, Reilly LA, Sweeney FP, et al. Is Mycobacterium bovis in the environment important for the persistence of bovine tuberculosis? *Biol Lett* 2006;2(3):460-462.

23. Hutchings MR, Harris S. Effects of farm management practices on cattle grazing behaviour and the potential for transmission of bovine tuberculosis from badgers to cattle. *Vet J* 1997;153(2):149-162.

24. Phillips CJ, Foster CR, Morris PA, et al. The transmission of Mycobacterium bovis infection to cattle. *Res Vet Sci* 2003;74(1):1-15.

25. Denny GO, Wilesmith JW. Bovine tuberculosis in Northern Ireland: a case-control study of herd risk factors. *Vet Rec* 1999;144(12):305-310.

26. Johnston WT, Gettinby G, Cox DR, et al. Herd-level risk factors associated with tuberculosis breakdowns among cattle herds in England before the 2001 foot-and-mouth disease epidemic. *Biol Lett* 2005;1(1):53-56.

27. Gilbert M, Mitchell A, Bourn D, et al. Cattle movements and bovine tuberculosis in Great Britain. *Nature* 2005;435(7041):491-496.

28. Macdonald DW, Riordan P, Mathews F. Biological hurdles to the control of TB in cattle: A test of two hypotheses concerning wildlife to explain the failure of control. *Biol Conserv* 2006;131(2):268-286.

29. Woodroffe R, Donnelly CA, Jenkins HE, et al. Culling and cattle controls influence tuberculosis risk for badgers. *Proc Natl Acad Sci U S A* 2006;103(40):14713-14717.

30. Gibson AL, Hewinson G, Goodchild T, et al. Molecular Epidemiology of Disease Due to Mycobacterium bovis in Humans in the United Kingdom. *J Clin Microbiol* 2004;42(1):431-434.

31. Jalava K, Jones JA, Goodchild T, et al. No increase in human cases of Mycobacterium bovis disease despite resurgence of infections in cattle in the United Kingdom. *Epidemiol Infect* 2007;135(1):40-45.

32. Ryan TJ, Livingstone PG, Ramsey DSL, et al. Advances in understanding disease epidemiology and implications for control and eradication of tuberculosis in livestock: The experience from New Zealand. *Vet Microbiol* 2006;112(2-4):211-219.

33. Corner LA. The role of wild animal populations in the epidemiology of tuberculosis in domestic animals: how to assess the risk. *Vet Microbiol* 2006;112(2-4):303-312.

34. de Lisle GW, Mackintosh CG, Bengis RG. Mycobacterium bovis in free-living and captive wildlife, including farmed deer. *Rev sci, tec Off int Epiz* 2001;20(1):86-111.

35. Livingstone PG, Ryan TJ, Hancox NG, et al. Regionalization: a strategy that will assist with bovine tuberculosis control and facilitate trade. *Vet Microbiol* 2006;112(2-4):291-301.

36. Porphyre T, McKenzie J, Stevenson JS. A descriptive spatial analysis of bovine tuberculosis in intensively controlled cattle farms in New Zealand. *Vet Res* 2007;38:465-479.

37. Porphyre T, Stevenson MA, McKenzie J. Risk factors for bovine tuberculosis in New Zealand cattle farms and their relationship with possum control strategies. *Preventive Veterinary Medicine* 2008;86(1-2):93-106.

38. O'Brien DJ, Schmitt SM, Fierke JS, et al. Epidemiology of Mycobacterium bovis in free-ranging white-tailed deer, Michigan, USA, 1995-2000. *Prev Vet Med* 2002;54(1):47-63.

39. Miller R, Kaneene JB. Evaluation of historical factors influencing the occurrence and distribution of Mycobacterium bovis infection among wildlife in Michigan. *Am J Vet Res* 2006;67(4):604-615.

40. Palmer MV, Whipple DL, Waters WR. Experimental deer-to-deer transmission of Mycobacterium bovis. *Am J Vet Res* 2001;62(5):692-696.

41. O'Brien D, Fitzgerald S, Lyon T, et al. Tuberculous lesions in free-ranging white-tailed deer in Michigan. *J Wildl Dis* 2001;37(3):608.

42. Palmer MV, Whipple DL, Payeur JB, et al. Naturally occurring tuberculosis in white-tailed deer. *J Am Vet Med Assoc* 2000;216(12):1921-1924.
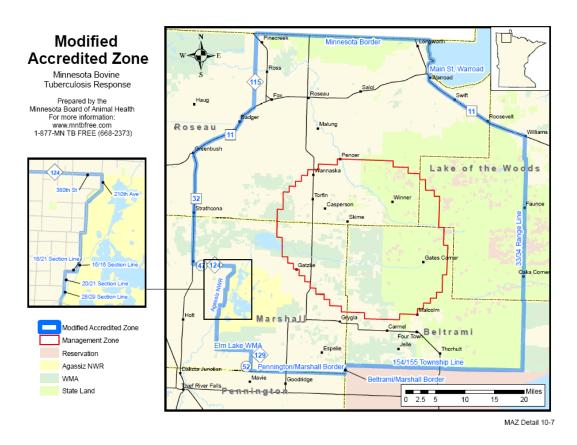
43. Diefenbach DR, Long ES, Rosenberry CS, et al. Modeling Distribution of Dispersal Distances in Male White-Tailed Deer. *J Wildl Manage* 2008;72(6):1296-1303.

44. Nelson ME, Mech LD. Home-range formation and dispersal of deer in northeastern Minnesota. *J Mammal* 1984;65(4):567-575.

45. Nelson ME. Development of migratory behavior in northern white-tailed deer. *Can J Zool* 1998;76:426-432.

46. McCarty CW, Miller MW. A versatile model of disease transmission applied to forecasting bovine tuberculosis dynamics in white-tailed deer populations. *J Wildl Dis* 1998;34(4):722-730.

47. Blanchong JA, Scribner K, Epperson BK, et al. Changes in Artificial Feeding Regulations Impact White-Tailed Deer Fine-Scale Spatial Genetic Structure. *J Wildl Management* 2006;70(4):1037-1043.

48. Rudolph BA, Riley SJ, Hickling GJ, et al. Regulating Hunter Baiting for White-Tailed Deer in Michigan: Biological and Social Considerations. *Wildl Soc Bull* 2006;34(2):314-321.

49. Miller R, Kaneene JB, Fitzgerald SD, et al. Evaluation of the influence of supplemental feeding of white-tailed deer (Odocoileus virginianus) on the prevalence of bovine tuberculosis in the Michigan wild deer population. *J Wildl Dis* 2003;39(1):84-95.

50. Obrien DJ, Schmitt SM, Fitzgerald SD, et al. Managing the wildlife reservoir of Mycobacterium bovis: the Michigan, USA, experience. *Vet Microbiol* 2006;112(2-4):313-323.

51. Miller RA, Kaneene JB, Schmitt SM, et al. Spatial analysis of Mycobacterium bovis infection in white-tailed deer (Odocoileus virginianus) in Michigan, USA. *Prev Vet Med* 2007;82(1-2):111-122.

52. Kaneene JB, Bruning-Fann CS, Granger LM, et al. Environmental and farm management factors associated with tuberculosis on cattle farms in northeastern Michigan. *J Am Vet Med Assoc* 2002;221(6):837-842.

53. Nelson B, Wilson T. Risk Mitigation at the Wildlife–Livestock Interface: A Preliminary Report from USDA/MDA Wildlife Risk Assessments, in Michigan Bovine Tuberculosis Eradication Project Activities Report and Conference Proceedings, 2006 2006.

54. Butchko P. An Update of Activities to Reduce the Spread of Bovine Tuberculosis in Michigan, in Michigan Bovine Tuberculosis Eradication Project Activities Report and Conference Proceedings, 2006 2006.

55. Tilden J. Michigan Department of Agriculture Bovine Tuberculosis Program Update, in 2008 Michigan Bovine TB Meeting 2008.

56. Wilkins MJ, Bartlett PC, Frawley B, et al. Mycobacterium bovis (bovine TB) exposure as a recreational risk for hunters: results of a Michigan Hunter Survey, 2001. *Int J Tuberc Lung Dis* 2003;7(10):1001-1009.

57. O'Brien DJ, Yereb DJ, Cosgrove MK, et al. An occupational safety program for wildlife professionals involved with bovine tuberculosis surveillance. *Wildl Soc Bull* 2004;32(3):992-999.

58. Wilkins MJ, Meyerson J, Bartlett PC, et al. Human Mycobacterium bovis Infection and Bovine Tuberculosis Outbreak, Michigan, 1994–2007. *Emerging infectious diseases* 2008;14(4):657.

59. State of Minnesota Bovine TB Response. Available at: http://www.bah.state.mn.us/tb/wildlife.html. Accessed 11/17/2008.

60. Shaw S. Public Health Implications of Surveillance Programs for Zoonotic Pathogens: A case study of Mycobacterium bovis in the state of Minnesota. Master's Thesis, 2008.

61. Minnesota Department of Natural Resources. Managing Bovine Tuberculosis in Minnesota's Wild Deer. 2008.

62. Managing Bovine Tuberculosis in Minnesota: Minnesota DNR. Available at: http://www.dnr.state.mn.us/hunting/deer/tb/index.html. Accessed 12/6/2007.

63. Vercauteren KC, Lavelle MJ, Hygnstrom S. Fences and Deer-Damage Management: A Review of Designs and Efficacy. *Wildl Soc Bull* 2006;34(1):191-200.

64. Raizman EA, Wells SJ, Jordan PA, et al. Mycobacterium avium subsp. paratuberculosis from free-ranging deer and rabbits surrounding Minnesota dairy herds. *Canadian Journal of Veterinary Research* 2005;69(1):32.

65. Raizman EA, Wells SJ, Godden SM, et al. Characterization of Minnesota dairy herds participating in a Johne's disease control program and evaluation of the program risk assessment tool. *Preventive Veterinary Medicine,* 2006;75(1-2):22-33.

66. VerCauteren K, Pipas M, Peterson P, et al. Stored-crop loss due to deer consumption. *Wildl Soc Bull* 2003;31(2):578-582.

67. Putman R, Staines B. Supplementary winter feeding of wild red deer Cervus elaphus in Europe and North America: justifications, feeding practice and effectiveness. *Mamm Rev* 2004;34(4):285-306.

68. Berentsen AR, Miller RS, Dunbar MR, et al. Risk factors associated with transmission of bovine tuberculosis from white-tailed deer to cattle in northern Michigan: research update, 2008 Bovine TB Scientific Meeting.

69. Berteaux D, Crête M, Huot J, et al. Food choice by white-tailed deer in relation to protein and energy content of the diet: a field experiment. *Oecologia* 1998;115(1):84-92.
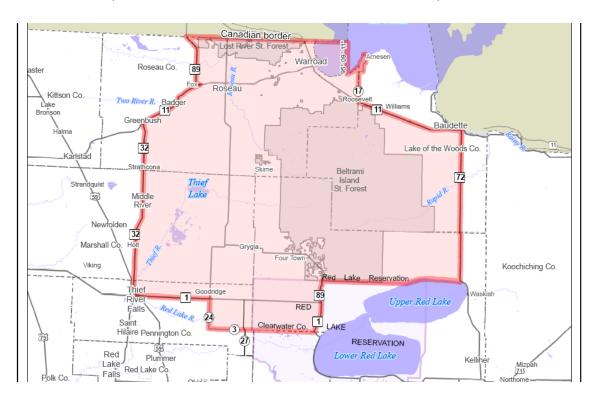
70. Enticott G. The spaces of biosecurity: prescribing and negotiating solutions to bovine tuberculosis. *Environ Plann A* 2008;40:1568–1582.

71. Glanz K, Rimer BK, National Cancer Institute (US). *Theory at a Glance: A Guide for Health Promotion Practice.* US Dept. of Health and Human Services, National Cancer Institute, 2005.

72. Brook RK, McLachlan SM. Factors influencing farmers' concerns regarding bovine tuberculosis in wildlife and livestock around Riding Mountain National Park. *J Environ Manage* 2006;80(2):156-166.

73. Bennett R, Cooke R. Control of bovine TB: preferences of farmers who have suffered a TB breakdown. *Vet Rec* 2005;156(5):143-145.

74. Nishi JS, Shury T, Elkin BT. Wildlife reservoirs for bovine tuberculosis (*Mycobacterium bovis*) in Canada: Strategies for management and research. *Vet Microbiol* 2006;112(2-4):325-338.

IX. Appendices

    a. Map of bovine Tuberculosis control areas in northwestern Minnesota (source: Minnesota Board of Animal Health)

b. Map of feeding ban area in northwestern Minnesota
   (source: Minnesota Board of Animal Health)

Minnesota Wildlife Interface Risk Assessment

Instructions: This risk assessment form is to be used to evaluate cattle operations to determine risk of disease transmission at the livestock and wildlife interface. If cattle are kept at multiple sites, please complete an additional risk assessment form for each site. Age groups of cattle on the farm can be altered to fit the management of the individual farm, but it is most important to include animals that will remain on the farm for more than 1 year after performing the survey. (**version 1/5/08**)

Date: _____

Survey Conducted by: _____

Name of Farm Owner: _____

Mailing Address: _____

City: _____ **Zip:** _____ **Phone:** _____

Premises ID: _____ **National Premises ID:** _____

County: _____ **Township:** _____ **Range:** _____

Section: _____ **Latitude:** N_____ **Longitude:** W _____

Total acreage (own and/or lease): _____

Additional cattle locations (please circle)**:** Yes   No   (If yes, complete additional form)

Cattle Address: _____

County: _____ **Township:** _____ **Range:** _____

Section: _____ **Latitude:** N_____ **Longitude:** W _____

1. Type of operation? Circle all that apply. (note: indicate how many separate groups are present at time of risk assessment)

1. Beef cow-calf
2. Beef feeding
3. Dairy cattle

4. Dairy heifer raiser
5. Cervid (captive)
6. Other (describe) _____

2. Number of cattle?

1. Adult beef cattle_____
2. Beef youngstock_____

3. Adult dairy cattle_____
4. Dairy youngstock_____

3. Number of other livestock on premises?

1. Sheep_____
2. Goats_____
3. Cervids (captive)_____

4. Camelids_____
5. Swine_____
6. Horses_____

4. Over the past 36 months, how many cattle were introduced into the herd for each source?

Source of Cattle to herd	Number of cattle introduced to herd:
☐ No cattle introduced including bulls	
☐ Known source of cattle	_____
☐ Dealer, sale barn, or unknown	_____

5. Does this farm have fence line contact with other neighboring cattle herds (please circle)**?**

1. Yes   # Herds: _____

2. No

6. If yes to 5, is fence line shared with a herd previously positive for TB?

1. Yes

2. No

7. If yes to 5, are purchases of cattle on neighboring farm from TB accredited herds?

1. Yes

2. No

8. Land type around main farm operation (please write in %):
1. Crop Fields_____%
2. Upland Hardwoods_____%
3. Lowland Swamp_____%
4. Pasture_____%
5. Other (please describe): _____%

9. Is there suitable daytime cover for deer to inhabit the area immediately around the farm during winter to early spring?

1. Yes   2. No

10. Has there been documented deer damage to stored feed in the past 12 months (please circle)**?) Please rank on scale.**

1   2   3   4   5

None--------------------------------→Severe

11. Have congregations of greater than ten deer been noticed around feed locations during the winter to early spring months?

1. Yes   2. No

12. Do any neighbors leave field crops for deer?

1. Yes   2. No

13. Has a deer hunting or removal program been implemented on the property?

1. Yes   2. No

14. Is there an outside dog located on the premises?

1. Yes   2. No

15. What type of fencing is used on the farm?
1. Barbed Wire
2. Electrified wire
3. Combination barbed wire/electrified
4. Woven wire

16. What is the minimum fence height (perimeter fence) on the farm?
1. Less than 6 feet
2. 6-9 feet
3. At least 10 feet

17. What time of year are deer most often seen on the farm?

Cattle - Wildlife Interactions Risk Assessment

Scoring guide: see pages 6-8

Management area	Max risk	Herd risk	Notes
A. Feed Storage			

1. Hay storage
    A. Alfalfa storage
    B. Grass hay storage
	20
	5		

2. Silage	10		
3. High moisture corn	10		
4. Grain and concentrates (please note type)	10		
5. Beet Pulp	20		
Total Feed Storage	**75**		
B. Feeding Practices			
6. Location of feeding site—adult cattle	15		
7. Location of feeding site—yearlings	15		
8. Location of feeding site—calves prior to breeding	15		
9. How quickly is feed consumed?	15		
10. Where are minerals given?	15		
Total Feeding Practices	**75**		
C. Cattle Housing			
11. Cattle housing—adult cattle	5		
12. Cattle housing—yearlings	5		
13. Cattle housing—calves	5		
Total Housing	**15**		
D. Water			
14. Primary source—adult cattle	5		
15. Primary source—yearlings	5		
18. Primary source—calves	5		
Total Water	**15**		
Total Risk	**180**		

Herd Management Plan
Mitigation of Critical Risk Management Measures Identified from Risk Assessment

Directions: After adding up the scores within the risk assessment section, prioritize management areas that had the highest risk score for this farm. Using the following list of critical risk factors, please write a plan for minimizing deer-cattle interactions for the prioritized risks.

A. **Feed storage:** Measures to protect stored feed from access by wildlife.
B. **Feeding practices:** Measures to minimize access by wildlife to uneaten or presented feeds.
C. **Deer exclusion:** Measures to exclude or deter deer from entering the premise; ex: fencing
D. **Water:** Measures to exclude or deter deer from sharing the same water sources as cattle.
E. **Deer Hunting:** Measures to manage deer populations using available hunting seasons.
F. **Other practices:** Other measures to help to mitigate the TB risk from wildlife on this farm.

1st Priority:

_____

2nd Priority:

_____

3rd Priority:

_____

Risk Assessment Scoring Guidelines

A. Feed Storage

Risk Factor	Scoring Guidelines	Score
1. Alfalfa Hay Storage	outside, in suitable deer cover habitat, uncovered	20
	outside, in field/fence row, uncovered	20
	outside, near animal housing, uncovered	15-20
	outside, in suitable deer cover habitat, covered	10-14
	outside, in field/fence row, covered	10-14
	outside, near animal housing, covered	10-14
	in an open building	1-9
	in an enclosed building	0-5
	completely fenced so as to restrict access to deer	0
1. Grass Hay Storage	outside, in suitable deer cover habitat, uncovered	5
	outside, in field/fence row, uncovered	5
	outside, near animal housing, uncovered	1-4
	outside, in suitable deer cover habitat, covered	1-3
	outside, in field/fence row, covered	1-3
	outside, near animal housing, covered	1-3
	in an open building	0-2
	in an enclosed building	0-1
	completely fenced so as to restrict access to deer	0
2. Silage Storage	bunk silo	10
	silage bags	6
	baleage	4
	upright silo	2
	completely fenced so as to restrict access to deer	0
3. High Moisture Corn Storage	bunk silo	10
	ag bags	6
	upright silo	2
	completely fenced so as to restrict access to deer	0
4. Grain and concentrate	open containers (bulk bay, corn cribs, etc.)	10
	closed containers (grain bins, bags, etc.)	0-6
5. Beet Pulp	open containers (bulk bay, corn cribs, etc.)	20
	closed containers (grain bins, bags, etc.)	0-10
	Maximum Score	**75**

B. Feeding Practices

Risk Factor	Scoring Guidelines	Score
6-8. Feeding Site—All groups	in or within 100 yards of suitable deer cover habitat greater than 100 yards from main farm buildings within 100 yards of main farm buildings indoors	15 10-14 6-9 0-2
9. How Quickly is Feed Consumed?	ad lib/ Feed is always available between 2-12 hours within 2 hours	15 6-8 0-4
10. Where are minerals given?	In Pasture in open feeder In Pasture in closed feeder In Dry Lot In Barn/Cattle housing	10-15 4-6 6-8 0-4
	Maximum Score	**75**

C. Cattle Housing

Risk Factor	Scoring Guidelines	Score
11-13. Cattle Housing	Outdoor only, pastured Outdoor only, enclosure Outdoors 4-14 hours/day Indoors/Confinement primarily	5 3-4 1-2 0
	Maximum Score	**15**

D. Water

Risk Factor	Scoring Guidelines	Score
16-18. Source of water	Pond, reservoir, wetland Creek, stream Watering tank with secondary natural source Watering tank without secondary natural source Automatic watering system with secondary Automatic watering system without secondary	5 1-2 2-3 4-5 2-3 0-1
	Maximum Score	**15**

X. Tables, Figures

Table 1. Questions regarding deer presence on farms visited by U of M and BAH groups.
a.) Responses from U of M risk assessments, n = 53. b.) Responses from BAH risk assessments, n = 45. c.) Chi-square test comparing difference in response between U of M and BAH groups.
€Fisher's exact test used to calculate difference in response, due to small table count values.

U of M risk assessment responses compared to BAH risk assessment responses Question	a. U of M herds Yes	b. BAH herds Yes	c. X^2 score (p-value)
Is there adequate cover for deer immediately around farm?	50 (94 %)	27 (60 %)	€ (<.0001)
Have congregations of greater than 10 deer been seen on farm?	33 (63 %)	7 (15 %)	23.5 (<.0001)
Do neighbors feed deer or leave field crops/feed plots?	26 (50 %)	12 (27 %)	5.51 (0.019)
Are deer hunted on the property?	48 (91 %)	30 (65 %)	9.47 (0.002)
Is there an outside dog located on the premises?	32 (60 %)	32 (70 %)	0.9 (0.34)
Has there been documented damage by deer to stored feeds in the last 12 months?	27 (51 %)	9 (20 %)	10.47 (0.001)

Table 2. Risk assessment scores for U of M and BAH groups. a.) Maximum possible score for each risk category. b.) Mean scores for herds visited by U of M group, n = 53. Scores for each farm were the mean between the two evaluators. c.) Spearman rank correlation score measuring agreement between the two U of M evaluators. d.) p-value of Spearman rank correlation score. e.) Mean scores for herds visited by BAH group, n = 45. f.) T-test result comparing average scores between U of M and BAH groups. g.) p-value of t-test. ¥ Housing scores for all three housing groups were averaged together. Numbers listed in parentheses are the total mean scores for all three housing groups added together.

| Risk Management Area	Max possible Score	Mean Score- UM	Spearman coefficient	Corre- lation p-value	Mean Score- BAH	t-test statistic	t-test p-value
Total Risk Management Area	180	169	.91	<.0001	171	0.59	0.5598
Number adult cattle	--	**73**	--	--	**59**	1.06	0.29
% cattle introduced	--	**24%**	--	--	**21%**	0.36	0.71
% Deer cover	--	**34%**	--	--	**33 %**	0.25	0.8
1. Feed Storage							
Alfalfa hay	20	**15.4**	.78	<.0001	**12**	2.78	0.005
Grass hay	5	**3.4**	.66	<.0001	**3.6**	-0.61	0.54
Silage (corn)	10	**8.5**	.29	.48	**NA**	--	--
Grain	10	**3.3**	.82	<.0001	**2.9**	0.52	0.61
Beet Pulp	20	**14.9**	.44	.047	**16.7**	-0.91	0.39
Total Feed Storage	65	**27**	.92	<.0001	**19**	3.58	0.0005
2. Feeding Practices							
Feeding Site A	15	**10.4**	.77	<.0001	**--**		
Feeding Site B	15	**7.0**	.76	<.0001	**--**		
Feeding Site C	15	**6.6**	.70	<.0001	**--**		
Mean feeding site location¥	15 (45)	**8.5 (25.5)**	--	--	**7 (21)**	2.56	0.01
How quickly feed is consumed	15	**9.4**	.46	.0006	**13.7**	-6.76	<.0001
Where minerals are given	15	**5.1**	.49	.0003	**7.7**	-3.75	0.0003
Total Feeding Practices	75	**33**	.81	<.0001	**40**	-2.9	0.005
3. Cattle Housing and Water							
Cattle Housing A	5	**3.4**	.68	<.0001	**--**		
Cattle Housing B	5	**2.5**	.48	.003	**--**		
Cattle Housing C	5	**2.3**	.80	<.0001	**--**		
Mean cattle housing score¥	5 (15)	**2.9 (7.8)**	--		**2.5 (7.5)**	2.15	0.034
Total Cattle Housing	15	**6.5**	.84	<.0001	**6.9**	-0.71	0.48
Water A	5	**1.4**	.76	<.0001	**--**		
Water B	5	**0.8**	.48	.003	**--**		
Water C	5	**0.9**	.47	.009	**--**		
Mean water source score ¥	5	**1.1 (3.3)**	--	--	**1.9 (5.8)**	-3.54	0.0008
Total Water	15	**2.4**	.74	<.0001	**5.3**	-4.24	<.0001
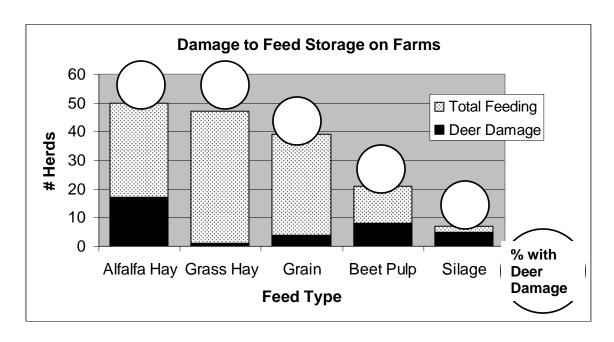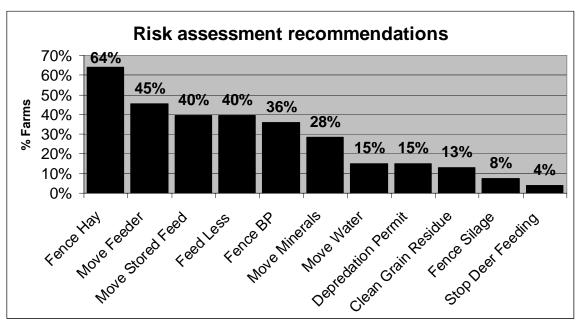
Figure 1. Herds feeding various types of feed, and percentage of those farms with evidence of deer damage to stored feeds at the time of the risk assessment.

Figure 2. Recommendations made by U of M group. Each farm received more than one recommendation as a result of the on-farm risk assessment.

Table 3. Comparison of risk parameters between farms that had deer damage and farms that did not.

Risk Factor	Damage (+) (n=27)	Damage (-) (n=26)	t-test statistic	p-value
Herd size (# adult cattle)	75	73	0.3	.76
% Deer Cover	40.6	28.2	2.6	.01
Total Feed Storage Score	29.7	24.6	1.84	.07
Total Feed Practices Score	35.7	30.0	2.50	.02
Total Cattle Housing Score	6.9	6.5	1.04	.2
Total Water Score	2.6	2.2	1.03	.3
Total Risk Score	74.7	62.7	2.61	.01

Table 4. Logistic regression model predicting deer damage to stored feed.

Parameter Model 1	Maximum Likelihood Estimate	Wald x^2 value	p-value (Wald $x^{2)}$	OR (95% CI)
Intercept	-2.586	3.79, 1 DF	0.052	
Total risk score	0.04	3.94, 1 DF	0.047	1.039 (1.001, 1.08)
Model 2				
Intercept	-1.474	4.53, 1 DF	0.033	
% Deer cover	0.04	5.63, 1 DF	0.018	1.044 (1.007, 1.08)
Model 3				
Intercept	-3.654	5.67, 1 DF	0.017	
Total risk score	0.034	2.79, 1 DF	0.095	1.035 (0.99, 1.077)
% Deer cover	0.039	4.52, 1 DF	0.034	1.04 (1.003, 1.078)

Table 5. Example probabilities of deer damage with given risk score & deer cover values, using Logistic Regression Model 3.

		% Deer Cover		
		20	**50**	**70**
Total Risk Score	**40**	0.18	0.41	0.61
	70	0.38	0.66	0.81
	100	0.63	0.84	0.92