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Evaluating use of cattle winter feeding areas by elk and white-tailed deer: Implications for managing bovine tuberculosis transmission risk from the ground up

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ABSTRACT

Transmission of bovine tuberculosis (*Mycobacterium bovis*) among wildlife and livestock has created important risks for conservation and agriculture. Management strategies aimed at controlling TB have typically been top-down, regionally focused, and government-led programs that were at best only partially successful. The purpose of this study was to quantify co-mingling of elk and white-tailed deer (WTD) with cattle at multiple spatial scales (i.e., the regional farm scale and winter cattle feeding area patch) in southwestern Manitoba, Canada, to assess the potential for bovine tuberculosis transmission and identify alternative management strategies. For each spatial scale we quantified use of cattle farms by elk and white-tailed deer. We mailed questionnaires to rural households and then conducted personal interviews with 86 cattle farmers to map the spatial distribution of their cattle winter feeding areas at a fine scale. We deployed Global Positioning System (GPS) collars on 48 wild elk and 16 wild white-tailed deer from 2003 to 2011. Elk were observed on farms by 66% of cattle producers, including 5% and 20% who observed direct and indirect contact, respectively, between elk and cattle. Cattle producers consistently (≈100%) observed white-tailed deer on their farms, including 11% and 47% whom observed direct and indirect contact, respectively, between white-tailed deer and cattle. A higher probability of white-tailed deer–cattle contact at the regional scale occurs on farms that (1) left crop residues specifically for wildlife, (2) had larger cattle herds, (3) used round bale feeders, and (4) were farther away from protected areas. None of the GPS-collared elk locations overlapped with cattle winter feeding areas. In contrast, 21% of GPS-collared white-tailed deer locations overlapped with winter cattle winter feeding areas (22% of these were from male WTD and 78% were from female WTD). White-tailed deer selected cattle winter feeding areas with higher (1) forage crop, (2) grassland/rangeland, and (3) forest cover around the cattle feeding area. Farmers overall expressed strongly negative attitudes toward eradicating the elk population or fencing the park to eradicate TB, but were generally supportive of less invasive and farm-based approaches. Our results suggested that management efforts to prevent TB transmission at the wildlife-agriculture interface can be effectively implemented using a 'bottom-up' approach that focuses on practical, farm-based mitigation strategies.

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This approach can be implemented by individual farm operators, is relatively low cost, and is generally well supported by farmers relative to other more extreme and controversial measures like wildlife eradication.

1. Introduction

Interactions between wildlife and livestock create important risks for disease transmission (Kuiken et al., 2005). Among the zoonoses of foremost and worldwide importance is *Mycobacterium bovis* (bovine tuberculosis or, hereafter TB). TB currently has a broad global distribution (Cosivi et al., 1998) adversely affecting livestock and subsequently human health. Managing TB is particularly challenging due to its persistence in a wide range of wildlife species, including cervids (Brook and McLachlan, 2009), badgers (Woodroffe et al., 2009), and possums (Ramsey and Efford, 2010). These species are likely vectors for transmission to cattle (*Bos taurus*) with important economic impacts. Ongoing failures throughout the world to eradicate TB or even effectively manage it have been in part due to the challenging nature of the disease, which is persistent and has a long latent period (Maddock, 1933; Phillips et al., 2003). However many of the failures are also be due to the widespread mistake of managing TB as a conventional agricultural or veterinary epidemiology predicament. Recognizing TB as a social–ecological problem that has both agricultural and ecological challenges but also has important social and political drivers is a critical first step in effective TB management (Brook and McLachlan, 2006, 2009).

Currently, most regional TB management efforts, such as culling wildlife, have been at best only partially successful at controlling the disease in wildlife and livestock. Indeed there are numerous examples where these kinds of programs have been unsuccessful and in some cases have had serious negative unintended effects (Nishi et al., 2006; Jenkins et al., 2010). New approaches are required in many areas of the world (Benham and Broom, 1989; Ji et al., 2005; Vial and Donnelly, 2012). Past efforts to control TB in livestock have typically been 'top-down' and science-based initiatives mandated by governments, e.g., wildlife culling or cattle testing and depopulating infected herds. Such interventions to block transmission at the wildlife–livestock interface typically take a 'one-size-fits-all' approach where the same policy applies to all individual farms regardless of the unique situation on each farm. This regional fixed approach has had mixed results, but has been largely successful in removing TB in areas where there is no wildlife reservoir (Hogarth et al., 2010). Applying similar agricultural approaches for eradicating TB in wildlife have not been successful in unbounded populations (Jenkins et al., 2010), thus current programs are largely aimed at managing rather than eradicating TB from ecosystems. Given the complexity of ecological communities and the low likelihood of eradication using current strategies, we argue here that managing TB will likely benefit from a 'bottom-up' approach.

A bottom-up approach to managing disease involves dealing with the factors that can influence disease transmission within and between species, e.g., spatial overlap, resource use, animal behaviour, and farm management (Kaneene et al., 2002; Knust et al., 2011; Vander Wal, 2011). For example, the development of spatial models that integrates data on resource selection by wildlife and farm management practices can inform the risks of pathogen transmission and identify possible routes for mitigating the probability of transmission (Brook and McLachlan, 2009). However, research at the wildlife–livestock interface has rarely integrated habitat models with farm management practices to effectively model risk of disease transmission and provide empirical evidence to identify mitigation options. Furthermore, there has rarely been paired social research that examines stakeholder attitudes toward management options. This overall approach requires an interdisciplinary integration of social and biological sciences and is critical for fully explaining the biophysical relationships between wildlife, livestock, and TB (Brook and McLachlan, 2009). The process of incorporating the knowledge and perspectives of stakeholders in research can greatly increase local participation in management initiatives and facilitate greater motivation of stakeholders (Brook and McLachlan, 2006, 2009; Mauro and McLachlan, 2008). Taking a bottom-up approach recognizes considerable variability in responses within a region and attempts to develop site-specific responses (i.e., at the farm level and even within different parts of a single farm) rather than one inflexible overall regional response.

Transmission of TB among livestock and wildlife normally occurs either indirectly through shared contaminated pasture or feeds with saliva, urine, or feces from infected animals (Briscoe, 1912; Phillips et al., 2003; Hutchings and Harris, 1997); or directly through coughing, sneezing, or licking (Garnett et al., 2002). That TB occurs at a community-scale is a challenge for understanding and managing the disease. TB often infects multiple hosts, each with a unique ecology, thus requiring a diverse set of approaches to understanding and managing disease (Olea-Popelka et al., 2005; Nugent, 2011). One such approach is to examine spatial overlap of sympatric species to identify factors influencing disease transmission risk such as environmental factors (e.g. forest cover and creeks) and farm management practices (e.g. cattle herd size, cattle housing practices, and fencing) (Garnett et al., 2002; Kaneene et al., 2002; Brook and McLachlan, 2009).

Here we quantify interactions of elk and white-tailed deer with cattle at multiple spatial scales in southwestern Manitoba, Canada: first at the regional overall farm scale and then specifically at the winter cattle feeding area patch. With this we assess the potential for bovine tuberculosis transmission and identify possible mitigation options. For each spatial scale we (1) quantified the distribution of cattle farms and the co-mingling of cattle with elk and white-tailed deer; and (2) modeled the environmental and farm management factors influencing the use of cattle farms by

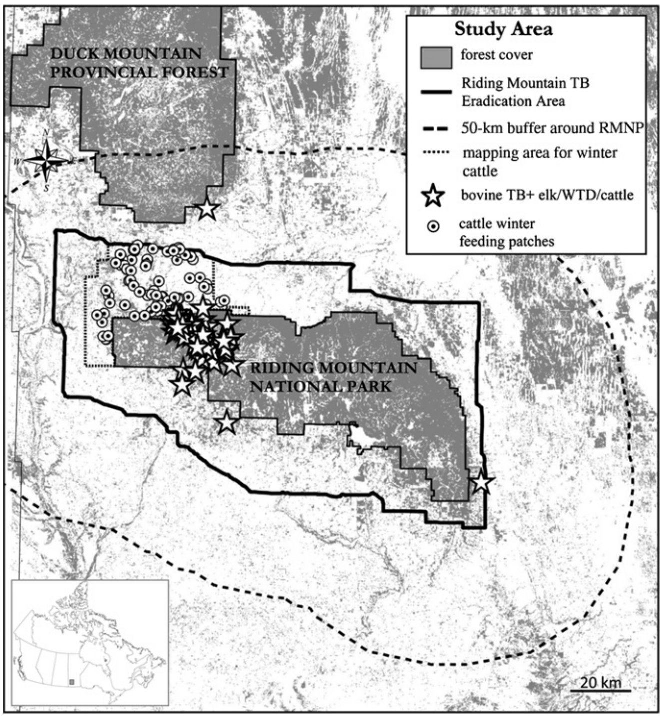

Fig. 1. Study area in southwestern Manitoba, Canada.

elk and white-tailed deer. Furthermore, we evaluated the relationship between farmer local knowledge and ecological field data to better understand their combined roles in facilitating disease management at the livestock–wildlife interface.

2. Methods

2.1. Study area

2.1.1. Regional scale

Our study area for the regional scale analysis (22,260 km²) included all of the farmland within 50 km of Riding Mountain National Park (RMNP; Fig. 1). Outside of RMNP, the region is dominated by cereal, oilseed, and forage crop production. The landscape has been dramatically modified by agriculture, but small isolated patches of deciduous forest remain. Farms in the region are, on average, 467 ha in size, although some exceed 5600 ha (Brook and McLachlan, 2006). Half of all farm operations raise beef cattle, and 28% have >100 cattle. The park is largely forested with aspen and conifer.

Wild elk and white-tailed deer have been endemic to southern Manitoba, Canada and have used our study area continuously for more than a century (Green, 1933). Bovine tuberculosis was widespread in cattle in the study area from early settlement in the 1880s up to the 1970s but was largely brought under control in cattle through an intensive test and slaughter program (Brook, 2009; Koller-Jones et al., 2006; Wobeser, 2009). Since 1991, the occurrence of the same strain of bovine TB (Lutze-Wallace et al., 2005) in elk ($n = 46$), white-tailed deer ($n = 11$) and cattle ($n = 14$ herds) in this region has intensified concerns that bovine TB is spreading from wildlife to domestic cattle (Lees et al., 2003; Brook and McLachlan, 2006; Shury and Bergeson, 2011). Transfer of TB from cattle to wildlife has received much less attention and it is often erroneously assumed that transmission is only one-way from wildlife to livestock (Phillips et al., 2003).

In response to these recent outbreaks of bovine TB in cattle herds, the 8000 km² Riding Mountain Eradication Area (RMEA) was created in 2003 by the Canadian Food Inspection Agency (CFIA) around RMNP. The RMEA was designated as part of an active attempt to eradicate the disease in livestock through intensive testing and controls on cattle movement. Elk and white-tailed deer likely represent the two primary bovine TB wildlife hosts in the Riding Mountain ecosystem (Shury and Bergeson, 2011). The known cases of TB in these wildlife species underscore the need to better understand the spatiotemporal nature of their contact with cattle to mitigate risk and protect the integrity of the cattle industry in Canada while addressing important wildlife conservation concerns.

2.1.2. Patch scale

Our fine-scale analysis of the cattle winter feeding area patches was focussed within the northwest corner of (1000 km², Fig. 1) of the RMEA. This area encompasses 75% of the bovine TB outbreaks in cattle and it contains 92% of TB positive elk and white-tailed deer occurring in the region from 2001 to 2011 (Shury and Bergeson, 2011).

2.2. Community engagement process

Research on topics such as bovine TB which are associated with extreme levels of conflict and concern and are best done as part of a collaborative process with affected stakeholders (Brook and McLachlan, 2005, 2009). Local knowledge was documented throughout this study (2001–2012), initially through community meetings to discuss project objectives and methods, then a mail-out survey, and later through participatory mapping exercises. We also participated in meetings, and weekly informal discussions with cattle producers and other stakeholders regarding project outcomes to keep stakeholders informed about our research progress and findings.

2.3. Elk and white-tailed deer co-mingling with cattle (regional scale)

As part of a comprehensive study of wildlife–agriculture interactions, we mailed a questionnaire to all households identified as farms by Canada Post within 50 km of RMNP in the spring of 2002 since no mailing lists of cattle producers were available for rural Manitoba (Brook and McLachlan, 2006; Stronen et al., 2007, in press). The questionnaire included questions regarding farm management practices and wildlife observations along an ordinal scale (Supplemental file 1). Recipients were asked to describe their farm management practices and to indicate if they observed contact between wild elk or white-tailed deer with their cattle. We defined contacts as either physical contact (nose-to-nose contact or sniffing, touching or licking each other, including through the fence) or indirect contact (e.g. eating sequentially from the same food source e.g. mineral blocks, hay, and grain at some time, without actually touching). Since no mailing lists of cattle producers were available, we sent surveys to all rural residents and used only those questionnaires where respondents indicated they owned cattle. Adjusted response rate to the mail-out survey was 56%; this was calculated as the number of cattle producers responding to the survey divided by the number of known cattle operations from CFIA mandatory cattle testing (Brook and McLachlan, 2006). In total, 436 completed questionnaires were returned by cattle producers. In order to check for non-response bias, seventy-five non-respondents were telephoned and asked five questions selected from the original questionnaire. Results were also compared with data from the 2001 Agriculture Census of Canada for this region (Statistics Canada, unpublished data 2002). Mail-out data were considered representative of the regional population of cattle producers as no significant differences were identified between either approach (Brook and McLachlan, 2006).

2.4. Farmer attitudes toward TB management options (regional scale mail survey)

We determined farmer attitudes toward a wide range of existing or hypothetical management options for bovine tuberculosis in the region. Options included both on-farm options like electric fencing or page wire fencing as well as regional options such as test and cull of wildlife, fencing the national park to keep elk in, or total eradication of the elk herd. We summarized overall responses to these diverse questions by means and standard errors.

2.5. Elk and white-tailed deer co-mingling with cattle (patch scale during winter)

We determined the spatial distribution of cattle using participatory mapping interviews conducted during the winter months (December–February). In total, 86 of the 88 (≈98%) cattle producers in this area participated. Each participant delineated the boundaries of cattle winter feeding areas on a 1:5000 scale orthophoto of their farm and indicated areas used by elk and white-tailed deer. Maps were digitized using ArcGIS10 Geographic Information System (GIS, ESRI Inc., USA). During weekly telemetry flights to relocate collared animals throughout this study we also observed and recorded the placement of winter feeding areas. We did not identify any changes to the distribution of cattle winter feeding areas during the study.

To monitor the movements of elk and white-tailed deer relative to cattle winter feeding areas, wildlife were captured within the regional study area from 2003 to 2009 using a net-gun fired from a helicopter (Cattet et al., 2004). A total of 48 wild elk (42% males; 58% females) and 16 wild white-tailed deer (40% males; 60% females) were fitted with GPS collars. Locations of GPS collared animals were obtained daily (8–18 locations per day) for up to two years. Spatial error associated with the GPS collars (mean ± SE = 14 ± 17 m) was determined by placing collars at known locations for four weeks. Collar data from the period 1 December–31 March of each year were used to correspond with the period when cattle were held in their winter feeding areas. Outside of this period cattle are moved onto more expansive summer pastures (Brook and McLachlan, 2009). The number and duration of collared elk and white-tailed deer locations on each patch were determined as indices of contact frequency and diversity, both of which can influence disease transmission (Ji et al., 2005; Brook and McLachlan, 2009).

2.6. Environmental and farm management variables and modelling (regional & patch scales)

Environmental and farm management variables hypothesized to influence elk and white-tailed deer (Table 1) were evaluated at the regional scale with the mail survey data using binomial logistic regression to compare used and available sites (taking the form of a Resource Selection Function: RSF; sensu Boyce, 2006). We used thirteen environmental and farm management variables after first screening for correlation and variance inflation. All variables in the models had $r < 0.6$ and VIFs < 3. Formal statistical inference was based on all of the models in the set (Table 2) as well as development of a set of a priori models (Table 3) to identify the single best model (Burnham and Anderson, 2002). Akaike's information criterion difference with small sample bias adjustment ($\Delta\mathrm{AIC}_c$) and Akaike weights (w) were used to evaluate models (Burnham and Anderson, 2002). Cumulative AICc weights (w+) were calculated for each of the

Table 1
Independent variables used to assess factors associated with cattle interactions with elk and white-tailed deer at the landscape based on mail survey results and at the winter cattle feeding area patch during winter using GPS-collar data and farmer interviews. A detailed summary of the questions used is provided in Supplementary file 1.

Abbreviation	Regional mail survey mean (min–max)	Winter cattle feed area mean (min–max)	Variable
Cattle[a]	86	–	Size of beef cattle herd (0, 1–20, 21–40 . . . >160)
Protectedarea[a]	14 (0–63)	–	Min. distance to protected area boundary (km)
Grain[a,b]	31 (0–100)	19 (0–100)	% cover annual grain crop (e.g. wheat, canola)
Haybales[a]	29% = yes	–	Farmer provides hay bales for wildlife (yes/no)
Forage[a,b]	37 (0–100)	4 (0–92)	% cover perennial forage cropland
Unrollbale[a]	37% = yes	–	Farmer feeds cattle unrolling haybales (yes/no)
Cropresidue[a]	38% = yes	–	Farmer provides crop residues (yes/no)
Forest[a,b]	13% (0–100)	20 (0–100)	% cover deciduous forest
Forestbuffer[b]	–	12 (0–43)	% cover deciduous within 800 m of farm
Baleshred[a]	24% = yes	–	Farmer shreds hay bales to feed cattle (yes/no)
Wetland[a]	6 (0–41)	–	% cover wetland
Distcattlefeed[a]	6% = yes	–	Distance of cattle feed area to residence (km)
Mineral[a]	9% = yes	–	Farmer provides mineral for wildlife (yes/no)
Rndbalefeed[a]	86% = yes	–	Farmer feeds cattle in round balefeeder (yes/no)
Water[b]	–	1 (0–33)	% cover water (rivers, lakes, streams, ponds)
Grassland[b]	–	56 (0–100)	% cover grassland/rangeland

[a] Used in regional landscape scale analysis.
[b] Used in cattle winter feeding area patch scale analysis.

independent variables using all possible combinations of models ($n = 8191$) for all covariates and summing the AICc weights for all models with that variable present (Burnham and Anderson, 2002). The variable with the highest cumulative AICc weight has the greatest influence on elk–white-tailed deer–cattle co-mingling (see Table 2).

Habitat selection by white-tailed deer on cattle winter feeding areas was assessed using selection ratios for each environmental variable (Manly et al., 2002). The selection ratios were calculated using the ratio of the proportion of each habitat variable used to the proportion of that habitat variable that is available within the study area (Manly et al., 2002):

$$w_i = \frac{o_i}{\pi_i}$$

where o_i is the proportion of the ith habitat variable used, and π_i represents the proportion available of that same habitat covariate within the area where cattle winter feeding areas were mapped. The threshold for selection is 1. If the selection ratio is >1 that indicates that the use of a specific habitat is greater than its availability and the habitat variable is selected. If the selection ratio is <1 then the habitat is used less than it is available and the habitat is considered avoided.

3. Results

3.1. Elk and white-tailed deer co-mingling with cattle (regional scale mail survey)

The majority of cattle producers (66%) observed elk on their farms at some point over five years, and 5% observed

Table 2
Resource selection functions based on cumulative AICc[a] weights (w^+) representing the relative importance of habitat and farm management variables hypothesized to influence elk and white-tailed deer interaction with cattle on farms at the landscape scale around Riding Mountain National Park in southwestern Manitoba. All variables with $w^+ \geq 0.5$ are bolded.

Variable[b]	Cumulative Elk AICc weight[c]	Elk selection (+) or avoidance (−)	Cumulative WTDeer AICc weight[c]	WTDeer selection (+) or avoidance (−)
Cattle	**0.90**	+	**0.91**	+
Protectedarea	**0.71**	−	**0.50**	+
Grain	**0.69**	−	0.37	−
Haybales	**0.54**	+	0.33	+
Forage	**0.51**	+	0.29	+
Unrolbalegrnd	0.48	+	0.31	+
Cropresidue	0.46	+	**0.94**	+
Forest	0.35	+	0.28	+
Baleshred	0.33	+	0.37	+
Wetland	0.32	+	0.35	+
Distcattlefeed	0.30	−	0.27	−
Mineralblocks	0.29	+	0.28	+
Roundbalefeed	0.29	+	**0.85**	+

[a] AICc, Akaike's Information Criterion with small-sample bias adjustment (Burnham and Anderson, 2002).
[b] Variables are described in Table 1.
[c] Cumulative AICc weight of a variable, the percent of weight attributable to models containing that particular variable and is calculated by summing the AICc model weights of every model containing that variable.

Table 3
Number of model parameters, differences in Akaike information criterion (Δ-AIC$_c$), and AIC$_c$ weights (w) for candidate models developed to predict elk and white-tailed deer interaction with cattle on farms at the landscape scale around Riding Mountain National Park in southwestern Manitoba.

	−2Log(L)	k	Δ-AIC$_c$	AIC$_c$ w
Model structure elk				
Cattle + protectedarea + grain + haybales + unroll	325.0	6	0.0	0.63
Cattle^2 + protectedarea + grain + haybales + unroll	325.4	7	2.4	0.19
Protectedarea + cattle + wetland + forage + grain + cropresidue + haybales + unroll	322.8	9	3.8	0.10
Cattle + protectedarea^2 + grain + haybales + unroll	328.5	7	5.5	0.04
Protectedarea + cattle + forest + wetland + forage + grain + cropresidue + haybales + unroll + baleshred	321.8	11	6.8	0.02
Protectedarea + cattle	340.2	3	9.2	0.01
Protectedarea × cattle + grain + unroll	335.4	6	10.4	0.00
Forage	344.0	2	11.0	0.00
Cattle	345.0	2	12.0	0.00
Protectedarea + cattle + forest + wetland + forage + grain + cropresidue + haybales + mineralblocks + distcattlefeed + roundbalefeeder + unroll + shred	321.4	14	12.4	0.00
Protectedarea	350.7	2	17.7	0.00
Protectedarea × cattle	353.2	3	22.2	0.00
Model structure white-tailed deer				
Cattle + cropresidue + roundbalefeed	431.7	4	0.0	0.69
Protectedarea^2 + cattle + cropresidue + roundbalefeed	431.0	6	3.3	0.13
Protectedarea + cattle + cropresidue	436.6	4	4.9	0.06
Protectedarea + cropresidue + roundbalefeed	437.3	4	5.6	0.04
Cattle × roundbalefeed + cropresidue	437.4	4	5.7	0.04
Protectedarea × cattle + cropresidue + roundbalefeed	436.6	5	6.9	0.02
Protectedarea^2 + cattle + cropresidue	437.5	5	7.7	0.01
Protectedarea^2 × cattle + cropresidue + roundbalefeed	438.6	6	10.9	0.00
Cropresidue^2	448.3	3	14.6	0.00
Protectedarea + cattle + forest + wetland + forage + grain + cropresidue + haybales + mineralblocks + distcattlefeed + roundbalefeeder + unroll + shred	426.4	14	14.7	0.00
Protectedarea^2 + cattle	450.6	4	18.8	0.00
Protectedarea^2	461.5	3	27.8	0.00

direct and 20% observed indirect contact between elk and cattle, based on the results of the regional scale mail survey (Fig. 2). Elk were observed during the day and night, and many farmers confirmed elk presence on their land using faeces and tracks. Farms that (1) had larger cattle herds, (2) were situated closer to Riding Mountain National Park, (3) produced lower amounts of grain, (4) purposely left hay bales for wildlife, and (5) had higher proportion of

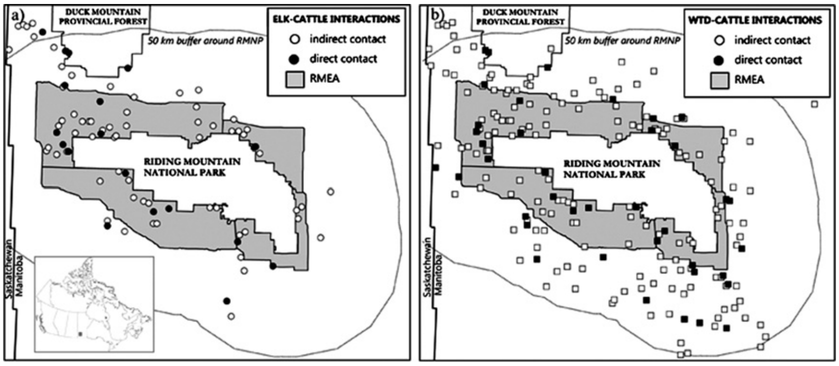

Fig. 2. Distribution of cattle farms responding to the mail-out survey that observed direct (5% of respondents) and indirect (20% of respondents) elk–cattle interactions (a); and cattle farms responding to the mail-out survey that observed direct (11% of respondents) and indirect (47% of respondents) white-tailed deer–cattle interactions.

Table 4
Perceptions of cattle producers around Riding Mountain National Park, Manitoba, Canada toward 24 existing and hypothetical management options to reduce the risk of disease transmission between wildlife and cattle, strongly disagree (−3), neutral (0), strongly agree (+3).

Management option	Mean response	Standard error
Cull TB positive wild elk[a,c]	2.10	0.07
Fully compensate agriculture producers for economic losses[a]	2.05	0.08
More TB testing of wild elk[a,c]	1.92	0.07
Improve the quality of elk habitat inside Riding Mountain Park[b]	1.91	0.08
Meaningful participation of rural people in management of TB[a,c]	1.75	0.07
Additional hunting for landowners with wildlife damage[b]	1.69	0.09
Reduce the number of elk in areas where TB has been identified[a]	1.11	0.10
Reduce the amount of wildlife baiting and feeding[a,c]	0.92	0.10
Develop a landowner guide to farm management for reducing TB[a]	0.85	0.09
Intercept feeding[a]	0.76	0.10
Page wire fencing of hay yards[b,c]	0.73	0.10
Habitat modifications (e.g. prescribed burns)[b]	0.57	0.10
Increase number of hunting licenses[a,c]	0.53	0.10
Electric fencing of hay yards[b]	0.21	0.10
Increase length of hunting season[a,c]	0.20	0.10
Barb-wire fencing of hay yards[b]	−0.16	0.11
Substantially reduce the entire Riding Mountain elk population[a,c]	−0.22	0.11
Fence around Riding Mountain National Park[a]	−0.46	0.11
Substantially reduce entire RMNP elk population[a,c]	−0.67	0.10
Meaningful participation of Aboriginal (Native) groups[a,c]	−0.72	0.10
Guard dogs[a,c]	−0.92	0.09
Chemical repellants[a]	−1.19	0.09
Remove the bison population from Riding Mountain National Park[a]	−1.26	0.09
Completely eradicate the entire Riding Mountain elk population[a]	−1.65	0.09
Reduce cattle populations in close proximity to RMNP[a]	−1.98	0.07
Allow Aboriginal (Indian) hunting on your land[b]	−2.26	0.08

[a] Hypothetical management option at the time of the survey which was not being conducted.
[b] Existing management practice used or supported by some farmers at the time of the survey.
[c] Has been implemented to some degree since the survey was completed.

forage crop had a higher probability of elk–cattle contact at the regional scale, as determined using cumulative AICc weights (w^+) (Table 2). All other variables examined were of minimal relative importance in the set (i.e., $w^+ < 0.5$) (Table 2).

All but one cattle producer from the mail survey (≈100%) observed white-tailed deer on their farms over a five year period, and 11% observed direct and 47% observed indirect contact between white-tailed deer and cattle (Fig. 2). Farms that (1) left crop residues specifically for wildlife, (2) had larger cattle herds, (3) used round bale feeders, and (4) were farther away from Riding Mountain National Park had a higher probability of white-tailed deer–cattle contact at the regional scale, as determined using cumulative AICc weights (w^+) (Table 2). All other variables examined were of minimal importance (i.e., $w^+ < 0.5$) (Table 2). Evaluation of sets of a priori models indicated that the best model predicting elk use of cattle farms included cattle herd size, distance to protected area, percent grain crop cover on the farm, hay bales provided by the farmer for wildlife, and feeding practice of unrolling hay bales on the ground for cattle (Table 3). The best overall model for white-tailed deer use of cattle farms from the mail survey data included cattle herd size, farmer leaving crop residue for wildlife, and round bale feeding of cattle (Table 3).

3.2. Farmer attitudes toward TB management options (regional scale mail survey)

Cattle farmers around RMNP expressed a broad range of responses toward existing and hypothetical TB management options (Table 4). There was overall negative responses by farmers toward extreme measures such as fencing around RMNP to keep the elk and white-tailed deer inside the park (42% of cattle producers strongly or moderately disagreed and only 27% strongly or moderately agreed) and even more so toward completely eradicating the entire RMNP elk population (65% of cattle producers strongly or moderately disagreed and only 11% strongly or moderately agreed). In contrast, there was overall strong support for less extreme efforts such as culling TB positive elk, compensating farmers for losses due to TB, and increased testing of elk.

3.3. Elk and white-tailed deer co-mingling with cattle (patch scale during winter)

In total, 83 winter cattle feeding patches were mapped (average size = 0.06 km^2, range 0.001–0.600; 7.6% of cattle winter feeding area intensive study area). In three cases, a single winter-feeding area was shared by two neighbouring farms. Cattle winter feeding areas were not randomly distributed within the intensive study area; the proportions of habitats on cattle winter feeding areas were different from the proportions of habitats within the entire intensive study area. Grassland was more likely to be present on cattle winter areas at 2.5 times its availability, and grain crop and water bodies were less likely to be present on these cattle winter areas at <0.5 times their availability (Fig. 3).

Of the 34,765 locations of collared elk collected from 2002 to 2011 during the winter months (December 1–March 31), none overlapped with cattle winter feeding

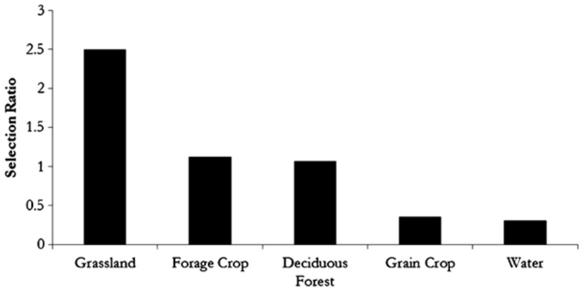

Fig. 3. Cattle winter feeding areas are not distributed randomly across the landscape. Resource selection ratios (SR) for the winter cattle feeding areas representing the proportion of used habitats as a function of available habitats indicate grassland are represented in the cattle winter feeding areas more than available on the landscape (i.e., SR > 1) and water and grain crop are represented less than available on the landscape (i.e., SR < 1).

areas when cattle were present. However, farmers that were interviewed identified seven (8% of the total) of the cattle winter feeding areas used by elk during the winter months. Of the 7794 GPS-collared white-tailed deer locations collected from 2004 to 2007 during the winter months (December 1–March 31), there were 1607 locations (21% of all winter collar locations) that overlapped with 13 (16% of the total) of the cattle winter feeding areas when cattle were present. Farmers that were interviewed identified twenty-one (25%) of the cattle winter feeding areas used by white-tailed deer during the winter.

Of the white-tailed deer collar locations on cattle winter feeding areas, 22% were from males and 78% were from females. Of these, GPS locations for white-tailed deer on winter feeding areas were most common in March (Fig. 4). The GPS-collared white-tailed deer selected cattle winter feeding areas with higher forage crop, grassland/rangeland, and forest cover in the area within an 800 m buffer around the winter cattle feeding area (selection ratios > 1). Cattle winter feeding areas that were not used by white-tailed deer had lower cover of deciduous forest, water bodies, and grain crop (Fig. 5).

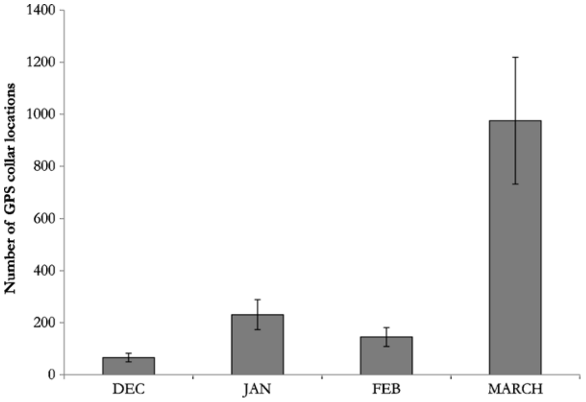

Fig. 4. Temporal use of cattle winter feeding areas by GPS-collared white tailed deer during the winter months near Riding Mountain National Park in southwestern Manitoba, Canada.

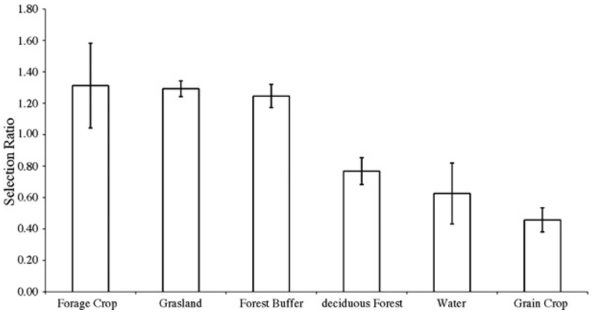

Fig. 5. Habitat selection by GPS-collared white-tailed deer at the scale of the cattle winter feeding area patch during the winter months (1 December–31 March) based on selection ratios and 95% Bonferroni-corrected confidence intervals. All habitat variables were significantly different from 1, indicating selection or avoidance of that habitat by white-tailed deer.

4. Discussion

Our findings indicate that white-tailed deer and elk co-mingle frequently with cattle on farms around Riding Mountain National Park in southwestern Manitoba. White-tailed deer make considerable use of cattle winter feeding areas and elk use cattle winter feeding areas much less so. Bovine tuberculosis appears to be endemic in elk and white-tailed deer in and around Riding Mountain National Park and this has important implications for these observed interactions between wildlife and livestock. Environmental variables such as proximity to protected area at the regional scale and forest cover around cattle feeding areas at the patch scale were important predictors of elk- and white-tailed deer–cattle interactions at both the landscape and patch scales. Farm management variables also had substantial influence on elk and white-tailed deer use of cattle farms. Indeed, at the regional scale (from the mail survey), for white-tailed deer and elk, size of the cattle herd was the most important predictor of co-mingling. Further, 80% of the important landscape variables (cumulative AIC weight > 0.5) explaining elk use and 75% of the important variables explaining white-tailed use of farms were related to farm management variables and thus could be relatively easily modified by individual farmers.

Our results indicate that a number of practical on-farm options exist to address overall risks on farms and those specific to cattle winter feeding areas. Overall risk management options for elk include reducing cattle densities by expanding their distribution to several separate areas, moving cattle as far as possible from protected areas (especially during high risk periods), and modifying cropping patterns where appropriate to minimize access by elk. For white-tailed deer, overall farm management efforts should focus on also reducing cattle densities, moving cattle away from protected areas, avoid leaving crop residues for wildlife, and providing protection for round bale feeders from white-tailed deer.

Farm management strategies such as bale and swath grazing, as well as intercept feeding (Wood and Wolfe, 1988) where feed is placed at the periphery of a farm to keep wildlife away from cattle were identified in our interviews as commonly used approaches. These are likely high risk strategies that ultimately increase overall disease transmission risk but they will require further evaluation through research as they were not addressed specifically in our mail survey and were not studied specifically within the cattle winter feeding areas. Efforts to mitigate indirect contact between elk and white-tailed deer with cattle in our study area have been reasonably successful through the provision of hay yard barrier fences (Brook, 2010). A federal/provincial funded program provided free page wire fences for hay bale storage with the goal of reducing TB transmission risk to cattle. While these have been effective at protecting hay bales, there remain important unaddressed opportunities for TB transmission on summer pastures (Brook and McLachlan, 2009). Our current results also highlight important unaddressed risks during the winter months.

For cattle winter feeding areas, there are only a small number that were used by elk and a moderate number used by white-tailed deer, but these represent important potential sites for TB transmission. Our research has identified key farms with cattle winter feeding areas, allowing targeted mitigation. White-tailed deer selected winter cattle feeding area patches with a higher proportion of forage crop and grassland and avoided patches with high proportion of grain crop. Thus, modifications to the spatial distribution of cattle winter feeding areas to reduce the proportion of habitats selected by white-tailed deer are likely to reduce risk of overlap and thus bovine TB transmission risk. However, these options are most likely to at best reduce but not eliminate use of cattle winter feeding areas. As such, more effective options should focus on barrier fencing of those cattle winter feeding areas identified as being used by white-tailed deer or elk. Fencing with game wire or electric fencing can control wildlife movement and potentially reduce the bovine tuberculosis transmission opportunities (Webb et al., 2009; Brook, 2010; Fischer et al., 2011).

The winter period is a critical time for elk and white-tailed deer, especially late winter as suggested by Fig. 4, when they are nutritionally stressed after vegetation has senesced, when temperatures frequently drop below −30 °C, and when thick snow limits movements (Sweeney and Sweeney, 1984; Jenkins and Starkey, 1993). During this period, elk and white-tailed deer are particularly attracted to stored hay bales, which represent important sites for indirect bovine TB transmission, especially since cold temperatures allow *M. bovis* to survive for up to six months in the environment (Phillips et al., 2003). Cattle herds are also more concentrated in winter feeding areas and are fed concentrated feed creating important opportunities for TB transmission, in contrast to summer conditions when cattle and wildlife are much more dispersed (Brook and McLachlan, 2009). Thus, winter likely remains an important risk period for intra- and inter-specific bovine TB transmission.

While licensed hunting can influence ungulate behaviour, it does not appear to have an important influence on white-tailed deer use of cattle winter feeding areas. Our results indicated that the majority (69%) of all white-tailed deer GPS collar locations on cattle feeding areas was in March. The big game hunting seasons in the study area last from late August until the end of January, yet deer–cattle overlap on winter feeding areas remains low in February and rises dramatically in March. While there does not appear to be an effect of general licensed hunting, there may be opportunities to apply targeted (licensed or subsistence) hunting in high risk areas, especially during March when high use of cattle winter feeding areas by white-tailed deer occurs. This peak in March may be a result of snow accumulation and temperature. Snow thickness normally peaks in December, January, and February and melting typically occurs through March, but snowfall does peak in March. Similarly, temperatures average −16 °C in December, −20 °C in January, and −15 °C in February, warming to −8 °C in March (Environment Canada unpublished data). Temperature and snow have been shown elsewhere to significantly affect white-tail deer activity patterns and large scale movements (Nelson, 1995).

The farm management variables that we identify in our results all represent 'bottom-up' responses that are under the control of farmers and rural communities. However, they currently receive little attention from decision makers and experts, with the exception of the hay bale fencing program. The current TB management program is largely based on top-down approaches such as disease testing of wildlife and livestock, management of hunting, and regulations related to baiting and feeding of wildlife. An approach that is aimed at on-farm risk assessment and management could address a wide range of issues identified through our research, recognizing that each farm is unique and requires a tailored approach to risk mitigation.

While the potential changes to farm management practices that are likely to reduce elk and white-tailed deer use of cattle farms and winter feeding areas appear relatively straightforward, effectively involving farmers to actually implement these changes is not (Brook, 2008). Farmers alter their management practices in response to numerous factors, many of which may not be immediately obvious, and not all will be easily modified (Ajzen and Fishbein, 1980; Kilvington et al., 1999). Ultimately, undertaking changes which reduce personal and global risk of TB transmission are influenced by how individuals perceive the social pressures that affect behaviour and subsequent personal attitudes toward that behaviour (i.e., subjective norms, Ajzen and Fishbein, 1980). A successful approach to motivate farmers to modify their practices to reduce elk and white-tailed risk of bovine TB transmission will be multifaceted. It will include the need to (1) address financial incentives or disincentives. To properly understand the perception of personal risk (2) and (3) the sense of community responsibility and personal pride in farm management. Furthermore (4) the approach needs to quantify the relative priority of bovine TB control relative to other farm responsibilities, costs, and time involvement (e.g. Brook and McLachlan, 2006). Any successful approach would also have to be based on meaningful involvement of farmers in design and implementation of mitigation response and priority setting (5). Lastly (6), such an approach should provide an opportunity to measure success or failure, and ethical issues of management practices (Kilvington et al., 1999).

Our results indicate important similarities between the findings from the social research (mail survey and farmer interviews) documenting farmer observations and ecological research using the GPS-collar data in that all three datasets independently illustrate that white-tailed deer co-mingle with cattle at a much higher rate than do elk. The three approaches were also complementary with respect to farm management practices. Here through the social research we documented information that would have been very difficult to obtain without actually asking the farmers to share these data (Kirkwood and Dumanski, 2003). However, the actual observations by farmers of elk and white-tailed deer on their own farms are rarely recognized as accurate and useful information by government agencies, despite research indicating that lay observations are appropriate at these time scales (Huntington, 2000; Usher, 2000; Brook and McLachlan, 2009). GPS collar data provide frequent and spatially accurate locations of wildlife throughout the day and night, but even hourly relocations of collared animals likely underestimates frequency and duration of co-mingling with cattle. Our results indicated that GPS collars did not detect elk use of cattle winter feeding areas, yet farmers did observe this occurring. Similarly, farmers observed white-tailed deer use of cattle winter feeding areas in more cases than was detected by the GPS collar data.

The majority of the farmers in our study area (69% of the total) feed their cattle daily or more than once per day during winter. Farmers also check their cattle regularly throughout the day and night and are able to recall both observations of elk and white-tailed deer as well as signs of their activities such as tracks in the snow, feces, and damage to fences and stored crops (Brook and McLachlan, 2009; Brook, 2010). The majority (71%) of cattle producers in the region also hunt white-tailed deer and elk or charge visitors to hunt them on their farms. There is strong local interest in observing these species on their farms because of their economic benefits from hunting and negative impacts due to extensive crop damage and bovine TB transmission concerns (Brook and McLachlan, 2006).

5. Conclusion

Management of diseases at the wildlife–agriculture interface, such as TB, have typically focused on top-down approaches led by government agencies such as local and regional wildlife population culls. These top down strategies are typically highly controversial, expensive, and of questionable actual benefit in addressing the disease problem (Jenkins et al., 2010; Ramsey and Efford, 2010). Here we demonstrated the potential opportunities for a bottom-up approach that focuses on working with individual farmers to help them modify their individual farm risk factors. This bottom-up approach that we advocate here does provide important opportunities for reducing the regional risks associated with co-mingling of wild ungulates and cattle, particularly white-tailed deer and elk interacting with cattle around Riding Mountain National Park. However, there will likely be little uptake and possibly significant controversy if these management responses are defined only by government and other outside stakeholders. A bottom-up approach has a strong potential to engage local people as active participants in managing bovine TB rather than vocal opponents. Collaborative processes provide important opportunities for on-going communication and co-operation to facilitate education and could ultimately form the basis of a program aimed at on-farm risk assessment and mitigation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.prevetmed.2012.07.017.

References

Ajzen, I., Fishbein, M., 1980. Understanding Attitudes and Predicting Social Behavior. Prentice-Hall, Englewood Cliffs.

Benham, P.F., Broom, D.M., 1989. Interactions between cattle and badgers at pasture with reference to bovine tuberculosis transmission. Brit. Vet. J. 14, 226–241.

Boyce, M.S., 2006. Scale for resource selection functions. Div. Distrib. 12, 269–276.

Briscoe, C.F., 1912. Fate of Tubercle Bacilli Outside the Animal Body. University of Illinois Agricultural Experiment Station Publication, p. 161.

Brook, R.K., 2008. Elk–agriculture conflicts in the Greater Riding Mountain ecosystem: building bridges between the natural and social sciences to promote sustainability. Dissertation. University of Manitoba.

Brook, R.K., 2009. Historical review of elk interactions with agriculture around Riding Mountain National Park, Manitoba, Canada. Hum. Wildl. Confl. 3, 72–87.

Brook, R.K., 2010. Incorporating farmer observations in efforts to manage bovine tuberculosis using barrier fencing at the wildlife–livestock interface. Prev. Vet. Med. 94, 301–305.

Brook, R.K., McLachlan, S.M., 2005. On using expert-based science to "test" local knowledge. Ecol. Soc. 10, r3, URL: http://www.ecologyandsociety.org/vol10/iss2/resp3/ (online).

Brook, R.K., McLachlan, S.M., 2006. Factors influencing farmers' concerns associated with bovine tuberculosis in wildlife and livestock around Riding Mountain National Park, Manitoba, Canada. J. Environ. Manage. 161, 156–166.

Brook, R.K., McLachlan, S.M., 2009. Transdisciplinary habitat models for elk and cattle as a proxy for bovine tuberculosis transmission risk. Prev. Vet. Med. 91, 197–208.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach, 2nd ed. Springer-Verlag, New York.

Cattet, M.R., Caulkett, N.A., Wilson, C., Vandenbrink, T., Brook, R.K., 2004. Intranasal administration of xylazine to reduce stress in elk captured by net gun. J. Wildl. Dis. 40, 562–565.

Cosivi, O., Grange, J.M., Daborn, C.J., Raviglione, M.C., Fujikura, T., Cousins, D., Robinson, R.A., Huchzermeyer, H.F., de Kantor, I., Meslin, F.X., 1998. Zoonotic tuberculosis due to *Mycobacterium bovis* in developing countries. Emerg. Infect. Dis. 4, 59–70.

Fischer, J.W., Phillips, G.E., Baasch, D.M., Lavelle, M.J., Vercauteren, K.C., 2011. Modifying elk (*Cervus elaphus*) behavior with electric fencing at established fence-lines to reduce disease transmission potential. J. Wildl. Manage. 35, 9–14.

Garnett, B.T., Delahay, R.J., Roper, T.J., 2002. Use of cattle farm resources by badgers (*Meles meles*) and risk of bovine tuberculosis (*Mycobacterium bovis*) transmission to cattle. Proc. Roy. Soc. Lond. B 269, 1487–1491.

Green, H.U., 1933. The wapiti of the Riding Mountain, Manitoba: an ecological study and commentary. Can. Field Nat. 47, 105–174.

Hogarth, P.J., Hewinson, R.G., Vordermeier, H.M., 2010. Development of vaccines against bovine tuberculosis. J. Pharm. Pharmacol. 58, 749–757.

Huntington, H.P., 2000. Using traditional ecological knowledge in science: methods and applications. Ecol. Appl. 10, 1270–1274.

Hutchings, M.R., Harris, S., 1997. Effects of farm management practices on cattle grazing behaviour and the potential for transmission of bovine tuberculosis from badgers to cattle. Vet. J. 153, 149–162.

Jenkins, K.J., Starkey, E.E., 1993. Winter forages and diets of elk in old-growth and regenerating coniferous forests in western Washington. Am. Midl. Nat. 130, 299–313.

Jenkins, H.E., Woodroffe, R., Donnelly, C.A., 2010. The duration of the effects of repeated widespread badger culling on cattle tuberculosis following the cessation of culling. PLoS One 5 (2), e9090.

Ji, W., White, P.C., Clout, M.N., 2005. Contact rates between possums revealed by proximity data loggers. J. Appl. Ecol. 42, 595–604.

Kaneene, J.B., Bruning-Fann, C.S., Granger, L.M., Miller, R., Porter-Spalding, B.A., 2002. Environmental and farm management factors associated with tuberculosis on cattle farms in northeastern Michigan. J. Am. Vet. Med. Assoc. 221, 837–842.

Kilvington, M., Allen, W., Kravchenko, C., 1999. Improving farmer motivation within Tb vector control. In: Landcare Research Contract Report: LC9899/110.

Kirkwood, V., Dumanski, J., 2003. Indicators of sustainability based on expert prairie farmer knowledge. Centre for Land and Biological Resources Research Report. http://paridss.usask.ca/factbook/kirkwood.html.

Knust, B.M., Wolf, P.C., Wells, S.J., 2011. Characterization of the risk of deer–cattle interactions in Minnesota by use of an on-farm environmental assessment tool. Am. J. Vet. Res. 72, 924–931.

Koller-Jones, M.A., Turcotte, C., Lutze-Wallace, C., Surujballi, O., 2006. Effect of bovine tuberculosis in wildlife on a national eradication program – Canada. In: Thoe, C.O., Stelle, J., Gilsdorf, M.J. (Eds.), Mycobacterium Bovis Infection in Animals and Humans. , 2nd ed. Blackwell Science, Oxford, pp. 226–237.

Kuiken, T., Leighton, F.A., Fouchier, R.A.M., LeDuc, J.W., Peiris, J.S.M., Schudel, A., Stohr, K., Osterhaus, A.D.M.E., 2005. Pathogen surveillance in animals. Science 309 (5741), 1680–1681.

Lees, V.W., Copeland, S., Rousseau, P., 2003. Bovine tuberculosis in elk (Cervus elaphus manitobensis) near Riding Mountain National Park. Manitoba, from 1992 to 2002. Can. Vet. J. 44, 830–831.

Lutze-Wallace, C., Turcotte, C., Sabourin, M., Berlie-Surujball, G., Barbeau, Y., Watchorn, D., Bell, J., 2005. Spoligotyping of *Mycobacterium bovis* isolates founding Manitoba. Can. J. Vet. Res. 69, 143–145.

Maddock, E.C.G., 1933. Studies on the survival time of the bovine tubercle bacillus in soil, soil and dung, in dung and on grass, with experiments on the preliminary treatment of infected organic matter and the cultivation of the organism. J. Hyg. 33, 103–117.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L., Erickson, W.P., 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies. Kluwer Academic Publishers, Boston, Massachusetts.

Mauro, I.J., McLachlan, S.M., 2008. Farmer knowledge and risk analysis: post-release evaluation of herbicide-tolerant canola in western Canada. Risk Anal. 28, 463–476.

Nelson, M.E., 1995. Winter range arrival and departure of white-tailed deer in northeastern Minnesota. Can. J. Zool. 73, 1069–1076.

Nishi, J.S., Shury, T., Elkin, B.T., 2006. Wildlife reservoirs for bovine tuberculosis (*Mycobacterium bovis*) in Canada: strategies for management and research. Vet. Microbiol. 112, 325–338.

Nugent, G., 2011. Maintenance, spillover and spillback transmission of bovine tuberculosis in multi-host wildlife complexes: a New Zealand case study. Vet. Microbiol. 151, 34–42.

Olea-Popelka, F.J., Flynn, O., Costello, E., McGrath, G., Collins, J.D., O'Keeffe, J., Kelton, D.F., Berke, O., Martin, S.W., 2005. Spatial relationship between *Mycobacterium bovis* strains in cattle and badgers in four areas in Ireland. Prev. Vet. Med. 71, 57–70.

Phillips, C.J.C., Foster, C.R.W., Morris, P.A., Teverson, R., 2003. The transmission of *Mycobacterium bovis* infection to cattle. Res. Vet. Sci. 74, 1–15.

Ramsey, D.S.L., Efford, M.G., 2010. Management of bovine tuberculosis in brushtail possums in New Zealand: predictions from a spatially explicit, individual-based model. J. Appl. Ecol. 47, 911–919.

Shury, T.K., Bergeson, D., 2011. Lesion distribution and epidemiology of *Mycobacterium bovin* in elk and white-tailed deer in south-western Manitoba. Canada. Vet. Med. Int., Article ID 591980, 11 pages.

Stronen, A., Brook, R.K., Paquet, P.C., McLachlan, S.M., 2007. Farmer attitudes toward wolves: implications for the role of predators in managing disease. Biol. Conserv. 135, 1–10.

Stronen, A.V., Schumaker, N.H., Forbes, G.J., Paquet, P.C., Brook, R.K. Landscape resistance to dispersal: predicting long-term effects of human disturbance on a small and isolated wolf population in southwestern Manitoba, Canada. Environ. Monit. Assess., in press.

Sweeney, J.M., Sweeney, J.R., 1984. Snow depths influencing winter movements of elk. J. Mammal. 65, 524–526.

Usher, P.J., 2000. Traditional ecological knowledge in environmental assessment and management. Arctic 53, 183–193.

Vander Wal, E., 2011. Sex, friends, and disease: the social ecology of the elk with implications for pathogen transmission. PhD Thesis. University of Saskatchewan.

Vial, F., Donnelly, C.A., 2012. Localized reactive badger culling increases risk of bovine tuberculosis in nearby cattle herds. Biol. Lett. 8, 50–53.

Webb, S.L., Gee, K.L., Demarais, S., Strickland, B.K., DeYoung, R.W., 2009. Efficacy of a 15-strand high-tensile electric fence to control white-tailed deer movements. Wildl. Biol. Pract. 5, 45–57.

Wobeser, G., 2009. Bovine tuberculosis in Canadian wildlife: an updated history. Can. Vet. J. 50, 1169–1176.

Wood, P., Wolfe, M.I., 1988. Intercept feeding as a means of reducing deer–vehicle collisions. Wildl. Soc. Bull. 16, 376–380.

Woodroffe, R., Donnelly, C.A., Gilks, P., Jenkins, H.E., Johnston, W.T., Le Fevre, A.M., Bourne, F.J., Cheeseman, C.L., Clifton-Hadley, R.S., Gettinby, G., Hewinson, R.G., McInerney, J.P., Mitchell, A.P., Morrison, W.I., Watkins, G.H., 2009. Bovine tuberculosis in cattle and badgers in localised culling areas. J. Wildl. Dis. 45, 128–143.