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Modeling and mitigating winter hay bale damage by elk in a low prevalence bovine tuberculosis endemic zone

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ABSTRACT

Wildlife causes extensive crop damage throughout much of North America and these shared feeds are a key risk factor in the transmission of diseases between wildlife and livestock, including bovine tuberculosis (TB). Predicting wildlife use of agricultural crops can provide insight directed toward targeted disease mitigation at areas of potential indirect interaction. In this study, we quantified use of hay bales by elk (*Cervus canadensis*) during the winter in southwestern Manitoba, Canada using a database of 952 damage claims paid compensation from 1994 to 2012. We evaluated environmental factors predicted to determine risk of hay bale damage on each quarter section by elk using a Resource Selection Probability Function (RSPF) model. The most important variables (as measured for each quarter section and based on cumulative Akaike weights that scale from 0 to 1) were distance to protected areas (1.00), forest including a buffer around the quarter section (1.00), forage crop including a buffer around the quarter section (1.00), distance from streams (0.99), forage crop (0.92), cereal and oilseed crop cover including a buffer (0.85), and forest cover (0.82). We then developed an RSPF-based predictive map of damage to hay bales by elk that identified key areas with high probability of damage (RSPF $\geq$ 0.6), accounting for 3.5% of the study area. We then multiplied the RSPF values by the inverse of the proximity to known cases of TB positive elk and determined that 0.51% of the study area had an overall high combined probability of hay bale damage and proximity to TB positive elk (i.e. adjusted probability of $\geq$0.6). In the southern half of the study area where 164 hay yard barrier fences have been implemented since 2002, there has been a significant decrease in the number of annual claims. Barrier fencing around Riding Mountain National Park has been successful at reducing elk damage where it has been implemented. In our study area, prevalence of TB in both cattle (0.003%) and elk (0.89%) is very low, precluding conventional epidemiological analyses. In the absence of clear evidence of specific routes of TB transmission, we advocate that on-farm risk assessments and mitigation efforts should continue to address areas where elk cause damage to hay bales in winter using barrier fencing. Mitigation effort should especially focus on areas where TB positive elk have been identified, as these sites provide potential for indirect interaction between cattle and elk.

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1. Introduction

Wildlife make extensive use of agricultural landscapes throughout much of North America (Stewart et al., 2002; Brook et al., 2012), most notably in order to access to high quality food resources such as pasture, hay, and grain (Brook and McLachlan, 2009; Brook et al., 2012). This association results in widespread and often intensive crop damage by wildlife (Conover, 1994) that is on the order of $0.5 billion annually in the United States alone (Wywialowski, 1994; Conover et al., 1995). Use of agricultural crops by wildlife is also a key risk factor in the transmission of diseases between wildlife and livestock (Yuill, 1987; Conover, 1998; Witmer et al., 2010). Risk of such disease transfer may be exacerbated around parks and other protected areas bordered by agricultural land, as wildlife associated with the protected areas may feed on agricultural products and return to the protected area for cover and to avoid hunting pressure (Brook et al., 2012). Diseases of critical importance to the health of wildlife, humans, and domestic animals include brucellosis, chronic wasting disease, and bovine tuberculosis (*Mycobacterium bovis*, hereafter TB).

Despite its global distribution and severe socio-economic impact, the transmission of TB among wildlife and livestock is still not well understood, despite over a century of research (Briscoe, 1912; Brook et al., 2012). TB is persistent in the environment and has a long latent period (Phillips et al., 2003). The transmission of TB among livestock and wildlife normally occurs either indirectly through shared feeds or pasture contaminated with saliva, urine, or feces from infected animals (Briscoe, 1912; Phillips et al., 2003); or directly among animals through coughing, sneezing, or licking (Garnett et al., 2002). Agricultural products have been identified as important risk factors for inter- and intra-specific TB transmission in many different regions of the world.

The importance of hay bales in concentrating wildlife and as acting as a disease fomite is well established. Damage to hay bale by wildlife, primarily ungulates, is widespread in North America (Irby et al., 1997; Brook, 2010), costing producers millions of dollars annually in direct losses, in addition to being associated significantly with disease transmission risk. In Michigan, indirect interactions between cattle and white-tailed deer (*Odocoileus virginianus*) were closely associated with deer fed from hay racks, stored feed, including hay (Hill, 2005). Furthermore, Palmer and Whipple (2006) demonstrated that bovine TB survived on hay for at least 7 days at 23 °C and up to 112 days at −20 °C and Fine (2006) found that TB remained viable on hay for up to 58 days in Michigan. Brook (2010) found that elk (*Cervus canadensis*) in Manitoba, Canada made extensive use of hay bales and Brook et al. (2012) found that when hay bales were provided for wildlife, elk made greater use of cattle winter feeding areas. Palmer et al. (2004) experimentally demonstrated that feed contacted by infected white-tailed deer effectively transmitted TB to naïve deer that were separated from other potential transmission routes. Furthermore, Miller et al. (2003) demonstrated that supplemental feeding of white-tailed deer in Michigan was associated with higher prevalence of bovine TB and that increasing the quantity of feeds provided was associated with increasing risk of TB in the local deer population.

Modeling spatial aspects of risk for wildlife use of hay bales must address environmental variables that influence how wildlife select hay as a resource and needs to recognize that wildlife select habitat at multiple scales (Boyce, 2006, Van Beest et al., 2013). Selection can be assessed using a resource selection probability function (RSPF), which represent the probability of resource use by animals (Manly et al., 2002). RSPFs and resource selection functions (RSFs) are similar in that they are both statistical models that can be applied to effectively characterize the distribution and abundance of organisms and explain the nature of the variables that drive how resources are selected (Boyce and McDonald, 1999; Manly et al., 2002). The primary difference between RSPF and RSF is based on the sampling approach, where a particular set of points are either used or unused by an animal (RSPF), whereas for many applications it is relatively easy to define used points but unused points are difficult to identify and so used and available points are compared (RSF) (Boyce and McDonald, 1999). These models have been applied to studies of disease risk and mitigation, for example, Brook and McLachlan (2009) applied RSFs to characterize risk of bovine tuberculosis transmission between elk and cattle on summer cattle pastures. Similarly, Brook et al. (2012) used an RSF to evaluate risk of TB transmission between elk, white-tailed deer, and cattle on cattle winter feeding areas.

A key challenge in managing bovine tuberculosis transmission at the wildlife-livestock interface is to effectively mitigate opportunities for wildlife to access hay bales. Compensation programs for wildlife crop damage are common in North America, especially for elk and deer (Wagner et al., 1997). The extensive and long term data provided by these crop damage compensation programs provide an important opportunity to quantify potential indirect contact between elk and cattle via hay bales and interpret these indirect contacts in the context of potential routes of TB transmission. The objectives of this study were to: (1) quantitatively determine the relative importance of environmental factors that we hypothesized determined overall risk of damage to hay bales by elk; (2) develop a spatial model that accurately predicts the spatial distribution of damage to hay bales by elk in winter using a Resource Selection Probability Function (RSPF); (3) integrate the spatial model of hay bale winter damage by elk with known locations of TB positive elk to develop a spatial model of disease risk that can be used to target and evaluate management strategies; and (4) determine if damage to hay bales by elk was significantly reduced in the area where hay yard barrier fences have been provided using a case-control study of damage claims.

2. Methods

2.1. Study area

The study area comprises 14,000 km^2 of agriculture-dominated lands outside of Riding Mountain National Park (RMNP) and Duck Mountain Provincial Forest (DMPF) in