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Modeling cost-effectiveness of risk-based bovine tuberculosis surveillance in Minnesota

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ABSTRACT

In the United States, slaughter surveillance combined with other measures has effectively maintained a very low prevalence of bovine tuberculosis (bTB). However, bTB continues to be sporadically detected, causing substantial economic burden to the government and cattle producers. To detect the infection earlier and reduce sudden economic losses, additional risk-based surveillance of live animals might be more cost-effective than slaughter surveillance alone to detect and prevent bTB infection. The objective of this study was to evaluate alternative risk-based surveillance strategies targeting high-risk herds to complement slaughter surveillance in a region with very low bTB prevalence. We developed an integrated within- and between-herd bTB transmission model with simulated premises-level cattle movements among beef and dairy herds in Minnesota for 10 years. We constructed ten risk-based surveillance strategies for beef herds and dairy herds, and predicted the epidemiological outcomes and costs for each strategy in combination with slaughter surveillance. Our models showed that slaughter surveillance alone resulted in low risk of between-herd transmission with typically small outbreak sizes, and also cost less compared to alternative risk-based surveillance measures. However, risk-based surveillance strategies could reduce the time to detect infection and the time to reach disease freedom by up to 9 months. At a higher initial prevalence, alternative risk-based surveillance could reduce the number of infected herds and shorten the time to disease freedom by almost 3 years (34–35 months). Our findings suggest that risk-based surveillance could detect infection more quickly and allow affected regions to reach disease freedom faster. If the bTB status of the affected regions changes after an outbreak happens, the reduced time to disease freedom could reduce the economic impact on the affected region.

1. Introduction

The US CooperativeState-Federal Bovine Tuberculosis (bTB) Eradication Program has successfully reduced the incidence of bTB cases in US cattle herds since its inception in 1917 (National Research Council, 1994). However, bTB continues to be sporadically detected in the US. Since 2007, bTB cases have been detected in numerous states, including California, Indiana, Michigan, Minnesota, Nebraska, New Mexico, North Dakota, South Dakota, and Texas, resulting in substantial economic losses (United States Animal Health Association; USDA-APHIS).

Bovine TB outbreaks pose a substantial economic burden to both cattle producers and government agencies at state and federal levels due to the costs of testing, indemnification, and movement restrictions. When an infected herd is detected, the producers are encouraged to depopulate or required to remain under quarantine for an extended period until its bTB-free status can be confirmed through repeated negative skin-test results. The skin tests in use in the US include the caudal fold tuberculin (CFT) test, followed by comparative cervical tuberculin (CCT) test (and sometimes other tests) among cattle with positive CFT test results (USDA-APHIS, 2004). The financial burden of depopulation to the infected herd is partially mitigated by federal indemnity funding through the Commodity Credit Corporation or through contingency funds from USDA Animal and Plant Health Inspection Service (United States Animal Health Association), which shifts costs to the federal government. State and federal governments bear other outbreak costs,

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including the cost of the epidemiologic investigation to identify potential sources of infection and potential exposures to other herds. If more than one herd is confirmed bTB-positive within an affected region (e.g., a geographic zone, often a state, designated by animal health agencies for disease eradication purposes), the region may lose its bTB-free status, resulting in movement restrictions on other herds in the vicinity, increasing regulatory costs and reducing revenue. The 2005–2009 bTB outbreak in Minnesota, which involved 12 infected herds, was estimated to cost approximately $60 million for epidemiological investigation, depopulation, and decontamination of infected herds (Buhr et al., 2009). This estimate did not include the cost of ongoing heightened surveillance efforts in the region, nor the economic impact of the outbreak on the broader Minnesota cattle industry.

Slaughter surveillance is the backbone of the US bTB national surveillance system and herd-based testing is not routinely performed at present. The process of slaughter surveillance relies on visual identification of lymph node lesions of animal carcasses at slaughter, followed by confirmatory laboratory testing of lesioned tissue (USDA-APHIS-VS, 2009). If tested positive, an epidemiological investigation would be initiated to trace back to the herd of origin (USDA-APHIS-VS, 2009). However, the sensitivity of slaughter surveillance has been estimated to be as low as 28.5% at the animal level (USDA-APHIS-VS, 2009), indicating that up to two thirds of infected animals would not be detected at slaughter. The likelihood of detection of bTB at the herd-level through slaughter surveillance varies by herd size and production type, as these factors influence the number and type of cattle sent to slaughter each year (USDA, 2009, 2008). For example, beef cow-calf herds send less than 10% of adult cattle to slaughter annually, while dairy herds have a much higher annual slaughter rate (25–30%) (USDA, 2009, 2008). The median time-to-detection of bTB through slaughter surveillance was estimated to be 5.8 years among dairy herds in the Netherlands, which is an officially bTB-free country (Fischer et al., 2005).

To reduce the time-to-detection of a bTB outbreak in the US, a more active surveillance system may be needed. In countries where the disease is present (e.g., Spain, UK, and Uruguay), routine herd screening of a large number of cattle herds is performed on a regular basis (Alvarez et al., 2012; Brooks-Pollock et al., 2014; Picasso et al., 2017). A routine herd testing program would be very costly if implemented for all cattle herds in a very low prevalence country like the US, where the prevalence is estimated at 0.0006% at the herd level (USDA-APHIS-VS, 2009). Risk-based surveillance using antemortem testing of cattle herds at higher risk of infection could reduce the time delay in bTB detection in a low prevalence setting by optimizing surveillance sensitivity, and could help allocate testing resources more efficiently than routine or random testing. Previous studies have demonstrated that herd size and animal movements are often associated with higher risk of bTB infection at the herd level (Bessell et al., 2012; Brooks-Pollock and Keeling, 2009; Gilbert et al., 2005; Gopal et al., 2006; Picasso et al., 2017; Singhla et al., 2017; USDA-APHIS-VS, 2011). Risk-based surveillance targeting larger herds with frequent animal movements could detect more outbreaks than slaughter surveillance in the UK (Salvador et al., 2015), and were less costly than routine screening among all herds, as shown in Uruguay (VanderWaal et al., 2017). However, these studies focused on areas with higher bTB prevalence than the US, and on reducing the number of herds already being routinely tested. In the US, risk-based surveillance, if implemented, would be used in addition to slaughter surveillance, though the cost-effectiveness of such a strategy should be evaluated first.

Simulation is a flexible and inexpensive tool to predict complex disease transmission processes under various hypothetical scenarios. The disease dynamics for within-herd transmission of bTB have been previously investigated in detail (Barlow et al., 1997; Álvarez et al., 2014). For between-herd transmission, cattle movement is a major route for bTB dissemination (Bessell et al., 2012; Gilbert et al., 2005; Gopal et al., 2006; Picasso et al., 2017; USDA-APHIS-VS, 2011). In addition, local spread through environmental exposures (including fence-line contacts or through wildlife exposures) could also result in between-herd transmission (Brooks-Pollock et al., 2014; Green et al., 2008). Although studies integrating within- and between-herd transmissions are rare, some studies have employed this method to predict bTB transmission among cattle farms in various hypothetical scenarios and to evaluate surveillance strategies (Brooks-Pollock et al., 2014; Green et al., 2008; VanderWaal et al., 2017).

The purpose of this study was to evaluate risk-based bTB surveillance strategies in the context of a very low prevalence region. We constructed a simulation model of bTB transmission within and between herds, including dairy and beef herds in Minnesota, USA. We used this model to simulate hypothetical bTB outbreaks and project epidemiological and economic outcomes under slaughter surveillance alone and in five different risk-based surveillance strategies that screened high-risk beef or dairy herds. Specifically, we (i) evaluated which surveillance strategy, including risk-based surveillance strategies and slaughter surveillance alone, performed better in terms of epidemiological outcomes and (ii) ranked surveillance strategies according to their cost-effectiveness in an outbreak situation in which bTB was either initiated in dairy herds and beef herds.

2. Methods

2.1. Overview

The purpose of the model developed here was to compare alternative risk-based surveillance and current slaughter surveillance by simulating the spread of bTB in the state of Minnesota. The cattle herds in the model included simulated dairy herds and beef herds in the state. The bTB transmission model integrated a) within-herd bTB transmission processes amongst cattle mixing in a herd, and b) between-herd bTB transmission processes through premises-level cattle movements and local spread. Farm locations (latitudes and longitudes) and initial herd sizes for both beef herds (~13,500) and dairy herds (~4700) in the state were obtained from the Farm Location and Agricultural Production Simulator (FLAPS). FLAPS was developed to simulate the locations and sizes (number of adult cows) of the herds based on data obtained through the Census of Agriculture (Burdett et al., 2015; Colorado State University and USDA). For animal movements, we used 1000 simulated county-level cattle movement networks from the United States Animal Movement Model (USAMM) (Lindström et al., 2013, 2011, 2009) to inform the variation of shipment frequency and origin/destinations at the county level. We constructed the premises-level cattle movements based on the county-level network and reports from the National Animal Health Monitoring System (NAHMS beef, dairy, and heifer raisers) (USDA, 2016, 2012, 2009, 2008). After the movement networks among cattle herds in Minnesota was developed, we simulated the within-herd and between-herd bTB transmission for 10 years with a seasonal time step (3 months) using the movement networks, herd locations, and herd demographics. We developed five alternative risk-based surveillance strategies screening high-risk beef or dairy herds, with the initial infection starting in beef or dairy herds, respectively. We projected the effectiveness and cost for slaughter surveillance alone (status quo) and for each alternative risk-based surveillance. Finally, we conducted a cost-effectiveness analysis to compare between the alternative strategies and slaughter surveillance alone in Minnesota over 10 years. The simulation model and the projected outcomes were developed and analyzed in R v3.3.3 (R Core Team, 2017). The code is available upon request.

2.2. Cattle herd dynamics

2.2.1. Simulating state-wide cattle movements

The movements of cattle between herds were modeled using the United States Animal Movement Model (USAMM), which created