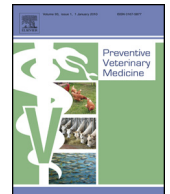




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Local cattle movements in response to ongoing bovine tuberculosis zonation and regulations in Michigan, USA



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ABSTRACT

Bovine tuberculosis (*Mycobacterium bovis*) is an ongoing management issue in the state of Michigan with eradication from livestock as the ultimate goal. Eradication has been a challenge owing to the presence of a wildlife reservoir; competing interests in managing the livestock and wildlife hosts; and many uncertainties in transmission dynamics of *M. bovis*. One of the cornerstones of the eradication effort has been to stop movement of infected cattle among farms by imposing strict pre-movement testing on cattle being moved within, into and out of the Modified Accredited Zone (MAZ) in northeastern Michigan. In addition to pre-movement tuberculosis testing, detailed information about the origin and destination premises of all movements within the MAZ has been recorded in Michigan. The aim of this study was to describe the farm-to-farm movements of cattle within the MAZ, report changes in the network of movements during a 6-year period when the MAZ was a constant size (2004–2009), and examine changes in cattle movement patterns when the MAZ was reduced from 11 to 5 counties in 2010. Non-slaughter cattle movement within the MAZ was characterized by predominantly local movements at a sub-county scale. Premises that shipped cattle were primarily senders or receivers, but rarely both. From 2004 to 2009, the number of cattle shipped, size of shipments, number of shipments and distance of shipments decreased; there was little change in the network patterns of interaction among individual premises; and interactions among all premises became more disconnected. After accounting for MAZ size, there were also no changes in cattle movement network patterns following the reduction of the MAZ in 2010. The movement of cattle was likely not a key risk factor in bTB spread among premises in the MAZ during the study period and the effect of zonation and movement regulations appeared to further reduce the risk of tuberculosis spread via cattle movements among farms in Michigan's MAZ.

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1. Introduction

Bovine tuberculosis (*Mycobacterium bovis*, bTB) in livestock and wildlife in Michigan is one of the last endemic areas of ongoing bTB transmission in the United States. The current Michigan bTB Eradication Project was initiated in 1995 in response to a confirmed case of bTB in wild white-tailed deer (*Odocoileus virginianus*); the first case of bTB in Michigan wildlife or livestock since Michigan obtained

bTB free status in 1979 (Schmitt et al., 1997). Bovine tuberculosis was confirmed in 3 cattle herds in 1998 and at least one confirmed bTB cattle premises has been identified every year since (Okafor et al., 2011). The presence of bTB in Michigan is primarily restricted to the northeastern counties in the Lower Peninsula, but eradication has been a challenge owing to the presence of a wildlife reservoir; competing interests in managing the livestock and wildlife hosts; and many uncertainties in transmission dynamics of *M. bovis*.

In 2000, the United States Department of Agriculture (USDA) revoked Michigan's bTB accredited-free status and the entire state was dropped to modified accredited status. In response, the Michigan Department of Agriculture and Rural Development (MDARD) and the Michigan Department of Natural Resources (MDNR) performed intensive surveillance in livestock and wildlife from 2000 to 2003. In 2004, the USDA granted Michigan split state status by having 11 counties in the northern Lower Peninsula remaining Modified Accredited Zone (MAZ) and the rest of the state was elevated to a Modified Accredited Advanced Zone (MAAZ). In 2005, the Upper Peninsula was granted TB-free status (MDARD, 2011) and in 2010, the USDA reduced the MAZ to the 5 northeastern counties in Lower Peninsula. The remaining 68 counties in the Lower Peninsula were split into three subzones of MAAZ based on infection risk (Fig. 1; MDARD, 2011). The MAZ represents an area where there is apparent active transmission of bTB among wildlife and cattle with prevalence of less than 0.1% in cattle herds. The MAAZ represents areas with apparent bTB prevalence of less than 0.01% of cattle herds (details of accreditation zone definitions and status can be accessed through, USDA, 2005 and MDARD, 2011). In addition, each bTB zone in Michigan has different requirements for whole-herd testing, testing prior to and post movements of individual cattle, and recording of cattle shipments (USDA, 2005). All herds in the MAZ are required to conduct annual whole-herd testing, identify all animals using a radio-frequency identification (RFID), test all animals greater than 2 months old 60 days prior to movements within or out of the MAZ, and record all animal shipments within and out of the MAZ (MDARD, 2011).

The movement of live animals among premises has been identified as a primary risk factor for introduction and spread of livestock disease (van Schaik et al., 2002; Ortiz-Palaez et al., 2006), including bTB (Gopal et al., 2006; Karolemeas et al., 2010; Okafor et al., 2011; Skuce et al., 2012). For example, Conlan et al. (2012) identified that movement of cattle or infectious materials was a strong driver of herd breakdown in Great Britain prior to 2006, and from 2009 to 2011, pre-movement testing identified 7–8% of new herd infections (DEFRA, 2010, 2011). As such, bTB control regulations that aim to identify and remove infected cattle before they are moved among premises are a key component of bTB mitigation programs in Michigan and elsewhere.

Our goal was to characterize the effect of the bTB accreditation regulations and zonation by describing the changes in cattle movement in relation to the risk of live-animal movement-mediated bTB spread. We described the characteristics of the network of cattle shipments within

Michigan's MAZ from 2004 to 2010. We examined the changes in the network of shipments over a 6 year period when the MAZ geography and regulations were constant, as well as a response to the reduction of the MAZ to a subset of counties in 2010.

2. Methods

2.1. Study area

We focus on the northern eleven counties of Michigan's Lower Peninsula for the time period of 2004–2010 because the bTB zones and regulations were consistent from 2004 to 2009 with a reduction of accreditation zones in 2010 (USDA, 2005; MDARD, 2011; Fig. 1). During this time period, bTB in cattle was restricted to the northeastern counties in the Lower Peninsula (Okafor et al., 2011).

2.2. Data sources

Records of all cattle shipments in relation to the MAZ 2004–2010 were provided from the MDARD database. This included all animals moving within the MAZ, all movements that originated within the MAZ and were destined for other accreditation zones (MAAZ and TB-free), and all movements destined for the MAZ that originated from other zones. Each record contained unique origin and destination premises identification. We considered shipments of animals the primary unit of study and did not consider movement patterns of individual animals in this study. The classification of shipment purpose was defined from the MDARD database as: Slaughter, Feeding, Breeding, and Calf (<2 months). The premises were recorded with unique state identification numbers so that the origin and destination of transports had consistent identity through the time period. Premises were assigned latitude and longitude coordinates by georeferencing the addresses listed in the state premises database. The coordinates were used to calculate Euclidean distance of transports and assign premises to a county and accreditation zone. To focus on the effects of zonation and regulations on cattle movement in relation to potential bTB spread, from this point on we present only non-slaughter movements recorded within the MAZ because these shipments are the most likely sources of animal mixing and onward bTB transmission. A detailed summary of movements by all purposes into, out-of, and within the MAZ are presented in Appendix A.

2.3. Network description

To summarize the network of non-slaughter cattle movement within the MAZ, any pair of premises that moved cattle was defined as a network edge. Edges were directional, such that a shipment from premises, i , to premises, j (edge $_{i,j}$) was unique from an edge in the opposite direction (edge $_{j,i}$). Each edge was assigned attributes for purpose, distance (km), and number of shipments (edge weight). The purpose for an edge was defined from aggregating all shipments over the edge, such that the purpose was assigned (*feeding, breeding, or calf*) if all shipments over the edge were the same type or *mixed purpose* if

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