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Deer response to exclusion from stored cattle feed in Michigan, USA

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ABSTRACT

Disease and damage from white-tailed deer (*Odocoileus virginianus*) continually threaten the livelihood of agricultural producers and the economy in the United States, as well as challenge state and federal wildlife managers. Threats can be partially addressed by excluding free-ranging deer from livestock-related resources. Throughout the year, use of stored livestock feed by deer in northern Lower Michigan (MI), USA fluctuates, though their presence is relatively consistent. Since 2008, use of livestock areas and resources by deer has been reduced through intensive efforts by livestock producers in cooperation with state and federal agencies. These efforts focused on excluding deer from stored cattle feed in areas where deer were abundant. We monitored deer activity from Jan 2012 to June 2013 on 6 cattle farms in northern MI using GPS collars to evaluate behavioral effects of excluding deer from stored feed. We characterized areas deer occupied before and after installing 2361 m of fences and gates to exclude deer from stored cattle feed. Following fence installation, 9 deer previously accessing stored feed shifted to patterns of habitat use similar to 5 deer that did not use stored feed. However, continued attempts to regain access to stored feed were made at low frequencies, emphasizing the need to maintain the integrity of fences and keep gates closed for damage prevention and biosecurity.

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1. Introduction

Wildlife species frequently exploit accessible high-quality feed destined for livestock (VerCauteren et al., 2003; Atwood et al., 2009; Tsukada et al., 2010). Contamination of livestock feed by wildlife often occurs as well, rendering feed unusable and creating a source for dissemination of pathogens (Daniels et al., 2003; VerCauteren et al., 2003; Tsukada et al., 2010). A primary concern of livestock producers and wildlife managers in northeastern Lower Michigan (MI), USA is the potential for contamination of stored feed with bovine tuberculosis (bTB) bacteria (*Mycobacterium bovis*) by infected white-tailed deer (*Odocoileus virginianus*; Palmer et al., 2004a,b; Knust, 2008).

Many methods for deterring deer exist, though relative levels of efficacy vary considerably along with associated costs, maintenance, longevity, and ease of use (VerCauteren et al., 2006a,b, 2008; Brook, 2010). The level of motivation of deer to breach exclusionary installations usually is the primary factor in resulting efficacy (Gilsdorf et al., 2002; VerCauteren et al., 2006a, 2010; Lavelle et al., 2010). During winter and other periods of increased nutritional needs (i.e., parturition, gestation), deer become highly motivated to gain access and consume feed stored for cattle, focusing on feed of high nutritional value (VerCauteren et al., 2003; Knust, 2008). To minimize access to high quality feed by deer, various proven fence designs are available (VerCauteren et al., 2006a; Knust, 2008; Lavelle et al., 2010). We assessed the effects of installing exclusionary fences around stored cattle feed by monitoring deer visitation rates to these sites as well as in adjacent land cover types before and after installation. Our objectives were to: (1) evaluate the efficacy of exclusionary fences on deer activity at the stored feed, and (2) examine whether the fences caused shifts in deer home range size or land cover usage patterns.

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2. Materials and methods

2.1. Study area

We conducted our study on 6 privately owned cattle operations in the northeastern Lower Peninsula of MI, USA within Montmorency, Presque Isle, and Alpena Counties. Average size of cattle operations was 169 ha (SD = 73.84) and 210 cattle (SD = 222.13). This area was within the core endemic area of bTB in MI (Walter et al., 2012; Berentsen et al., 2013) and provided highly suitable habitat for deer (Felix et al., 2007). We condensed land cover types in our study areas into five classes: (1) stored feed, including all developed areas associated with stored feed sites; (2) farmyard, including roads, buildings, animal pens, and residential homes; (3) cattle pasture, including grassy areas devoted to cattle grazing; (4) natural areas, including upland and lowland forests, wetlands, and shrub or scrub stands, and (5) crops, including all row crops and alfalfa. Although livestock production occurs in this area, densities were low, only averaging 1 beef-cattle farm per 21.5 km^2 and 1 dairy-cattle farm per 130.0 km^2 (Berentsen et al., 2013). Elevations range from 150 to 390 m above sea level with annual precipitation averaging 72.5 cm of rain and 175 cm of snow (Sitar, 1996). Winter snow depths seldom exceed 50 cm, usually melting by mid-April (Beyer et al., 2010). Weather in this region was notably more variable than elsewhere in the state with average summer temperatures of 24.8 °C and average winter temperatures of −10.8 °C (Sitar, 1996). Regional deer densities were estimated at 10 deer/km^2 (O'Brien et al., 2011), although concentrations of deer around accessible food during winter reached 19 deer/km^2 (Beyer et al., 2010) and have been reported as high as 35 deer/km^2 (Sitar, 1996). In conjunction with the estimated deer densities the apparent bTB prevalence rates in deer in the region fluctuated around 2% (O'Brien et al., 2011).

3. Fence design and construction

Experimental treatments in the form of exclusionary gates and fences were installed around stored livestock feed accessible to deer at all study sites, thus applied to all study animals within the vicinity. More specifically, we constructed fences or installed gates on existing structures to enclose stored feed and exclude deer ("exclosure" hereafter). A fence contractor prepared all sites and installed posts prior to installing fence to facilitate simultaneous construction of fences across sites and to minimize potential confounding factors such as weather. All fence installation was completed in January 2013 after deer use of stored feed had been documented.

Construction and design varied to fit requirements unique to each site and cattle producer. Fence material (Black Plastic Net; Kencove Farm Fence Supplies, Blairsville, PA) was provided to cooperating producers at no cost. If producers elected to install a more permanent fence, they could substitute woven-wire mesh (i.e., Solidlock® Game Fence 2096-6; Bekaert, Marietta, GA) at their expense. We installed plastic mesh fences at 2.0-m high (with 0.1-m fence material draped on ground outside the stored feed to deter entry) and woven-wire mesh tight to the ground and 2.4-m high. We attached plastic mesh with hog rings at 1-m increments to 12-ga high-tensile-steel wire run at ground level, 0.9 m, and 2.0 m. Having sufficient rigidity, woven-wire mesh was attached directly to wood posts with 4-cm galvanized-steel staples. Gate and corner posts, as well as in-line h-braces (every 100 m) were constructed of treated wooden posts (10.2-cm or 15.2-cm square and 3.0-m long) set 0.6-m deep in concrete 3-m apart and connected by horizontal 10.2-cm square posts with diagonal wire strainers. Gates were fabricated by a local contractor and consisted of 2.13-m tall welded 3.5-cm diameter galvanized-steel pipe frames covered with woven-wire mesh. Following installation, we conducted weekly inspections of fences at each site and made necessary adjustments and repairs as needed.

4. Site-specific details

Site 1: We constructed a 491-m long, 2.4-m tall, woven-wire mesh fence (1.16-ha) on 23 January 2013 to protect high moisture corn, silage, and round hay bales. Land cover types adjacent to the farm were dominated by: 47% natural areas and 43% crops.

Site 2: We installed six 2.3-m tall gates on a pre-existing 0.04-ha metal pole barn on 24 January 2013 to protect round hay bales. Land cover types adjacent to the farm were dominated by: 65% natural areas and 32% crops.

Site 3: We constructed a 709-m long, 3.10-ha, 2.0-m tall plastic mesh deer fence on 19 January 2013 to protect high moisture corn, haylage, and silage. Land cover types adjacent to the farm were dominated by: 53% natural areas and 41% crops.

Site 4: We constructed a 623-m long, 1.48-ha, 2.0-m tall plastic mesh deer fence on 30 January 2013 to protect high moisture corn, haylage, round hay bales, and silage. Land cover types adjacent to the farm were dominated by: 53% crops and 45% natural areas.

Site 5: We constructed a 709-m long, 3.10-ha 2.0-m tall, plastic mesh deer fence on 15 January 2013 to protect silage, beets, and potatoes. Land cover types adjacent to the farm were dominated by: 71% natural areas, 15% crops, and 13% cattle pasture.

Site 6: We completed (added 2 gates) a pre-existing 623-m long, 1.48-ha, 2.3-m tall 4-strand electrified poly-rope fence on 30 January 2013 to protect round hay bales. Land cover types adjacent to the farm were dominated by: 71% natural areas and 28% crops.

5. Deer capture and monitoring

Movements of deer were monitored before and after fence installation to evaluate behavioral effects of excluding them from stored feed resources. To achieve this, we captured and collared free-ranging adult female deer with netted cage traps (VerCauteren et al., 1999), air-cannons (Schemnitz et al., 2009), and remote chemical immobilization (Kilpatrick et al., 1997) primarily in January of 2012 and 2013, though also as needed throughout the study to maintain ≥3 collared deer per site. Trap locations were dispersed across suitable habitat on each farm, thus all deer were considered potential study animals. Collared deer were located weekly with very high frequency (VHF) receivers and observed when possible to ensure good health and collar fit was maintained throughout the study. We used VHF-equipped GPS collars (TGW-4501, Telonics, Inc., Mesa, AZ) to record locations of deer every 2 h for the duration of the study and used programmed collar-release mechanisms (CR-2a, Telonics, Inc., Mesa, Arizona, USA) to facilitate data retrieval at the conclusion of the study. Accuracy testing of GPS collars at a fixed location (n = 348 fixes) revealed a median position error of 8.5 m and a 95% circular error of probability of 21.4 m. All procedures were approved by the Institutional Animal Care and Use Committee of the U.S. Department of Agriculture-Animal and Plant Health Inspection Service-Wildlife Services-National Wildlife Research Center (USDA-APHIS-WS-NWRC, QA-1940) and conducted under Michigan Department of Natural Resources Scientific Collector's Permit SC1455.

6. Data processing

We focused all analyses to within 120 days before and 120 days after installation of fences. We also ran all of our analyses with 30-day periods before and after fence installation to determine if the longer 120-day period included too much variation to detect an effect of the fence. All results were identical in significant findings, therefore we only report our 120-day analyses. Individual deer were our experimental units, thus we further reduced our final dataset to eliminate non-independent samples resulting from deer pairs exhibiting correlated movements (Schauber et al., 2007). We also differentiated between non-migrant and migrant deer, thus excluded deer that were absent from the farm ≥30 days (migrants) to eliminate potential confounding movement data due to seasonal migration. Post-hoc determination of treatment versus control deer was based on whether GPS locations indicated visitation to stored feed prior to installation of fences (Gulsby et al., 2011). Further, as deer capture was distributed across study sites and pre-fence use of stored feed was beyond our control, assignment of treatment level was considered random. We omitted the first 7 days of GPS data to limit potential bias resulting from capture and handling. We also discarded any locations with poor locational confidence (Dilution of precision >10) (Berentsen et al., 2013). To evaluate potential shifts in habitat use by deer following installation of fences and gates, we only used locations recorded between 1900 and 0700 (i.e., nocturnal locations), focusing our analyses on periods when deer are most active and feeding.

7. Data analysis

Changes in habitat use due to fence installation were analyzed using a generalized linear mixed model (GLMM) using the lme4 package in R (Version 3.0.1; R Foundation for Statistical Computing, Vienna, Austria). We condensed all available land cover types within the range of deer movements into 5 categories that likely pose differing levels of risk for disease spillover to cattle: stored feed, farmyard, occupied cattle pasture, natural habitat, and crops. Our response variable was the difference between the proportion of locations in each land cover type during the 120-day time period after fences were installed and the proportion of locations in each land cover type for 120 days prior to fences being installed (i.e., positive differences are an increase in use post-fence). For each land cover type except the stored feed, we used a normal distribution to model the effects of treatment on the after-before fence differences. For stored feed and any land cover type where treatment deer and control deer had significant differences in use we used an arc-sine square root transformation and a normal distribution to model the difference between the proportion of locations by treatment deer to stored feed before and after the fence. In both types of models we included individual farms as a random effect to account for correlated errors due to more similar behavior among deer from the same farm. Similarly, in the analysis of visitation to stored feed, where we compared before and after visitation frequencies (i.e., repeated measures), we also included individual deer as a random effect to account for error correlations due to repeated measures on the same individual.

To evaluate space use effects of exclosures on deer activity, we used 3 separate a priori approaches to identify shifts in space use potentially suggesting a treatment effect. First, for each period, we calculated home ranges (95%) and core use areas (50%) using a biased random bridge approach, or a movement-based kernel density estimator (MKDE), to estimate utilization distributions (UD; Benhamou and Cornelis 2010; Benhamou, 2011). The MKDE incorporates movement trajectories and accounts for serial autocorrelation of relocations when estimating UDs. We set the upper time limit for GPS fixes to be included in the analysis at 6 hrs and considered locations less than 50 m apart to be inactive. We used the adehabitat package in R (Version 3.0.1; R Foundation for Statistical Computing, Vienna, Austria) to compute MKDE UDs. Second, we calculated the mean geographic center of GPS fixes, using ArcGIS 10.0 (Environmental Systems Research Institute, Redlands, CA, USA), during each period and compared the distance from the center of the stored-feed exclosure to the center of the fixes for each period to estimate shifts toward or away from the exclosure (Gulsby et al., 2011). As in the land cover usage analysis, we calculated the difference between the after and before-fence estimates and used a GLMM with a normal distribution and farms as random effects.

8. Results

Overall, we collected complete data (i.e., having both 120 days pre- and post-fence) from 19 healthy individual adult female deer, including 9 resident treatment deer, 5 resident control deer, 1 migrant treatment deer, and 4 migrant control deer. We documented visitation rates to stored feed by 11 deer on 4 farms during the study; however, one migrant and another lacking independence (i.e., apparent members of same social group) were excluded from analyses. Visitation to stored feed was quite variable though common until fences were installed. After fences were installed, nocturnal habitat use by deer differed between control and treatment deer in only 2 cover types (Fig. 1), farmyard ($\beta = -0.004$, SE = 0.002) and cattle pasture ($\beta = -0.033$, SE = 0.015). Additionally, use was significantly reduced in stored feed ($\beta = -0.185$, SE = 0.057) and farmyard ($\beta = -0.039$, SE = 0.015) by treatment deer after the fences were installed. Yet, deer continued to gain access through gates occasionally left open by producers which is reflected in our <100% exclusion of deer at stored feed. Motion-activated cameras at one farm recorded deer lingering outside recently closed gates and passing through opened gates within 30 min of producer activity (Fig. 2). Use was not significantly reduced in cattle pastures ($\beta = -0.060$, SE = 0.033). In relative terms, the estimated 8.21% reduction in stored feed visitation by treatment deer corresponded to an average reduction of 82.5% relative to before the fence was erected. Treatment and control deer did not significantly differ in use of the other 2 land cover types, natural areas ($\beta = -0.066$, SE = 0.072) and crops ($\beta = 0.093$, SE = 0.083).

Average distance from stored feed to mean geographic centers for control deer was 956 m (SE = 231.323) and treatment deer was 535 m (SE = 45.574) before installation of fences, with no significant change before and after the fence ($\beta = 51.20$, SE = 222.20; Fig. 3). Average pre-fence core range for control deer was 18.265 km^2 (SE = 3.250) and treatment deer was 29.464 km^2 (SE = 2.681), again with no significant change from pre-fence to post-fence periods ($\beta = -1.118$, SE = 9.116). Average pre-fence home range of control deer was 106.279 km^2 (SE = 12.675) and treatment deer was 147.489 km^2 (SEn= 13.960), also with no significant change from pre-fence to post-fence periods ($\beta = 14.66$, SE = 33.99).

9. Discussion

Our results from GPS locations demonstrated that fences and gates excluded deer from stored feed and reduced visitation to farmyards. During routine fence inspections, however, we occasionally observed deer and tracks of deer that revisited stored feed sties and attempted to gain access following installation of fences and gates (see also Brook, 2010). Similarly, it was found that deer with established home ranges maintain those home ranges, even after being disrupted by installation of exclusionary fences (Gulsby et al., 2011). Further, our findings demonstrated the persistence to continue accessing habitually used resources by deer even after human intervention. Removal of persistent individual deer may eliminate potential for contamination by those particular individuals as well as reduce potential for learning by other deer. Alternatives to traditional gates, such as automatically clos-

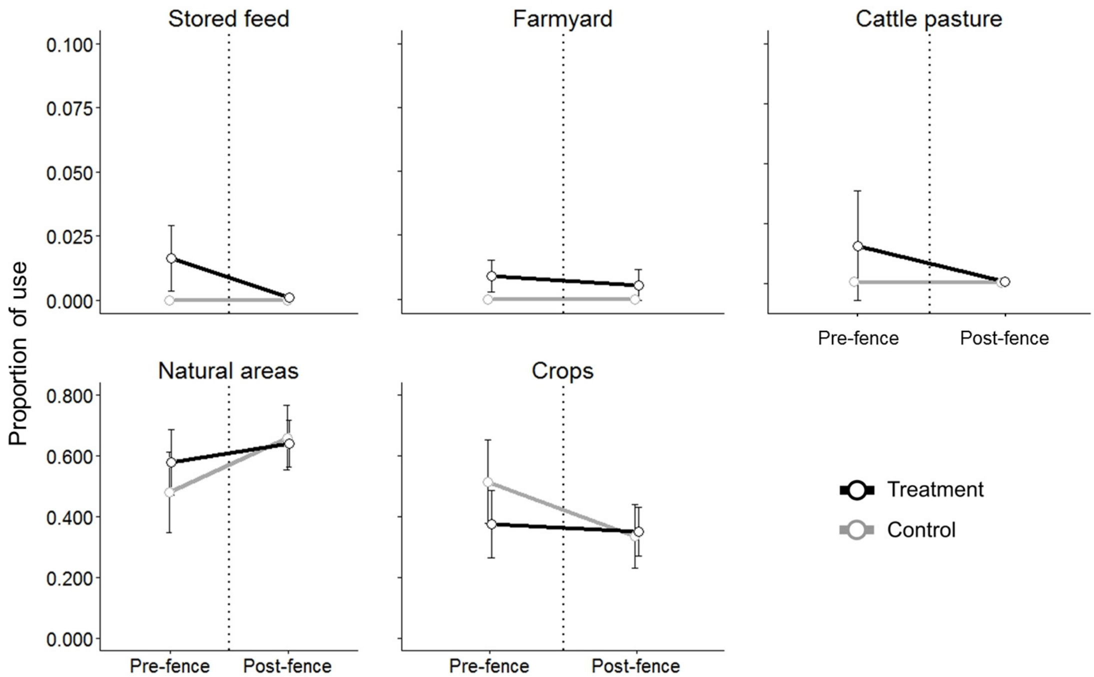

Fig. 1. Proportion of nighttime (7 pm–7 am) locations of white-tailed deer (*Odocoileus virginianus*) within condensed land cover designations from before (120 nights) and after (120 nights) installation of exclusionary fences and gates to reduce potential pathogen contamination of feed destined for cattle in northeastern Lower Michigan, USA.

ing bump gates have demonstrated potential for excluding deer while still facilitating vehicular access to stored feed (VerCauteren et al., 2009; Berentsen et al., 2010).

In wildlife damage situations in which non-lethal management strategies are implemented, potential exists for simply displacing use to other accessible resources within their home range (Tolhurst et al., 2008; Judge et al., 2011). By the time we conducted our study, nearly all livestock producers within northeastern Lower MI (98%) had already implemented exclusionary measures thus minimizing the possibility of deer shifting to other comparable stored feeds. After we excluded non-independent and migratory deer, the initial change in habitat use by treatment deer after the fences were constructed was an increased occupancy in natural areas. This pattern was similar in control deer, indicating that this shift in habitat use was likely caused by factors other than the fence being installed (e.g., seasonal changes in use, behavior, forage availability).

Since its inception in 1933, bTB, has repeatedly plagued cattle producers in North America (e.g., Cosgrove et al., 2012; Miller and Sweeney, 2013; Palmer, 2013). In the northern portion of the Lower Peninsula of MI, bTB spilled into and is currently maintained in free-ranging white-tailed deer, providing a source for reinfection and perpetuation of the problem (O'Brien et al., 2006; Fitzgerald and Kaneene, 2013). Deer-to-cattle interactions are rare (Hill, 2005), suggesting that pathogen transmission risk through direct interaction is less of a concern than indirect transmission through shared use of common resources such as stored feed (Portacci et al., 2009; Walter et al., 2012; Berentsen et al., 2013). Allowing potentially infected wildlife access to stored feed appears to be the most plausible means for bTB transmission (Palmer and Whipple, 2006; Ward et al., 2006; Walter et al., 2012). Development and implementation of methods for reducing transmission events are essential for effective suppression of bTB. Our study supports the hypothesis that when properly used, well-constructed exclusionary fences and gates may eliminate a plausible route for transmission of *M. bovis* from deer to cattle (Judge et al., 2006, Tolhurst et al., 2008).

Management of disease and damage involving wildlife often requires an integrated management approach in which several methods are used in combination to achieve a goal (DeNicola et al.,

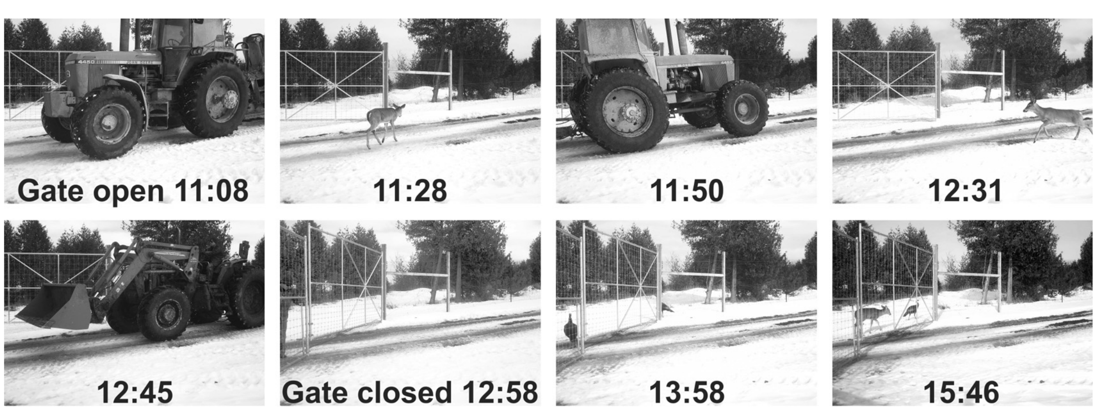

Fig. 2. Sequential images taken over nearly 5 hrs at a frequently used access point to enclosed feed on 8 March 2013, demonstrating persistence of white-tailed deer (*Odocoileus virginianus*) to gain access following installation of exclusionary fences and gates to reduce potential contamination of feed destined for cattle in northeastern Lower Michigan, USA.

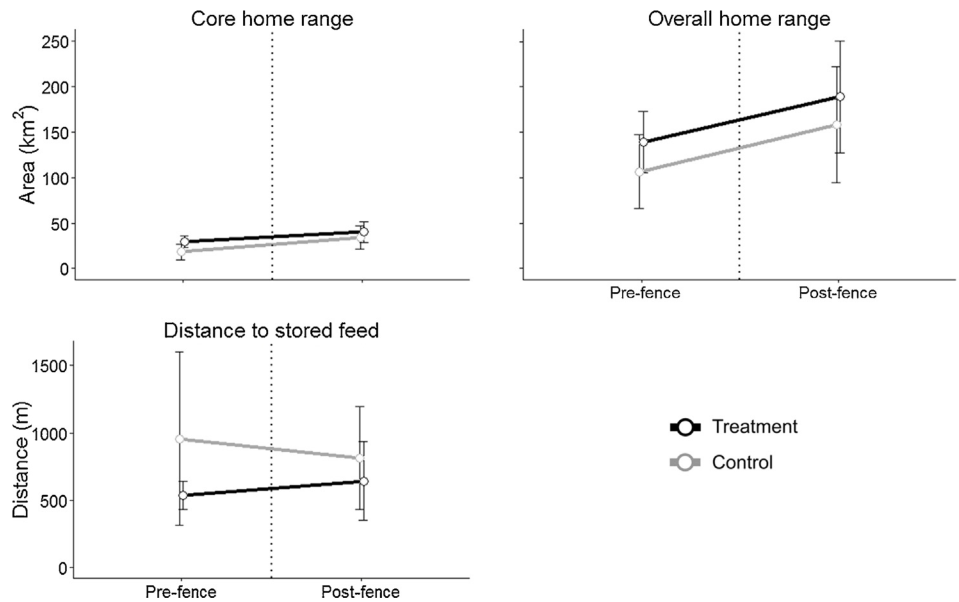

Fig. 3. Changes in average space-use characteristics of adult female white-tailed deer (*Odocoileus virginianus*) from before (120 nights) and after (120 nights) installation of exclusionary fences and gates to reduce potential contamination of feed destined for cattle in northeastern Lower Michigan, USA.

2000; Lees, 2004; Putman et al., 2011; Cosgrove et al., 2012). Typical strategies for suppressing bTB in Michigan include fences to exclude deer from stored feed, fences to exclude cattle from wetlands, and practices such as providing only enough feed that cattle will eat in one day (Walter et al., 2012). Of these methods, eliminating access to feed by deer addresses contamination of feed, thereby minimizing risk of indirect pathogen transmission from deer to cattle (Okafor et al., 2011). Well-maintained fences and closed gates can be straightforward and effective means for eliminating access to stored feed, although they are costly and require considerable labor to install and maintain (VerCauteren et al., 2006a,b). Temporary and less-expensive deterrents are available, though extent and duration of efficacy are typically lower than exclusion with fences. For example, livestock protection dogs comingling with cattle (VerCauteren et al., 2008; Gehring et al., 2010), a round-bale feeder protection device (Seward et al., 2007), and species-specific gates that allow exclusive access to resources by livestock (VerCauteren et al., 2009; Barasona et al., 2013) have demonstrated promise in reducing potential for pathogen transmission. As with all non-lethal techniques, motivation of the offending animals must be considered when selecting appropriate strategies (VerCauteren et al., 2006a, 2010).

Disease management strategies such as those used in this study have wide-spread utility worldwide in situations where risk of inter-species transmission of disease exists at the wildlife-livestock interface (Barasona et al., 2013; Gortazar et al., 2015). For example, in Spain where potentially bTB-infected wild boar and domestic cattle share water sources, fences with species-specific gates have proven effective in minimizing shared use (Barasona et al., 2014). Additionally, temporary fences like plastic mesh can quickly provide a barrier for sporadic, transient, or seasonal needs that are associated with spatially confined focal sites (Lavelle et al., 2010, 2011; Barasona et al., 2014; Gortazar et al., 2015).

10. Conclusion

Suppression of bTB in MI has improved considerably in the last decade, especially due to the implementation of intensive efforts to segregate cattle and deer and reduce antlerless deer numbers. When high-quality feed is stockpiled and stored for future use in areas adjacent to deer habitat, deer often find and attempt to exploit these resources. Installation and maintenance of exclusionary fences and gates minimizes contamination of stored feed and unnatural concentrations of deer, thereby reducing the risk of deer-pathogen transmission. Although fences used in disease management efforts are in no way new or innovative, they are highly effective when used with vigilance. When integrated with other management strategies, such as focusing on reducing the number of antlerless deer, MI may be able to further reduce transmission of bTB between free-ranging deer and livestock. Such strategies are examples of straightforward management actions that producers can implement to help ensure biosecurity of their operations while generating a broader and healthier environment for neighboring wildlife populations. Our results demonstrated that exclusionary fences can reduce use and thus potential contamination of stored cattle feed by deer by at least 82.4%, and induce a shift in deer use away from developed livestock-related areas, further decreasing potential for direct and indirect interaction between deer and livestock.

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