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No trespassing: using a biofence to manipulate wolf movements

David E. Ausband[A,C], *Michael S. Mitchell*[A], *Sarah B. Bassing*[A] *and Craig White*[B]

[A]Montana Cooperative Wildlife Research Unit, 205 Natural Sciences Building, University of Montana, Missoula, MT 59812, USA.
[B]600 S. Walnut Street, Boise, ID 83712, USA.
[C]Corresponding author. Email: david.ausband@mso.umt.edu

Abstract

Context. Conserving large carnivores can be challenging because of conflicts with human land use and competition with humans for resources. Predation on domestic stock can have negative economic impacts particularly for owners of small herds, and tools for minimising carnivore depredation of livestock are needed. Canids use scent marking to establish territories and avoid intraspecific conflict. Exploiting scent-marking behaviour may provide a means for manipulating canid movements.

Aims. We hypothesised that human-deployed scent marks (i.e. 'biofence') could be used to manipulate the movements of grey wolves (*Canis lupus*) in Idaho, USA.

Methods. We deployed 65 km of biofence within three wolf-pack territories during summer 2010 and 2011 and used location data from satellite-collared wolves and sign surveys to assess the effectiveness of biofencing.

Key results. Location data provided by satellite-collared wolves and sign surveys in 2010 showed little to no trespass of the biofence, even though the excluded areas were used by the packs in previous summers. We also opportunistically deployed a biofence in between a rendezvous site of a resident pack and a nearby sheep grazing allotment; the pack was not implicated in any depredations in summer 2010, even though they had killed sheep every year since 2006. Location data provided by satellite-collared wolves in summer 2011 showed that wolves did trespass biofences.

Conclusions. Biofencing effectively manipulated the movements of wolves in the first year of our study, but not the second.

Implications. Our work suggests that biofencing may be most limited by the apparent necessity to maintain a continuous presence once the biofence is established. The inherent labour and costs associated with such efforts may limit the usefulness of biofencing. Our work can be improved on through further testing that maintains biofencing over a longer timeframe (>3 months), samples several animals per treatment pack, and uses a treatment and control design.

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Introduction

Conserving large carnivores can be challenging because of conflicts with human land use and direct competition with humans for resources. Wild canids, in particular, have a long history of associating with humans (Zimen 1981; Robinson 2005; Hayes 2010); however, conflict arose most notably when herding societies began to form and humans provided a new source of relatively docile livestock prey for large carnivores (Reynolds and Tapper 1996). Currently, much of the conflict between humans and canids arises from canid predation on domestic stock (Sillero-Zubiri *et al*. 2004). Predation on domestic stock can have negative economic impacts (Sillero-Zubiri *et al*. 2004), although Berger (2006) did not detect negative impacts at an industry-wide scale when analysing effects of coyote (*C. latrans*) depredation on sheep (*Ovis* spp.) production. For individual stock growers, particularly families in developing countries, the loss of livestock can have severe negative impacts. Further, predation on livestock creates a social environment where the benefits of conserving large carnivores are not apparent to people living with them on a daily basis. Numerous imperiled canid species occupy landscapes where humans and livestock are abundant, the potential for conflict is large, and the conservation challenge is great (Macdonald and Sillero-Zubiri 2004).

Some strategies exist for mitigating canid predation on livestock, including lethal techniques such as eradication, population reduction and selective lethal removal (Treves and Naughton-Treves 2005). Existing non-lethal tools include increased vigilance, relocation of offending animals, fladry, hazing, radio-activated guard (RAG) boxes, fencing, guard dogs and llamas, and covering stock with unpalatable substances (Nickel 1993; Green *et al*. 1994; Breck *et al*. 2002; Musiani *et al*. 2003; Bradley *et al*. 2005; Gehring *et al*. 2010). All of these methods have been tested to some extent on both wolves and coyotes in North America, with most producing temporarily effective, or generally ineffective, results. Although canids will avoid new objects in their environment, their ability to rapidly learn about and accept these objects (e.g. RAG boxes, fladry) is

commonly observed. A non-lethal method to reduce canid and livestock conflicts is needed that does not rely on hazing, translocation, or a short-lived frightening device, yet effectively deters depredations.

The scent-marking behaviour of wild canids provides an opportunity to develop a non-lethal tool that can be used to mitigate the canid–livestock conflict. Wild canids will often use chemicals to transfer information between individuals via scent marking. Scent marking involves deposition of urine or scat at a prominent landmark or trail junction (Barja *et al*. 2004), sometimes over another individual's scent mark (i.e. over-marking). Scent marks contain pheromones, chemical signals that elicit responses from other individuals. Pheromones are substantially different from auditory or visual forms of communication because they can remain in the environment for extended periods of time, are effective even at night, and can transmit their message around objects (Feldhamer *et al*. 2004). Canids, particularly dominant individuals (Rothman and Mech 1979), routinely use scent marks to maintain territories and avoid conflict. Moorcroft *et al*. (1999) showed that coyotes maintained territories and moved away from foreign scent marks of adjacent packs. Peterson (1977) reported that wolves on Isle Royale reversed direction of travel and retreated when they encountered a foreign scent mark along the edge of their territory. Scent marks are routinely maintained and are so important to territory maintenance that coyotes in Yellowstone National Park usurped the territory of an adjacent pack within 3 days of the death of one of the α animals of the adjacent pack (Gese 1998). Additionally, Rothman and Mech (1979) observed that lone wolves, in an apparent attempt to go undetected by resident wolves, seldom scent marked along roads and trails when dispersing through occupied wolf habitat. Because canids are generally territorial, we hypothesised that their movements could be manipulated by constructing 'biofences' made of conspecific scent marks. Our objective was to manipulate grey wolf movements using human-distributed scent marks in central Idaho, USA, during summers 2010 and 2011. We predicted that the use of portions of wolf territories excluded by biofencing would decrease after biofence deployment.

Materials and methods

Study area

We tested the effectiveness of biofencing near Garden Valley, Idaho, USA, from June to August 2010 and 2011. The study area is mountainous and is dominated by a mix of ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*) and spruce (*Picea englemannii*) forests. Annual precipitation ranges from 89 to 178 cm and temperatures range from −34°C in winter to 38°C in summer (Western Regional Climate Center 2011).

Field methods

We evaluated biofencing in three wolf packs (Archie Mountain, Timberline and Wapiti packs) that fluctuated between 8 and 14 individuals and whose annual movements were well documented (USA Fish and Wildlife Service 2005, 2006, 2007, 2008, 2009). These three packs occupied a core area of wolf habitat in central Idaho where pack territories are contiguous and wolf density is relatively high (~12 wolves per 1000 km^2; Stenglein *et al*. 2010). Location data from GPS-collared wolves in each pack provided from three to four locations per wolf each day. Several major roads and trails bisected the territories of these packs and provided reasonable access for deploying biofences and for sampling wolf signs. We wanted to select areas for biofencing that we could reasonably assume the pack would normally use if the biofence were not in place. We, therefore, mapped 2008 and 2009 summer (from 15 May to 15 September) location data for satellite-collared wolves (Archie 2008, $n = 3$; Archie 2009, $n = 4$; Timberline 2008, $n = 2$; Timberline 2009, $n = 4$; Wapiti 2009, $n = 3$) in the three wolf packs (only 2009 data were available for Wapiti). To supplement knowledge from local biologists about pack movements and habits, we pooled location data from collared wolves in each pack and used Home Range Tools in ArcGIS 9.3 (ESRI, Redlands, CA, USA) to generate a kernel-density estimator (smoothing parameter = 80% of href) and quantitatively determine areas used by the resident wolf packs during two summers (except Wapiti pack, where just 1 year of data existed). We did not think that biofencing would be effective at manipulating wolf movements in the core of their territory. We, therefore, selected areas in the territories with >50% kernel density estimates and reasonable access for sampling, as candidates for biofencing. In early June 2010, we placed biofences that began at the 75% kernel-estimate areas of use and radiated out to the territory edge. We altered the Wapiti and Timberline biofences slightly in early June 2011, to attempt to achieve independence between years. We constructed the Wapiti biofence, beginning at the 50% kernel-estimate areas of use and altered the Timberline biofence to begin at the 75% kernel estimate, to exclude more of their territory and bisect the 50% and 75% kernel-estimate areas of use (Figs 1–5). The Archie Mountain biofence remained the same in both years, to avoid potential interference with ongoing elk (*Cervus elaphus*) research in the area. In addition, we opportunistically placed a biofence in 2010 between the rendezvous site of Timberline wolf pack and a band of domestic sheep ($n = 2400$) at a distance of <1.6 km. This area began at the edge of the estimated 50% kernel-density core area of the pack.

We used scats and urine from wolves other than those in the resident pack when constructing our biofences, although we could not feasibly control for the sex and status of the wolves whose scats we collected. In winter 2009/2010, we collected scats from three wolf packs in western Montana where we had detailed knowledge of their historic movements and use of road and trail systems, specifically the Deborgia, Dutch and Ninemile wolf packs. In winter 2010/2011, we collected scats from the Big Hole, Dutch and Ninemile wolf packs in western Montana (30 8-h days each winter). We placed scats in individual plastic bags and labelled them by pack origin. We purchased wolf urine ($60US L^{-1}) from Leg Up Enterprises (Lovell, ME, USA). To create scratch marks, we initially used wolf paws collected by Idaho Department of Fish and Game from dead 42-kg and 41-kg male wolves, both of unknown pack status. We were unable to keep wolf paws from degrading in the field and, beginning in mid-summer 2010 through 2011, we placed a piece of scat on the tip of a stick and scratched the ground with the stick to simulate scratch marks.

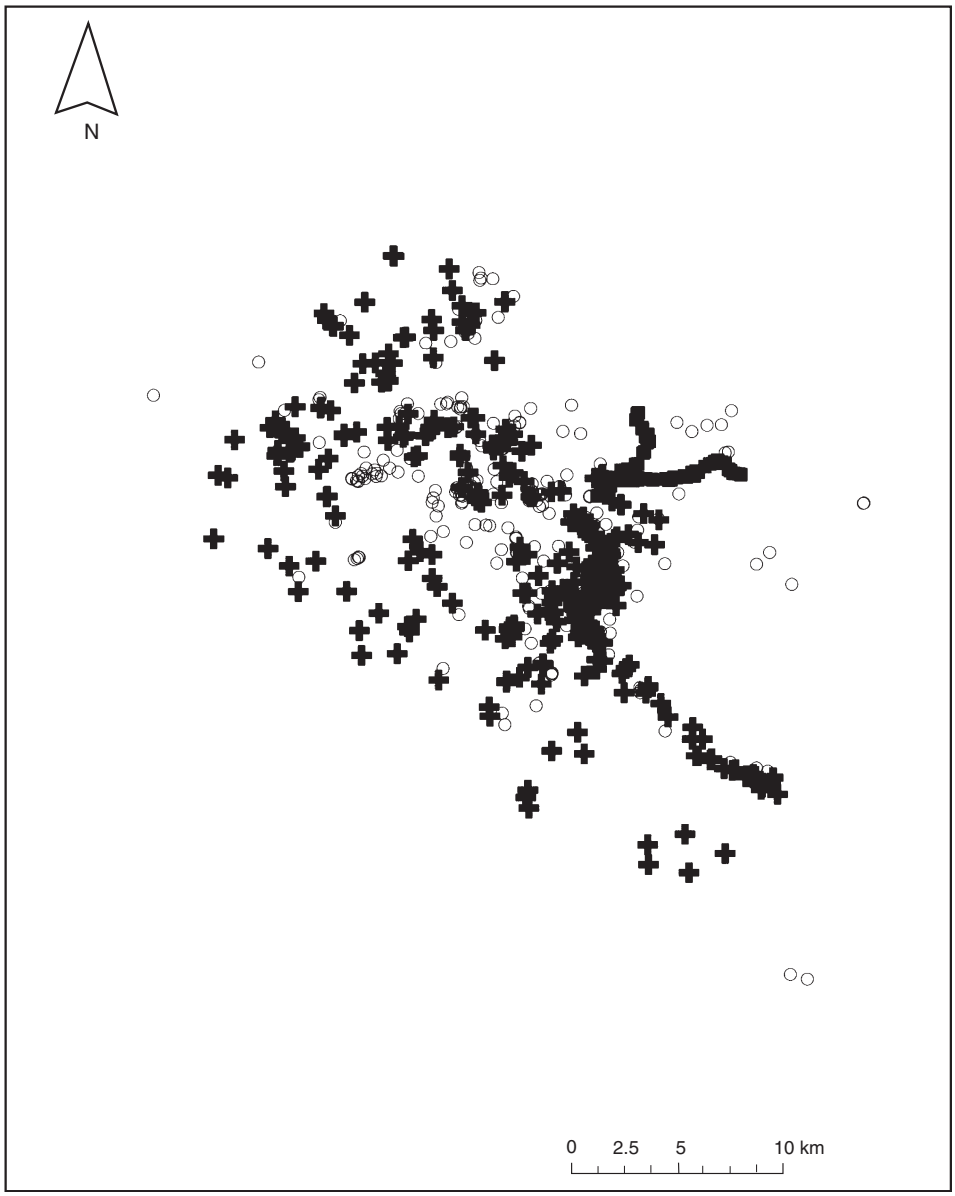

Fig. 1. Locations of the biofence and satellite collars of Wapiti wolf pack in 2010, Idaho, USA. Dark squares are the locations of the biofence. Open circles are wolf locations before biofence deployment in Summer 2009 and black crosses are the locations of two resident wolves after biofence deployment (7 June–31 August 2010).

Each biofence consisted of a primary line of scent marks and a parallel secondary line that was offset from placement of marks in the primary line (at a 45° angle, and a distance of 100 m). To create scent marks for our biofences, we simulated four behaviours used by wolves when marking territories, including raised-leg urinations (RLUs), squat urinations (SQUs), scats and scratch marks accompanied by a RLU and scat. We placed RLUs approximately every 500 m by spraying a stream of 3.0 mL of urine at 30.5-cm height on a rock or other prominent object. We deployed SQUs approximately every 750 m, using 6.0 mL of urine sprayed directly onto the ground, and placed scats approximately every 1 km. We deployed scratch marks approximately every 2 km by depositing a scat at the base of a prominent object, spraying the object with an RLU, and then scratching the ground 1.2 m from the scat, throwing dirt towards the excrement. We also overmarked any observed scats from resident wolves with a RLU. We inserted toothpicks 75% into deployed scats to allow us to detect scats that may have been deposited as overmarks by resident wolves. We recorded simulated scent mark locations with a GPS and wrote a brief description of each site. Scats collected from a single pack in western Montana were deployed in a single pack in Idaho (e.g. scats from the Dutch pack in Montana were the only scats deployed in the territory of Timberline pack in Idaho). From early June to late August, we refreshed simulated scent marks between 10 and 14 days and recorded whether resident wolves

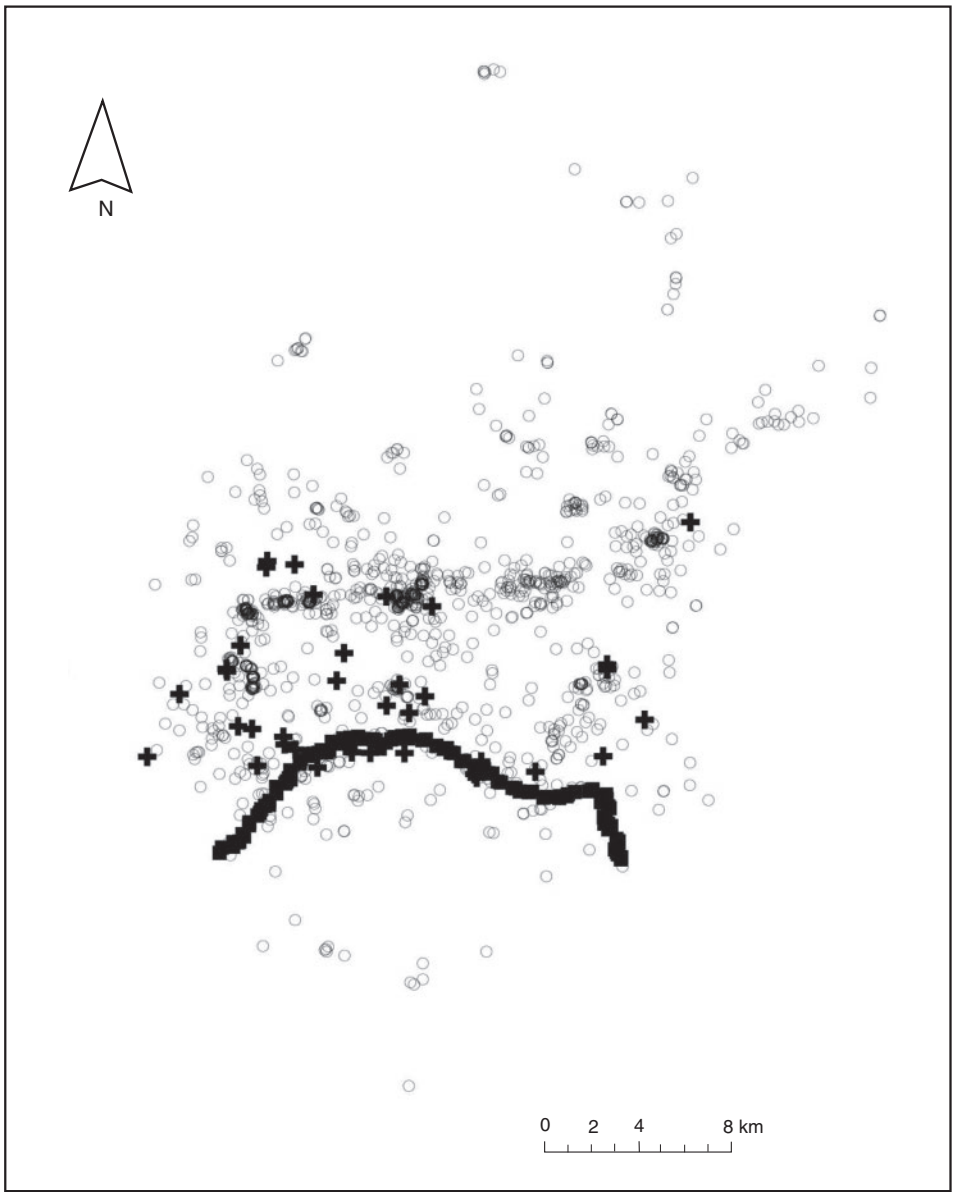

Fig. 2. Locations of the biofence and satellite collars of Archie wolf pack in 2010, Idaho, USA. Dark squares are the locations of the biofence. Open circles are wolf locations before biofence deployment in Summers 2008 and 2009. Black crosses are the locations of one resident wolf after biofence deployment (3 July–2 September 2010).

had investigated (via tracks present at scent mark) or overmarked the marks (Rothman and Mech 1979; Gese 1998; Jedrzejewski *et al*. 2001; Mech and Boitani 2003).

We used a combination of metrics to assess the effectiveness of our biofencing. First, we used location data provided by satellite collars in Archie Mountain ($n=1$ in 2010, $n=2$ in 2011), Timberline ($n=2$ in 2011) and Wapiti ($n=2$ in 2010, $n=3$ in 2011) wolf packs to summarise the number of trespass locations across biofences. Some level of territorial trespass is common in wolf packs (Mech and Boitani 2003). Historically, the percentage of locations of wolves in Idaho that trespassed into the territory of an adjacent pack ranged from 0.6% to 10.0% and wolves were not detected farther than 2.8 km into the territory of the adjacent pack (D. Ausband, unpubl. data). Trespass distance was calculated as the shortest straight-line distance to the biofence. Second, because we experienced a large number of collar failures, we conducted sign surveys at 20 potential rendezvous sites (Ausband *et al*. 2010) in the exclusion areas created by our biofencing in the territories of Archie Mountain and Timberline packs. Technicians went to highly suitable rendezvous-site habitat, gave a series of wolf howls, then surveyed each site for $\geq$30 min to look for tracks and scat. Third, because of the particular history and proximity to sheep of the pack, we assessed whether the Timberline wolf pack was implicated in any sheep depredations while the biofences were deployed.

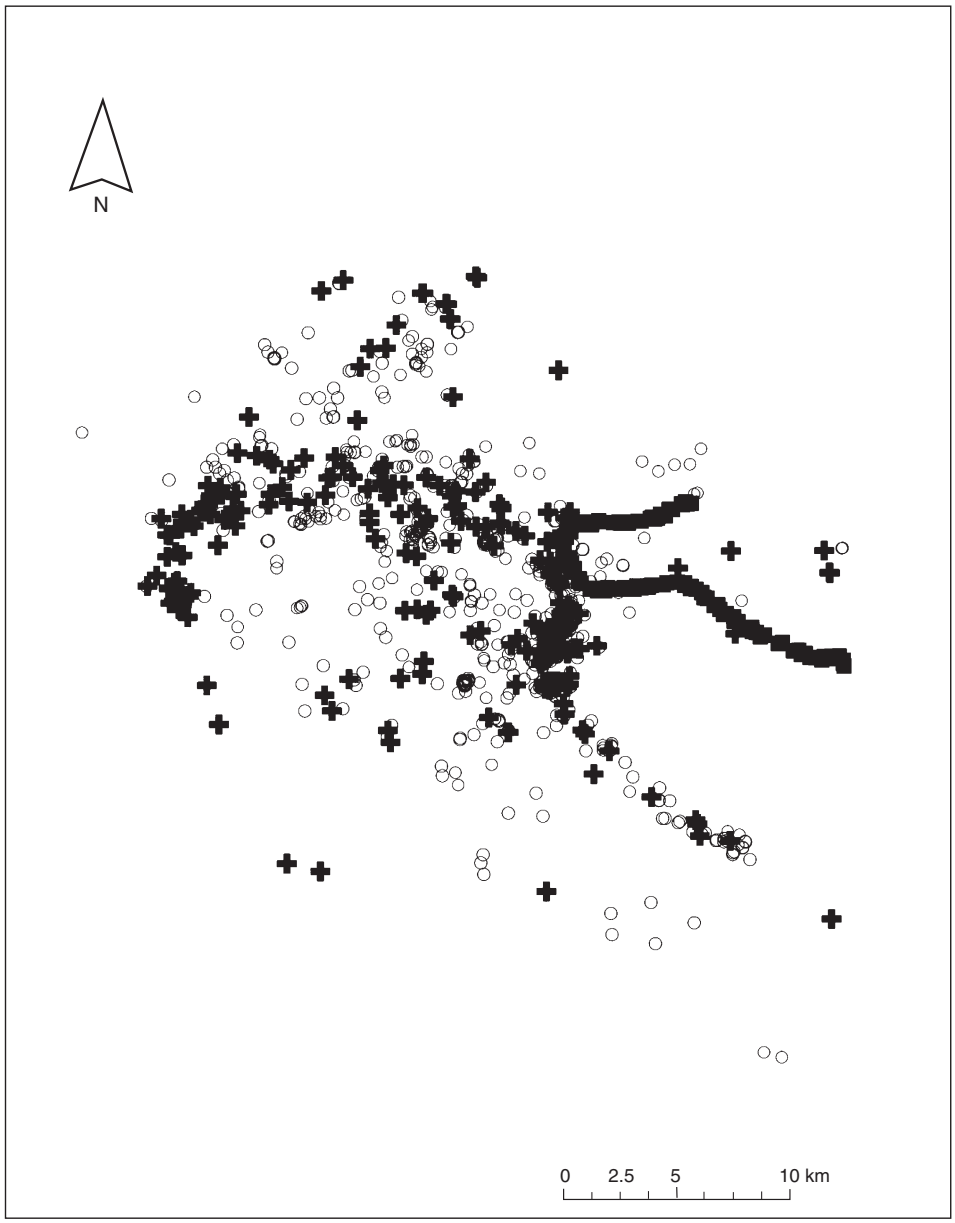

Fig. 3. Locations of the biofence and satellite collars of Wapiti wolf pack in 2011, Idaho, USA. Dark squares are the locations of the biofence. Open circles are wolf locations before biofence deployment in Summers 2009 and 2010. Black crosses are the locations of three resident wolves after biofence deployment (6 June–28 August 2011).

Results

Effort of biofence deployment

In 2010, we deployed 19.2 km of biofence in Archie Mountain, 35.7 km in Timberline and 9.8 km in Wapiti wolf-pack territories, using 440 scats collected in winter 2009/2010 and 11.4 L of urine. In 2011, we deployed 21.8 km of biofence in Archie Mountain, 23.0 km in Timberline and 20.0 km in Wapiti wolf-pack territories. We deployed 505 scats collected in winter 2010/2011 and 12.0 L of urine. Scat collection was most efficient in late spring when snow began to melt and scats deposited over winter were observable yet still intact. While deploying the biofences in 2010, we overmarked 27 resident wolf scats on the primary line and six resident wolf scats on the secondary line. In 2011, we overmarked 65 resident wolf scats on the primary line and two resident wolf scats on the secondary line while deploying the biofences. Resident wolves overmarked, or investigated, 6.1% of components on the primary line and 2.8% on the secondary line of the biofences in 2010, whereas in 2011, they overmarked or investigated 5.7% of components on the primary line and 1.1% of components on the secondary line. It is difficult to detect RLU or SQU overmarks without snow cover and it is likely that some urine overmarks went undetected both years.

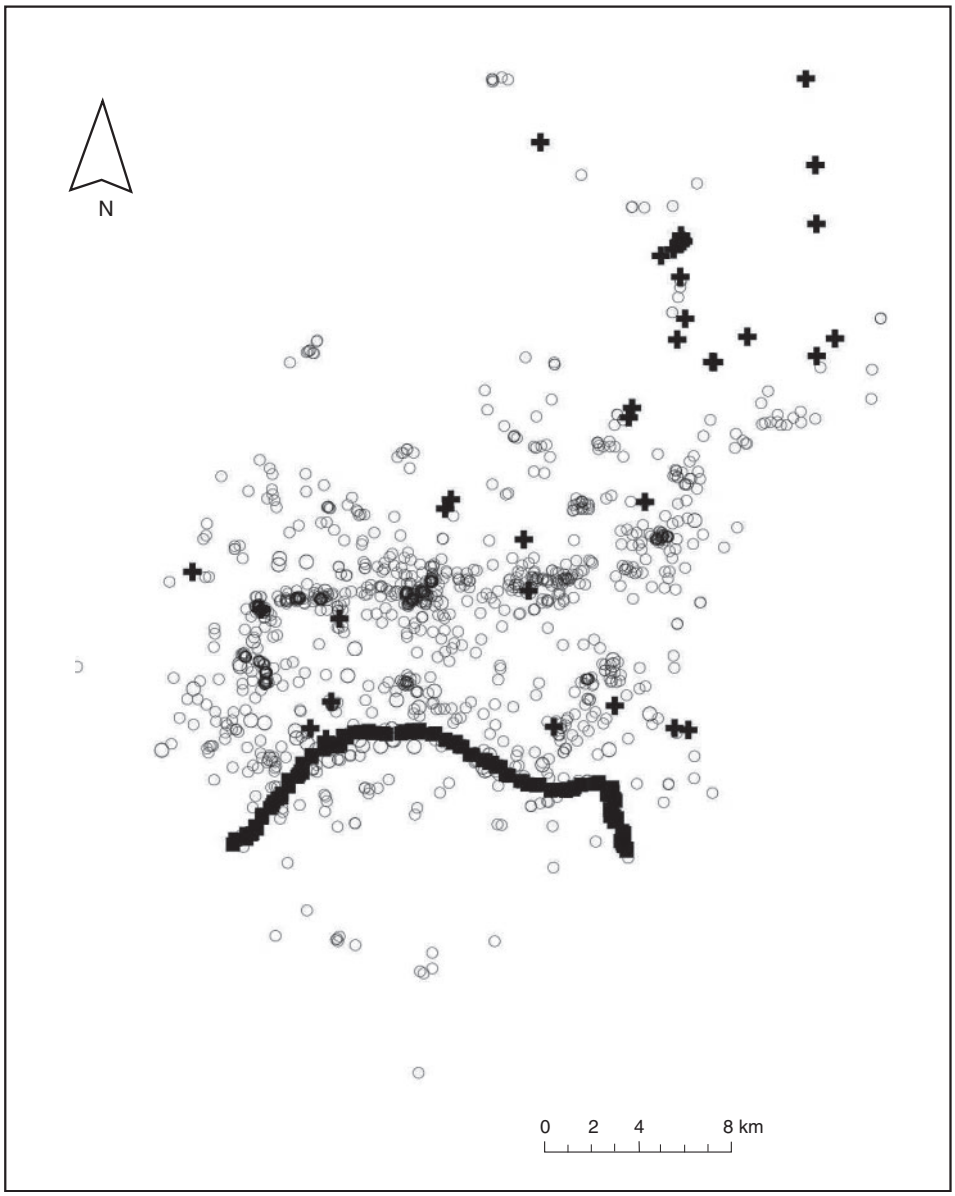

Fig. 4. Locations of the biofence and satellite collars of Archie wolf pack in 2011, Idaho, USA. Dark squares are the locations of the biofence. Open circles are wolf locations before biofence deployment in Summers 2009 and 2010. Black crosses are the locations of two resident wolves after biofence deployment (24 June–28 August 2011).

For both years, it took two technicians 1 day to deploy an average of 5.1 km and 1 day to refresh an average of 7.7 km of two-walled biofence.

Biofence effectiveness in Summer 2010

Location data from satellite-collared wolves in the Wapiti pack indicated no trespass of our biofences in 2010 (Table 1, Fig. 1). The collared wolf in the Archie Mountain pack had nine locations in the exclusion area, although the trespass distance was very short (average = 0.46, range 0.29–0.65 km), as was the average maximum duration of 17.5 h (range ≤15–22.5 h; Table 1, Fig. 2). This resident Archie wolf trespassed 10 days after the biofence was refreshed (s.e. = 1.4 days, range 5–14 days). Sign surveys in 2010 yielded wolf scat at 20% of potential rendezvous sites in areas excluded by our biofences, although these scats ($n = 4$) appeared old (i.e. crumbly and chalky, or consisting of mostly hair, with little fecal matter present) and were likely deposited before biofence deployment. We detected seven incidental scats while travelling to the predicted rendezvous sites. These seven scats were clustered (1.3-km radius), appeared old and were 4.0 km from the den site of the resident pack used in the spring. We did not detect tracks or obtain howl responses at the 20 predicted rendezvous sites. The Timberline wolf pack did not depredate sheep during Summer 2010.

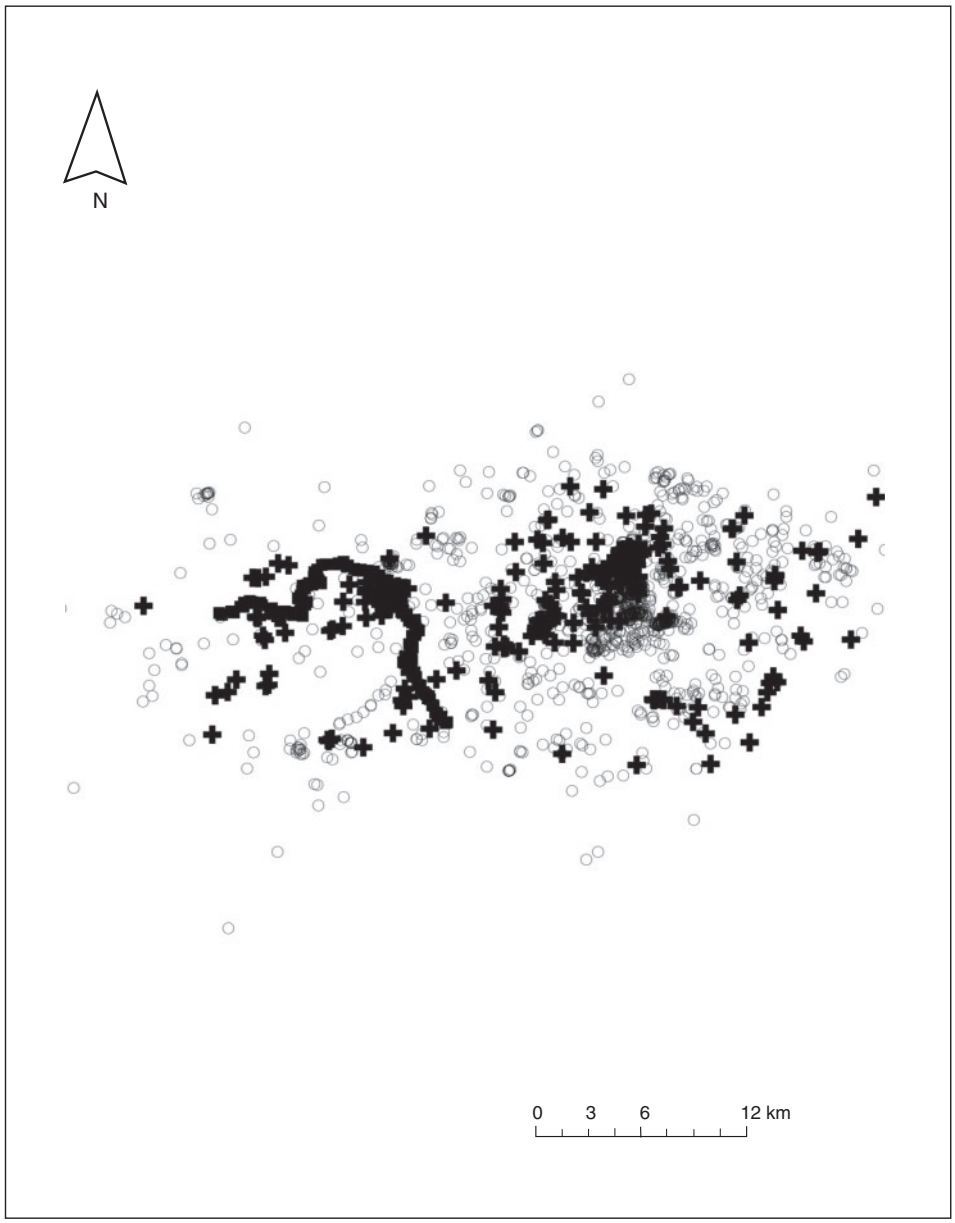

Fig. 5. Locations of the biofence and satellite collars of Timberline wolf pack in 2011, Idaho, USA. Dark squares are the locations of the biofence. Open circles are wolf locations before biofence deployment in Summers 2008 and 2009. Black crosses are the locations of two resident wolves after biofence deployment (28 June–31 August 2011).

Biofence effectiveness in Summer 2011

In 2011, the collared wolves in the Wapiti pack showed limited trespassing, with seven trespasses averaging 1.87 km (s.e. = 0.87 km, range ≤0.10–3.45 km) and an average maximum duration of 22.5 h (range ≤15–30 h; Table 1, Fig. 3). The satellite-collared Archie Mountain wolves indicated no trespass of our biofences (Fig. 4), whereas the satellite-collared Timberline wolves trespassed 85 times, with an average distance of 1.56 km (s.e. = 0.29 km, range ≤0.87–6.90 km) and average maximum duration of 27.8 h (range ≤1.5–108.5 h; Table 1, Fig. 5).

Similar to 2010, most trespassing of biofences occurred approximately 1 week or more after the biofence was refreshed. In 2011, resident wolves in the Wapiti and Timberline wolf packs trespassed 6 days after the biofences were refreshed. Wapiti wolves trespassed an average of 6.8 days after refreshment (s.e. = 1.0 days, range 4–9 days) and Timberline wolves trespassed an average of 6.3 days after refreshment (s.e = 0.3 days, range 1–13 days).

Discussion

Results from 2010 suggested that the movements of wolves could be manipulated with biofencing; however, the results in 2011 indicated that biofencing did not have a measurable effect on wolf-pack movements. In 2010, both location and

Table 1. Resident wolf packs and their biofence trespass activity, central Idaho, USA, before and after biofence deployment, 2008–2011

Year	Pack	Before or after biofence deployment	Number of days pack monitored	Number of locations	Number of trespass locations (%)	Average distance trespassed (km)	Average max. time trespassed (h)
2008	Archie	Before	124	717	36 (5.0)	1.2	33.0
2009	Archie	Before	124	629	37 (5.9)	2.9	28.9
2010	Archie	After	87	40	9 (22.5)	0.4	17.5
2011	Archie	After	66	41	0	0	0
2008	Timberline	Before	124	622	8 (1.3)	0.8	18.1
2009	Timberline	Before	124	785	95 (12.1)[A]	3.1[A]	33.4[A]
2011	Timberline	After	65	425	85 (20.0)	1.6	27.8
2009	Wapiti biofence 1	Before	100	323	7 (2.2)	1.4	27.5
2010	Wapiti biofence 1	After	86	456	0	0	0
2009	Wapiti biofence 2	Before	100	323	9 (2.8)	1.1	20.8
2010	Wapiti biofence 2	Before	86	456	6 (1.3)	0.6	20.6
2011	Wapiti biofence 2	After	84	358	7 (2.0)	1.9	22.5

[A]In 2009, Timberline had locations >10 km from where the biofence would be deployed in 2010. Including these 'outlier' locations, the number of trespass locations before deployment increased to 136 (17.3%) for an average distance of 10.2 km and an average maximum of 38.8 h.

sign-survey data indicated that resident wolf packs showed limited use of the exclusion areas. Overmark and collar-location data suggested these wolves approached the biofence, and even walked along it, but then returned in a direction towards the centre of their territory rather than trespass the biofence. In 2011, however, the wolves, particularly the Timberline α female, showed little aversion to trespassing the biofence. For most wolves, both the distance and duration of the trespasses we observed in both years were relatively short and within the normal range of trespass reported for neighbouring packs (Mech and Boitani 2003). Brief trespassing events may explain why sign and howling surveys indicated little to no wolf use of portions of the resident-wolf territories excluded by the biofences in 2010. For example, we observed no tracks in the exclusion areas in 2010, despite a historic track-detection rate of 18.8% at sites in this region (Ausband *et al*. 2010). Trespass that is short in duration and distance may also explain why wolves in the Timberline pack did not prey on sheep during summer 2010, despite their rendezvous site being <1.6 km from a band of 2400 sheep. This pack has been implicated in multiple depredations in one of the exclusion areas in previous years; however, none was reported in this area in Summer 2010 or Summer 2011. These results are unexpected, given the level of trespass we observed in Timberline in 2011; trespassing took place, but depredations did not. We readily acknowledge the role that sheep herders may have played in averting wolf depredations in 2010 and 2011, although herders were ineffective in previous years when their presence did not deter depredations on both sheep and guard dogs by this pack. The Archie Mountain pack did not trespass the biofence in 2011; however, this pack failed to successfully breed in 2011 and may be disbanding, making interpretation of their response to the biofence difficult (D. Ausband, unpubl. data). Two satellite collars in this pack failed to obtain locations on a regular basis, so knowledge of their movements is limited.

One potential explanation for the disparity in biofence effectiveness between years may be that we did not deploy biofences year-round and maintain the perception of a continuous presence of the adjacent pack. Additionally, because of the difficulties in obtaining sufficient numbers of scats from the wild for use in biofence deployment, we were unable to control for whether a pack consistently encountered (via scent) the same individuals when visiting our biofences. If resident packs detected discontinuity in the presence of established, adjacent wolves (i.e. the biofence), they could have been less averse to crossing the biofence in 2011 than they were in 2010. Any further research on biofencing should attempt to maintain the biofence over a longer timeframe, while controlling for pack affiliation (or individual if possible) of the scats used during biofence and maintenance. Last, wolves may have showed less aversion to the biofence over time because there were no visual or auditory cues indicating the presence of another pack in the immediate area of the biofence.

The social status of a wolf affects its response to foreign scent marks (Rothman and Mech 1979); however, with four dominant-status wolves (6 wolf-years) radio-collared, we did not detect a strong trend between trespass and social status. Additionally, we would expect the dominance of the individual whose scent mark was deployed on the biofence to have an effect on biofence efficacy. Seasonality and associated pheromone levels in scats and urine also play a role in how canids respond to foreign scent marks. Controlling for these factors is, of course, difficult in a field-based study using wild wolf scats. Exploring the effectiveness of using more easily obtainable, and selectable, scats from captive wolves would be worthwhile.

Wolves travel roads and established trails and the deployment and maintenance of the primary line of the biofences required less time and effort than the secondary line which was generally off-trail. Wolves, however, seldom overmarked the secondary line of the biofence and one line may be sufficient, thereby greatly decreasing biofence deployment and refreshment time. Given that trespass between adjacent wolf packs is expected and common (Mech and Boitani 2003), we suggest placing biofences between 2 and 3 km from an attempted exclusion area. On the basis of the average trespass distances observed, we believe this would be a suitable distance when using biofencing to create an adequate buffer between resident wolves and the attempted exclusion area.

We have limited inference to other canids, although similar experiments with this technique have shown promise in African wild dogs (*Lycaon pictus*; Jackson *et al*. 2012). Shivik *et al*. (2011) recently found that biofencing using only urine was ineffective for manipulating the movements of three coyotes, whereas Arnold *et al*. (2011) found that the use of territory by red fox (*Vulpes vulpes*) decreased in females and increased in males following deployment of conspecific urine. We do not know why biofencing would be ineffective for coyotes and equivocal for red foxes, although the addition of scats and scratch marks may have made it more effective as a deterrent to movement, had they been used. Smaller canids may respond more strongly to biofences if they are constructed with scent marks of larger, dominant species (e.g. wolves). Indeed, some studies have indicated that urine and scat from dominant species can manipulate the movements of other species, although results have been mixed (Paquet 1991; Scheinin *et al*. 2006). A major goal when deploying a biofence is to have the target species visit, investigate and respond in a directional manner to the scent marks; therefore, any future work should continue to focus on the animal's response after encountering the scent mark and not just whether the animal investigated the urine or scat deposit.

Our sample size ($n = 3$ packs) and limited study design (i.e. no controls) limit generalisation, and further evaluation of biofencing is needed to determine its efficacy for deterring depredations by wolves and other canids. Furthermore, surrounding natural prey density may confound the effectiveness of biofencing near livestock. A study that samples many animals per pack and employs a treatment and control design would be beneficial, albeit expensive and logistically difficult. Additionally, testing the efficacy of biofencing in core portions of an animal's territory or near livestock producers that have experienced persistent depredation events would be useful. More frequent refreshing, an adequate buffer distance (range 2–3 km) from the area to be excluded, and the use of automated howling devices (Ausband *et al*. 2011) may fortify biofencing (Harrington and Mech 1979) and increase its effectiveness. Our work suggests, however, that biofencing may be most limited by the apparent necessity to maintain a continuous presence once the biofence is established. The inherent labour and costs associated with such efforts may limit the usefulness of biofencing.

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