Wildlife barriers: The effectiveness of electrified barriers to keep large mammals out of fenced road corridors

NDOT Research Report No. 701-18-803 TO 6 Part 2

Wildlife Vehicle Collision Reduction and Habitat Connectivity Pooled Fund Study, TPF-5(358)

REDUCE Wildlife Vehicle Collisions

INCREASE Habitat Connectivity

IMPLEMENT Cost Effective Sollutions

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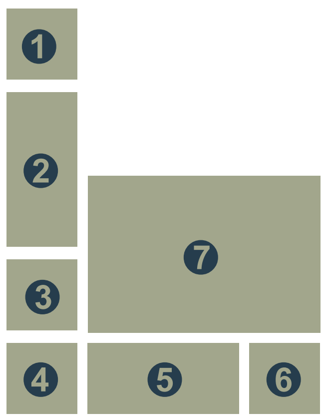

❶ M. Huijser, WTI/MSU
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❹ M. Huijser, WTI/MSU
❺ M. Huijser, WTI/MSU
❻ M. Huijser, WTI/MSU
❼ M. Huijser, WTI/MSU

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NDOT Research Report

Report No. 701-18-803 TO 6 Part 2

TPF-5(358) PART 2 - WILDLIFE BARRIERS: THE EFFECTIVENESS OF ELECTRIFIED BARRIERS TO KEEP LARGE MAMMALS OUT OF FENCED ROAD CORRIDORS

September 2022

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

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16. Abstract

For this project the researchers investigated the effectiveness of different types of electrified barriers for varying traffic volume and traffic speed. Some barriers were investigated for carnivores only, whereas others were evaluated for both ungulates and carnivores. Finally, we combined the data from our field studies with those reported in the literature and conducted a meta-analysis to investigate the effectiveness of different types and dimensions of barriers for both ungulates and carnivores. In general, electrified barriers can be a substantial barrier to species with paws, including black bears. However, careful maintenance and monitoring is required for these measures to succeed.

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The effectiveness of electrified barriers to keep large mammals out of fenced road corridors

Prepared for

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1263 South Stewart Street

Carson City, NV 89712

For the following larger project:

Wildlife Vehicle Collision (WVC) Reduction and Habitat Connectivity

Task 1 – Cost Effective Solutions

Transportation Pooled-Fund Project TPF-5(358)

(Administered by the Nevada Department of Transportation)

Prepared by:

Marcel P. Huijser, PhD
Samantha C. Getty, BSc

30 September 2022

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DISCLAIMER

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SUMMARY

Most wildlife mitigation measures along highways are aimed at improving human safety, reducing direct wildlife mortality, and providing safe crossing opportunities for wildlife. Fences in combination with wildlife crossing structures are probably the most effective combination of mitigation measures to achieve these objectives. For fences to be reliably reducing collisions with large wild mammals by 80% or more, at least 5 kilometers (3 miles) of road length needs to be fenced, including a buffer zone that extends well beyond the known hotspots for wildlife-vehicle collisions. Collisions that still occur within the fenced road sections tend to be concentrated near the fence-ends. In addition, gaps in fences, including at access roads, can result in concentrations of collisions inside fenced road sections.

Gates are commonly used at gaps in the fence at access roads with low traffic volume, but they are often left open allowing wildlife to access the road. While single wide cattle guards or wildlife guards (2.1-3.0 m) can be effective for some ungulate species, double wide cattle or wildlife guards (4.6-6.6 m (15-22 ft)) consisting of round bars or bridge grate material, situated above a pit, are generally recommended for ungulates. However, such guards are not a substantial barrier for species with paws, including many carnivore species. Electrified mats or electrified guards can be a barrier for both ungulates and species with paws, but to prevent animals, especially ungulates, from jumping across the barrier, they need to be 4.6-6.6 m (15-22 ft)) wide. Combinations of electrified barriers and non-electrified guards are also possible.

For this project the researchers investigated the effectiveness of different types of electrified barriers for varying traffic volume and traffic speed. Some barriers were investigated for carnivores only, whereas others were evaluated for both ungulates and carnivores. Finally, we combined the data from our field studies with those reported in the literature and conducted a meta-analysis to investigate the effectiveness of different types and dimensions of barriers for both ungulates and carnivores.

In general, electrified barriers can be a substantial barrier to species with paws, including black bears. However, careful and consistent maintenance and monitoring is required for these measures to succeed.

1 INTRODUCTION

Most wildlife mitigation measures along highways are aimed at improving human safety, reducing direct wildlife mortality, and providing safe crossing opportunities for wildlife (e.g. Ford et al. 2009; van der Grift et al. 2017). Fences in combination with wildlife crossing structures are probably the most effective combination of mitigation measures to achieve these objectives (Clevenger & Waltho 2000; Rytwinski et al. 2016). For fences to be reliably reducing collisions with large wild mammals by 80% or more, at least 5 kilometers (3 miles) of road length needs to be fenced, including a buffer zone that extends well beyond the known hotspots for wildlife-vehicle collisions (Huijser et al. 2015; Huijser et al. 2016a). Collisions that still occur within the fenced road sections tend to be concentrated near the fence-ends (Huijser et al. 2016b; 2022; Plante et al. 2019). In addition, gaps in fences, including at access roads, can result in concentrations of collisions inside fenced road sections (Sawyer et al. 2012; Cserkész et al. 2013; Yamashita et al. 2021).

Gates are commonly used at gaps in the fence at low traffic volume access roads, but they are often left open allowing wildlife to access the road corridor (VerCauteren et al. 2009; Sawyer et al. 2012). While single wide cattle guards or wildlife guards (2.1-3.0 m) can be effective for some ungulate species (Huijser et al. 2015), double wide cattle or wildlife guards (4.6-6.6 m (15-22 ft)) consisting of round bars or bridge grate material, situated above a pit, are generally recommended for ungulates (Cramer & Flower 2017; Gagnon et al. 2020). However, such guards are not a substantial barrier for species with paws, including many carnivore species (Allen et al. 2013; Clevenger & Barrueto 2014; Huijser et al. 2015; 2016; Honda et al. 2020). Electrified mats or electrified guards can be a barrier for both ungulates and species with paws, but to prevent animals from jumping across the mat, they need to be 4.6-6.6 m (15-22 ft)) wide. Combinations of electrified barriers and non-electrified guards are also possible (Gagnon et al. 2020).

For this project we investigated the effectiveness of different types of electrified barriers for varying traffic volume and traffic speed (Table 1). Some barriers were investigated for carnivores only, whereas others were evaluated for both ungulates and carnivores. Finally, we combined the data from our field studies with those reported in the literature and conducted a meta-analysis to investigate the effectiveness of different types and dimensions of barriers for both ungulates and carnivores (Chapter 5).

Table 1: Barriers at gaps in fence (access roads or fence-ends) that are investigated for this project. The letters and numbers between parentheses refer to different experiments further described in the text.

	Traffic speed		
Traffic volume	**Low (<10 MPH (<16.1 km/h))**	**Medium (10-<45 MPH (16.1-<72.5 km/h))**	**High (45-70 MPH (7.5-112.7 km/h))**
Low (a few vehicles/day, local landowner)	Electrified gates without wildlife guards and electrified drive-over wires (Dixon Melon Farm, Chapter 2)		
Medium (dozens of vehicles/day)	Drive-over mat (Dixon Melon Farm, Chapter 2)	Drive-over mat (Dixon Melon Farm, Chapter 2)	
High (e.g. up to hundreds or thousands of vehicles per day)		Electrified wildlife guards (Parks Canada, Chapter 3)	Electrified mats integrated in pavement (Thompson Falls, Chapter 4)

2 ELECTRIFIED GATES AND DRIVE-OVER BARRIERS AT THE DIXON MELON FARM, MONTANA

2.1 Introduction

In this chapter we investigate the barrier effect of an electric fence and different types of electrified barriers in keeping black bears (*Ursus americanus*) out of a melon patch near Dixon, Montana. In the past, the farmer has seen up to 7 individual black bears eating melons in the patch at the same time (personal communication Cassie Silvernale) In 2019, before the electrified fence and barriers were put in place, the economic losses because of black bears were estimated at 5% of the crop or about 5,000 melons (Andrews 2020) (Figure 1). It is not good for black bears either as eating melons with high sugar and carbon content may affect their health, e.g. through tooth decay. Furthermore, reducing conflict between farmers and bears in general, can help build a willingness to co-exist on the same landscape (e.g. Wilson et al. 2017). Depending on the location this may benefit both black bears and grizzly bears (*Ursus arctos*), as well as other species that may eat commercial crops and that are present in the area. Because farm vehicles need access to the melon patch, electrified barriers were installed at the vehicle access points. This included a swing gate, and different types of drive-through and drive-over barriers. Although the effectiveness of these barriers was investigated on private land, the results may be applicable to low traffic volume and low traffic speed access points along fenced public highways.

Figure 1: Half-eaten melon by a black bear at the melon patch.

2.2 Methods

2.2.1 Study Area

The study area is a melon patch (about 8 ha (20 acres)) located immediately south of the Bison Range, about 2 miles west of Ravalli, Flathead Indian Reservation, Montana (Figure 2). The melon patch is just north of MT Hwy 200, and just south of the Jocko River and the associated trees and shrubs in the riparian area (Figure 3). While the patch was dominated by different varieties of melons, there was also some corn planted along an edge of the field.

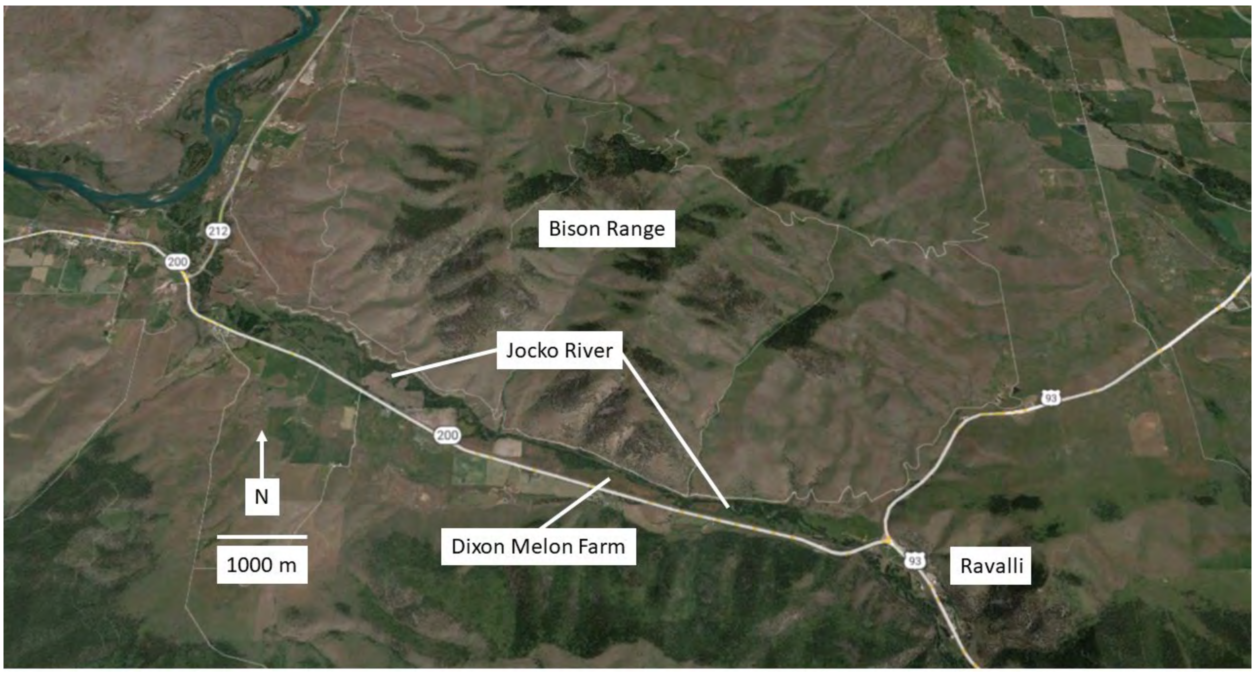

Figure 2: The location of the melon patch.

2.2.2 Electric Fence and Barriers at Vehicle Access Points

A Non-Governmental Organization, “People and Carnivores”, built an electric fence around the melon patch in the summer of 2020 (Figure 3). The fence was constructed before the harvest of the melons, to keep black bears, and potentially also grizzly bears, out of the melon patch. In addition, electrified barriers were installed at 4 vehicle access points to the melon patch (Figure 3). The electric fence consisted of 4 wires attached to composite fence posts made from polypropylene and wood (PasturePro®) (Figure 4), similar to designs used by others to keep different bear species from accessing crops and other attractants (Huygens & Hayashi 1999, Otto & Roloff 2015, Khorozyan & Waltert 2020). Corner posts and braces, including at vehicle access points, were treated wood posts. The height of the fence was just about 3 ft (91 cm) (Figure 4). This fence was designed to keep both black bears and grizzly bears out of the melon patch. It was not designed to keep other species from accessing the melon patch; ungulates (e.g. white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), and elk (*Cervus canadensis*)) can easily jump this fence. The farmer sprayed herbicides along the fence to reduce voltage drop. At first, the 2nd wire from the bottom was a designated ground wire, with the other 3 wires being hot (i.e. carrying current). After 27 August 2020, the 2nd wire from the ground was made into a hot wire also, which meant that from then on, the current received by an animal depended on the contact points of the animal with the ground, which varies with the conductivity of the animal itself, and the conductivity of the ground or vegetation. A solar panel, and associated battery and energizer powered the fence and all 4 access points. However, from 6 August 2021 onwards, access point 3 had the drive-over mat installed which was powered by its own solar panel and associated battery and energizer.

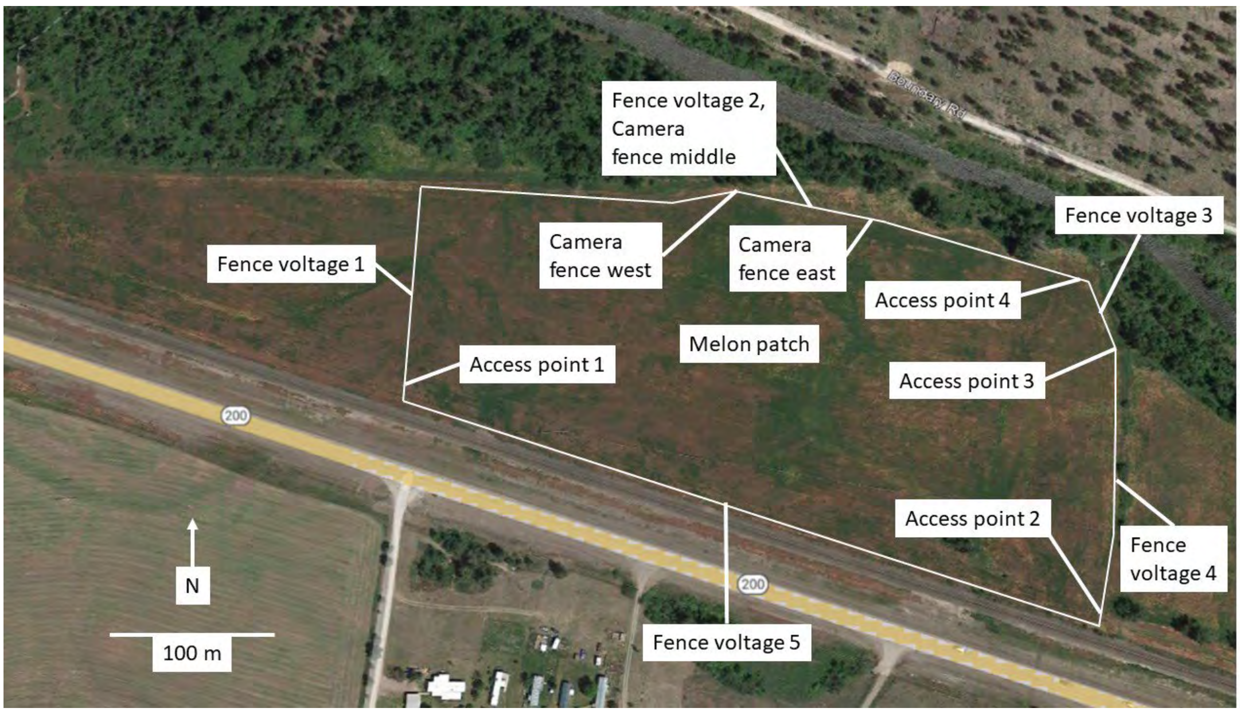

Figure 3: The melon patch (roughly 450 m (525 yds) east-west and 180 m (197 yds) north-south), the electric fence (white line), the 4 vehicle access points, the 5 locations along the fence where fence voltage was measured, and the location of 3 cameras placed along the fence.

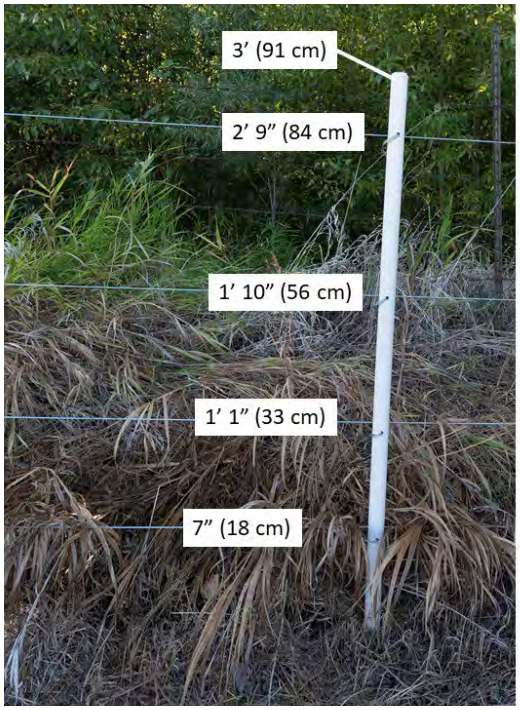

Figure 4: The approximate height and wires of the electric fence.

The researchers evaluated 5 different electrified barrier designs at 4 access points in 2020 and 2021 (Table 2, Figures 5-9). In addition, the swing gate at access point 2, and the drive-over mat at access point 3 were monitored from 23 May 2022 until 25 Sep 2022. The drive-through bump-gates were originally installed at 2 access points, but 1 of them was modified in 2020. The drive-over wires barrier was replaced by a drive-over mat in 2021 (Table 2).

Table 2: The electrified barrier at the vehicle access points, brand, approximate costs, location, and the period over which they were evaluated.

Electrified barrier type	**Brand, approximate costs (US$)**	**Location**	**Evaluation start-end 2020**	**Evaluation start-end 2021**
Swing gate (modified with 4 hot wires)	Hutchison, $290 for gate only (excl. installation)	Access point 2	10 July 2020 – 12 Dec 2020	28 Apr 2021 – 19 Nov 2021
Bump-gate (not modified)	Koehn, $180, (excl. installation)	Access point 1	10 July 2020 – 12 Dec 2020	28 Apr 2021 – 19 Nov 2021
Bump-gate (not modified)	Koehn, $180 (excl. installation)	Access point 4	10 July 2020 – 27 Aug 2020	None
Bump-gate (modified with netting)	Koehn, $180 (excl. installation, excl. netting)	Access point 4	27 Aug 2020 – 12 Dec 2020	28 Apr 2021 – 19 Nov 2021
Drive-over wires	Fully custom (Bryce Andrews, People and Carnivores), cost under $500 (excl. installation)	Access point 3	10 July 2020 – 12 Dec 2020	28 Apr 2021 – 4 Aug 2021
Drive-over mat	Crosstek™, $11,250 (incl. installation)	Access point 3	None	6 Aug 2021 – 19 Nov 2021

Figure 5: The electrified swing gate (16' (4.88 m) wide, 4'6" (1.37 m) tall, about 7" (18 cm) gap between ground and bottom of gate). The wires were mounted at 6" (15 cm), 1'7" (48 cm), 3'2" (97 cm), and 4'7" (140 cm) above the ground.

Figure 6: A drive-through bump gate (not modified) (about 16’ (4.88 m) wide, about 3’ (91 cm) tall), with vertical electrified wires. The orange horizontal pole is metal and carries current. The green horizontal part is fiberglass and does not carry current.

Figure 7: A modified drive-through bump gate (with conductive netting) (about 16’ (4.88 m) wide, about 3’ (91 cm) tall), with vertical electrified wires and custom conductive netting (about 2’ (61 cm) high) attached.

Figure 8: The drive-over wires, about 14’3” (4.34 m) wide (post-post) and 10’2” (3.10 m) long. The 18 drive-over wires are about 7” (18 cm) above the ground and the gaps between the wires vary between 5-12” (13-30 cm). There are “side-board” wires that angle toward the ground from the post along the sides of the barrier to reduce the likelihood of an animal bypassing the drive-over wires. However, these “side-boards” do not cover the full length of the barrier.

Figure 9: The drive-over mat about 14’3” (4.34 m) wide (post-post) and about 10’ (3.05 m) long. On the far side, the habitat side, there is metal mesh on the ground, connected to a grounding rod (about 2 ft (61 cm) wide). This is followed by 8 sections of 10-11” (25-28 cm) wide expanded metal sheeting (alternating positive and negative (ground)) mounted on wooden planks. This drive-over mat is powered by its own solar panel, battery and energizer.

The fence and the electrified barriers at the 4 access points were modified during the study. The most important modifications, and the associated evaluation periods, are summarized in Table 3.

Table 3: Major modifications to the electrified fence and vehicle access points. The number of days relates to the length of each period with a particular set of conditions.

From	Until	Days (N)	Description of changes that applied to the period
10-Jul-20	21-Aug-20	11	Electricity turned "on" on 10 July 2020 through 12 Dec 2020
21-Aug-20	27-Aug-20	6	Wires lowered at select locations, access points permanently "on"
27-Aug-20	9-Sep-20	13	Mesh added access point 4, motion light fence west, 2nd wire from bottom hot
9-Sep-20	12-Dec-20	94	Additional post and a 5th wire at fence west and fence middle
12-Dec-20	28-Apr-21	N/A	Electricity turned "off on 12 Dec 20, turned back “on” on 28 Apr 2021
28-Apr-21	4-Aug-21	98	Fence "on" on 28 Apr 2021 through 19 Nov 2021
6-Aug-21	19-Nov-21	105	New drive-over barrier at access point 3
19-Nov-21		N/A	Electricity turned “off”

2.2.3 Data Collection

Each access point had a trail camera installed (Reconyx™ PC 900). The cameras fully covered the area up to 2 m (6.6 ft) in front of each access point. The 2 m (6.6 ft) distance from the access point was visible on each image based on the line between the camera’s viewpoint and a stick on the other end. This allowed the researchers to consistently evaluate the behavior of large mammals that approached each access point within 2 m (6.6 ft). The researchers evaluated whether the animals succeeded in accessing the melon patch by crossing the electrified barriers. However, some large mammals were also detected further away from the access point, but those animals were not included in the evaluation of the effectiveness of the electrified barriers at the four access points. The researchers also detected or suspected that bears were digging under the electrified fence at 3 locations (Table 4). These locations were also monitored with trail cameras. Interestingly these locations were all adjacent to the riparian habitat along the Jocko River and not along the roadside or adjacent agricultural fields. The memory cards in all cameras were replaced about once a month. The batteries (Energizer® Ultimate Lithium™) were replaced about every 3 months.

Table 4: The 3 fence locations and the periods these were monitored with a trail camera.

Fence location	**Evaluation start – end 2020**	**Evaluation start – end 2021**
West	6 July 2020 - 12 Dec 2020	28 Apr 2021 - 19 Nov 2021
Middle	27 Aug 2020 - 12 Dec 2020	28 Apr 2021 - 19 Nov 2021
East	6 July 2020 - 12 Dec 2020	28 Apr 2021 - 19 Nov 2021

For most of the camera checks during the melon harvest seasons, the voltage of the electrified fence (on each wire) was measured at 5 locations (Figure 3). At each location, the voltage was measured on each of the 4 wires (Figure 4). In addition, during most camera checks during the harvest season, the voltage of the electrified barriers at the 4 access points was measured. For the bump gate designs at access point 1 and 4, the voltage was measured for both the right and the left part of the gate. The voltage measurements showed us whether we could expect the electric fence and electrified barriers at the access points to have discouraged bears from entering the melon patch.

2.2.4 Data Analyses

2.2.4.1 Voltage

For most of the camera checks during the harvest season, the researchers calculated the average voltage for each of the 4 wires of the fence based on the 5 measurement locations. In addition, the researchers calculated the average voltage for each of the 2 sides of the bump gates. The voltage at access point 2 and 3 was always a single measurement.

2.2.4.2 Barrier Effect

Each barrier design at a vehicle access point was evaluated for its barrier effect on black bears through counting the number of black bears that were recorded in the area up to 2 m (6.6 ft) immediately in front of each access point. If a black bear was recorded within 5 minutes of the previous event involving a black bear, it was considered the same bear and it was counted and evaluated as 1 event. However, if there was evidence (e.g. based on body size, hair color) that these were different individuals, then it resulted in 2 events. If more than 5 minutes passed between consecutive black bear observations, then these were considered different events. The researchers reviewed the images and calculated the percentage of black bears that successfully accessed the melon patch (undesired result) vs. the percentage of black bears that were deterred (desired result, equivalent to the barrier percentage).

2.2.4.3 Breaking the Addiction

Modifications to the barriers at the vehicle access points and the fence were recorded and grouped into different periods (Table 3). The absolute number of black bears accessing the melon patch in each period was calculated for each access point and for each of the three fence locations that were monitored with a camera. Since the periods varied greatly in length, the counts were standardized for the number of days in each period. This analysis shows potential increases or decreases in black bears accessing the melon patch, and the locations of the intrusions in association with the modifications to the barriers at the vehicle access points and the fence. In addition, the researchers counted the total number of black bear events inside and outside the fenced melon recorded by the 7 cameras, regardless of the distance to the fence, vehicle access point or camera, per month for both 2020 and 2021. This analysis showed potential differences in the attraction of the melon patch and whether the bleak bears' habit of trying to eat the melons was broken.

2.3 Results

2.3.1 Voltage

The voltage on the fence was almost always 7-9 kV (Figure 10). The 2nd wire from the bottom was a ground wire until 27 August 2020, hence the lack of voltage before that date. In general, the 2 bump gates (access point 1 and 4) had lower voltage (usually between 4-6 kV) than the barriers at the other two locations (usually between 7-10 kV) (Figure 11). Note that the measurements in 2021 at access point 3 related to a drive-over mat with its own power source that was independent from that of the fence and the three other access points. Also note that the voltage at the end of November in 2021 was lower everywhere.

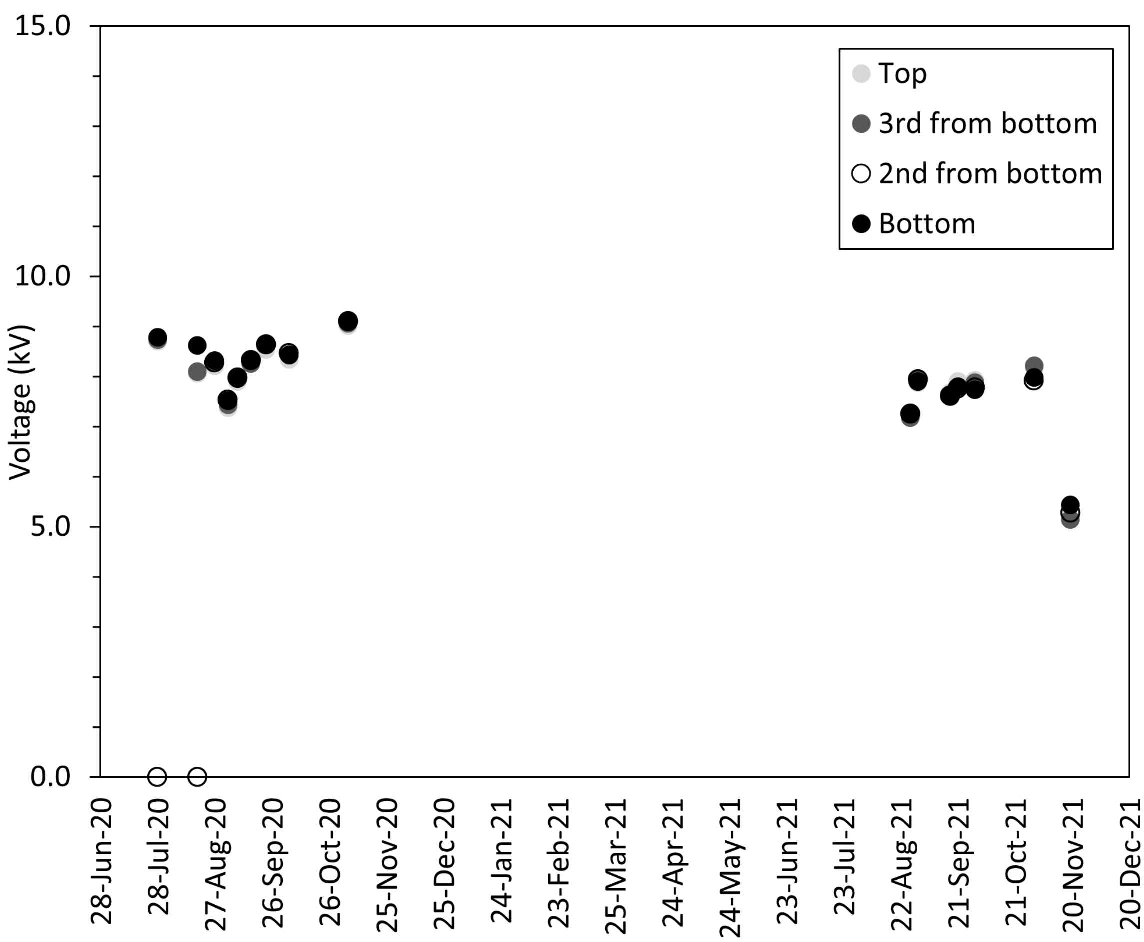

Figure 10: The average voltage on the 4 fence wires for each date that measurements took place during the harvest season in 2020 and 2021.

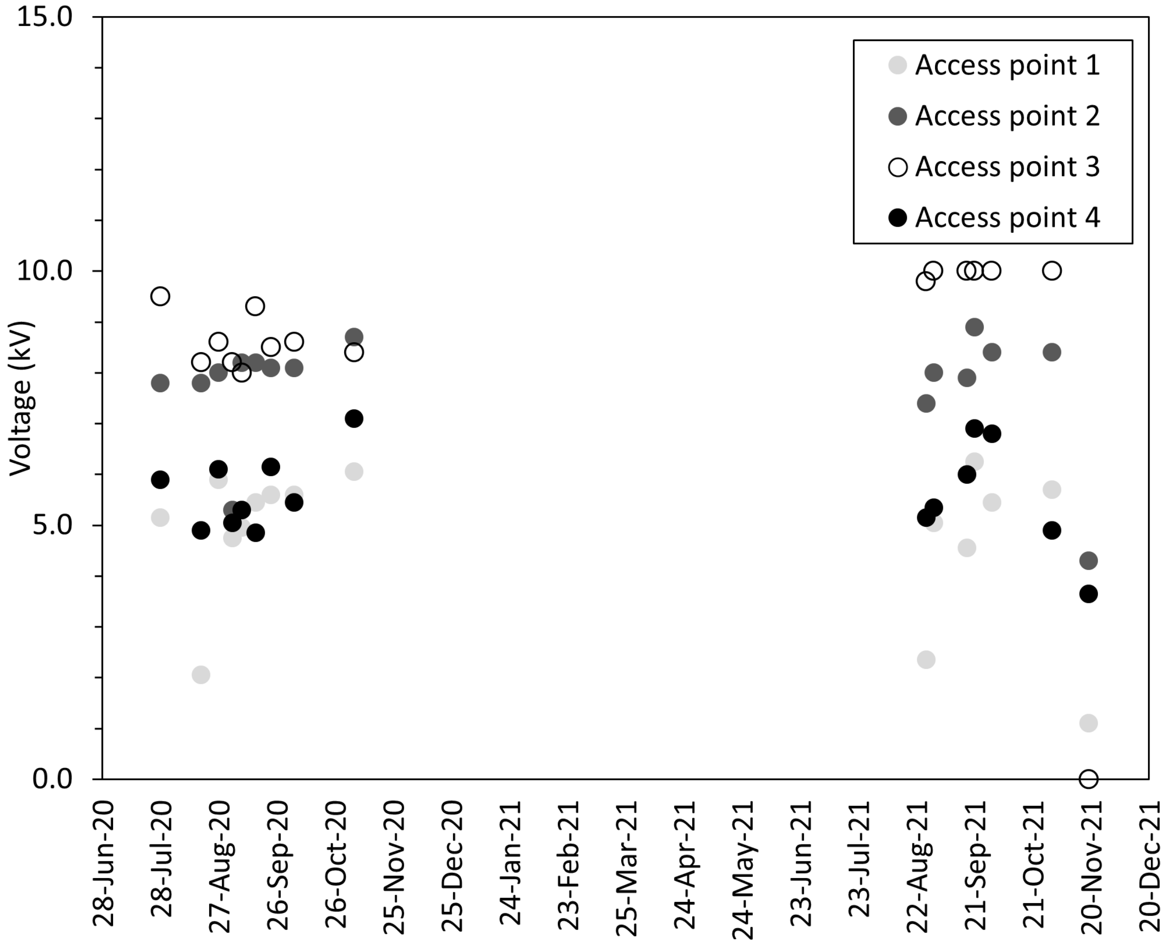

Figure 11: The voltage on the four access points wires for each date that measurements took place during the harvest season in 2020 and 2021.

2.3.2 Barrier Effect Access Points

All the bears that were recorded were black bears; there were no observations of grizzly bears. All the black bear events related to single animals; there were no events involving multiple black bears (e.g. a sow and cubs). Four out of the 5 electrified barrier designs for access points were an absolute (100%) or near absolute barrier (91.4%) for black bears (Figure 12). However, the bump-gates that were originally designed for cattle were a poor barrier for black bears (46.9%). Based on the images from the cameras, the bears usually passed in between the vertical electrified strands, and thus minimized contact with the wires (Figure 13). After conductive netting was attached to a bump gate, the bears no longer passed through the bump gate (100% barrier) (Figure 12) and they did not even touch the electrified barrier. The same was true for the swing gate, drive-over wires, and drive-over mat; most bears that approached the barriers did not touch the electrified components at all. Three out of 35 black bears passed the drive-over wires above the ground (Figure 12). All 3 intrusions involved a bear bypassing most of the wires by coming in or leaving from the side (Figures 14-16).

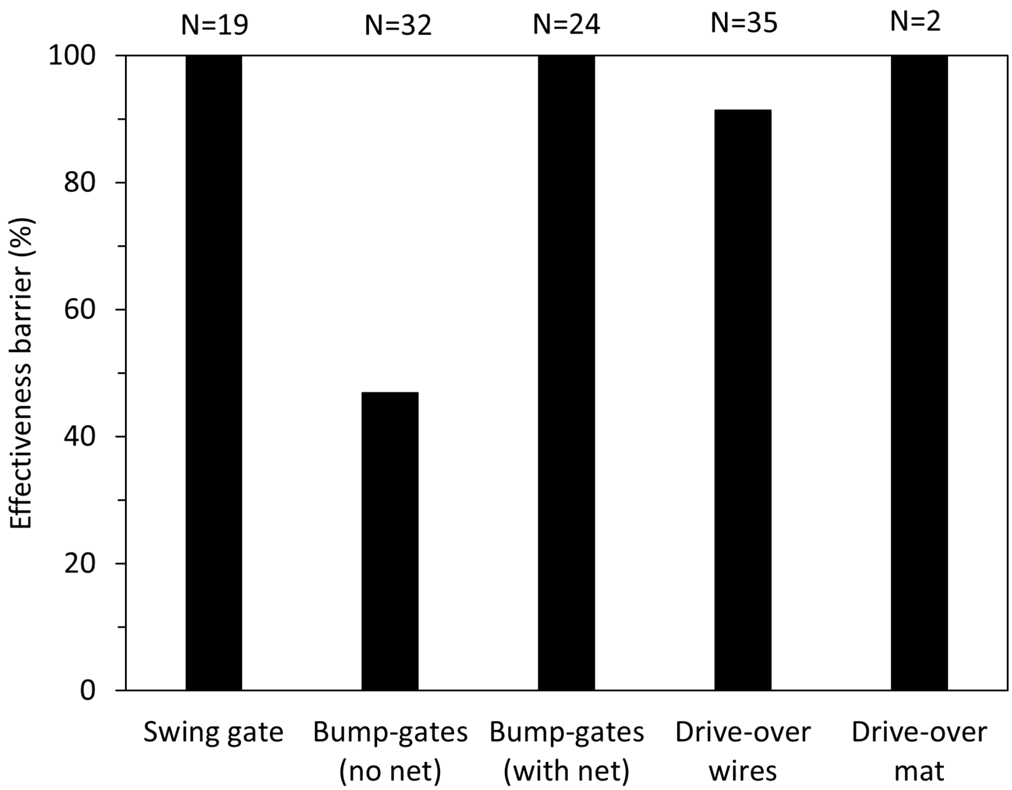

Figure 12: The effectiveness of the different barrier types in keeping black bears out of the melon patch.

Figure 13: Black bear accessing the melon patch at a bump gate at access point 4, entering in between the vertical electrified wires. The black bears tended to choose the location where the space between the vertical wires was widest, at the transition of the orange and green parts of the horizontal pole.

Figure 14: Black bear bypassing most of the wires above the ground and taking advantage of the space between the wires and the electrified gate on the side (1st out of 3 intrusions). Note that the electric wires on the side of the barrier (to the right of the bear) only cover the side partially.

Figure 15: Black bear bypassing most of the wires above the ground by taking advantage of the partial electric fence on the side of the barrier (2nd out of 3 intrusions).

Figure 16: Black bear bypassing most of the wires above the ground by taking advantage of the partial electric fence on the side of the barrier (3rd out of 3 intrusions).

2.3.3 Breaking the Addiction

At the 7 locations that were monitored with a camera, the number of black bear intrusions into the melon patch varied between about 2.5 and 4.5 per day during much of the 2020 harvest season (Figure 17). Access point 4, the non-modified bump gate adjacent to the Jocko river, and “fence west” accounted for the vast majority of the intrusions. After conductive netting was attached to the bump gate at access point 4, black bear pressure increased on “fence west”, and also “fence middle” (Figure 18-20). After fence modifications on 9 September 2020, almost no bears were able to enter the melon patch. There were only 2 black bears that entered after that date, and both did so through largely bypassing the drive-over wires at access point 3. The researchers did not have any evidence that black bears entered the melon patch at any other location that was not monitored with a camera. The total number of black bears was highest in August through October (Figure 21). The total number of black bear observations at any of the 7 locations monitored with a camera, regardless of which side of the fence or electrified barriers the bears were on, was 95% lower in 2021 (N=24) than in 2020 (N=527).

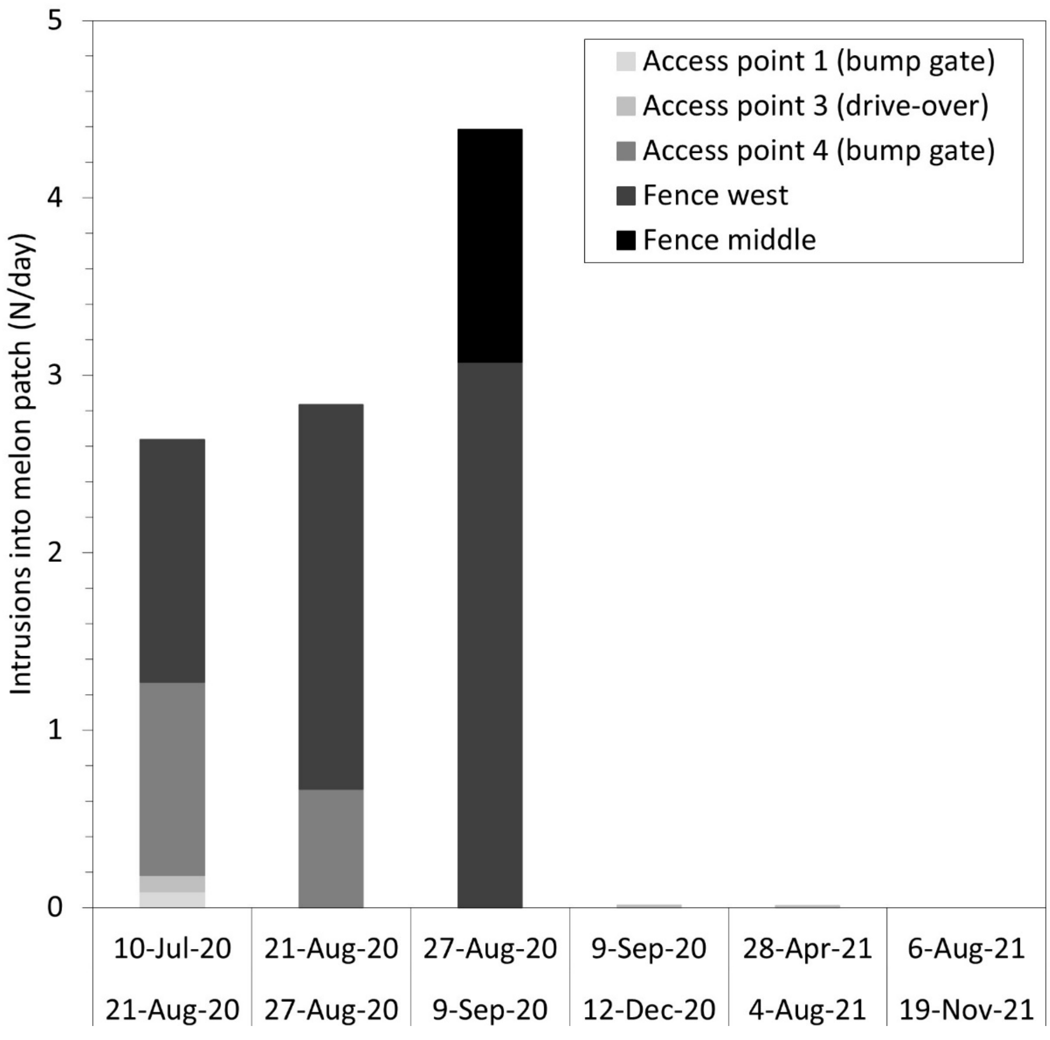

Figure 17: The number of black bear intrusions per day into the melon patch during different periods. Note: No intrusions were reported at access point 2 (swing gate) and “fence east”.

Figure 18: In some places black bears dug under the fence.

Figure 19: Black bear crawling under the fence.

Figure 20: Black bear crawling under the fence.

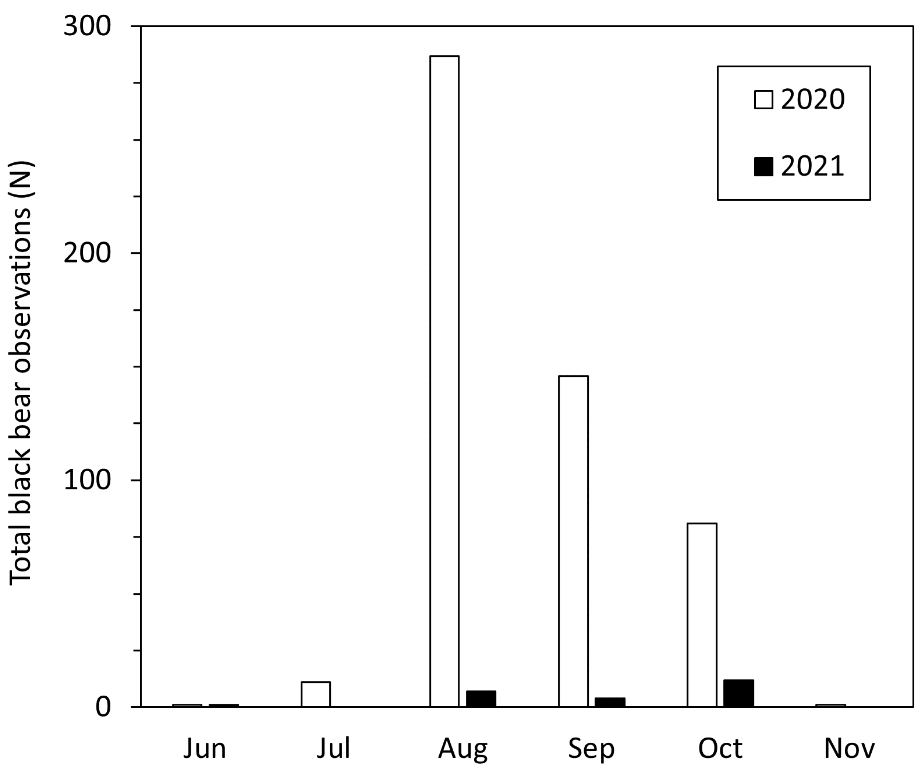

Figure 21: The total number of black bear observations per month in 2020 and 2021.

2.4 Discussion

2.4.1 Voltage

In general, the voltage on the fence and at access points 2 and 3 was almost always 7-10 kV. However, the 2 bump gates (access point 1 and 4) usually had lower voltage (usually between 4-6 kV), suggesting higher resistance of the materials or a short or voltage leak. The overall drop in voltage at the end of November in 2021 was most likely the result of shorter days (not enough daylight to recharge the batteries) and lower temperatures (reduced capacity of the batteries).

2.4.2 Barrier Effect Access Points

Four out of the 5 electrified barrier designs for access points were an absolute (100%) or near absolute barrier (91.4%) for black bears. However, non-modified bump-gates that were originally designed for cattle were a poor barrier for black bears (46.9%). Adding conductive netting made the bump gate into an absolute barrier though (100%). This is likely because the netting results in more contact points with an animal for a longer time if and when an animal tries to lift the fence material and pass under. Changing electrified wires to electrified netting also made a fence a much greater barrier to European wild rabbits (*Oryctolagus cuniculus*) (McKillop et al. 1992). The drive-over wires were partially bypassed by 3 bears, emphasizing the need for tight fences along the full length of the sides of the barrier. Interestingly, most bears that approached an absolute or near absolute barrier did not touch the barrier. This is consistent with other studies that reported that black bears and other large mammal species tend to stay away from electrified barriers, apparently because they know about its potential impact (Huygens & Hayashi 1999, Fischer et al. 2011, Otto & Roloff 2015, Teixeira et al. 2017).

2.4.3 Breaking the Addiction

Through a step-by-step process, the weak points of the barriers at the vehicle access points, particularly the bump gate at access point 4, and at two fence locations were addressed. From 9 September 2020 onwards, the melon patch became almost inaccessible to black bears. Interestingly, once the conductive netting was attached to the bump gate at vehicle access point 4, the bears increasingly used the weak locations at the fence to enter the melon patch. This illustrates that the pressure of black bears trying and succeeding to enter the melon patch at a particular location depends on how difficult it is to enter at other locations. The fence and vehicle access points function as a system rather than as individual features. Nonetheless, eventually the number of intrusions by black bear was reduced from around 2.5-4.5 per day to almost 0 per day. The total number of black bear observations at any of the 7 locations monitored with a camera, regardless of which side of the fence or electrified barriers the bears were on, was 95% lower in 2021 than in 2020. This suggests that after the black bears were no longer able to enter the melon patch, they drastically reduced their effort to try and access the melon patch. Apparently, the attraction of the melon patch and the associated habit of eating melons was “broken”. Note that there was no indication of a population crash of black bears in 2021 in the immediate vicinity, nor in the wider region.

2.4.4 Experiences with Operation and Maintenance

All 4 vehicle access points had manual switches allowing farm personnel to walk through the electrified barriers without shocking themselves. However, shortly after the electric barriers were activated, the farmer realized that the switches were sometimes accidentally left in the “off” position. From 29 August 2020 onwards, all switches were permanently taped in the “on position” (Figure 22). While relatively inexpensive, the bump gates required custom conductive netting to become a substantial barrier to black bears. The netting is subject to tearing and needs to be adjusted and reattached regularly (e.g. zip-ties). In addition, there are tensioners for the 2 horizontal poles of the bump gates (Figure 22). These also need to be adjusted on a regular basis to ensure that the two horizontal poles align and do not leave a gap in the middle. The horizontal poles are also subject to breaking; one of the poles broke after it got stuck in a bumper or wheel well of a pickup truck (Figure 23).

Figure 22: Switch at a bump gate taped in the permanently “on” position. Also note the adjustment bolts and nuts for the chain (lower left in image) that allows for the alignment of the horizontal pole.

Figure 23: Broken horizontal pole of a bump gate because of a vehicle passing through.

There were no operation or maintenance issues with the electrified swing gate. A design problem of the drive-over wires barrier was that the side fences were too short. All three intrusions for black bears bypassed most of the wires above the ground by accessing or leaving the barrier from one of the sides. Barriers or "side-fences" that run tight along the full length of the barrier would address this issue and force bears, if they try to access the crop, to walk on top of or in between the wires above the ground for the full length of the barrier. In contrast, the drive-over mat has side barriers that have a tight connection to the mat, and they do run the full length of the mat. Here, no large mammals were able to bypass the mat by coming in from or leaving at one of the sides. The researchers did observe that the drive-over mat may kill amphibians and small mammals. Between 6 August 2021 and 21 November 2021, the researchers found one dead toad and one dead mouse on the mat (Figure 24, 25).

Figure 24: A. Western toad (*Anaxyrus boreas*), presumably electrocuted, on the electrified drive-over mat (Crosstek™). B. Same animal with burn marks from the mat. (Copyright: Samantha Getty).

Figure 25: Deer mouse (*Peromyscus maniculatus*), presumably electrocuted, on the electrified drive-over mat (Crosstek™).

2.5 Conclusion

After modifications, a combination of an electric fence and electrified barriers at vehicle access points was able to keep almost all black bears out of a melon patch and break their habit of eating melons. However, bump gates required custom conductive netting and frequent adjustments and repairs. The electrified swing gate was a 100% barrier to black bears and had no maintenance issues. However, this design still requires people to get in and out of their vehicle when opening and closing the gate, and, as a consequence, the gate may be left open. The drive-over wires barrier was a near absolute barrier for black bears. Nonetheless, its effectiveness can likely be improved if the side barriers run tight along the full length of the barrier. The drive-over mat performed well but has only a small sample size. Downside of the drive-over mat, and possibly also of the drive-over wires, is that these types of electrified barriers may kill small animal species (e.g. amphibians, reptiles, small mammals).

2.6 Acknowledgements

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3 ELECTRIFIED WILDLIFE GUARDS, PARKS CANADA

3.1 Introduction

Parks Canada modified or installed 4 electrified wildlife guards along on/off ramps of the Trans-Canada highway and at the entrance of a campground. These locations had high traffic volume (e.g. up to hundreds or thousands of vehicles per day), and medium vehicle speed (10-<45 MPH (16.1-<72.5 km/h)). The electrified barriers were designed to keep large mammals (especially large ungulates and black bears and grizzly bears) out of the fenced highway or a campground.

3.2 Methods

3.2.1 Locations

3.2.1.1 Sunshine Road, near Banff, Banff National Park, Alberta

The barrier consists of 3 sections (Figure 26):

1. The grounding plate with strips to protect it from snowplows. This is the metal plate in front of the barrier, this is the habitat side where the animals would be approaching from.
2. A section with alternating positive (n=5) and negative (n=5) round bars. The positive bars have white insulators.
3. A section (far side in image, this is the highway side)) with flat bars (n=11, not electrified).

The barrier was briefly fully operational 8-20 October 2020, but a snowplow damaged the grounding plate as the protective strips had not been installed yet. After that, the damaged grounding plate was removed which meant that the animals were less likely to receive a full shock (variable conductivity of the pavement) or they would only be delivered a full shock after making contact with both a positive and negative bar. The grounding plate was reinstalled (with protective strips) at the end of September 2021 (personal communication Dan Rafla, Parks Canada).

Figure 26: Electrified barrier, Sunshine Road, Banff National Park, Canada.

3.2.1.2 Compound Road, near Banff, Banff National Park, Canada

The barrier at Compound Road is constructed similar to the one at Sunshine Road (Figure 27). This barrier did not receive a grounding plate (with protective strips) until the end of September 2021 (personal communication Dan Rafla, Parks Canada).

Figure 27: Electrified barrier, Compound Road, Banff National Park, Canada.

3.2.1.3 Lake Louise Campground, Lake Louise, Banff National Park, Canada

The barrier consists of 2 sections (Figure 28):

1. A section with alternating positive (n=3) and negative (n=3) round bars. The positive bars have a yellow insulator.
2. A section (far side in image, this is the campground side)) with yellow round bars (n=11, not electrified).

This barrier does not have a grounding plate. This barrier has been operational, but the electricity is turned off in winter when most bears are inactive.

Figure 28: Electrified barrier, Lake Louise Campground, Lake Louise, Canada.

3.2.1.4 Lake O'Hara exit, Yoho National Park, Canada

The barrier consists of 1 section (Figure 29):

1. A section with alternating positive (n=7) and negative (n=7) round bars. The positive bars have a white insulator.

This barrier does not have a grounding plate. The Trans-Canada Highway is in the far side of the image. The foreground is the habitat side. This barrier does not have a grounding plate. This barrier has been operational, but the electricity is turned off in winter when most bears are inactive.

Figure 29: Electrified barrier, Lake O'Hara exit, Yoho National Park, Canada.

3.3 Results

3.3.1 Barrier Effect

While cameras were installed at 3 of the 4 wildlife guards since the autumn of 2020, no data have been analyzed. Delays in the completion of installation of some of the guards and difficulties in exchanging the large volume of data pushed data analyses too far towards the end of the project.

3.3.2 Operation and Maintenance

- Protective strips for the grounding plates and the insulators are important; snowplows can otherwise damage the grounding plate and insulators.
- Guards filled up with snow in winter, making them not functional, as expected. “The accumulation of snow, salt, gravel, etc. between the negative and positive charge cause it to short, or the guard can be completely covered (Personal communication Dan Rafla, Parks Canada).
- During the winter, the wiring was not able to withstand the vibrations from vehicles and gravel/salt that fell between the pipes. The wiring had to be redone to more robust standard (Personal communication Dan Rafla, Parks Canada).

3.4 Discussion and Conclusion

The researchers suggest analyzing the available data in the future. In addition, the researchers suggest measuring voltage at regular intervals and keeping a log of potential issues or other relevant observations.

3.5 Acknowledgements

This research was funded by the following organizations: Alaska Department of Transportation and Public Facilities, Arizona Department of Transportation, California Department of Transportation, Iowa Department of Transportation, Michigan Department of Transportation, Minnesota Department of Transportation, Nevada Department of Transportation, New Mexico Department of Transportation, Ontario Ministry of Transportation, Oregon Department of Transportation, Parks Canada and Washington Department of Transportation through the Animal-Vehicle Collision (WVC) Reduction and Habitat Connectivity Transportation Pooled-Fund Project TPF-3 5(358). We thank the representatives of these organizations, as well as representatives of the Federal Highway Administration and ARC Solutions for serving on the advisory panel. Many thanks to the Parks Canada for managing the research cameras at the 4 locations. Special thanks are due to Mark Benson, Seth Cherry, Trevor Kinley, Terry Larsen, David Laskin, Thomas Niddrie, Dane Petersen, Dan Rafla, and Jón Stuart-Smith.

4 ELECTRIFIED WILDLIFE GUARDS, THOMPSON FALLS, MONTANA

4.1 Introduction

In November 2019, the Montana Department of Transportation (MDT) installed two electrified wildlife deterrent mats at fence-ends within the newly re-constructed asphalt road surface, along a 2-lane highway (MT Hwy 200) with an 8 ft (2.4 m) high wildlife fence just east of Thompson Falls, Montana (Figure 30). The barriers were designed and manufactured by CrossTek™ (the name of the product is ZapCrete™). The fence and fence-end treatments were designed for large ungulates (e.g. bighorn sheep, deer, elk) (personal communication Joe Weigand, Montana Department of Transportation). This highway has an Annual Average Daily Traffic (AADT) volume of about 2,000 vehicles (MDT 2020). The speed limit within the area and across the mats is 55 mph (88.5 km/h). The speed limit along this stretch of the highway was recently reduced from 70 mph (112.7 km/h) to 55 mph (88.5 km/h) to further help reduce collisions with bighorn sheep. The electrified mats are designed for highway speeds.

Figure 30: The locations of the electrified barriers along MT Hwy 200. West location is about 4.5 miles east of Thompson Falls at the Thompson River bridge; East location is about 7.2 miles east of Thompson Falls.

4.2 Methods

4.2.1.1 Electrified barriers

ZapCrete™ consists of concrete, conductive materials and insulation materials. The power source is a solar battery system. The dimensions of the electrified barriers are 40 ft x 12 ft (12.2 x 3.7 m) (west end) and 33 x 12 ft (10.1 x 3.7 m) (east end) (personal communication Tim Hazlehurst, CrossTek™ Wildlife Solutions) (Figure 31-34). Each mat is solar-powered and consists of metal strips embedded in concrete. There are 2 pushbuttons at each mat, one for each travel direction. These buttons are for pedestrians and other non-motorized traffic that may be at risk of receiving an electric shock (around 10kV). After the button has been pushed, the power turns off. After about 1 minute the power turns back on automatically. The total cost for two mats across 2 lanes was approximately US$ 247,000, including materials and labor (about US $ 123,500 per mat).

Figure 31: The electrified barrier at the west fence-end. Note that the bridge directly connects to the electrified barrier.

Figure 32: The electrified barrier at the west fence-end. Note that the bridge directly connects to the electrified barrier.

Figure 33: The electrified barrier at the east fence-end.

Figure 34: One of the push buttons for pedestrians at the electrified barrier at the east fence-end. There are 2 push buttons; one for each travel direction.

4.2.1.2 Research equipment

The west and east electrified barrier each had a trail camera installed (HyperFire 2 Professional Covert IR) (Figures 35, 36). To accommodate the heavy use of the cameras associated with the traffic volume (about 2,000 potential camera triggers per day on average), the cameras were customized with an external power. This allowed the cameras to be powered through a solar panel and associated battery. In addition, high-capacity memory cards (64 GB) were used. The cameras were checked, and the memory cards were exchanged about once a month. The camera at the west fence-end was installed 30 September 2020. The camera at the east fence-end required a new post for which a right-of-way encroachment permit was obtained from MDT on 8 October 2020. The post and camera were installed on 27 October 2020.

Figure 35: The camera, battery box and solar panel installed on a sign post behind the sign at the western electrified barrier.

Figure 36: The camera, battery box and solar panel installed on a designated newly installed post at the eastern electrified barrier.

4.2.2 Data Analyses

The images that contained wildlife were selected and saved. Wildlife that came within 7 ft (2 m) or 15 ft (5 m) of the electrified wildlife mats were evaluated for their behavior. The researchers calculated the barrier effect for each species based on the number of approaches, and the numbers of pass vs. no-pass events across the electrified wildlife deterrent mats.

4.2.3 Chronology of Challenges

- From the start, multiple deer and elk were seen crossing the barriers, apparently without getting shocked.
- MDT and Crosstek™ were alerted.
- Crosstek™ provided a voltage meter and instructions to check voltage.
- In June 2021 it was confirmed that MDT had the electrified barriers on only about 50% power (between 4.2-4.8kV) since installation because of complaints and fears by at least one driver.
- MDT then stated that they intended to increase the power to the settings recommended by the manufacturer (100%, about 10kV).
- WTI observed on 28 Aug 2021 that the voltage was increased to 9.6-10kV.
- Both mats were disabled by MDT in Nov 2021. The concrete between the metal strips at the western mat was crumbling, presumably because the bridge abutment has settled, and there is now a change in slope where the bridge connects to the electrified mat. This causes vehicles to exercise excessive stress on the pavement (Figure 37-38). There is no evidence that the material associated with the electric mat is more fragile than standard concrete.
- The eastern mat was switched on again a few months later.
- The western mat was half covered in asphalt to combat the crumbling concrete.

4.2.4 Data Selection and Barrier Effect Calculation

The researchers selected events that met the following criteria:

1. Confirmed full power (about 10kV) on the electrified mat(s).
2. Full width of the mat (i.e. exclude observations from the western mat after the width was reduced by asphalt over the damaged concrete).
3. Mammals observed on the unfenced road sections near the mat (i.e. exclude observations of animals attempting to leave the fenced road corridor).

An additional selection was made for animals that were observed within 2 m (6.6 ft) of the edge of the electrified mat. Animals observed near the mat were evaluated for a potential crossing across the electrified barrier into the fenced road corridor.

Figure 37: Crumbling concrete at the western electrified barrier, presumably associated with a change in slope after the bridge abutment settled (image Samantha Getty).

Figure 38: The crumbling concrete at the western electrified barrier was covered in asphalt.

4.3 Results

None of the animals (1 raccoon, 1 deer, 2 elk) that came close to the electrified mats crossed the electrified mat into the fenced road corridor. All the selected observations were on the east fence-end. However, the sample sizes were extremely small.

Table 5: Barrier effect for animals that came within 2 m of the electrified barriers outside the fenced road corridor.

Species	Total number of individuals observed near mat in unfenced road section	Total number of individuals observed within 2 m (6.6 ft) of mat in unfenced road section	Total number of individuals that has been or may have been shocked	Total number of individuals that crossed mat into fenced road section	Barrier effect (%) based on all individuals observed near mat	Barrier effect (%) based on individuals observed within 2 m (6.6 ft) of mat
Raccoon	1	1	1	0	100%	100%
Deer (unkn. species)	1	0	0	0	100%	100%
Elk	2	0	0	0	100%	100%

4.4 Discussion and Conclusion

When the electrified mats had full power (about 10kV), no mammal was observed entering the fenced road corridor. However, the period that the electrified barriers were on full power (about 10kV) was extremely short which resulted in very low sample sizes. Further monitoring is recommended. For future installation, consider having a setback between the edge of a bridge and the start of an electrified barrier.

4.5 Acknowledgements

This research was funded by the following organizations: Alaska Department of Transportation and Public Facilities, Arizona Department of Transportation, California Department of Transportation, Iowa Department of Transportation, Michigan Department of Transportation, Minnesota Department of Transportation, Nevada Department of Transportation, New Mexico Department of Transportation, Ontario Ministry of Transportation, Oregon Department of Transportation, Parks Canada and Washington Department of Transportation through the Animal-Vehicle Collision (WVC) Reduction and Habitat Connectivity Transportation Pooled-

Fund Project TPF-3 5(358). We thank the representatives of these organizations, as well as representatives of the Federal Highway Administration and ARC Solutions for serving on the advisory panel. Many thanks to the Montana Department of Transportation for allowing us to conduct the research at the electrified mats. Finally, thanks to Tim Hazlehurst of CrossTek™ Wildlife Solutions for advising on volt measurement procedures.

5 LITERATURE REVIEW

5.1 Review

Embedding barriers (e.g. wildlife guards or electrified barriers) in the travel lanes at fence-ends or at access roads, can reduce intrusions into the fenced road corridor at fence ends (Peterson et al. 2003; Gagnon et al. 2019; Honda et al. 2020). Double wide wildlife or cattle guards, usually situated above a pit, can be a very substantial barrier to large ungulates; 95-98% barrier for 4.6 m (15 ft) wide cattle guards with a 0.5-1.0 m (1.6-3.3 ft) deep pit for white-tailed deer (*Odocoileus virginianus*) (Belant et al. 1998), 75%-99.5% barrier for different types of wildlife guards (6.1 m (20 ft) wide, with pit) for Florida Key deer (*O. v. clavium*) (Peterson et al. 2003); 85% barrier for a 1.2 m (4 ft) wide electrified mat (5.9 kV on average) for white-tailed deer (Seamans & Helon, 2008), nearly 100% for 3m (5 ft) wide wildlife guards for white-tailed deer (VerCauteren et al. 2009), 85% barrier for mule deer (*O. hemionus*) and white-tailed deer combined for 6.6 m (21.7 ft) wide wildlife guards with a 0.45 m (1.5 ft) deep pit (Allen et al. 2013), 87% barrier for double wide wildlife guards (4.8 m (16 ft)) and 94% barrier for double wide (4.6 m (15 ft)) cattle guards, all with a 0.9 m (3 ft) deep pit, for mule deer (Cramer & Flower, 2017), 64-91% barrier for single wide cattle guards augmented with 0.9-1.2 m (3-4 ft) wide electrified (9.8-9.9 kV) pavement for mule deer and >99% barrier for elk (*Cervus canadensis*) (Cramer & Flower, 2017), 80-97% for single wide (2.4 m (8ft)) guards and 85-98% for double wide (4.9 m (16 ft)) guards and 78-89% barrier for single wide electrified barriers (2.1 m (7 ft)) for elk, 100% for single wide guards and 100% for double wide guards for deer (*O. spp*.), 87% for single wide guards combined with painted stripes, and 100% for double wide guards for bighorn sheep (*Ovis canadensis*) (Gagnon et al. 2020); 98.5% for 2.4 m (8 ft) wide guards sika deer (*Cervus nippon*) (Honda et al. 2020). Round bars for 4.9 m (16 ft) wide wildlife guards were more effective than flat bars: Round bars 91% for mule deer, 81% for elk, 100% for moose (*Alces americanus*), 82% for white-tailed deer, 100% for bighorn sheep, 100% for pronghorn (*Antilocapra americana*); Flat bars 84% for mule deer, 75% for elk, 70% for moose, 67% for white-tailed deer, 100% for bighorn sheep, 100% for pronghorn (Kintsch et al. 2021). However, some wildlife guard designs were less effective: 9% barrier for painted stripes only for elk (Gagnon et al. 2020), 11.2% barrier for 3.7-7.3 m (12-24 ft) wide deer guards for mule deer (Reed et al. 1974) and 38% barrier for deer and 50% barrier for elk for electrified barriers (1.8 m (6 ft) wide) (Gagnon et al. 2020). However, wildlife guards are not a substantial barrier to species with paws such as many carnivore species. This includes only 33% barrier for black bear (*Ursus americanus*) and 33% barrier for coyote (*Canis latrans*) (Allen et al. 2013); raccoon dog (*Nyctereutes procyonoides*), red fox (*Vulpes vulpes*), Japanese badger (*Meles anakuma*), masked palm civet (*Paguma larvata*), and domestic cat (Honda et al. 2020).

5.2 Width and Effectiveness

The researchers plotted the effectiveness of barriers for large ungulates against the length of the barrier (Figure 39). The length is the distance that animals would have to cross to reach the other side of the barrier. Most while most barriers of all types are a substantial barrier (>80%) to large ungulates, there is not a clear relation with the length of the barrier. This suggests that the target species (different large ungulate species) and differences in design and implementation and maintenance may cause substantial variation in the effectiveness of the barriers.

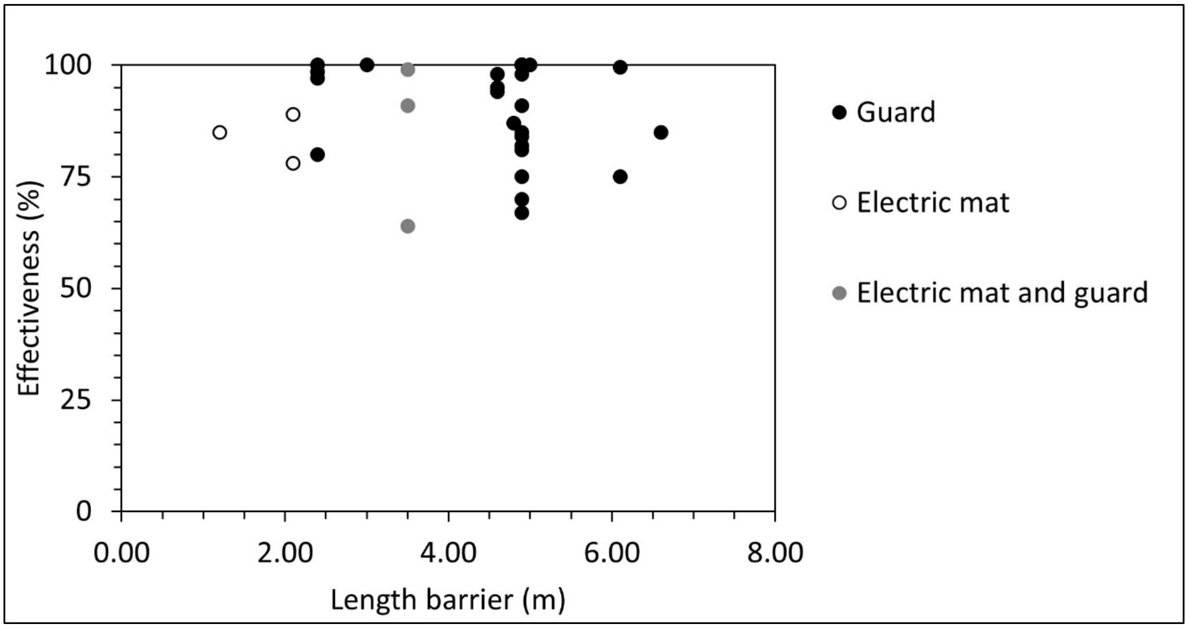

Figure 39: The effectiveness of different barrier types (guard, electric mat and a combination of an electric mat and guard) in relation to the length of the barrier. Based on Belant et al. 1998; Peterson et al. 2003; Seamans & Helon 2008; VerCauteren et al. 2009; Allen et al. 2013; Clevenger & Barrueto 2014; Cramer & Flower 2017; Gagnon et al. 2020; Honda et al. 2020; Kintsch et al. 2021.

6 REFERENCES

Allen, T.D.H, M.P. Huijser & D. Willey. 2013. Evaluation of wildlife guards at access roads. Effectiveness of wildlife guards at access roads. Wildlife Society Bulletin 37(2): 402–408.

Andrews, B. 2020. Breaking bad habits: bears and melons. Tracks. Fall 2020, p. 3. People and Carnivores. https://static1.squarespace.com/static/5f222a7c92ce383c8ff73e83/t/5f63a2bd375f63524fd1e491/1600365251240/PeopleAndCarnivores_Fall2020_Web.pdf

Belant, J.L., T.W. Seamans & C.P. Dwyer. 1998. Cattle guards reduce white-tailed deer crossings through fence openings. International Journal of Pest Management 44(4): 247-249. DOI: 10.1080/096708798228176

Clevenger, A.P. & N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology14: 47-56. doi: 10.1046/j.1523-1739.2000.00099-085.x

Clevenger, A.P. & M. Barrueto (eds.). 2014. Trans-Canada highway wildlife and monitoring Research. Final Report. Part B: Research. Prepared for Parks Canada Agency, Radium Hot Springs, British Columbia, Canada.

Cramer, P. & J. Flower. 2017. Testing new technology to restrict wildlife access to highways: Phase 1. Report No. UT-17.15. Utah State University, Logan, Utah, USA.

Cserkész, T., B. Ottlecz, Á. Cserkész-Nagy & J. Farkas. 2013. Interchange as the main factor determining wildlife–vehicle collision hotspots on the fenced highways: spatial analysis and applications. European Journal of Wildlife Research 59: 587–597. DOI 10.1007/s10344-013-0710-2

Fischer, J.W., G.E. Phillips, D.M. Baasch, M.J. Lavelle, & K.C. VerCauteren. 2011. Modifying elk (*Cervus elaphus*) behavior with electric fencing at established fence-lines to reduce disease transmission potential. Wildlife Society Bulletin 35(1): 9-14. DOI 10.1002/wsb.2

Ford, A.T., K. Rettie & A.P. Clevenger. 2009. Fostering ecosystem function through an international public-private partnership: a case study of wildlife mitigation measures along the Trans-Canada Highway in Banff National Park, Alberta, Canada. International Journal of Biodiversity Science & Management 5(4): 181-189. DOI:10.1080/17451590903430153

Gagnon, J.W., N.L. Dodd, S.C. Sprague, K.S. Ogren, C.D. Loberger & R.E. Schweinsburg. 2019. Animal-activated highway crosswalk: Long-term impact on elk-vehicle collisions, vehicle speeds, and motorist braking response. Human Dimensions of Wildlife 24(2): 132-147. DOI: 10.1080/10871209.2019.1551586

Gagnon, J.W., C.D. Loberger, K.S. Ogren, C.A. Beach, H.P. Nelson & S.C. Sprague. 2020. Evaluation of the effectiveness of wildlife guards and right of way escape mechanisms for large ungulates in Arizona. Report no. FHWA-AZ-20-729. Arizona Game and Fish Department, Phoenix, Arizona, USA.

Honda, T., Y. Kubota & Y. Ishizawa. 2020. Ungulates-exclusion grates as an adjoining facility to crop damage prevention fences. European Journal of Wildlife Research 66: 25. https://doi.org/10.1007/s10344-020-1362-7

Huijser, M.P., A.V. Kociolek, T.D.H. Allen, P. McGowen, P.C. Cramer & M. Venner. 2015. Construction guidelines for wildlife fencing and associated escape and lateral access control measures. NCHRP Project 25-25, Task 84, National Cooperative Highway Research Program, Transportation Research Board of the National Academies, Washington D.C., USA.

Huijser, M.P., E.R. Fairbank, W. Camel-Means, J. Graham, V. Watson, P. Basting & D. Becker. 2016a. Effectiveness of short sections of wildlife fencing and crossing structures along highways in reducing wildlife-vehicle collisions and providing safe crossing opportunities for large mammals. Biological Conservation 197: 61-68.

Huijser, M.P., W. Camel-Means, E.R. Fairbank, J.P. Purdum, T.D.H. Allen, A.R. Hardy, J. Graham, J.S. Begley, P. Basting & D. Becker. 2016b. US 93 North post-construction wildlife-vehicle collision and wildlife crossing monitoring on the Flathead Indian Reservation between Evaro and Polson, Montana. FHWA/MT-16-009/8208. Western Transportation Institute - Montana State University, Bozeman, Montana, USA.

Huijser, M.P. & J.S. Begley. 2022. Implementing wildlife fences along highways at the appropriate spatial scale: A case study of reducing road mortality of Florida Key deer. In: Santos S, Grilo C, Shilling F, Bhardwaj M, Papp CR (Eds) Linear Infrastructure Networks with Ecological Solutions. Nature Conservation 47: 283–302. https://doi.org/10.3897/natureconservation.47.72321

Huygens, O.C. & H. Hayashi. 1999. Using electric fences to reduce Asiatic black bear depredation in Nagano Prefecture, Central Japan. Wildlife Society Bulletin 27(4): 959-964.

Khorozyan, I. & M. Waltert. 2020. Variation and conservation implications of the effectiveness of anti-bear interventions. Scientific Reports 10:15341. DOI: 10.1038/s41598-020-72343-6

Kintsch, J., P. Cramer, P. Singer & M. Cowardin. 2021. State Highway 9 wildlife crossings monitoring. Report No. CDOT-2021-01. ECO-Resolutions, Golden, Colorado, USA.

Lehnert, M.E. & J.A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. Wildlife Society Bulletin 25(4): 809-818.

McKillop, I.G., K.V. Phillips & S.G.V. Ginella. 1992. Effectiveness of two types of electric fences for excluding European wild rabbits. Crop Protection 11(3): 279-285.

MDT. 2020. Traffic Data - Traffic AADT Maps. Montana Department of Transportation (MDT), Helena, Montana, USA. https://mdt.mt.gov/publications/datastats/traffic_maps.shtml

Otto, T.E. & G.J. Roloff. 2015. Black bear exclusion fences to protect mobile apiaries. Human-Wildlife Interactions 9(1): 78-86.

Peterson, M.N., R.R. Lopez, N.J. Silvy, C.B. Owen, P.A. Frank & A.W. Braden. 2003. Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin 31(4): 1198-1204.

Plante, J., J.A.G. Jaeger & A. Desrochers. 2019. How do landscape context and fences influence roadkill locations of small and medium-sized mammals? Journal of Environmental Management 235: 511-520.

Reed, D.F., T.M. Pojar & T.N. Woodard. 1974. Mule deer responses to deer guards. Journal of Range Management 27(2): 111-113. URL: https://www.jstor.org/stable/3896743

Rytwinski, T., K. Soanes, J.A.G. Jaeger, L. Fahrig, C.S. Findlay, J. Houlahan, R. van der Ree & E.A. van der Grift. 2016. How effective is road mitigation at reducing road-kill? A meta-analysis. PLoSONE 11(11): e0166941. doi:10.1371/journal.pone.0166941

Sawyer, H., C. Lebeau & T. Hart. 2012. Mitigating roadway impacts to migratory mule deer - A case study with underpasses and continuous fencing. Wildlife Society Bulletin 36(3): 492-498. DOI: 10.1002/wsb.166

Seamans, T.W. & D.A. Helon. 2008. Evaluation of an electrified mat as a white-tailed deer (*Odocoileus virginianus*) barrier. International Journal of Pest Management 54(1): 89-94.

Teixeira, D.L., L.C. Pinheiro Machado Filho, M.J. Hötzel & D. Enríquez-Hidalgo. 2017. Effects of instantaneous stocking rate, paddock shape and fence with electric shock on dairy cows' behaviour. Livestock Science 198: 170-173.

van der Grift, E.A., A. Seiler, C. Rosell & V. Simeonova. 2017. Safe roads for wildlife and people. SAFEROAD Final Report. CEDR Transnational Road Research Programme Call 2013: Roads and Wildlife. CEDR, Brussels, Belgium.

VerCauteren, K.C., N.W. Seward, M.J. Lavelle, J.W. Fischer & G.E. Phillips. 2009. Deer guards and bump gates for excluding white-tailed deer from fenced resources. Human-Wildlife Conflicts 3(1):145-153.

Wilson, S.M., E.H. Bradley & G.A. Neudecker. 2017. Learning to live with wolves: community-based conservation in the Blackfoot Valley of Montana. Human-wildlife conflicts 11(3): 245-257.

Yamashita, T.J., T.D. Livingston, K.W. Ryer, J.H. Young Jr. & R.J. Kline. 2021. Assessing changes in clusters of wildlife road mortalities after the construction of wildlife mitigation structures. Ecology and Evolution 11:13305–13320.

Nevada Department of Transportation

Kristina L. Swallow, P.E. Director
Ken Chambers, Research Division Chief
(775) 888-7220
kchambers@dot.nv.gov
1263 South Stewart Street
Carson City, Nevada 89712