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Wildlife friendly fence designs and elk fence crossing behavior

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Abstract

Fencing is a ubiquitous feature of our agricultural landscape. Fences necessarily have the potential to reduce habitat connectivity for resident ungulate populations. Unsuccessful fence crossings have the potential to cause injury or death to wildlife, as well as resulting in damage to the fence in terms of time and maintenance costs. Wildlife friendly fence designs may provide landowners and ungulate managers the opportunity to mitigate risks associated with wildlife crossings. Using remote cameras ($n = 12$) along the perimeter fence of the Wainwright Dunes Ecological Reserve, Alberta, we quantified and compared elk crossing behaviors at standard 4 strand fences and gates as well as 3 strand fences and gates both with experimentally modified top and bottom strand heights. We found that wildlife friendly designs promoted behavioral options for elk of various demographic classes to cross fences. Our results suggest that the number of strands and the height of the top and bottom strand are important determinants for animals deciding to cross over, through, or under fences. While difficult or problematic crossings were primarily determined by how the individual crossed and made up a proportionally small number of crossings, the sheer volume of crossings we observed suggests that any modification which increases fence permeability to elk will likely result in less damage to fences and the crossing individuals.

KEYWORDS

behavior, camera trap, *Cervus canadensis*, fence crossing, wildlife friendly fence designs

Fences criss-cross and fragment the global landscape, particularly in areas associated with agriculture (Gadd 2012, Jakes et al. 2018, McInturff et al. 2020). Though necessary for the containment of livestock or exclusion of animals or humans from different areas, fences also serve as a barrier to movement and a health hazard to native wildlife (Paige 2012). Fences fragment already disturbed habitats, limiting areas that are accessible and suitable for foraging or dispersion, and pose a risk of entanglement resulting in injury or death (Olson et al. 2009, Jakes et al. 2018). A wide variety of species can be affected by fences; however, animals most universally affected by fences are ungulates (Rey et al. 2012).

Despite the problems that rangeland fences pose for wildlife, they play an essential role in agriculture that cannot be dismissed (Halbritter 2013, McInturff et al. 2020). However, the inability of fences to facilitate safe passage (i.e., a reduction in difficulty associated with crossing) by wildlife also results in an economic cost as damage to fences is expensive and time consuming for landowners to repair and maintain (Hanophy 2009). Additionally, fence damage (loose or broken wires) or inadequate repairs potentially compound the problems associated with wildlife damage, as not only do damaged fences reduce their effectiveness for containing domestic species, but they also increase the chances of further wildlife entanglement (Harrington and Conover 2006, Hanophy 2009, Paige 2012). Improvements made to fence designs that promote landscape connectivity in ungulates through safe fence passages, while also reducing the economic cost associated with fence repairs will be beneficial to wildlife and landowners. Mitigative measures have been proposed to facilitate fence crossing and thereby enable animal movement and reduce the number of fence related injuries and deaths, all while maintaining the fence's effectiveness at containing livestock (Dolan and Mannan 2009). Modified fence designs, collectively termed wildlife friendly fences (hereafter WFF), typically consist of reductions in the number of total strands, lowered height of the highest strand, and an increase in height of the lowest strand (Hanophy 2009, Paige 2012).

Recent calls for a focus on fence ecology identified a need for research pertaining to the efficacy of fence designs, including elements constituting WFF designs (Jakes et al. 2018, McInturff et al. 2020). The increased attention has prompted research on whether and to what extent fence designs facilitate or hinder migratory movement of pronghorn (*Antilocapra americana*) as well as the crossing behavior of white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*; Burkholder et al. 2018; Jones et al. 2018, 2019, 2020). Less attention has been given to elk (*Cervus canadensis*; but see Knight et al. 1997, Bauman et al. 1999); however, due to their gregarious nature and large body size they may be of particular concern for landowners maintaining fences as impaired fence crossing may result in ongoing fence damage. Likewise, the differential effect of fences on individuals of varying demographic groups has been highlighted as a knowledge gap, which has only broadly been investigated (Jakes et al. 2018; Jones et al. 2018, 2020).

We used remote cameras to investigate how elk of different demographic classes cross fence lines (i.e., over, through, or under) that were experimentally modified following wildlife friendly designs. Further, we evaluated the factors that lead to difficult crossings involving an individual interacting with the fence in a manner that is damaging to the fence or the individual. We hypothesized that fence design elements commonly used in WFF designs including a reduction in the number of strands (from 4 to 3), increasing height of the bottom strand, and decreasing height of the top strand will play a key role in determining how an individual crosses fences (i.e., over, through, or under) and whether the crossing event proceeds with difficulty. We suggest that by better understanding the behavioral component of fence crossing decisions, we will inform questions about the efficacy of WFF designs and their implementation by landowners.

STUDY AREA

Wainwright Dunes Ecological Reserve (hereafter WDER) is located approximately 250 km southeast of Edmonton in the Parkland Natural Region of Alberta. The 2,821-ha WDER is located within an agricultural matrix and has an ongoing history of seasonal use as rangeland for cattle by a local grazing association (for additional details see Visscher et al. 2017; Figure 1). In 2011, portions of the WDER perimeter fence that required major repairs were reconstructed following WFF designs based on literature values for strand number and placement (Paige 2012).

METHODS

Cameras and fences

As part of our experimental study design, we placed 12 Reconyx motion activated cameras (PC900; Reconyx, Holmen, WI, USA) on both standard fences, and on new fences that had been built according to WFF design principles that enclosed the WDER to investigate their effect on elk. Standard rangeland fences had 4 barbed wire strands positioned at 40.64, 55.88, 81.28, and 106.68 cm from the ground, respectively. Wildlife friendly fences featuring 3 strands of barbed wire at 53.34, 81.28, and 106.68 cm from the ground, respectively. We placed 6 cameras along each type of fence, and selected sites based on the presence of known game trails that lead into and out of the WDER (Janzen et al. 2017, Visscher et al. 2017). Along both types of fences, we positioned 3 cameras at gate sites that could be opened, which typically occurred seasonally when domesticated animals were no longer in the vicinity. Gates embedded within sections of fence maintained the same construction and dimensions as the surrounding fence. However, only images obtained when the gates were closed and functioning

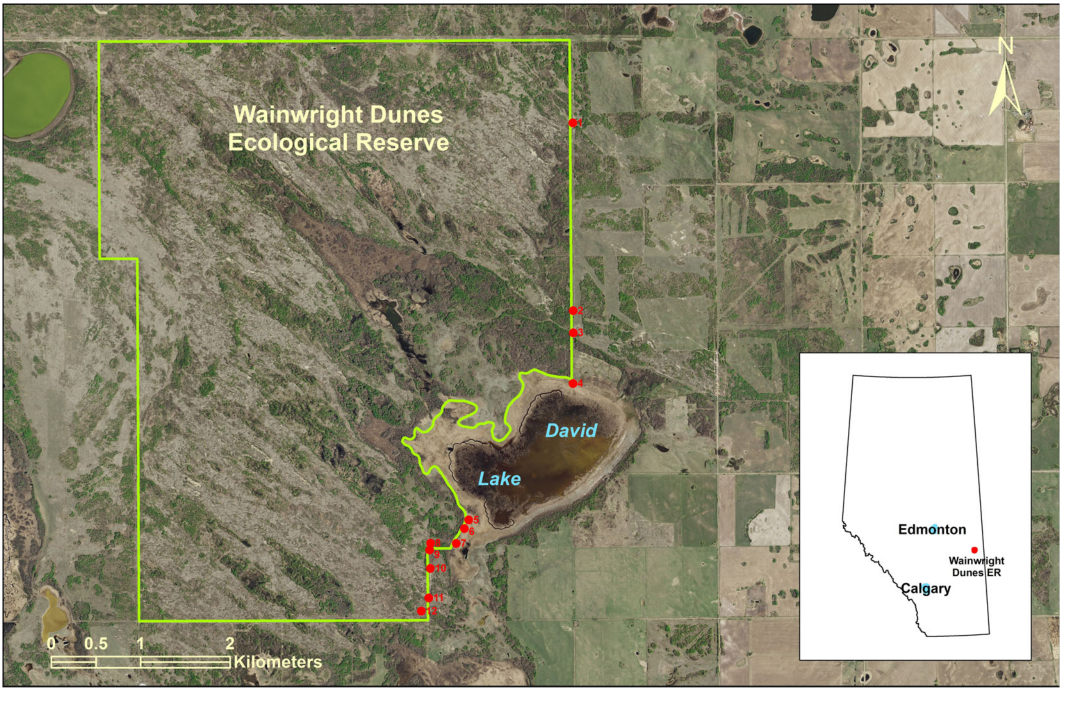

FIGURE 1 Location of the Wainwright Dunes Ecological Reserve (WDER) within the province of Alberta, Canada, and the location of motion-sensing cameras (red dots) along the eastern perimeter fence of the WDER.

in a fence-like manner were included in the analyses. During the summer of 2013, we modified the fences and gates as follows. For the standard 4 strand fences and gates, we applied WFF design principles and combined the bottom 2 strands (originally at 40.64 and 55.88 cm from the ground) into a single strand placed at 45.72 cm from the ground, thus creating a 3 strand fence or gate, with strands at 45.72, 81.28, and 106.68 cm, respectively. For the WFF fences and gates, we lowered the top 2 strands, resulting in strands at 53.34, 71.12, and 96.52 cm, respectively.

Data and statistical analysis

Every month between September 2011 and November 2014, we downloaded images and performed camera maintenance. Individual pictures were viewed and manually sorted, classified, and summarized using the Reconyx MapView Professional program by tagging each image with appropriate metadata including species, demographics, crossing events, crossing behavior, and whether the crossing was deemed difficult. We defined fence crossing difficulty as occurring when the individual significantly deflected the wires or was momentarily hung up in the wires when crossing fences. Images containing domesticated animals, humans, or non-target species were removed from subsequent analysis (Janzen et al. 2017). We constructed a multinomial model to predict how an elk moved through fences by determining the probability of crossing over, through, or under fences as a function of the number of strands, the height of the top and bottom strand, and whether the structure was a fence or a closed gate. Next, we devised a binomial model to predict whether the crossing individual experienced difficulty with its crossing as a function of how the individual crossed (e.g., over, through, or under fences), the number of strands, the height of the bottom strand, the height of the top strand, and whether the structure was a fence or a closed gate. We accounted for demographic class and incorporated a random effect for camera site in both models. All models were fit in R (version 4.1.0, R Core Team 2021) using the mclogit (Elff 2021) and lme4 (Bates et al. 2015) packages, using $\alpha = 0.05$, and results were visualized using ggplots2 (Wickham 2016).

RESULTS

We classified a total of 9,782 crossing events for which the crossing behavior of the individual was recorded. Elk comprised a majority ($n = 7{,}974$, 81.5%) of fence crossing events, followed by mule deer ($n = 803$, 8.2%), white-tailed deer ($n = 764$, 7.8%), moose (*Alces alces*, $n = 128$, 1.3%), unknown ungulates ($n = 112$, 1.1%), and a single instance of a domestic cow ($n = 1$, <0.1%).

Across all conditions, elk primarily crossed over fences ($n = 6{,}555$, 82.2%), followed by crossing under fences ($n = 1{,}031$, 12.9%), and through fence strands ($n = 388$, 4.9%). Adult males tended to cross over fences more often than adult females, while juveniles preferentially went under or through fences (Figure 2). The reduction in strands from 4 strand traditional fencing to a 3 strand WFF design resulted in an overall reduction in the percentage of over and through fence crossings (90.1% to 77.6% and 6.9% to 3.7%, respectively), while the percentage of under fence crossings increased (3.0% to 18.7%). However, after accounting for strand height and other factors in a multinomial model, 4 strand fences were significantly less likely than 3 strand fences to cause individuals to cross through fences relative to crossing over ($\beta = -2.283$, SE = 0.357, $P < 0.001$) and were not more likely to have crossings under fences relative to going over ($\beta = 1.40$, SE = 0.718, $P = 0.05$). Wildlife friendly fence designs with modified strand placement also played a role in how elk crossed fences. The height of the bottom strand, in particular, appears to impact the behavior exhibited by the crossing individual. When the bottom strand height was low (i.e., close to the ground), it resulted in individuals crossing through fences significantly more often, whereas a raised bottom strand resulted in individuals preferentially crossing under fences relative to going over fences (Table 1, Figure 3). When the height of the top strand was modified, it did not significantly change the probability that an individual would cross through relative to over fences ($\beta = -0.040$, SE = 0.027,

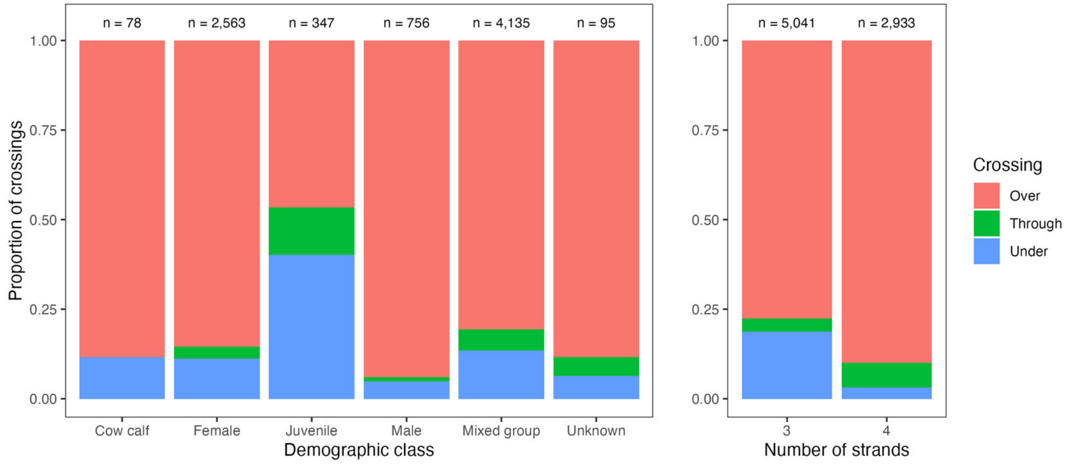

FIGURE 2 Proportion of crossing type (over, through, and under the fence) by demographic class (left panel) and the number of fence strands (right panel). The total number of crossing events by each grouping is given above each bar.

TABLE 1 Results from the random effects (for camera site) multinomial model of how (over, through, or under) elk cross a fence as a function of the structure type (type), where the reference category is fence, the number of strands of the fence (strand number, 3 or 4), the height of the bottom strand in centimeters (bottom), the height of the top stand in centimeters (top) and the demographic class (demo) of the crossing individual(s), where females are the reference category. The coefficient is given in the logit (log-odds) form and can be exponentiated to calculate the odds ratio.

	Through vs. Over			Under vs. Over		
Variable	**Coefficient**	**Std. Error**	***P*-value**	**Coefficient**	**Std. Error**	***P*-value**
Intercept	21.340	6.233	<0.001	−36.26	7.342	<0.001
Type = closed gate	0.369	0.248	0.136	2.01	0.202	<0.001
Strand number	−2.283	0.357	<0.001	1.40	0.718	0.050
Bottom	−0.270	0.059	<0.001	0.316	0.103	0.002
Top	−0.040	0.027	0.130	0.125	0.012	<0.001
Demo = cow calf	NA	NA	NA	−0.555	0.382	0.146
Demo = juvenile	1.94	0.212	<0.001	1.88	0.172	<0.001
Demo = male	−0.975	0.356	0.006	−1.41	0.192	<0.001
Demo = mixed group	0.563	0.143	<0.001	0.082	0.094	0.384
Demo = unknown	0.555	0.482	0.249	−0.695	0.452	0.124

$P = 0.13$), however as the height of the top strand increased there was an increasing probability that the elk would cross under fences relative to over fences ($\beta = 0.125$, SE = 0.012, $P < 0.001$, Figure 3). Closed gate sites were 7.5 times likely ($\beta = 2.01$, SE = 0.202, $P < 0.001$), relative to fence sites, to have elk go under rather than over the closed gate, but no more likely to go through versus over ($\beta = 0.369$, SE = 0.248, $P = 0.136$, Table 1). Our multinomial model of crossing behavior also suggests that there were significant differences between demographic groups, relative to the reference category of females (Table 1). As compared to females, males were 62.5% ($\beta = -0.975$, SE = 0.356, $P = 0.006$) and 75.3% ($\beta = -1.41$,

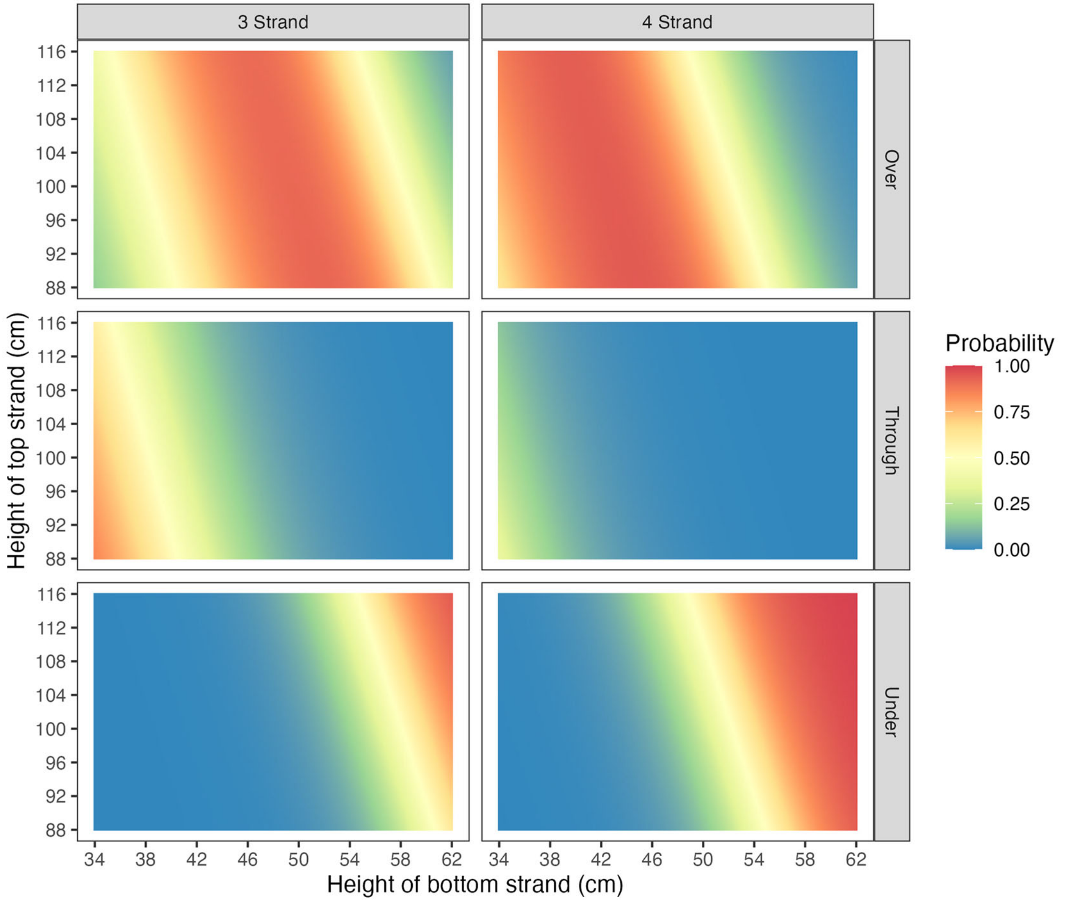

FIGURE 3 Population level model predictions for the probability of how (over, through, under; given in the rows of the figure) a female elk crossed fences based on the height of the bottom strand (x-axis), the height of the top strand (y-axis) and the number of strands (3 and 4 strands; given as the columns in the figure).

SE = 0.192, $P < 0.001$) less likely to cross through or under fences, respectively. Conversely, juveniles were 7.0 ($\beta = 1.94$, SE = 0.212, $P < 0.001$) and 6.6 ($\beta = 1.88$, SE = 0.172, $P < 0.001$) times more likely to cross through and under fences, respectively, as compared to females (Table 1).

We noted 323 events where the crossing elk experienced difficulties (4.1% of all crossings) where they interacted with the barbed wire strands (Figure 4). Our binomial model found elk were more likely to have difficulty crossing a fence when they crossed through (6.9 times, $\beta = 1.93$, SE = 0.161, $P < 0.001$) or under (1.7 times, $\beta = 0.492$, SE = 0.188, $P = 0.009$) fences, relative to going over fences. Fence characteristics that increased the likelihood of difficult crossings included 3 strand fences (4.1% vs 4.0% difficult crossing compared to 4 stand fences, $\beta = -0.750$, SE = 0.362, $P = 0.038$). The greatest differences between 3 and 4 strand fences appears to be with the proportion of difficult crossings through fences (19.9% and 17.8%, for 3 and 4 strand fences, respectively). The percentages of difficult crossings over fences were similar (3.2% and 3.0%, for 3 and 4 strand fences, respectively) and lower for difficult crossings under fences (4.3% and 5.6%, for 3 and 4 strand fences, respectively). Modifications to the strand placement, both the height of the bottom ($\beta = -0.084$, SE = 0.048, $P = 0.082$) and height of the top strand ($\beta = -0.020$, SE = 0.021, $P = 0.337$) did not have a significant effect on whether the crossing proceeded with difficulty. Similarly, there was no significant difference between fence and closed gate sites ($\beta = -0.097$, SE = 0.240, $P = 0.685$). Interestingly, the only demographic group that significantly

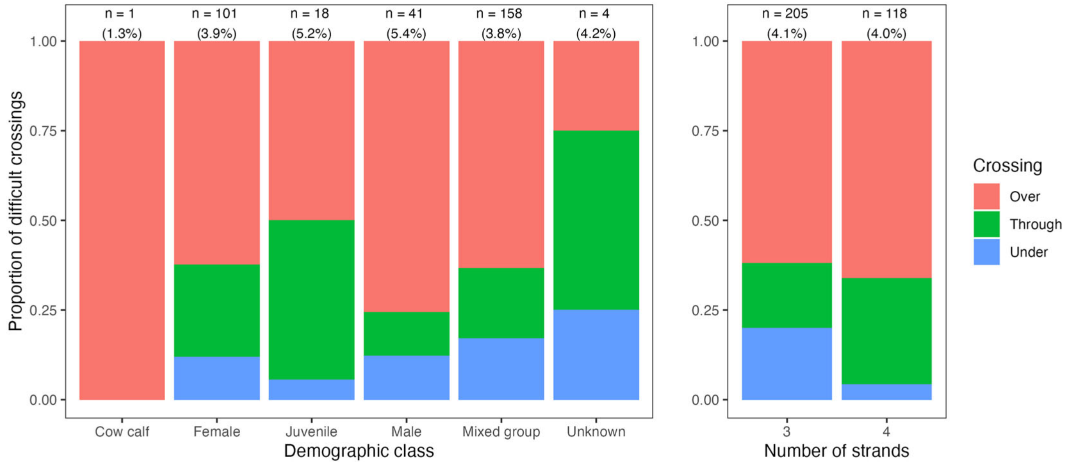

FIGURE 4 Proportion of crossing events that were classified as difficult, defined as significant deflection of the fence strands or the crossing individual was momentarily impeded or hung up by the fence strands, by crossing type (over, through, and under the fence) by demographic class (left panel) and the number of fence strands (right panel). The total number of difficult crossing events by each grouping is given above each bar.

differed from the female elk reference category were males, which had an increased likelihood of difficulty when crossing a fence (1.8 times, $\beta = 0.566$, SE = 0.195, $P = 0.004$; Table 2, Figure 5).

DISCUSSION

Several patterns relating to elk fence crossing behavior and fence structures commonly adjusted in WFF designs (typically the number and placement of strands) were revealed in our analysis, which may provide insight into the ways in which fence designs may mitigate the barrier effect posed by fences to elk. First, we found that a reduction in strand number increased the behavioral options available to crossing individuals influencing how they cross fences (Knight et al. 1997, Bauman et al. 1999). When faced with the need to cross a fence most of the elk we observed jumped over fences, consistent with findings elsewhere (Harrington and Conover 2006). A reduction from 4 barbed wire strands in standard fences to the 3 barbed wire strands used in WFF designs significantly increases the opportunity for individuals to cross under or through fences relative to going over fences. Fence strand adjustments seemed particularly important to support the passage of a wide variety of demographic classes, which appear to cross fences differently based on body size, a result that appears to extend to other species and their crossing preferences (Jones et al. 2020, Laskin et al. 2020).

Changes in strand placement also influence how individuals cross fences. Our modelling suggests that a trade-off occurs between the height of the top strand and the height of the bottom strand in determining how individuals cross. Lowering the top strand facilitates crossing by jumping over fences, an important consideration given that a majority of elk cross by jumping over fences (Knight et al. 1997, Bauman et al. 1999, Harrington and Conover 2006, Laskin et al. 2020). The height of the bottom strand seems to play an important role in determining whether an individual goes through or under the fence. As the height of the bottom strand increases, elk will preferentially cross under fences in favor of crossing through, a result consistent with deer (Burkholder et al. 2018, Jones et al. 2020). This advantage may be most significant for improving the ability of juvenile individuals to cross fences, as they are the most likely to cross through fences and crossings through fences are the most likely to cause difficulty. Our results are consistent with trends reported in other studies across species in that juveniles are relatively more impacted or likely to die in fences than adults (Harrington and Conover 2006, Paige 2012). In addition, calves also are easily separated from mothers when adults

TABLE 2 Results from the random effects (for camera site, variance =0.221, st.dev = 0.470) binomial model predicting whether an elk has difficulty crossing a fence (significantly deflected the fence strands and/or was momentarily hung up in the fence) as a function of how the elk crossed (cross) the fence (over, through, or under; where crossing over the fence is the reference category), the type of fence structure (type), where the reference category is a fence, the number of strands of the fence (strand numbers, 3 or 4), the height of the bottom strand in centimeters (bottom), the height of the top stand in centimeters (top) and the demographic class (demo) of the crossing individual(s), where females are the reference category. The coefficient is given in the logit (log-odds) form and can be exponentiated to calculate the odds ratio.

Variable	Coefficient	Std. Error	*P*-value
Intercept	5.141	4.404	0.243
Cross = through	1.93	0.161	<0.001
Cross = under	0.492	0.188	0.009
Type = closed gate	−0.097	0.240	0.685
Strand number	−0.750	0.362	0.038
Bottom	−0.084	0.048	0.082
Top	−0.020	0.021	0.337
Demo = cow calf	−0.860	1.001	0.390
Demo = juvenile	−0.030	0.281	0.914
Demo = male	0.566	0.195	0.004
Demo = mixed group	0.065	0.146	0.655
Demo = unknown	0.093	0.533	0.862

cross fences, leaving calves alone and susceptible to abandonment and predation (Gates 2006). While we have focused on elk, our results can also be applied to species of different body size and behaviors, providing crossing options for sympatric ungulates (Burkholder et al. 2018, Jones et al. 2020).

While difficult crossings were relatively infrequent (4.1% of all crossings) they have the greatest potential to damage fences and harm individuals crossing (Harrington and Conover 2006, Hanophy 2009, Paige 2012). Contrary to our hypothesis, we found that 3 strand fence design statistically caused more difficult crossings relative to standard 4 strand fences, despite similar overall rates of crossing difficulty. Three strand fences resulted in elk crossing through and under fences, both of which were more likely to result in a difficult crossing relative to jumping over fences. We also noted that males were the only demographic group to have a greater likelihood of a difficult crossing, again disproportionately, when they infrequently cross through or under fences. Perhaps this is due to their larger size and the presence of antlers (Laskin et al. 2020), however our analysis was not designed to account for potential seasonal shifts in how fences were crossed. The height of the bottom and top strand did not significantly affect whether a crossing was classified as difficult. We suggest that wildlife friendly designs indirectly affect crossing difficulty as they are an important determinant of how individuals cross, but it is the crossing type (i.e., over, through, or under) that presents the inherent difficulty. This also may explain the effect of the number of strands. Fence modifications that reduce the likelihood for individuals to try to cross through fences should be further studied. Unlike Jones et al. (2020), we did not quantify failed attempts where fences were approached, and a crossing was not attempted. Perhaps accounting for concurrent effects of failed attempts and difficult crossings would provide greater insight into how the number of fence strands may affect fence permeability. Thus, we suggest future work to determine if fence characteristics like strand number and strand placement may influence whether an individual attempts to cross a fence are warranted and may help explain the difference in crossing rates as a function of fence designs (Knight et al. 1997).

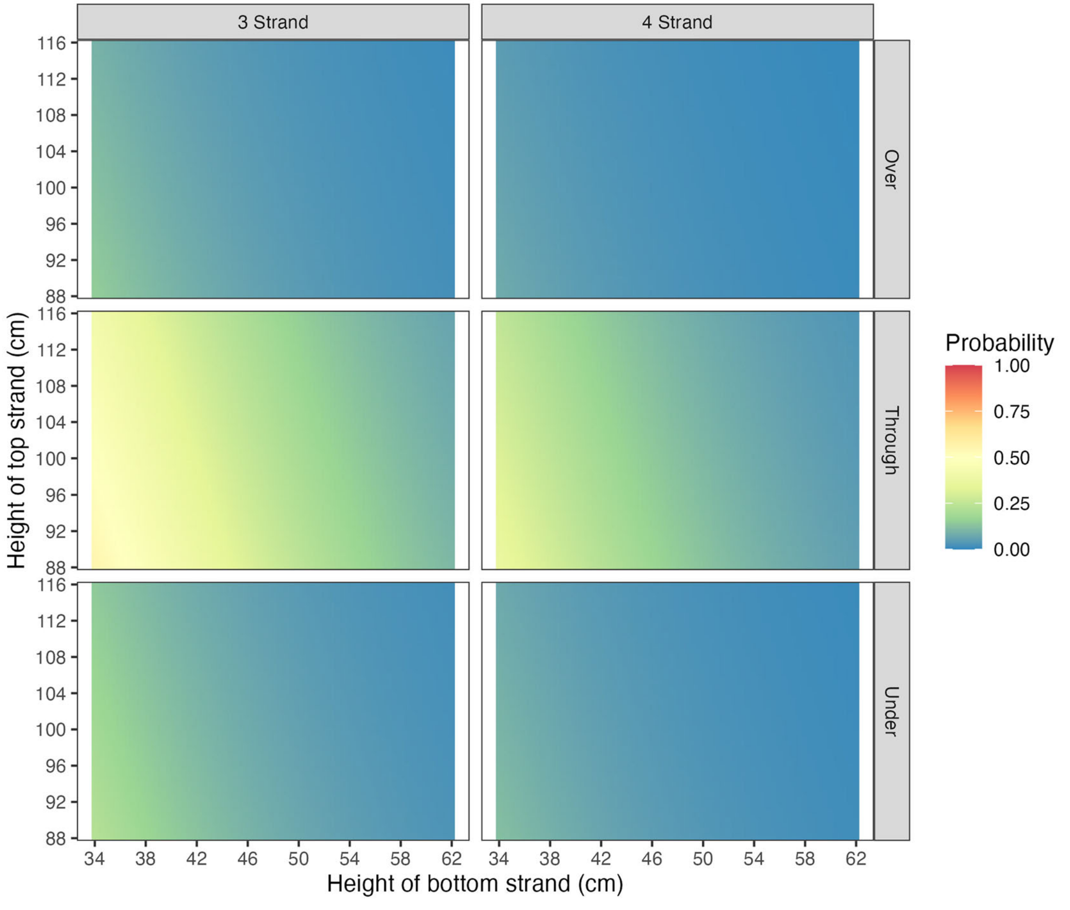

FIGURE 5 Population level model predictions for the probability of a female elk having a difficult or impeded fence crossing event as a function of how it crossed (over, through, under; given in the rows of the figure), the height of the bottom strand (x-axis), the height of the top strand (y-axis) and the number of strands (3 and 4 strands; given as the columns in the figure). Crossings where the individual tried to navigate a crossing through the fence were most problematic and this was accentuated by reductions the height of the bottom strand, effectively eliminating the behavioral option of passing under the fence.

We also note 2 further trends in the tagged images that did not form part of our analysis yet remain important results for practitioners and land managers seeking to maximize landscape connectivity while containing domestic animals. We noted that when the option of an open gate is provided, animals are most likely to use this interruption in fences as a movement corridor. Indeed, 90% of crossings at open gate sites occurred through the open gate (unpublished data), however, because these crossing events did not interact with the fence they were not included in our main analyses. While managers may be logistically prevented from leaving gates open due to grazing constraints, doing so whenever possible is preferable as this provides the safest crossing option for the widest demographics of all ungulate species. Further, we only observed a single domestic calf crossing under a fence at a WFF closed gate site out of the more than 3 million total images processed (most of which were cattle contained by fences but triggering our cameras), suggesting that the purpose of containing livestock is not mutually exclusive to facilitating increased permeability to native ungulates (Dolan and Mannan 2009).

Managers considering implementation of WFF design elements for elk should consider the trade-offs between mitigating the difficulty in most used crossing type (over), which has a relatively low probability of difficulty compared to mitigating the least frequent crossing type (i.e., through fences) that causes the most difficulty. In absolute terms, there were ~2.8 times as many crossings over fences that were classified as difficult relative to through fences. Likewise, WFF designs in many locations will need to account for a suite of sympatric ungulates and the optimal design may represent a compromise between species-specific designs (Burkholder et al. 2018; Jones et al. 2018, 2020; Laskin et al. 2020). For instance, Laskin et al. (2020) found that a 2 strand design with a higher bottom strand than we tested (80 cm) and a top strand approximately the same as ours (100 cm) was the optimal design across a suite of species while containing bison. Our results supports their recommendations for strand placement, and interestingly the 2 strand design creates little opportunity for individuals to cross through fences, something our 3 strand design seemed to encourage despite the potential for increasing the difficultly in crossing.

MANAGEMENT IMPLICATIONS

Wildlife friendly fence designs may mitigate the loss of landscape permeability resulting from ubiquitous rangeland fencing by altering the number of fence strands or modifying their placement. Modifications to the number and placement of fence strands do not compromise the need for fences to contain domestic livestock but simultaneously provide safe behavioral options for crossing individuals of a wide variety of demographic classes. Our results suggest that range managers and practitioners maximize the height of the bottom strand (53.34 cm in our study) and minimize the height of the top strand (96.52 cm in our study). These placement heights should encourage safe crossings over fences, the most common crossing for elk, as well as provide options for crossing under fences by juvenile elk (or smaller bodied ungulates). Placing a third (and fourth) strand between the top and bottom wires in such a way to minimize an individual's propensity to cross through fences will eliminate the crossing type with the most difficulty and reduce damage to fences and crossing individuals.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

ETHICS STATEMENT

No ethical information provided.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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