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Pronghorn Fencing Permeability in the NSS

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Prepared for Alberta Conservation Association and Environment and Climate Change Canada

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Executive Summary

Much of the Northern Sage Brush Steppe Ecosystem (NSS), particularly in Alberta and Montana, is a landscape dominated by fence infrastructure. The highest fence densities in this region are to the north of Suffield in Alberta and along Highway 2 in Montana. Pronghorn interactions with fences can disrupt movement patterns, fragment and reduce access to important habitats, and indirectly reduce an animal's reproductive fitness. Roadways, and additional linear infrastructure such as fences, have been identified as the most significant threat to ungulate migrations. To assist government agencies, ranching and farming organizations, and conservation groups to identify the best opportunities for fence modification projects, we analyzed individual behavioural responses of pronghorn to fences.

We used the R package "Barrier Behaviour Analysis (BaBA)" to examine individual pronghorn response to fences. We accessed pronghorn GPS data from 157 individuals and fencing datasets for Alberta, Saskatchewan, and Montana, pronghorn fence encounters were classified into normal, altered, and trapped animal movement types. A pronghorn interacted with fences on average 244 times annually with 66% of fence interactions classified as normal, 30% classified as altered movement and 2% trapped. Our results suggest that pronghorn have likely learned where they can move under fences, but that there are opportunities for improving movement through mitigation measures to enhance fence crossings. Fence interactions within 500 m of a paved road had a greater percentage of altered and trapped movements indicating paved roads may be further inhibiting pronghorn movement. We identified key areas on the landscape where fence mitigation could best improve pronghorn movement opportunities. Our model identified Suffield, AB as an area with quite a few impermeable fence sections as well as Malta and Glasgow, Montana as focal areas for fence mitigation.

Introduction

The Northern Sagebrush Steppe (NSS) of Canada and Montana (MT) is the northern terminus of sagebrush steppe and grassland habitats in North America and constitutes the northern range limit of pronghorn (*Antilocapra americana*). Because of diverse and ongoing anthropogenic pressures, native habitat is being converted and fragmented across the region. This is resulting in increased stress on wildlife populations and declines in overall ecosystem function (Alberta Biodiversity Monitoring Institute, 2016). To mitigate these pressures, scientifically informed large landscape-scale planning provide a defendable foundation that considers the region's ecological, societal, and anthropogenic attributes. Planning needs to account for landscape scale, linear anthropogenic disturbances in the NSS to maintain ecological processes such as large-scale movements, connectivity, and critical habitat protection (Hilty et al., 2020).

Linear infrastructure fragments the movement landscape and directly cause pronghorn mortality, disrupt movement patterns, and restrict and reduce access to important habitats (Eacker et al., 2023; Jakes et al., 2018b; Jones et al., 2022). Fragmentation from linear features can act as both semipermeable or complete movement barriers imposing indirect and direct consequences to pronghorn (Jones, 2014; Jones et al., 2022). Roadways and fences have been identified as the most significant threat to ungulate migrations (Jones et al., 2022; Yoakum et al., 2014). Indeed, fencing is ubiquitous across the prairies, is at higher densities in grazed pasture, and may cover an order of magnitude greater distance than roads (A.F. Jakes et al., 2018; McInturff et al., 2020). Given the sheer number of fences and costs of modification, it is important to prioritize where fence modifications can be made to most effectively alleviate barrier effects — it is unrealistic to target the entire fence network (Løvschal et al., 2017). Therefore, prioritizing mitigation projects for conservation impact, while accounting for human safety and livestock husbandry, is a necessary planning step (Huijser et al., 2009; Lee et al., 2023).

As a strategy to identify and prioritize mitigation opportunities, we assess the permeability of fences to pronghorn based on an existing research methodology (spatial-temporal individual animal response to linear barriers) developed by Xu et al. (2021). We identify areas within the NSS where fence modification projects would optimize pronghorn movement. Our objective therefore is to identify fence sections that are both along movement corridors and strong barriers to prioritize areas for investment in fence modification.

Methods

Study Area

The study area is part of a larger region known as the Northern Sagebrush Steppe (NSS). It covers ~315,000 km^2 of the Northern Great Plains that includes portions of Alberta and Saskatchewan in Canada, and Montana in the USA. The landscape is characterized by flat, open prairie and rolling hills, remnants of glacial recession and deposits with prevalent badlands and deep coulees throughout the region (Mitchell, 1980). Human settlements are sparsely distributed with few urban population centers. Cattle grazing is the predominant land use given that the soils, terrain, and precipitation is poorly suited for row crop agriculture. The region is considered semi-arid and received an annual mean of 39.2 cm of precipitation, with approximately 70% as rainfall (Jones et al., 2022). Where oil and natural gas wells occur in this area, they occur at high densities.

Pronghorn GPS collar data

We used GPS collar data from 157 female pronghorn from 2003 to 2011 collected at 2 (*n* = 51) or 4-hour intervals (*n* = 106) (Jones et al., 2019). For fencing analysis, pronghorn movements were determined using 61 individuals in Alberta, seven in Saskatchewan and 89 from Montana (Figure 1). For the purposes of our analyses, we defined the spring migration as spanning March to April and fall migration spanning October to November (Jakes et al., 2018a).

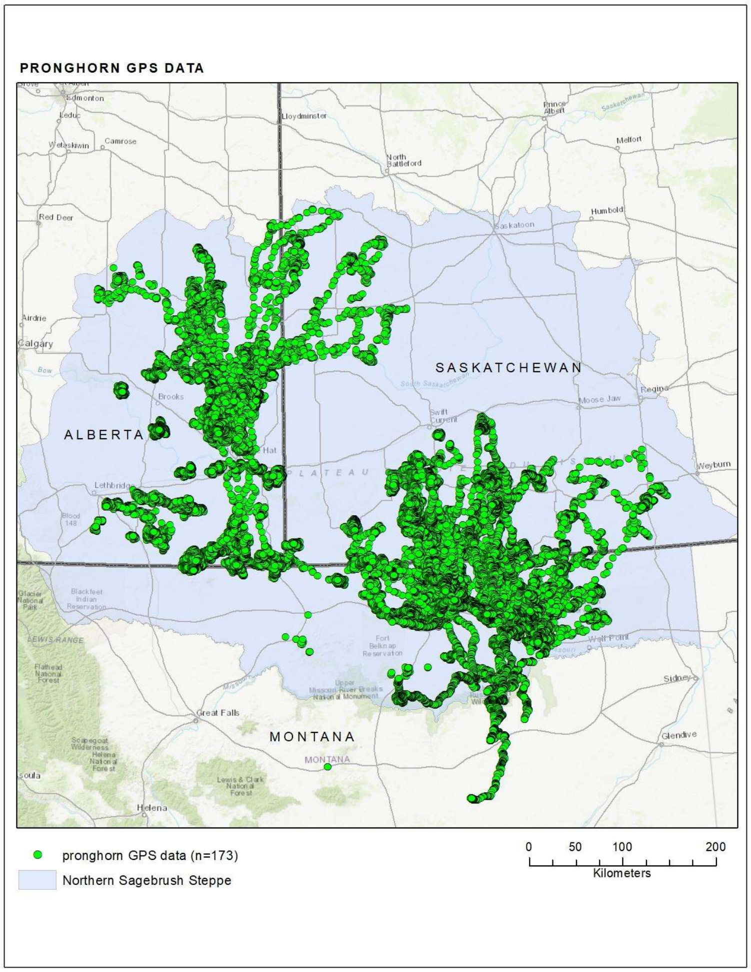

Figure 1: Northern Sagebrush Steppe study area and pronghorn GPS data for Alberta and Saskatchewan, Canada and Montana, USA.

Fencing data

In Alberta we used an existing fence layer derived from digital mapping of high-resolution aerial imagery between 1999 and 2001 (Jones et al., 2019; Seward et al., 2012). For Saskatchewan, we used a fence layer provided by Alberta Conservation Association with permission from Saskatchewan Environment developed from modeling (Jones et al., 2021). For Montana, we used the fence data modeled using the similar, yet jurisdictionally specific, approach applied in Saskatchewan (Poor et al., 2014). Datasets with cleaned fence sections greater than 1000 m long were partitioned into 500 m segments and all sections shorter than 100 m removed from the dataset. To visualize the NSS as a whole, we depict fences in all jurisdictions by their density per 100 km^2.

Pronghorn fence interaction analysis

We used the R package BaBA (Barrier Behaviour Analysis; (Xu et al., 2021))to examine individual-level response to fences. The analysis approach requires pronghorn GPS data and a fence spatial layer. The movement model classified pronghorn fence encounters into three animal movement types; normal, altered, and trapped movement based on six behavioural response types; quick cross, average movement, trace, bounce, back and forth, and trapped (Figure 2; Xu et al., 2021).

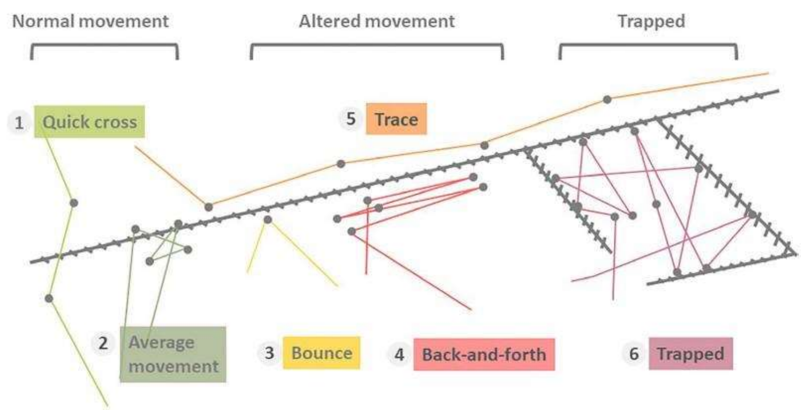

Figure 2: Extracted from Xu et al. (2021) demonstrating the three animal movement types (normal, altered, trapped) and six behavioural response categories: normal movement type includes quick cross and average behavioural categories, altered movement type includes bounce away, move back and forth, and trapped.

Parameter inputs to the BaBA program can be flexible including setting buffer distances from linear features for encounter events, defining the maximum duration of a barrier encounter that will be considered short interaction, minimum duration of a barrier encounter that will be considered a long interaction, movement duration that will define the "straightness" of an animal's expected movement (enabling BaBA to identify movement deviations that identify potential barriers), and an adjustment parameter, called maximum cross, that addresses animal trajectories that depend on straight barrier features (trace and back-and-forth) where the landscape may include a discontinuous barrier or non-straight linear feature. In our simulations, if the number of encounters is greater than the defined max_cross, the behaviour is classified as "unknown".

We defined the following parameters used in the BaBA model for our study area as follows:

- d: barrier buffer distance (m) was calculated as 70 m for animals with 2-hour recording interval GPS collars and 192 m for animals with 4-hour recording interval GPS collars. Buffer sizes were determined by calculating the mean step length of individual pronghorn and then, from this, an overall average step length among animals with 2- and 4-hour recording intervals independently.
- tb: four hours was the maximum duration of an encounter event that we considered to be a short barrier interaction (i.e., quick cross or bounce).

- w: we used seven days (168 hours) to be our event window. This defines the length of time where a moving window method will be applied to calculate average movement straightness.
- max_cross: we used four crosses (trajectory-barrier intersections) to be the maximum number allowed in trace and back-and-forth behaviour.

To visualize results, we plotted the number of events for the three animal movement types (normal, altered, trapped) per 100 km^2 hexagon grid. We selected hexagons as they more naturally represent curved patterns in spatial data than square grids. This enabled identification of focal areas for potential fence mitigation areas on the landscape. We evaluated animal movement types for pronghorn during all seasons, and for spring and fall migration. Finally, we evaluated the impact of paved roads on the animal movement type by separately considering the movement type dataset for pronghorn interactions with fences that are within 500 m of a paved road and those with fences more than 500 m from a paved road.

We then calculated a fence impermeability index (0 to 1) for fence sections (500 m or shorter) where 0 is the most permeable and 1 is impermeable. The index is based on the ratio of non-normal movement events (trace, back-and-forth, bounce, trapped) to total fence encounter events, weighted by the number of individual animals along that fence section. Therefore, fence sections that had more individual animals with altered movement scored higher on the impermeability index (Xu et al., 2021). We then plotted results for identified focal areas within the NSS to guide fence modification projects which have been shown to improve pronghorn, and other ungulate movements (Burkholder et al., 2018; Jones et al., 2018; MacDonald et al., 2022).

We developed a second fence impermeability index where we excluded weighting the number of individual animals to better identify responses to fence sections where only one or few animals interacted. We calculated this index because the collared pronghorn were not densely grouped but rather widely distributed across our large study area. This resulted in few animals interacting with some fence lines.

Results

There are 161,047,401 km of fences in the NSS study area, with an average fence density of 0.57 km^2 per 100 km^2 grid. Higher fence densities occur around Highway 9 in Alberta (north of CFB Suffield) and along Highway 2 in Montana.

A pronghorn encountered fences an average of 224 ± 133 (mean ± SD) times per year. There were 34,000 pronghorn interactions with fences in the study area; 66% of fence interactions were normal movement, 30% were altered movement, 2% were trapped behaviour, and 2% of interactions were not classified (Table 1). Our evaluation of fence interactions during spring and fall migration periods revealed similar patterns to annual movements but with slightly more altered/trapped movement types in the spring (31%) than fall migration (25%) (Figure 3).

Table 1: Percent pronghorn fence interaction movement types during all seasons, spring migration, and fall migration.

Movement type	% all season	% spring	% fall
Normal	66	65	73
Altered	30	29	24
Trapped	2	2	1
Unknown	2	3	2

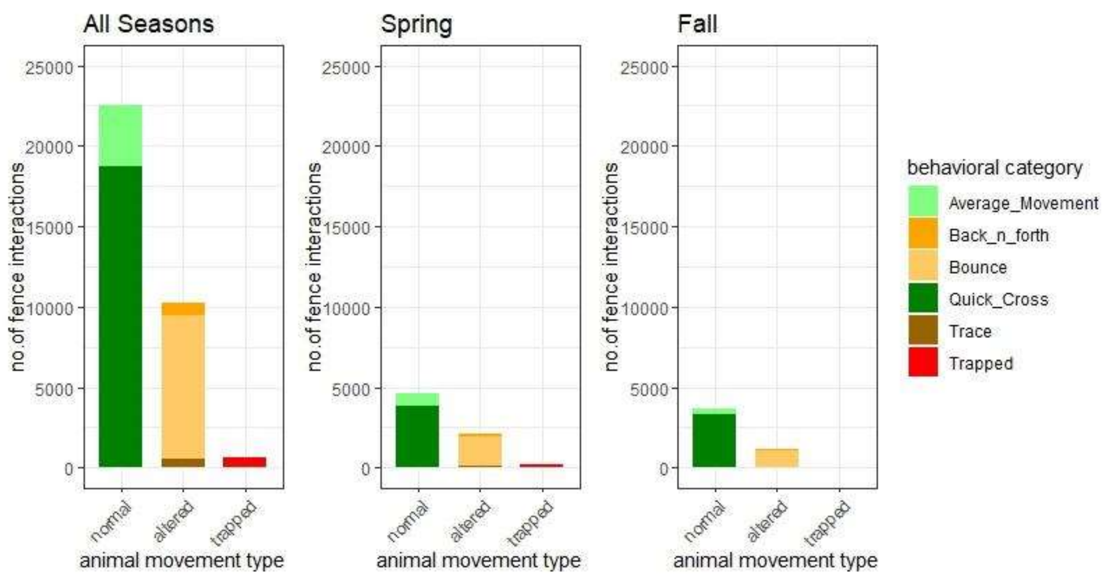

Figure 3: Number of pronghorn fence interactions for three animal movement types (normal, altered, trapped) during all seasons, spring migration, and fall migration. Movement types are further classified by behavioural category.

We found that fences associated with paved roads had more altered/trapped movement types (41%) than fences not within 500 m of a paved road (31%) (Table 2, Figure 4). Only 5% (n = 1732) of fence interactions were within 500 m of paved roads. A chi-squared test identified highly significant differences between movement and road buffer ($\chi^2 = 87.571$, P $< 2.2\ e^{-16}$, d.f.= 3).

Table 2: Percent pronghorn fence interaction movement types at fences within 500 m of paved roads and fences not near paved roads.

Movement type	% within 500 m from paved road	% > 500 m from paved road
Normal	57	66
Altered	40	29
Trapped	1	2
Unknown	2	2

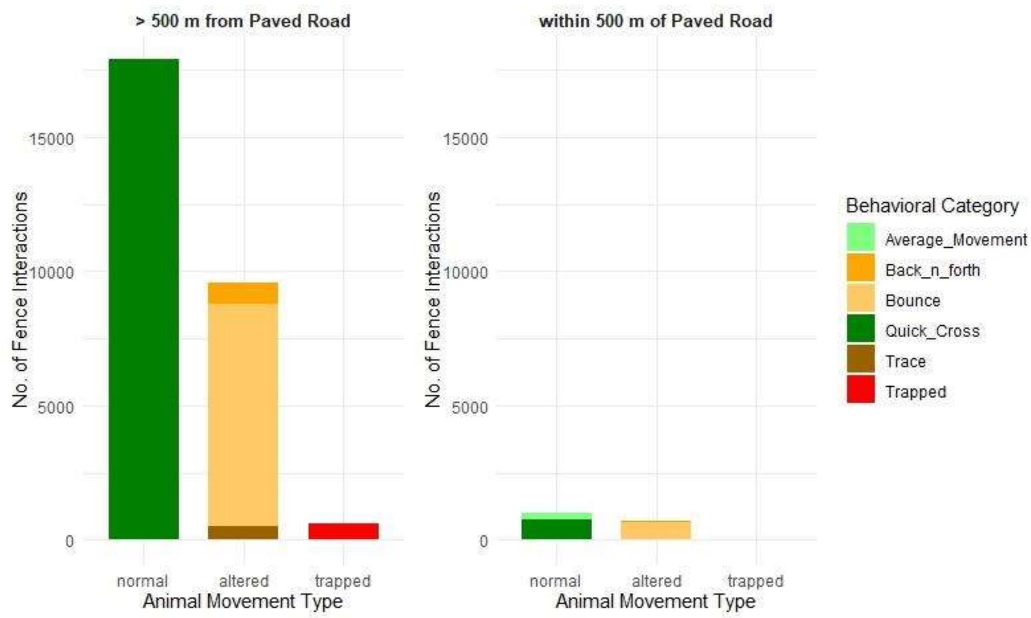

Figure 4: Number of pronghorn fence interactions for three animal movement types (normal, altered, trapped) for fences within 500 m of a paved road and fences not within 500 m of a paved road. Movement types are further categorized into behavioural categories.

Seasonal variability of pronghorn behaviour (based on an aggregate of all data) indicated that altered and trapped movements occur in all seasons and months (Figure 5). By categorizing pronghorn movement types by migration period, we determined more altered/trapped movement types occurring during the spring than during the fall migration (Table 3).

Table 3: Mean number of pronghorn fence interaction movement types annually, and during spring and fall migrations.

Movement type	Annual mean	Spring mean	Fall mean
Normal	15.8	16.3	16.4
Altered	7.34	7.38	5.59
Trapped	4.03	4.83	1.38
Unknown	1.98	1.96	1.94

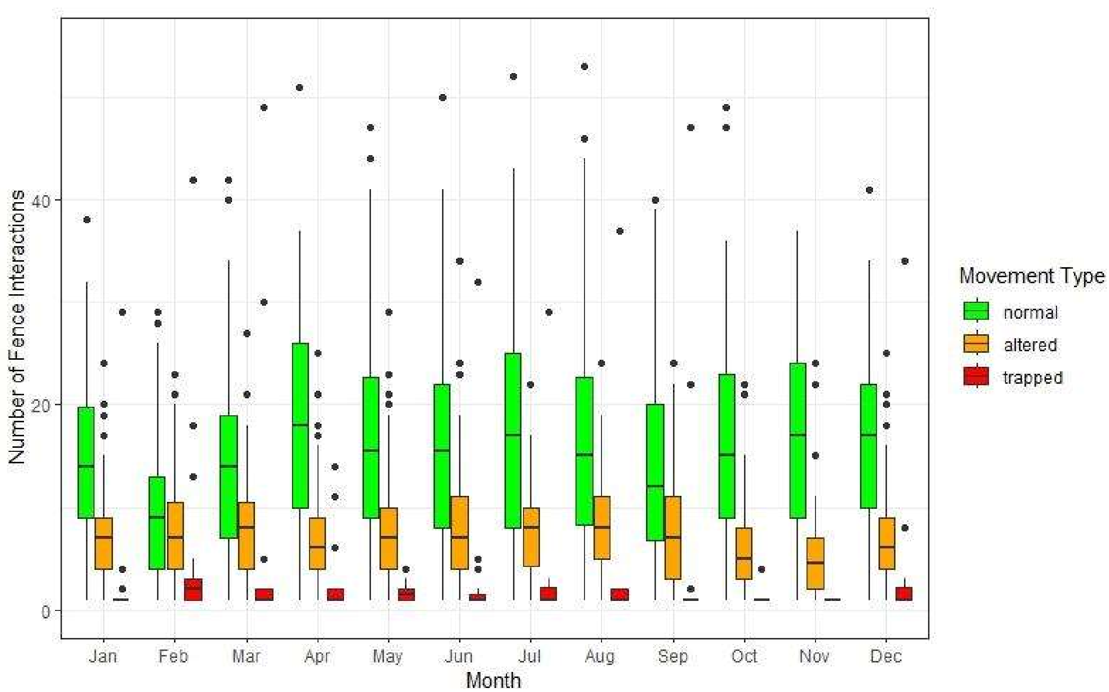

Figure 5: Seasonal variability of pronghorn behaviour per movement type in the NSS, where months 3–4 depict spring migration and months 10–11 depict fall migration. Black points represent outliers in the data that fall outside the average group of values per movement type per month.

Pronghorn movement types are displayed as counts per 100 km^2 to visually identify focal areas on the landscape where there are opportunities for fencing modification projects (Figure 6).

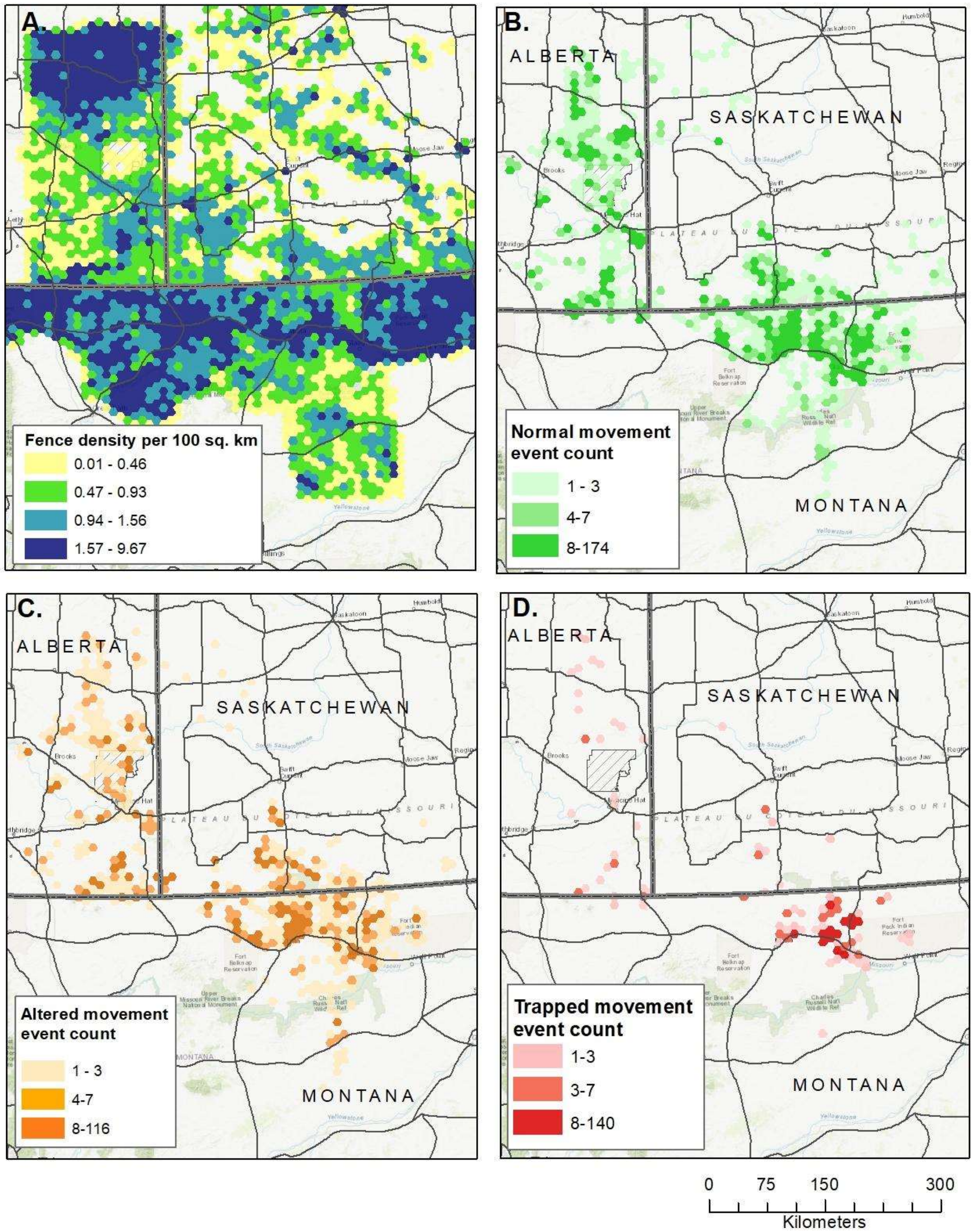

Figure 6: Fence density grid in the NSS (panel A.), normal pronghorn movement event count in green (panel B.), altered pronghorn movement event counts in orange (panel C.), and trapped pronghorn movement event counts in red (panel D.) per 100 km^2 grid.

The fence permeability index was developed for fence sections with four or more pronghorn interactions. A total of 2,376,244 km of fences (representing only 1.5 % of total fence length in the NSS) had four or more pronghorn interactions and were therefore included in the impermeability index. For fence sections with four or more pronghorn interactions, 92% were classified as permeable (index between 0 and 0.25) (Figure 7). The impermeability equation considers the number of unique animals interacting with a fence section and those with a higher number of unique animals are weighted higher. We tested how the impermeability index changed by removing the individual animal weighting, which resulted in more impermeable fence sections (Figure 7).

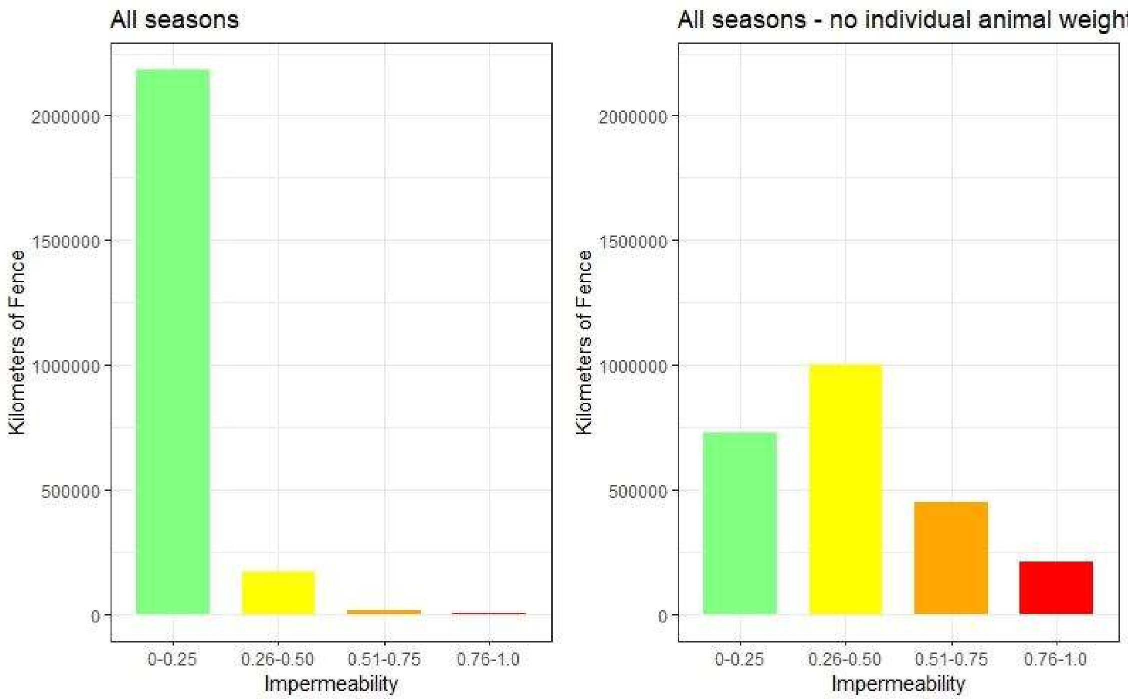

Figure 7: Fencing impermeability from 0 (permeable) to 1 (impermeable) and length of fencing (km) in specified index bins for pronghorn fence interactions. The left plot depicts impermeability index developed using equation developed in BaBA package where the number of individual animals is considered. The right plot depicts the impermeability index where number of individuals interacting with a fence section is not considered.

A focal area reference map (Figure 8) shows the impermeability index (weighted for number of animals), identifying five focal areas for fence mitigation; Suffield (Figure 9), Manyberries (Figure 10), Grasslands National Park (Figure 11), Malta (Figure 12), and Glasgow (Figure 13). Figure 14 focuses on the Glasgow focal area, where fence sections have high impermeability scores. We displayed the altered movement interactions and the number of individual animals associated with a fence section to show the influence of weighting the impermeability index by the number of individual animals.

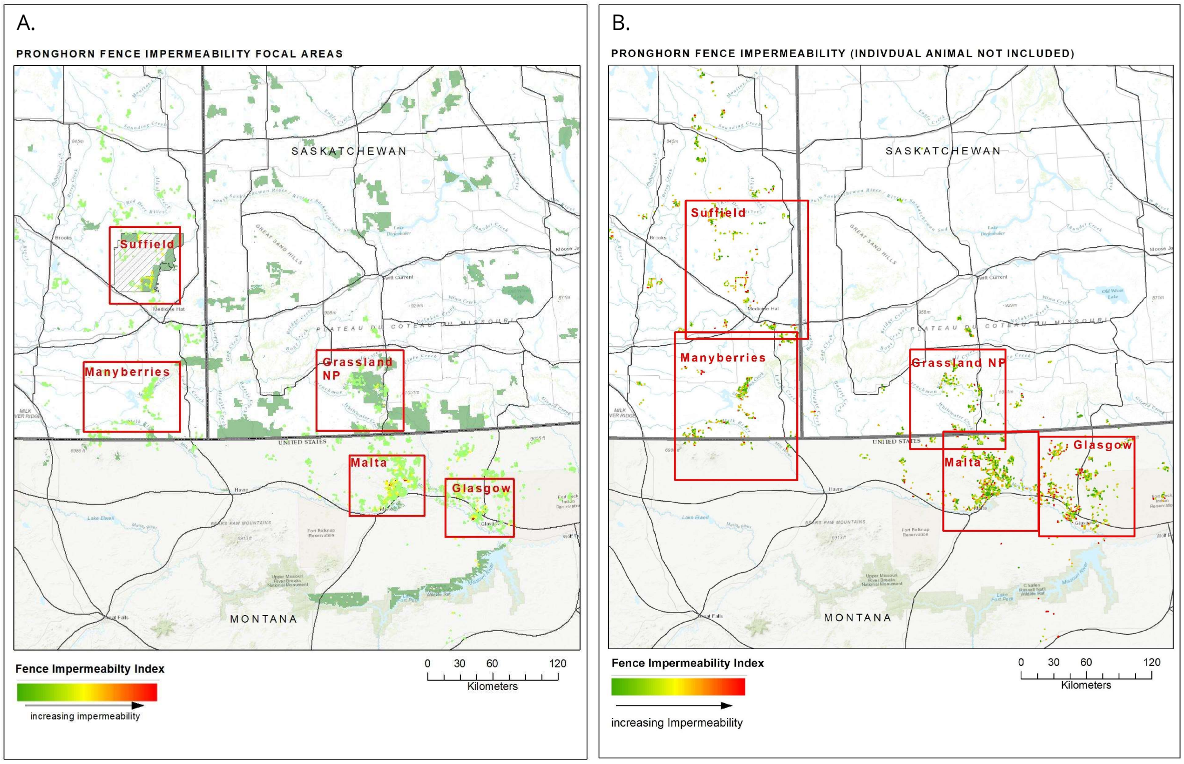

Figure 8: Focal area reference map outlining five focal areas in the NSS for consideration of fence modifications based on fence impermeability index (map A includes individual animal weighting and map B does not include individual animal weighting), where impermeability increases from green to red.

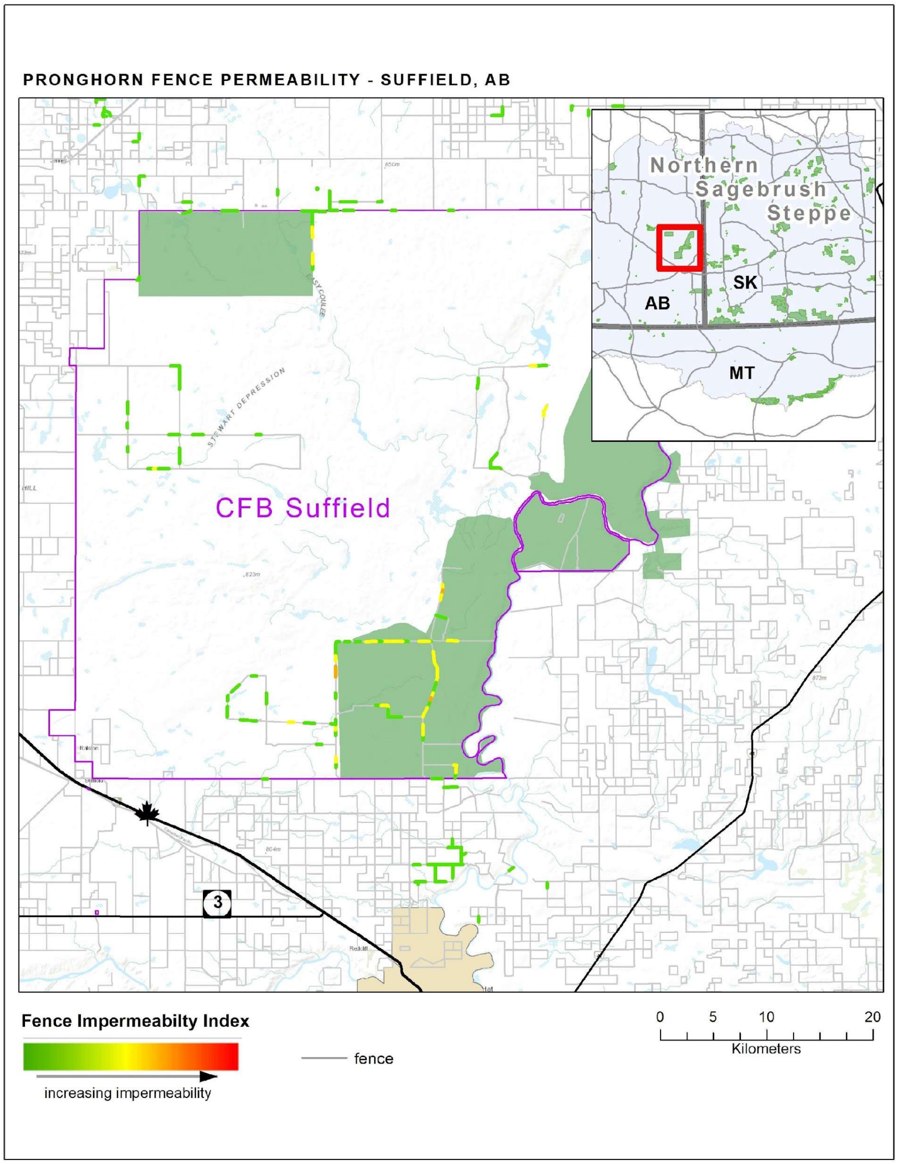

Figure 9: Fence impermeability index with individual animal weighting for CFB Suffield, Alberta focal area in the NSS, where impermeability increases from green to red.

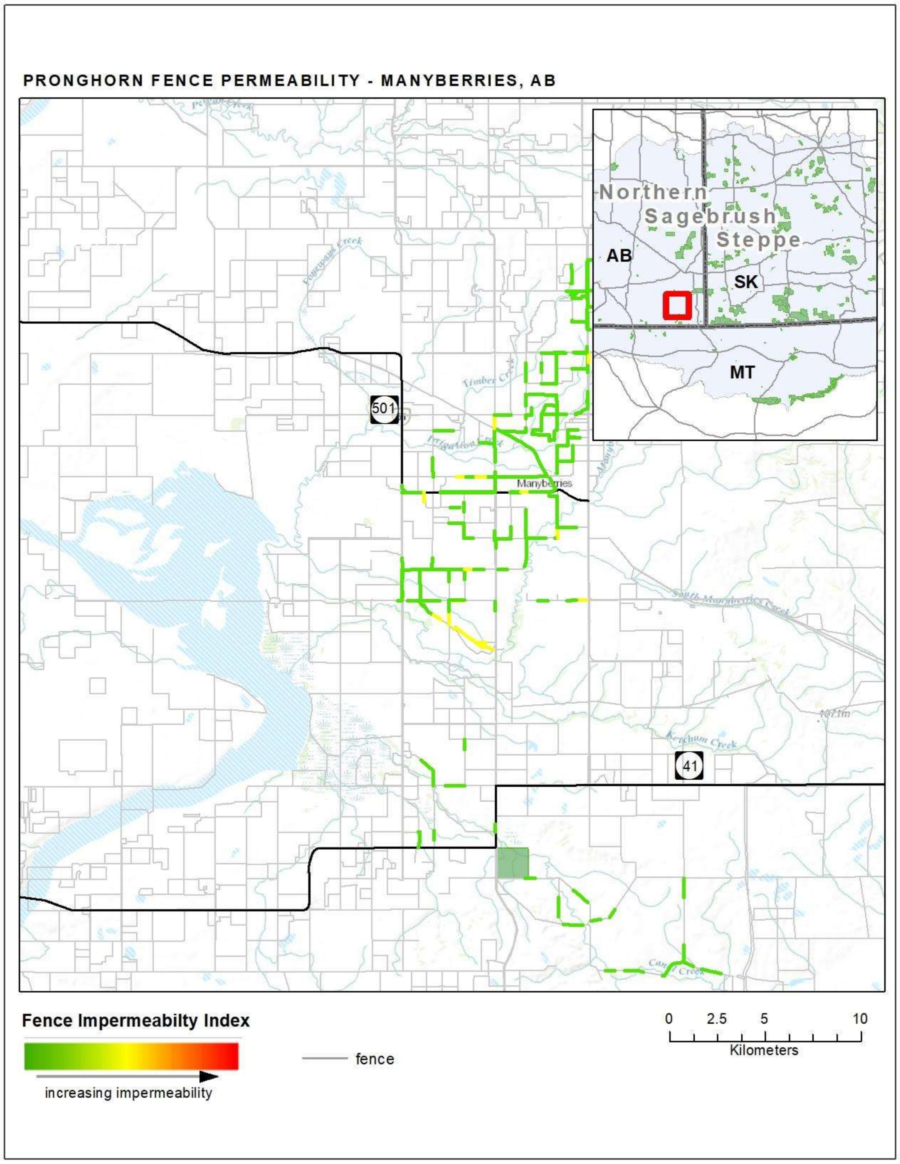

Figure 10: Fence impermeability index with individual animal weighting for Manyberries, Alberta focal area in the NSS, where impermeability increases from green to red.

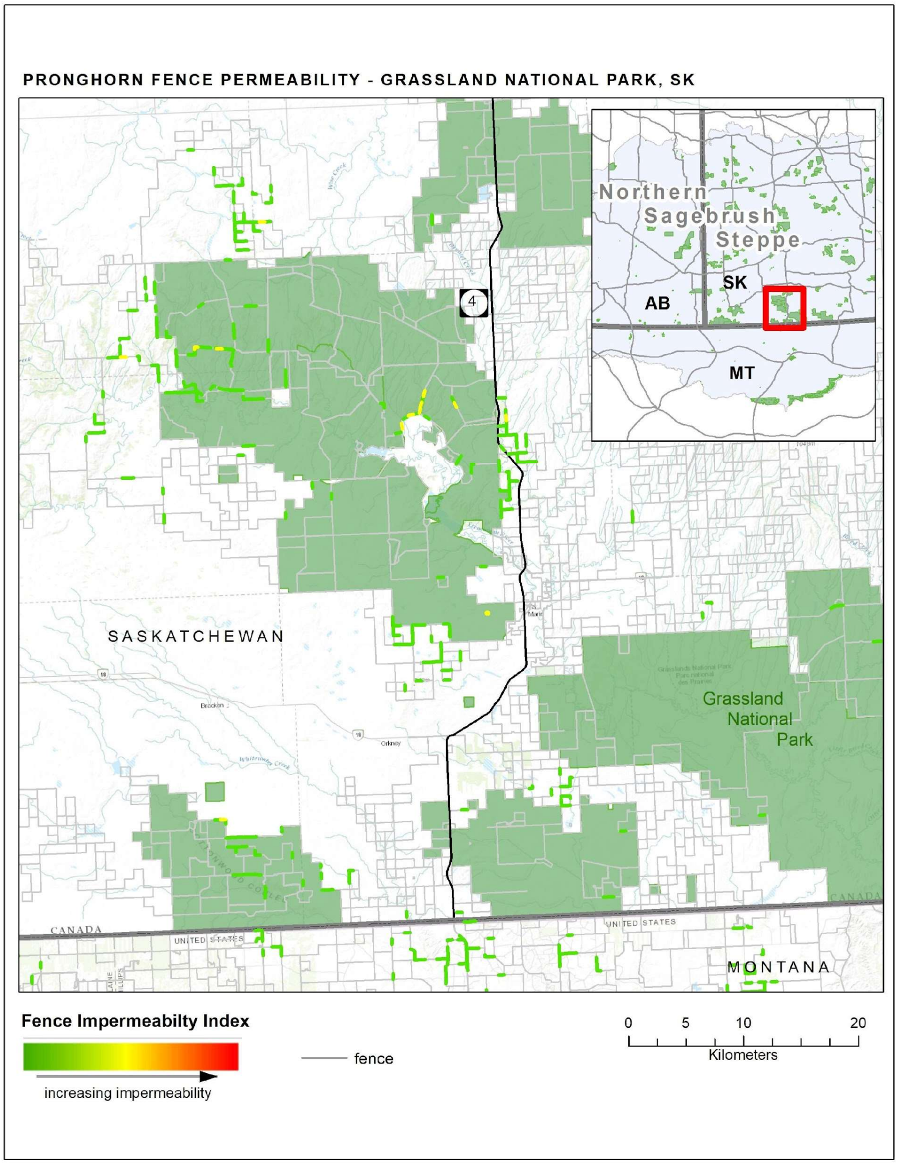

Figure 11: Fence impermeability index with individual animal weighting for Grassland National Park, Saskatchewan focal area in the NSS, where impermeability increases from green to red.

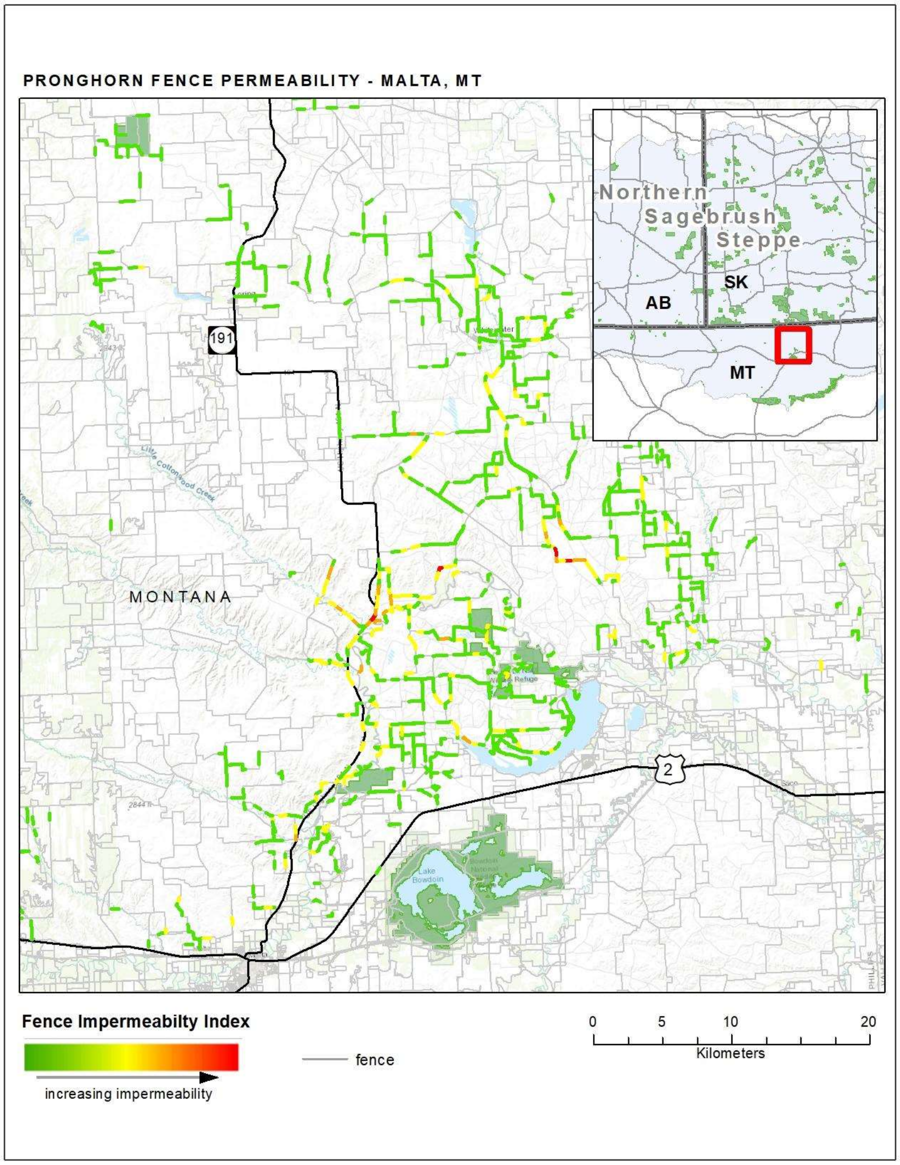

Figure 12: Fence impermeability index with individual animal weighting for Malta, Montana focal area in the NSS, where impermeability increases from green to red.

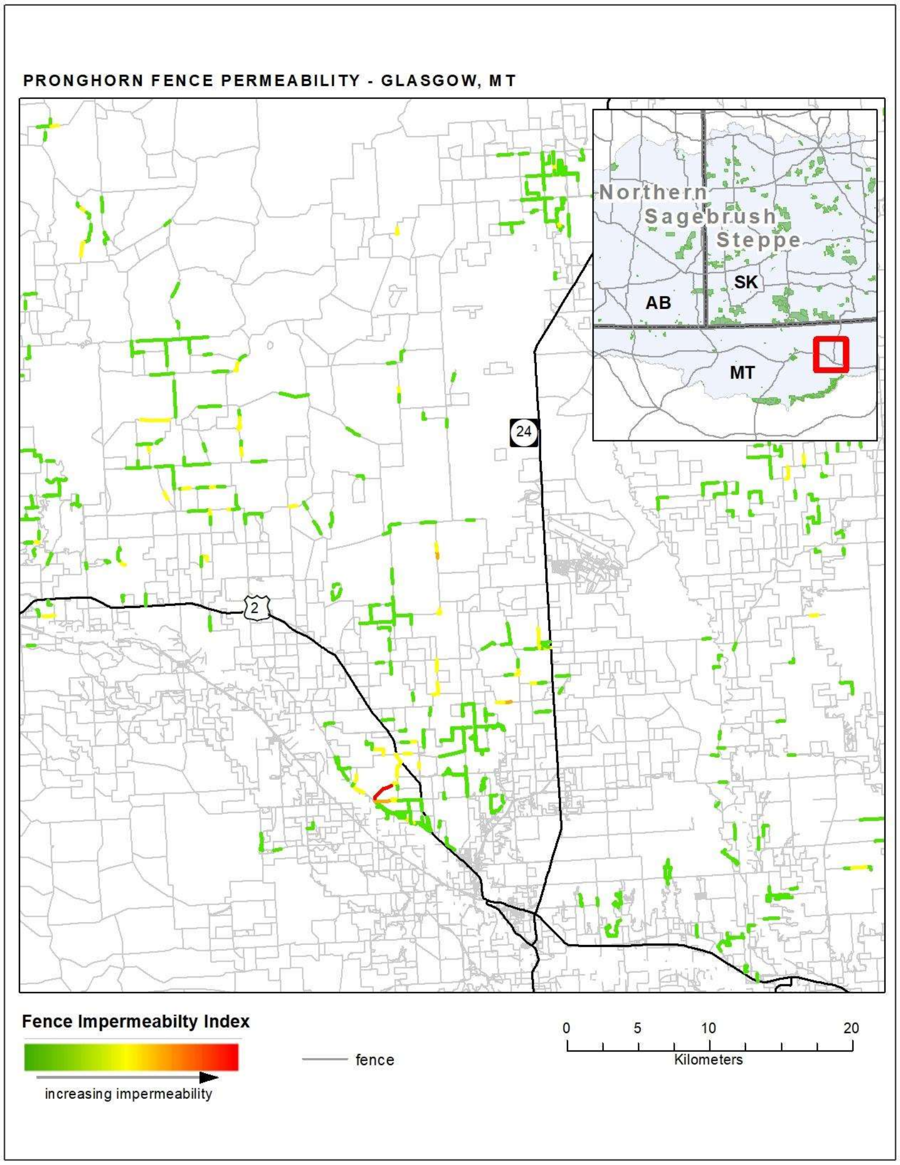

Figure 13: Fence impermeability index with individual animal weighting for the Glasgow, Montana focal area in the NSS, where impermeability increases from green to red.

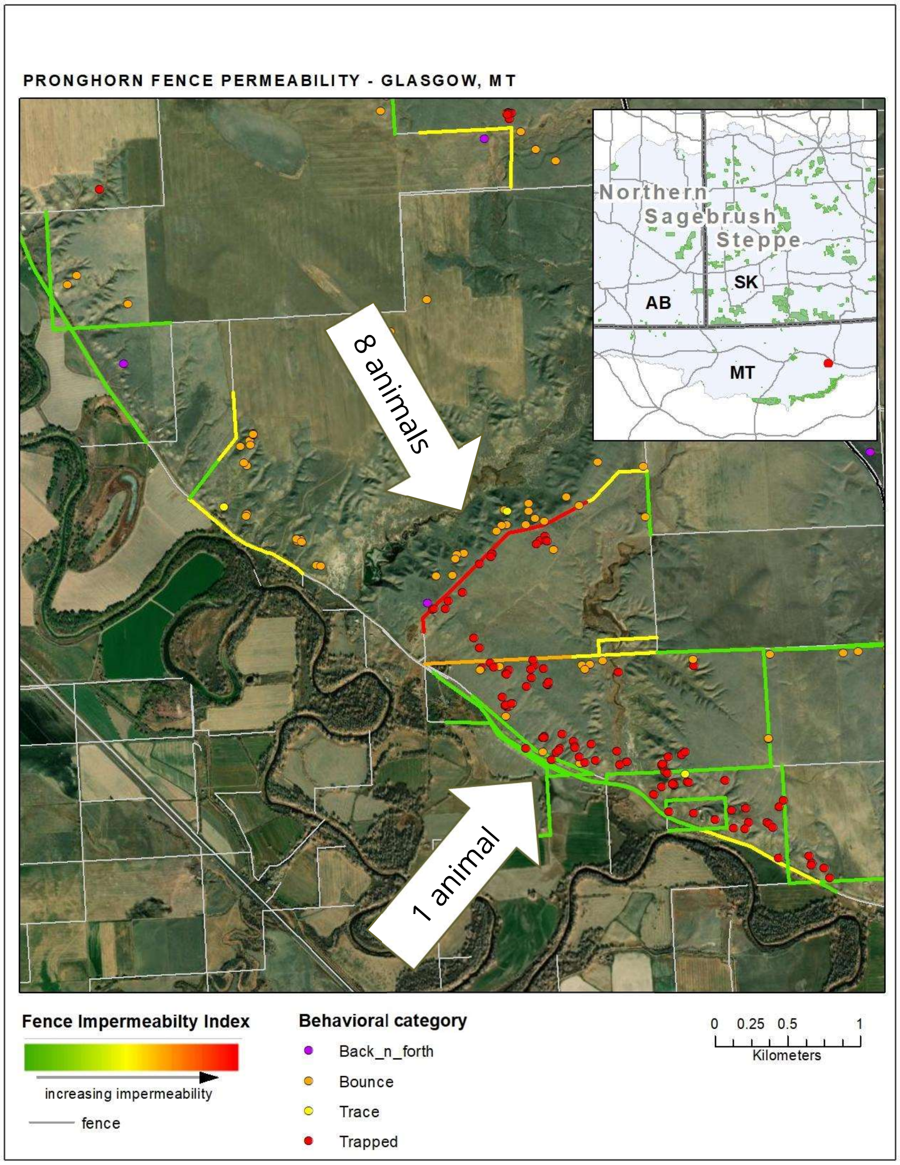

Figure 14: Fence impermeability (impermeability increases from green to red) in the Glasgow, MT Area. Behavioural categories (back and forth, bounce, trace and trapped) are displayed. We also show the behaviour response of a fence interaction with one vs. eight pronghorn and the resulting impact of the individual animal weighing on impermeability.

Discussion

There are multiple agencies, conservation groups, citizen organizations, and industry sectors working to improve wildlife movement and habitat conservation in the NSS. Here, we assessed individual behavioural response of pronghorn to fences with the goal of providing strategic advice for landscape planning. Our work will inform organizations working in the NSS where fence modifications will have the greatest benefit to pronghorn habitat and movements. This information is essential for the effective conservation of long-range migrants, like pronghorn, in human-dominated landscapes.

Much of the NSS, particularly in Alberta and Montana, is a landscape dominated by fence infrastructure, with the highest fence densities to the north of Suffield in Alberta and along Highway 2 in Montana. A recent study by Jones et al. (2019) modeled the impact of fewer fences or, alternatively, doubling fences, on pronghorn habitat availability and movement in the NSS. They found that a complete removal of fences from the landscape (i.e., natural conditions) predicted an increase in the area of high-quality habitat of 16–38%. In contrast, doubling fence density on the landscape decreased the amount of high-quality habitat by 1–11% and increased low-quality habitat by 13–21% (Jones et al., 2019). Our study shows that pronghorn winter and summer ranges can be improved by either reducing the density of fences on the landscape or mitigation measures to enhance fence crossings, to alleviate the indirect loss of habitat for this important endemic species (Jones et al., 2019).

We know that there is a conservation benefit to modifying fences for pronghorn movement as well as for other large mammals. However, prioritizing areas for investment based on where pronghorn are most likely to encounter fences further improves the efficiency of conservation measures. In our study area, most interactions with fences resulted in normal movement behaviour — perhaps a testament to pronghorn already adapting their travel routes to fence sections where they have already successfully crossed (Jones et al., 2018). In the NSS, 32% of pronghorn movements were impacted by fences, slightly less than a comparative study by Xu et al. (2021) in a smaller study area in Western Wyoming. Xu et al. (2021) documented 40% of fence interactions affected pronghorn movement. However, the temporal resolution of pronghorn locations used by Xu et al. (2021) was higher (2-hour fix rate) than for most of our animals (4-hour fix rate). This difference may have contributed to the lower impact we observed. Alerted and trapped movements in spring were slightly higher in our study, but were lower in fall when compared to the pooled data across all seasons.

Our comparison of pronghorn behaviour towards fences within 500 m of a paved road and those more than 500 m from a paved road showed a significant effect. Pronghorn display heightened alerted behaviour towards fences within 500 m of a paved road suggesting a compounding effect of roads and fences on pronghorn. This is similar to research by Jones et al. (2022) who found pronghorn resource use is spatially and behaviourally affected by roads, fences, and fenced roads. This highlights the importance of road mitigation measures that include fence modifications to ensure pronghorn continue to move safely through a landscape after crossing a road.

We developed a spatial impermeability index to identify focal areas with concentrations of problematic fences. Though pronghorn altered their movement patterns, most fences they encountered are permeable to them. It may be that pronghorn have adjusted their behaviour to travel to fence sections they know they can cross. Indeed, it has been shown that pronghorn (and deer) have spatial memory of fence crossing sites (Jones et al., 2020b, 2018). That is, it is possible that problematic fences still have sections where crossing is possible (crawling under a stretch of fence that has a higher bottom wire due to topography) that are known to pronghorn and targeted for crossing. Our model identified Suffield, AB as an area with quite a few impermeable fence sections as well as Malta and Glasgow, Montana as focal areas for fence mitigation.

There were many fence sections with few individual animal interactions. To calculate the impermeability index, the BaBA tool considers the number of individual animals with altered movement near a fence. Therefore a fence section with a high number of altered movement interactions by only one animal may still score as permeable by BaBA. Weighting for the number of individuals is an important consideration for addressing plasticity in pronghorn behaviour for the NSS. However, the low pronghorn density results in a conservative estimate of problematic fences given how few fences actually are encountered by many pronghorn. That is, the BaBA index assumes animals are concentrated on the landscape with multiple animals interacting with the same fences. This was not the case in our study area where animals were spatially and temporally distributed across a large landscape. We therefore also developed a second impermeability index where we removed the individual animal weighting to increase the number of areas considered for fence modification. The areas prioritized for fence modification by these different applications of the BaBA model should be verified by ground verification.

Like any spatial movement model, tradeoffs in data resolution, both spatial and temporal, affect the BaBA predictive accuracy. Four-hour GPS recording frequency extends the life of the collar but reduces the sensitivity of data related to fence behavioural interactions (Xu et al., 2021). Xu et al. (2021) recommend a time interval of two hours or less to truly capture the effects of fences on animal movements, hence our data likely underestimate the number of true altered behaviours (bounce and trace) observed at fences prior to a successful crossing.

Since 2009, the Alberta Fish and Game Association and Alberta Conservation Association have been working with local landholders to improve existing fence permeability. To date, over 550 km of fences have been improved in southern Alberta. Nevertheless, while we are able to identify fence sections that are permeable due to these efforts, and impermeable due to animal behaviour, we do not know what type of fence (4-strand barb, page wire, etc.) impermeable sections represent. Fence type is often excluded when fences are mapped (Buzzard et al., 2022; A.F. Jakes et al., 2018; McInturff et al., 2020). Verifying fence type for sections identified as impermeable will improve how the model selects priority areas for fence modifications.

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