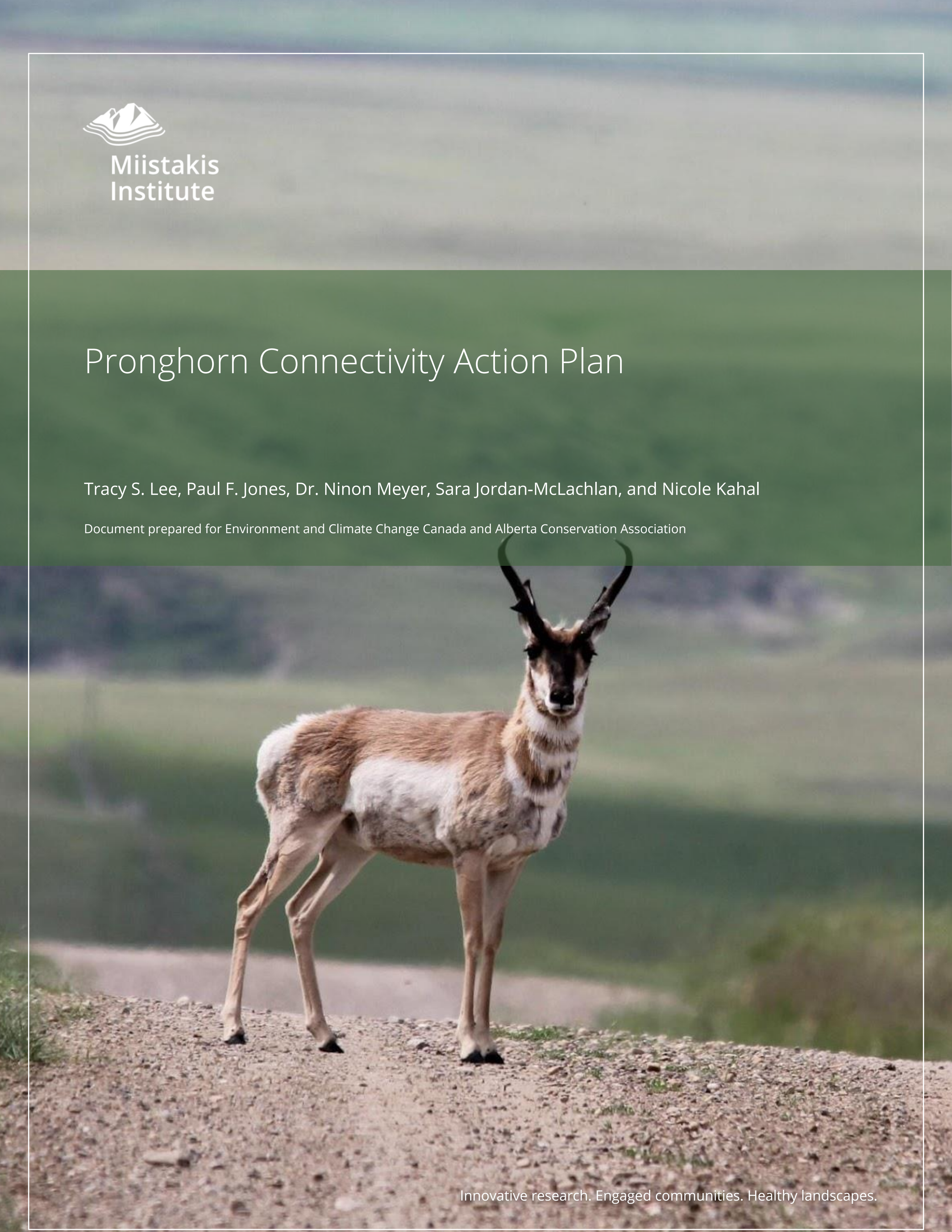

Miistakis Institute

Pronghorn Connectivity Action Plan

Tracy S. Lee, Paul F. Jones, Dr. Ninon Meyer, Sara Jordan-McLachlan, and Nicole Kahal

Document prepared for Environment and Climate Change Canada and Alberta Conservation Association

Innovative research. Engaged communities. Healthy landscapes.

Pronghorn Connectivity Action Plan

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Acknowledgements

The authors would like to thank the Pronghorn Xing working team who participated in meetings and field trips to inform development of the conservation plan:

Amanda MacDonald	Alberta Conservation Association
Cameron Wood	Nature Conservancy Canada_ Saskatchewan
George Guakun	Government of Saskatchewan Insurance
Jeffrey Holland	Saskatchewan Ministry of Highways
Joel Nicholson	Environment and Protected Areas
John Wilmshurst	Canadian Wildlife Federation
Katelyn Ceh	Nature Conservancy Canada_ Alberta
Kenneth Mullhall	Transportation and Economic Corridors
Kevin Pearson	Saskatchewan Ministry of Highways
Leanne Heisler	Saskatchewan Environment
Matthew Braun	Nature Conservancy Canada_ Saskatchewan
Megan Jensen	Nature Conservancy Canada_ Alberta
Michael Burak	Nature Conservancy Canada_ Saskatchewan
Nicole Kahal	Miistakis Institute
Ninon Meyer	University of Toronto
Paul Jones	Alberta Conservation Association
Revekah Vasylyev	Saskatchewan Ministry of Highways
Steven Smid	Transportation and Economic Corridors
Tracy Lee	Miistakis Institute
Trent Currie	Saskatchewan Ministry of Highways

The opinions and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of all individuals or organizations mentioned in the report.

We would like to thank Dr. Helene Wagner from University of Toronto for supporting ecological connectivity modeling work associated with this key component of this project. Dr. Ninon Meyer, University of Toronto contributions were supported by Natural Sciences and Engineering Research Council (NSERC) held by Dr. Helene Wagner. Modeling incorporated products created by the Alberta Biodiversity Monitoring Institute and Saskatchewan Environment. Dr. Andrew Jakes provided the pronghorn connectivity model.

We would like to thank Alberta Conservation Association (ACA), Environment and Climate Change Canada (ECCC), and National Fish and Wildlife Foundation (NFWF) for their support.

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Alberta Conservation Association

NFWF

Executive Summary

Pronghorn (*Antilocapra americana*) are a species of ungulate whose presence on the landscape across North America dates to the Pleistocene epoch, over 1 million years ago. Today their range in Canada is restricted to the open Northern Sagebrush Steppe (NSS) ecosystem in Alberta and Saskatchewan. Like all extant large mammals on the modern Great Plains, fragmentation and connectivity of their habitats have become critical issues to their persistence.

Pronghorn range has largely declined due to habitat loss and fragmentation resulting from agriculture, residential and industrial development. Pronghorn are a semi-migratory species with some individuals shifting their range seasonally while others remain resident in the same area throughout the year. Impediments to the movement of migratory and resident populations include anthropogenic linear infrastructure such as railways, roads, and fencing. Such barriers not only impede seasonal and local movements but can inhibit population growth and species recovery. Maintaining pronghorn populations requires careful consideration of their daily and migratory movement needs (referred to herein as pronghorn connectivity) and development of conservation strategies that better integrate pronghorn connectivity into conservation planning and policy.

To assist in developing a pronghorn connectivity conservation plan, we built on past achievements to develop a conservation action plan with the goal of maintaining pronghorn movement in the NSS. To assist in this effort, we undertook the following four assessments:

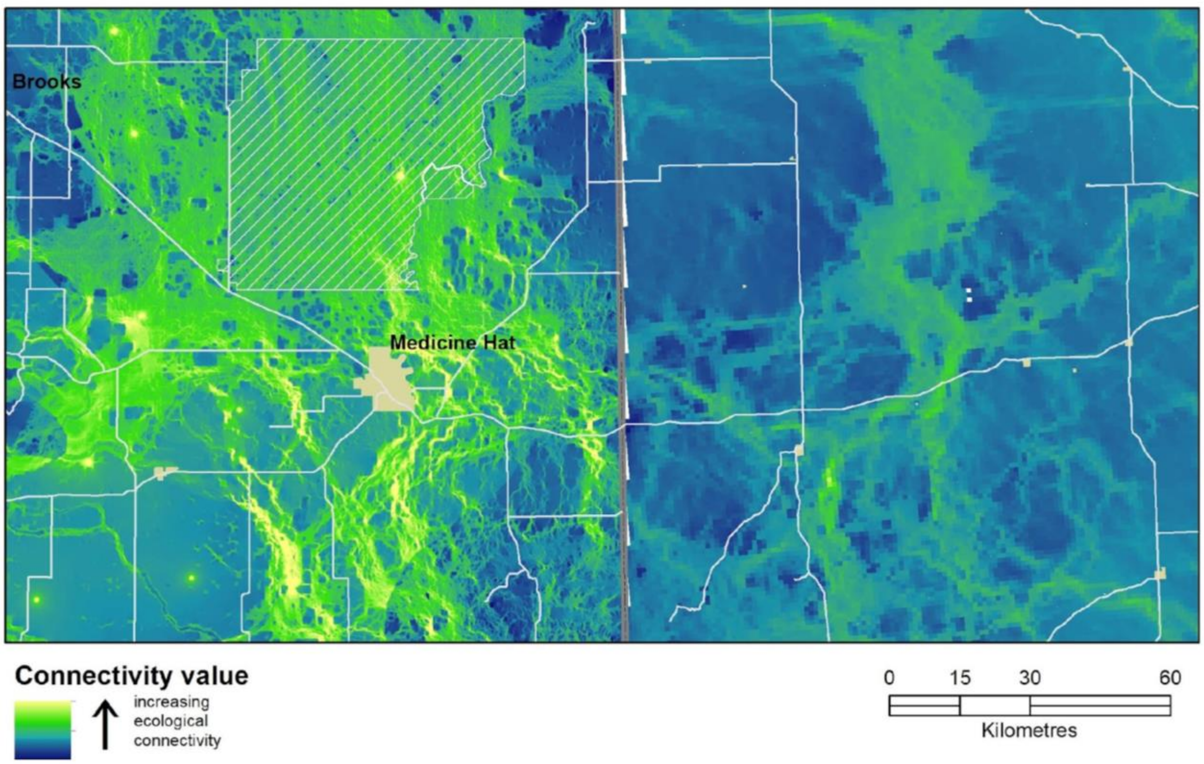
1. Fence impermeability prioritization.
2. High valued ecological connectivity areas.
3. Pronghorn crossing site prioritization.
4. Wildlife and motorist safety road mitigation system.

The fence impermeability prioritization assessment identifies areas in the NSS where fencing may be impeding pronghorn movement based on an analysis of pronghorn behavioural response to fences. We used the R package "Barrier Behaviour Analysis (BaBA)" to examine individual pronghorn response to fences. We used pronghorn GPS data from 157 individuals and fencing datasets for Alberta, Saskatchewan, and Montana. 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. Pronghorn fence encounters were classified into normal, altered, and trapped animal movement types.

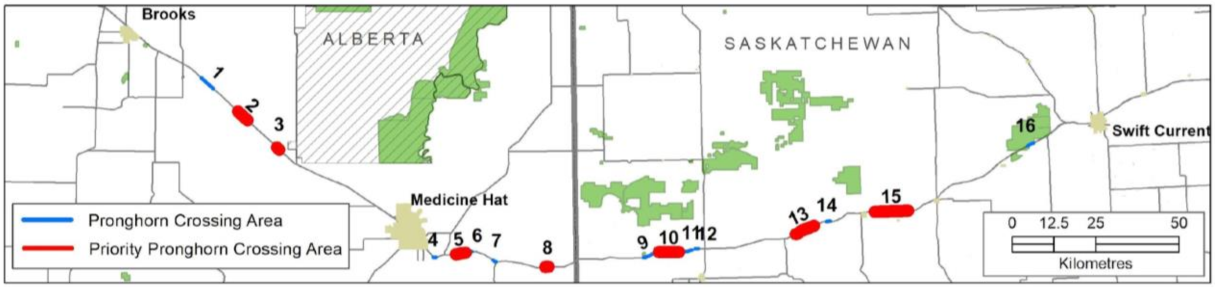
Pronghorn interacted with fences on average 244 times annually with 66% of fence interactions classified as normal, 30% as altered movement, and 2% trapped. Our results suggest that while pronghorn have likely learned where they can move under fences, opportunities still exist to improve movement with fence-crossing mitigations (replacing barbed wire with double-stranded smooth bottom wire 28–18 inches off the ground). We identified key areas in the NSS where ground validation could identify fencing projects, such as Suffield, Alberta and Malta and Glasgow, Montana.

The high valued ecological connectivity areas assessment uses overlapping connectivity models for grassland species to inform conservation planning and actions to maintain or restore movement for grassland species. As such, it identifies areas in the Canadian portion of the NSS with high ecological connectivity value. We created an ecological connectivity overlay based on pronghorn, mule deer, badger, rattlesnake, and structural connectivity models in Alberta at 100 m resolution and identified high ecological connectivity value based on their mean. We also developed an ecological connectivity overlay based on pronghorn, mule deer, and structural connectivity in Saskatchewan at 1000 m resolution to identify high ecological connectivity values based on their mean (*see ecological connectivity overlay map below*). The resulting overlays were converted into quarter section parcels in Alberta and dominion land parcels in Saskatchewan and assigned low, moderate, high, and very high connectivity classes to aid conservation planning. We identified very high ecological connectivity parcels occur on 10% of non-crown lands, and 3% on crown lands in Alberta, while in Saskatchewan very high ecological parcels occur on 21% of non-crown lands and 3% on crown lands. These values highlight the importance of private land conservation in maintaining animal movement in the NSS.

ECOLOGICAL CONNECTIVITY OVERLAY

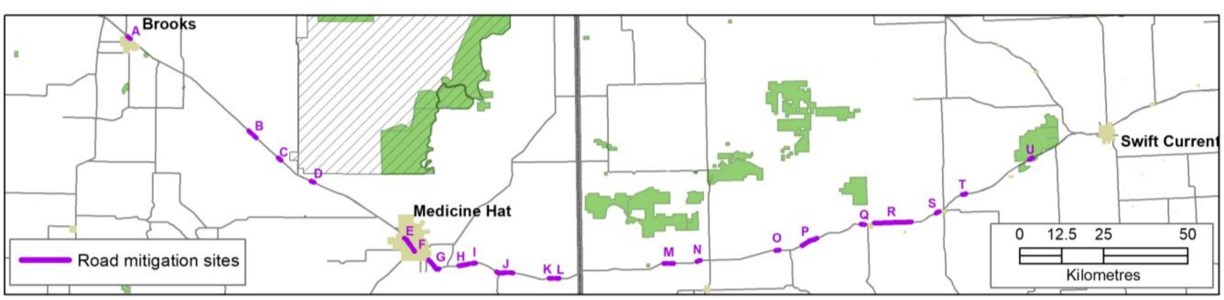


With the working team, we undertook a field-based pronghorn road mitigation site assessment to refine prioritization and inform conservation planning. This assessment builds on previous work where potential pronghorn crossing sites were identified and prioritized from Brooks, Alberta to Swift Current, Saskatchewan. To refine and order the prioritized pronghorn crossing sites and assess other characteristics important to road mitigation projects such as land ownership, other anthropogenic features, and site topography, the working team visited six sites in the field. Sites were ordered for importance in Alberta (sites 5, 8 and 3) and in Saskatchewan (sites 13, 10/15) to guide conservation planning and actions (*see map below*). We outline considerations for each in site to inform conservation strategy development.



Finally, we undertook a road mitigation assessment to identify road sections where grassland species intersect with the TCH and/or are a high risk to motorist safety. The TCH intersects movement pathways for wildlife leading to animal vehicle collisions (AVCs) resulting in direct mortality for wildlife and/or an increased risk to motorist safety. Additionally, wildlife may avoid crossing the TCH due to traffic volumes reducing their access to life requirements. Depending on the species, direct mortality from collisions with vehicles or avoidance behaviour can have a direct impact on population persistence. For most species (e.g., deer spp., coyote) direct mortality from collisions may not have population-level impacts. It is therefore important to understand which and how many individuals of a species are involved in AVCs. In our study area, we identified three species of concern where road mortalities and or avoidance may have population-level impacts, badger, rattlesnake, and pronghorn. We also undertook an AVC cluster analysis and identified eight strong AVC clusters along the TCH in our study area, predominantly driven by collisions with deer. Other studies have shown AVC clusters may not align with species movement needs. We therefore developed road indices to be able to inform where species movement needs (not collisions) intersect the TCH.

In addition to road indices for pronghorn, we included connectivity models for mule deer, badger, rattlesnake and structural connectivity and summed these indices to identify road sections with high ecological connectivity values. The results reinforce past studies and highlight the importance of considering both motorist safety risk and animal movement needs that do not always align. We identified 49 km of the TCH representing 14% of the study area where investment in road mitigation would enable safe passage for migrating ungulate species, as well as species at risk (badger and rattlesnake). Only 1.5% of the crossing areas align for motorist safety risk and animal movement needs. Therefore, if road mitigation planning only considers motorist safety risk, migratory ungulates and SAR movement needs will not be adequately addressed. We recommend developing a mitigation system to address both motorist safety and animal movement needs based and focused on the 49 km (14 % of study area, *see map below*) identified as priority through this assessment. A road mitigation system would include a series of crossing structures (tied together with fencing) to facilitate safe movement of grassland species while reducing risk to motorist safety.



The road mitigation areas are identified on the table below based on column (RS_ID), to identify each section's purpose, grasslands species movement across the TCH and/or motorist safety risk.

RS_ID	Province	Num. of km	Ecological Connectivity					Motorist Safety Risk	Notes
A	Alberta	1							
B	Alberta	3							pronghorn site 2
C	Alberta	1							pronghorn site 3
D	Alberta	1							
E	Alberta	3							
F	Alberta	1							
G	Alberta	5							
H	Alberta	3							pronghorn site 5
I	Alberta	4							
J	Alberta	1							
K	Alberta	1							Pronghorn site 8
L	Alberta	1							
M	Saskatchewan	1							Pronghorn site 10
N	Saskatchewan	1							
O	Saskatchewan	1							
P	Saskatchewan	5							pronghorn site 13
Q	Saskatchewan	1							
R	Saskatchewan	11							Pronghorn site 15
S	Saskatchewan	1							
T	Saskatchewan	1							
U	Saskatchewan	1							

To maintain and restore migratory movement and species at risk recovery along the TCH the working team developed strategies for the following goals:

- Implement road mitigation to support pronghorn and other grassland species movement across the TCH.
- Secure private land associated with road mitigation sites.
- Improve fence permeability in migration corridors and at road mitigation sites.
- Build policy support for ecological connectivity investments.
- Build social capital with local communities.
- Develop milestones and timeline for pronghorn conservation plan.

Introduction

Pronghorn (*Antilocapra americana)* are a species of ungulate whose presence on the landscape across North America dates to the Pleistocene epoch over 1 million years ago (O'Gara and Janis., 2004). Today their range in Canada is restricted to the open Northern Sagebrush Steppe (NSS) ecosystem in Alberta and Saskatchewan (Jakes et al., 2018a). Of the myriad recent changes to the grassland habitat in which they evolved, human infrastructure that impedes movement among habitat patches is both of critical conservation concern and one that has clear, tangible, and proven solutions.

Pronghorn range has become restricted largely due to habitat loss and fragmentation for agriculture, and residential and industrial development (Poor et al., 2012). Pronghorn are a semi-migratory species with some populations and individuals shifting their range seasonally while others remain in the same area throughout the year (Jakes et al., 2018a). Anthropogenic infrastructure such as railways, roads, and fencing impede their daily and seasonal movements (Jakes et al., 2020; Jones et al., 2020; Sawyer et al., 2016; Seidler et al., 2015a). Studies conducted in the NSS of southeastern Alberta and southwestern Saskatchewan have identified areas where pronghorn cross the Trans-Canada Highway (TCH) between Medicine Hat, Alberta and Swift Current, Saskatchewan (Lee et al., 2023). Conserving pronghorn requires careful consideration of their daily and migratory movement needs (referred to herein as pronghorn connectivity) and development of strategies that better integrate pronghorn connectivity into conservation planning and policy.

There are also many non-linear changes to the grassland biome that affect pronghorn connectivity, including the expansion of existing cities and towns, rural residential development, agriculture conversion, oil and gas development, and industrial scale renewable energy developments. Landscape changes for agricultural development have resulted in the greatest losses of native grassland ecosystems across the prairies (Alberta Biodiversity Monitoring Institute, 2016). This development has not only affected the grasslands directly through conversion but has also altered the surrounding landscape through water rerouting, access, and fencing. This change has affected the available habitat for pronghorn that prefer native habitats. Pronghorn will use the altered landscape, but individuals that reside year-round there have characteristics of sink populations (Jones, 2014). Oil and gas development also affects pronghorn movement through habitat fragmentation and avoidance behaviours (Jones et al., 2020). Studies looking at seasonal movements have shown pronghorn avoid areas with oil and gas wells during the spring, a time when pronghorn are working to regain energy stores lost over the winter (Jones et al., 2020). Oil and gas development also results in habitat loss and fragmentation that excludes pronghorn from the landscape (Donovan et al., 2024). As a result of these non-linear impacts, pronghorn are estimated to have lost 64% of their historic range in North America (Poor et al., 2012).

Industrial scale renewable energy developments are on the rise in Alberta, and southeastern Alberta is a hotspot for wind and solar[1]. There are several renewable energy projects, both wind and solar developed, approved or in various stages of permitting that could impact pronghorn movement. Recent research on the impacts of renewable energy development on pronghorn in Wyoming found a behavioural response to wind energy development, including faster movement through areas with wind turbines, avoiding turbines when selecting stopover sites (during migration), and reducing fidelity to migration routes during wind farm development. These responses are concerning

[1] https://abutilcomm.maps.arcgis.com/apps/webappviewer/index.html?id=81809f0f929c41f4b95d9abebba2e4fe

because they can reduce the functional, long-term benefits of pronghorn migration, such as foraging success or the availability of safe movement routes (Milligan et al., 2023)

Habitat loss also affects the ability of pronghorn to connect to native habitats as they move across an increasingly fragmented landscape. Both the development described above and linear features associated with development (roads, railways, and fences) create movement barriers among patches, shrink habitats, and increase the distances among habitat patches (Eacker et al., 2023). Roads can impact pronghorn in several ways: their construction can remove habitat, collisions with vehicles can result in direct mortality, and higher traffic volumes can result in movement barriers through avoidance behaviours, preventing animals from accessing habitat and other important resources. Avoidance of roads, particularly higher volume roads, has been previously documented for pronghorn (Jones et al., 2022; Robb et al., 2022). The impact of the TCH on pronghorn movement was identified as a key concern and research has identified six priority pronghorn road mitigation sites where safe movement across the highway could be facilitated (Lee et al., 2023).

Effective road mitigation for pronghorn includes building of crossing structures and fencing to facilitate safe movement (Lee et al., 2021). A key challenge for addressing pronghorn crossing locations along the TCH is misalignment of the sites with wildlife vehicle collision hotspots (Lee et al., 2020). This is an issue because investment in road mitigation tends to be driven by motorist safety risk typically identified through an assessment of animal-vehicle collision (AVC) clusters. AVCs in our area are driven by collisions with deer and not collisions with pronghorn. What is needed is a connected road mitigation system that considers both motorist safety and ecological connectivity. We identified a need to understand where a broader selection of grassland species movements intersects with the TCH and where these areas align and don't align with ACV clusters and existing pronghorn road mitigation sites.

Fencing, in particular barbed wire, has been identified as a major barrier to pronghorn movement (Jakes et al., 2018b; Jones et al., 2018). Adapted to a flat landscape as high-speed runners, pronghorn are not adept at jumping and avoid it wherever possible. Instead, pronghorn attempt to go under or will turn back, avoiding available habitat as a result. Agricultural and industrial development has increased the density of fencing in the NSS, thereby increasing habitat fragmentation across pronghorn range (Jones, 2014). Although efforts are in place to mitigate this impact (by modifying or installing new wildlife-friendly fencing), barbwire fences still present a major barrier to pronghorn movement (Jones, 2014; Paige, 2020). Given the high density of fences in the NSS, direction is needed to prioritize areas where fencing mitigation or replacement projects would best benefit pronghorn connectivity.

To assist in development of a pronghorn connectivity conservation plan we built on previous work to inform strategies to maintain and/or restore pronghorn movement in the NSS. To assist in development of conservation actions in the NSS we undertook the following four assessments:

1. **Fence impermeability prioritization:** This assessment prioritizes areas in the NSS where fencing may be impeding pronghorn movement based on an analysis of pronghorn behavioural response to fences.
2. **High valued ecological connectivity areas:** This assessment identifies areas in the Canadian portion of the NSS with high ecological connectivity value based on an overlap of different connectivity models for different grassland species. It informs conservation planning and actions to maintain or restore movement for grassland species.
3. **Pronghorn crossing site prioritization:** This assessment builds on previous work where potential pronghorn crossing sites were identified and prioritized from Brooks, AB to Swift Current, SK (Lee et al., 2023). To refine and order the prioritized pronghorn crossing sites and assess other characteristics important to road mitigation projects such

as land ownership, other anthropogenic features, and site topography, the working team visited six sites in the field. Sites were ordered for importance in Alberta and Saskatchewan to guide conservation planning and actions.

4. **Wildlife and motorist safety road mitigation system:** This assessment builds on past studies that identified potential pronghorn crossing sites along the TCH from Brooks, AB to Swift Current, SK where road mitigation would improve movement opportunities. We considered additional connectivity models for grassland species to understand where their movements intersect with the TCH. We compare road sections identified with high ecological movement needs for grassland species to road sections with high numbers of AVC and recommend a series of crossing sites to improve safe wildlife movement across the TCH and reduce motorist safety risk. We also assess if the potential pronghorn crossing sites from previous work support other grassland species movement opportunities.

Assessments were conducted by Miistakis Institute and were used to inform the development of the conservation actions by the working team. Conservation actions are presented at the end of the report as a road map for implementation.

Study Area

The study area is part of a larger region known as the Northern Sagebrush Steppe (NSS) which covers 315,000 km^2 of the Northern Great Plains and 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 are poorly suited for annual crop agriculture. The region is considered semi-arid and receives 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. Several renewable energy projects are/will be developed in the coming year.

The Trans-Canada Highway (TCH) runs through the NSS. Our study focused on a 340 km section along the TCH between Brooks, Alberta and Swift Current, Saskatchewan (Figure 1). This section experiences traffic volumes between 5000 and 6000 vehicles a day presenting a potential barrier and mortality risk for grassland species (Charry and Jones, 2009).

During migration pronghorn cross many different jurisdictions, including an international border, one state, and two provinces. In addition, land management jurisdictions include private land, federal, provincial, and municipal jurisdictions (Table 1). Conserving pronghorn will require a coordinated approach to planning across the NSS region. To better understand jurisdictional land management we identified land ownership, municipal planning areas, and land uses in the region.

Table 1: Crown and private land in acres for the Northern Sagebrush Steppe in Alberta and Saskatchewan. Note, privately conserved land is removed from the total private land.

Jurisdiction	AB acres	AB (%)	SK acres	SK (%)	Total NSS acres	NSS (%)
Crown	5,882,223	27	4,314,887	12	101,971,010	17
Protected areas	320,912	2	2,560,961	7	2,881,872	5
Private	1,5422,825	70	30,009,282	80	45,432,107	77
Conserved private land	265,152	1	515,671	1	780,823	1
Total	21,891,112		37,400,800		59,291,912	

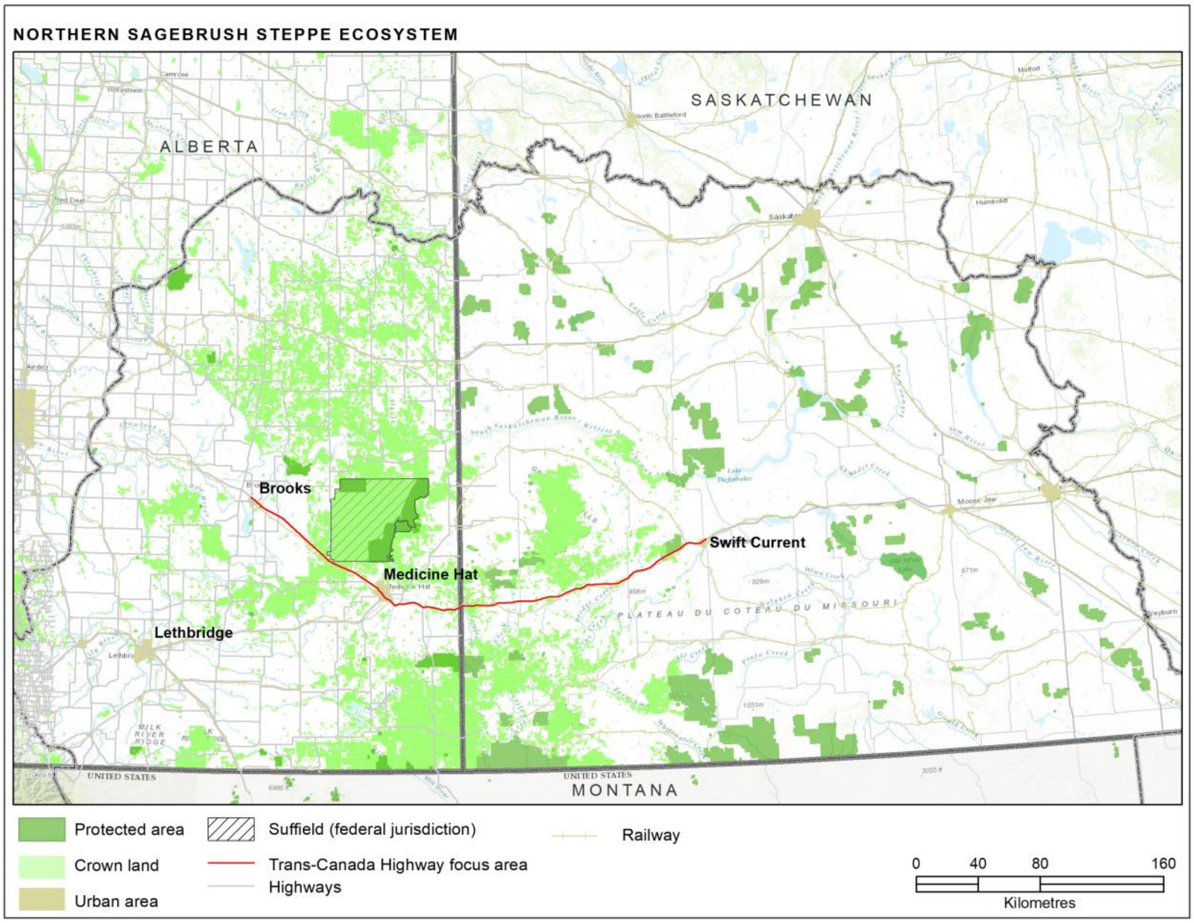


Figure 1: Land jurisdiction in Alberta and Saskatchewan NSS. P whereby private land is depicted in white and crown lands are green (non-protected in light green and protected in dark green).

Most of the land in the NSS is privately owned and is zoned as agricultural. County lands zoned for different types of development are outlined in Area Structure Plans (ASP). For example, in the ASP for Cypress County in Alberta, land use planning has been designated for rural residential expansion, industrial areas, aggregate mining, and natural areas. These plans are important considerations as they outline future development that is likely to occur. We were not able to find ASPs for Saskatchewan rural municipalities.

Fence Impermeability Prioritization Assessment

Much of the NSS, particularly in Alberta and Montana, is a landscape dominated by fence infrastructure. Fencing fragments an otherwise connected landscape and directly causes pronghorn mortality, disrupts movements patterns, and restricts and reduces access to important habitats (Eacker et al., 2023; Jakes et al., 2018a; Jones et al., 2022). Fencing can act as both a semipermeable or complete movement barrier, imposing indirect and direct consequences to pronghorn (Jones, 2014; Jones et al., 2022). Fences, in tandem with roadways, 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, with higher densities in grazed pasture, and may cover an order of magnitude greater distance than roads (Jakes et al., 2018a; 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 alleviate barrier effects most effectively — 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., 2022; Lee et al., 2023).

The results for this component of the pronghorn connectivity plan were extracted from the technical report "Pronghorn Fence Permeability in the NSS" (Lee and Sanderson, 2024). For detailed methodology and results please refer to this report[2]. In summary, we used the R package "Barrier Behaviour Analysis (BaBA)" to examine individual pronghorn response to fences (Xu et al., 2021). We used pronghorn GPS data from 157 individuals and fencing datasets for Alberta, Saskatchewan, and Montana. 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. Pronghorn fence encounters were classified into normal, altered, and trapped animal movement types.

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 at 41% (compared to 31% for interactions away from paved roads) 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 (see orange and red areas in Figure 2).

[2] https://www.rockies.ca/files/reports/Pronghorn%20Fence%20Permeability%20in%20the%20NSS_March2024.pdf

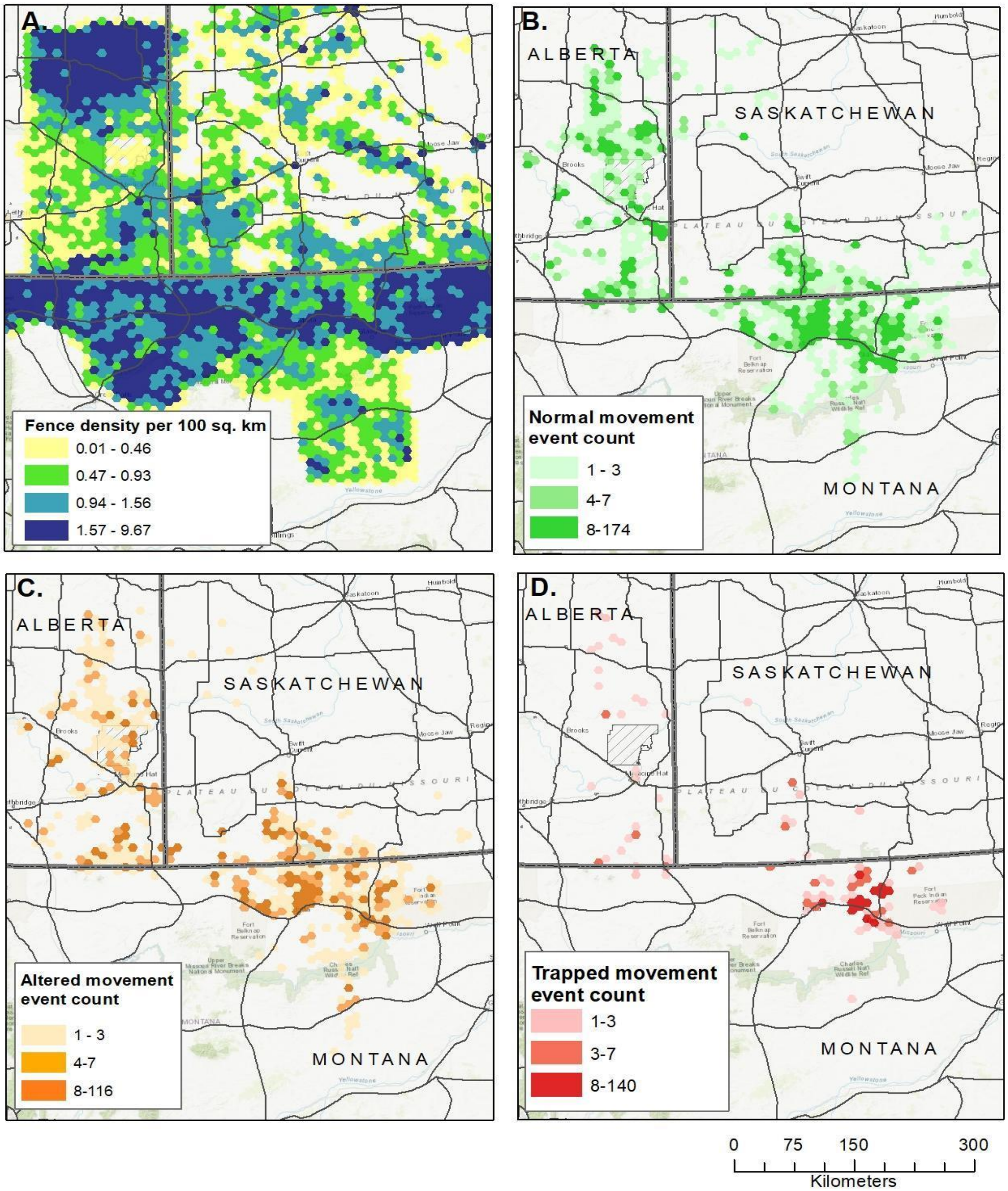


Figure 2: Fence density grid in the NSS (panel A.), normal pronghorn movement event count in green (panel B.), altered pronghorn movement event counts in orange (panel C.), and trapped pronghorn movement event counts in red (panel D.) per 100 km² grid.

High Value Ecological Connectivity Assessment

To inform conservation planning in the region we identified areas of high ecological connectivity value based on a series of focal species and remaining natural landscapes in the Canadian portion of the NSS. Connectivity models were used to identify private land parcels of high ecological connectivity value to better support land use planning and decision-making.

We combined five connectivity models, a structural model and four species-specific connectivity models, to identify areas of high ecological connectivity value in the NSS. Structural connectivity represents areas of naturalness based on the degree of human modification of the landscape. They do not consider species movement behaviour (also referred to as species agnostic models) (Theobald et al., 2012). The assumption is that naturalness will better support biodiversity over a large landscape where there has been significant human modification. Since structural connectivity does not depend on species movement data, it is an efficient process for documenting ecological flow or connected natural systems (Belote et al., 2022; Carroll et al., 2018; Krosby et al., 2015; Marrec et al., 2020).

Functional connectivity is the response of a species to its environment. Species-specific connectivity modeling considers a species movement or ecological requirements (i.e. habitat), or behaviours, such as dispersal distances or sensitivity to anthropogenic features or activity (Auffret et al., 2015). A common conservation approach for identifying areas of high ecological value for movement is to consider both structural and species-specific functional connectivity models.

We used the species-specific connectivity models and structural connectivity model to identify areas on the landscape with high ecological connectivity value and further identify low to very highly valued private land parcels to guide conservation planning.

Methods

We used connectivity models derived from published studies and those developed by Dr. Meyer of the University of Toronto (see appendix A for connectivity modeling methods for mule deer, badger, and structural connectivity. Species of regional concern (pronghorn, mule deer) were selected based on management considerations relating to hunting, motorist safety, and/or conservation and species at risk (badger and rattlesnake).

Table 2: Connectivity models used to identify high value ecological connectivity areas.

Species	Province	Data source	Resolution (m)	Reference
Sp. Agnostic	AB	ABMI human footprint	100	Marrec et al. 2020
	SK	SK human footprint	1000	Meyer (app. A)
Mule deer	AB	FWMIS point data	50	Meyer (app. A)
	SK	SK Environment HSI model	1000	Meyer (app. A)
Pronghorn	AB	GPS collar data	193	Jakes, 2015
	SK	GPS collar data	193	Jakes, 2015
Badger	AB	FWMIS point data	50	Meyer (app. A)
Rattlesnake	AB	FWMIS hibernacula point data	90	Lee et al. 2020

Connectivity models were resampled to a 100 m resolution in Alberta and 1000 m in Saskatchewan and standardized using Z-score. Z-score normalization transforms variables onto a standard scale with a mean of 0 and a standard deviation of 1 to enable comparisons among models. Models were then overlayed and reported as the mean connectivity value per pixel. Modeling results did not cover the full extent of the NSS due to data gaps.

The resulting ecological connectivity overlays were then mapped on quarter sections in Alberta and the Dominion Land Survey in Saskatchewan to identify the area of crown vs. non-crown land based on four classes: very high, high, moderate, and low (classes assigned based on a natural "Jenks" spatial pattern in the data).

Results and discussion

Here we present specific-specific models for mule deer (Figure 3), badger and rattlesnake (Figure 4), pronghorn, and the resulting overlay model (based on the mean) (Figure 5). Road sections with high ecological connectivity indicate good alignment with pronghorn crossing sites. The results also highlight consideration of a new site between the Saskatchewan border and Site 9 where natural structure is maintained, and mule deer movement intersects with the TCH.

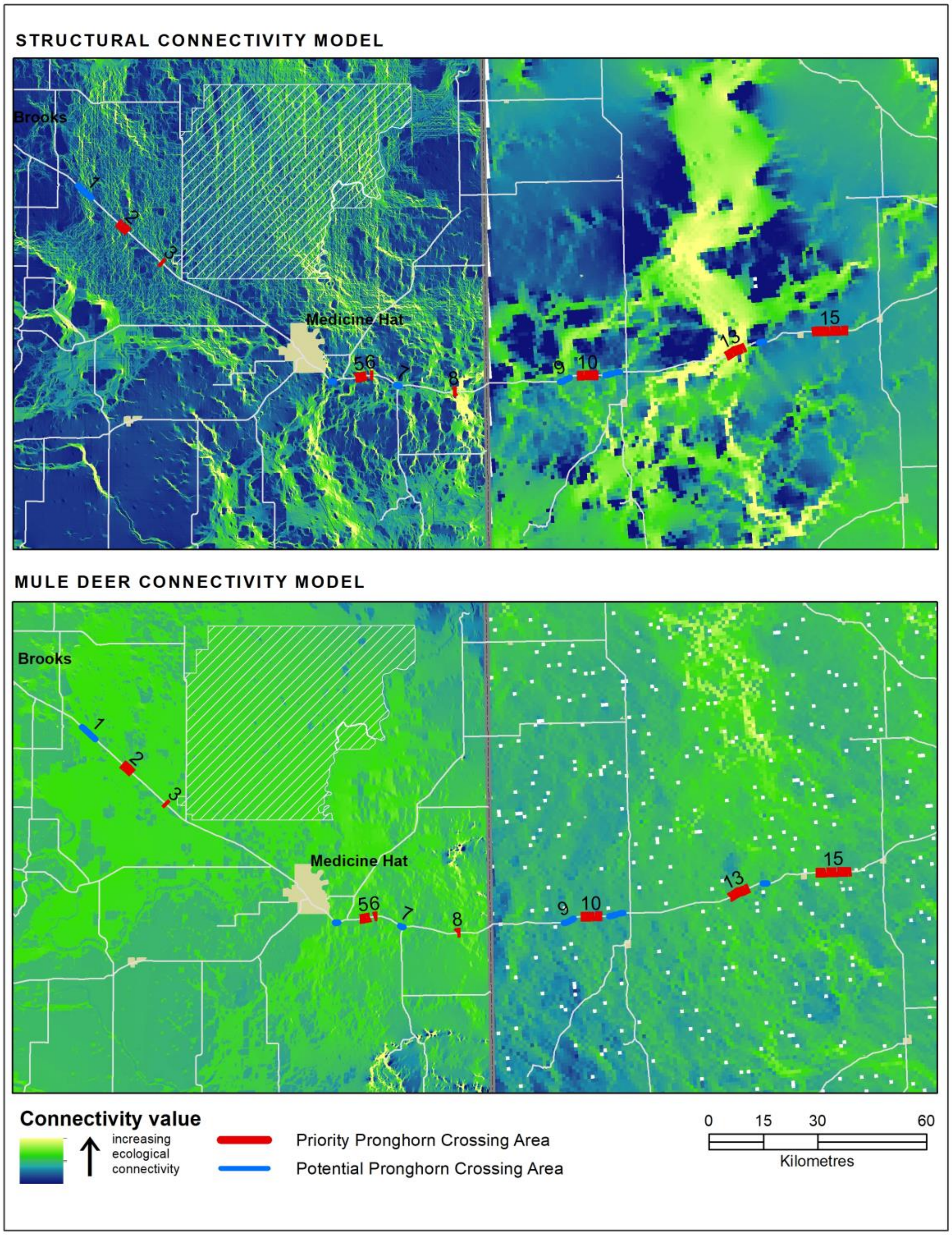


Figure 3: Structural connectivity model (top panel). Yellow pixels represent the more natural and constricted areas of ecological flow. In the mule deer connectivity model (bottom panel) yellow/green represents higher value areas for mule deer movement in southeastern Alberta and southwestern Saskatchewan. Canadian Forces Base Suffield is shown as a white striped box.

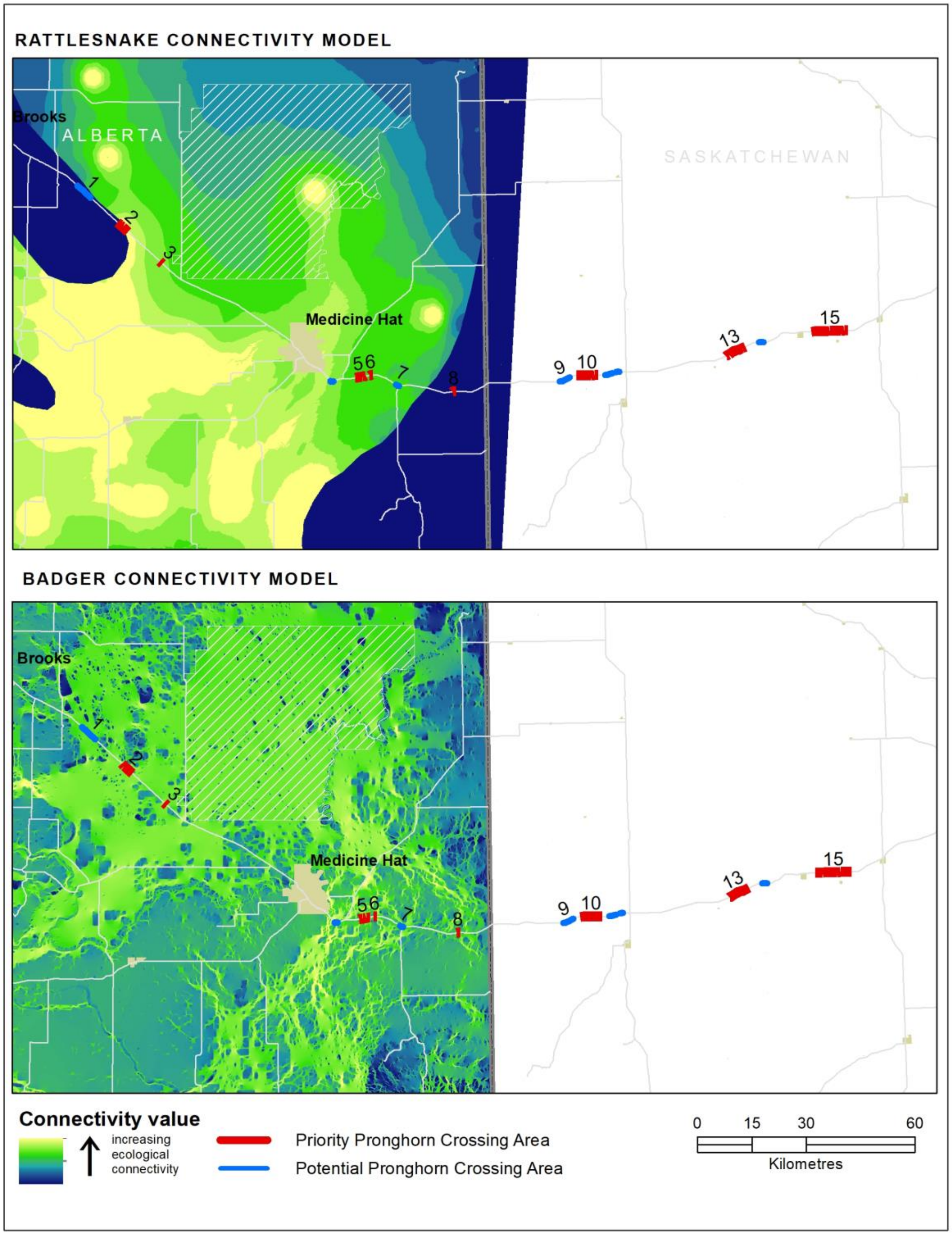


Figure 4: Rattlesnake connectivity model (top panel) and badger connectivity model (bottom panel). Yellow/green represents higher value movement areas in southeastern Alberta. Data not available for Saskatchewan. Canadian Forces Base Suffield is shown as a white striped box.

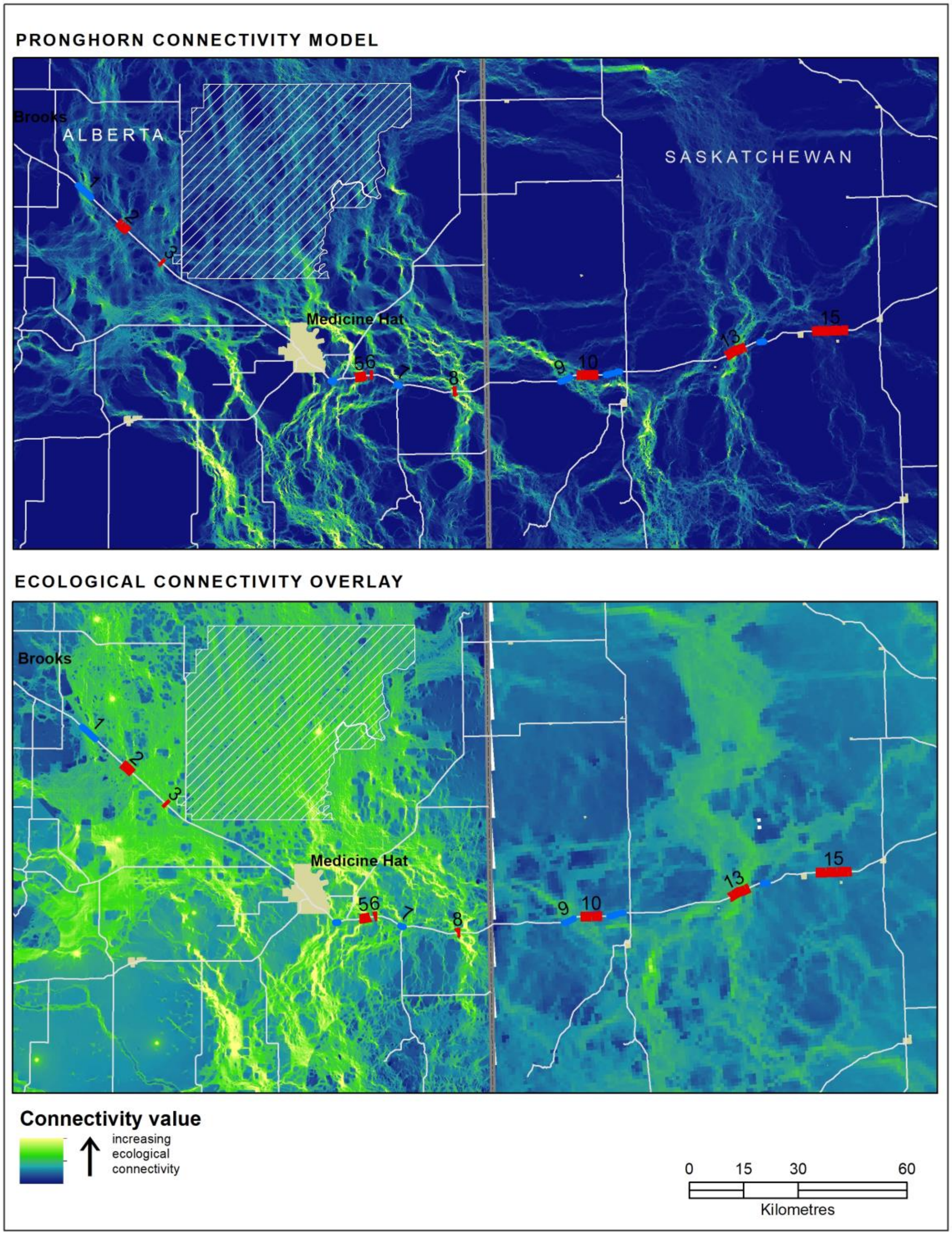


Figure 5: The pronghorn connectivity model (top panel). Yellow/green pixels represent higher value areas for pronghorn movement. The ecological connectivity overlay (bottom panel) where yellow/green are areas of higher ecological connectivity value throughout southeastern Alberta and southwestern Saskatchewan. Canadian Forces Base Suffield is shown as a white striped box.

For ease of presentation and conservation planning, we binned the continuous connectivity values into four value classes (very high, high, moderate, low; Figure 6), plotted value classes on non-crown land (Figure 7), and calculated the area of each class for both crown and non-crown lands (Table 3 and Table 4). It is important to note that the models did not cover the full extent of the NSS in Alberta or Saskatchewan and therefore a certain proportion of the landscape was not classified. We determined that 6% of very high ecological connectivity valued lands occur on non-crown land in the NSS. These lands are significant as they could be considered in future conservation planning (i.e., regional plans) or municipal planning (area structure plans). In addition, resource development decisions should consider ecological connectivity class and the impacts of industrial development on wildlife movement needs.

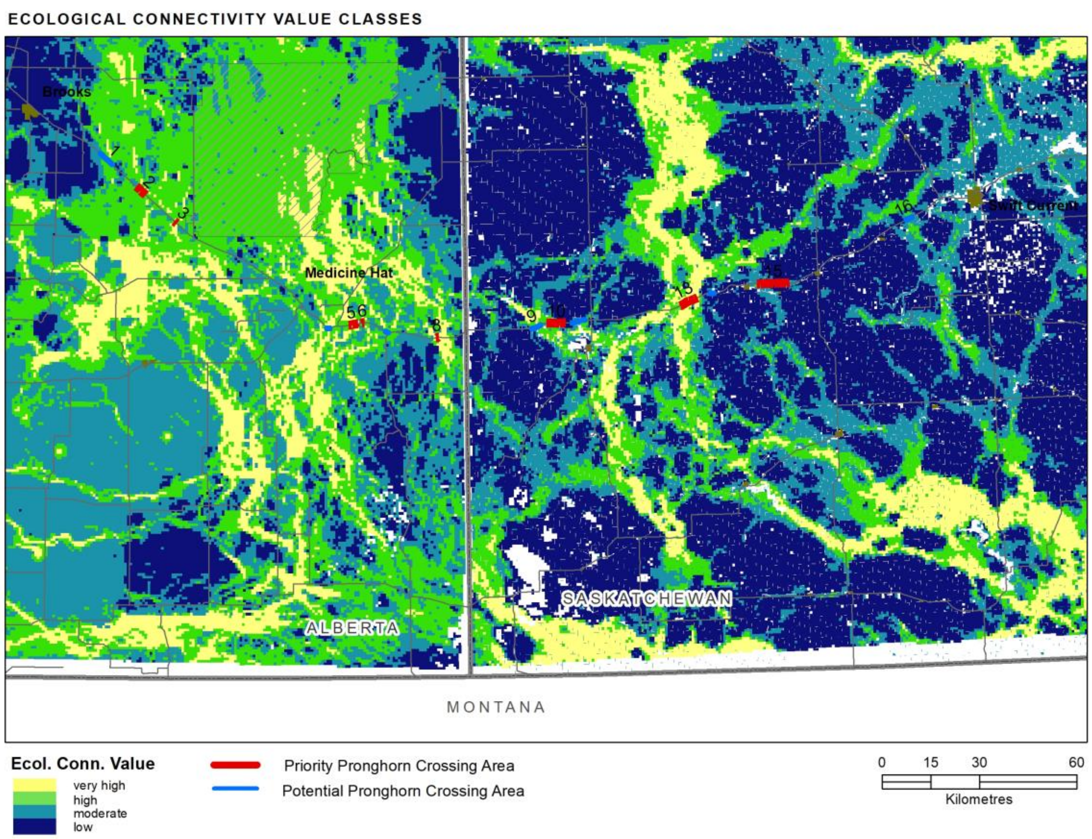


Figure 6: Ecological Conservation value classes from very high (yellow) to low (dark blue) in southeastern Alberta and southwestern Saskatchewan based on ecological connectivity overlay. White pixels represent areas with no-data and include towns, road allowances and other unknown features (in Saskatchewan). This map does not include the full NSS study area.

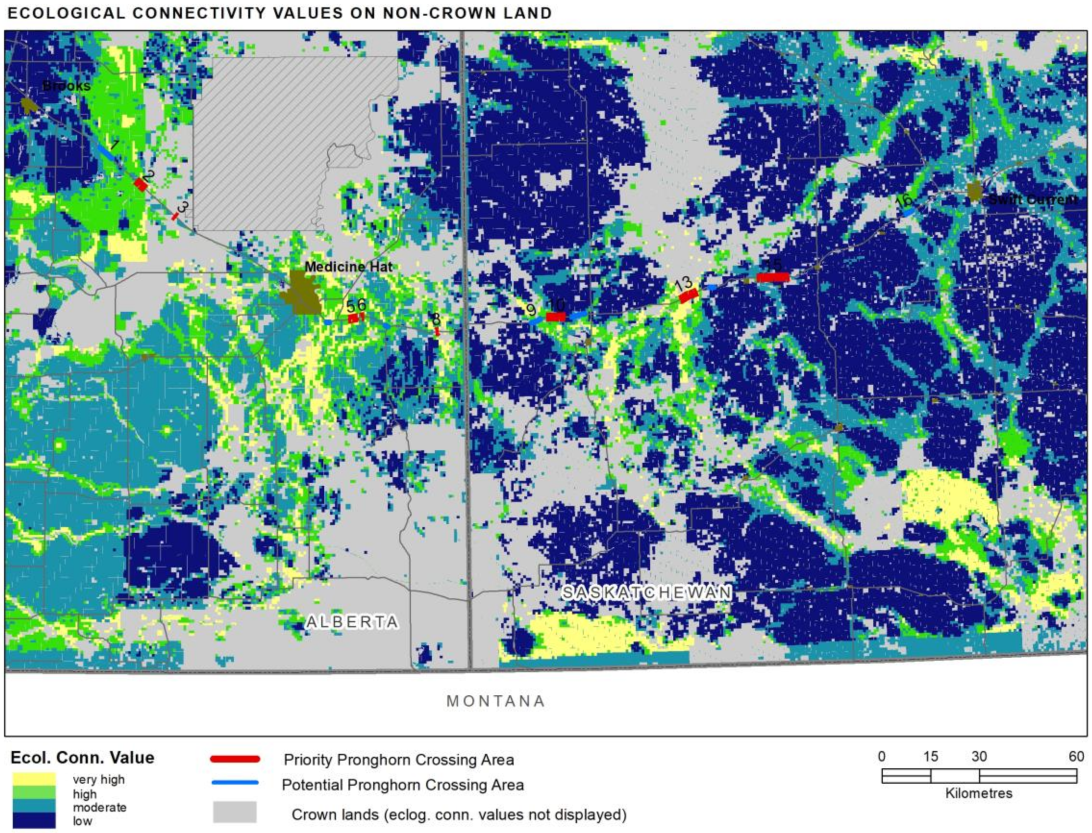


Figure 7: Ecological Conservation value classes from very high (yellow) to low (dark blue) on non-crown lands in southeastern Alberta and southwestern Saskatchewan based on ecological connectivity overlay. White pixels are areas with no-data and include towns, road allowances and other unknown features (in Saskatchewan). This map does not include the full NSS study area.

Table 3: Ecological connectivity value classes for crown and non-crown land in the Alberta portion of the NSS.

Ecol. Con. Value	Crown (acres)	Crown (%)	Non-crown (acres)	Non-crown (%)	Total area (acres)	Total area (%)
Very high	735,273	10	413,625	3	1,148,907	5
High	2,374,824	32	1,524,850	11	3,899,706	18
Moderate	1,435,404	19	3,822,986	27	5,258,409	24
Low	670,703	9	4,062,575	28	4,733,287	22
No-data	2,264,170	30	4,586,164	32	6,850,364	31

Table 4: Ecological connectivity value classes for crown and non-crown land in the Saskatchewan portion of the NSS.

Ecol. Con. Value	Crown (acres)	Crown (%)	Non-crown (acres)	Non-crown (%)	Total area (acres)	Total area (%)
Very high	1,113,776	21	780,127	3	1,893,903	5
High	1,635,742	31	4,563,606	15	6,199,348	18
Moderate	1,313,654	25	10,855,448	36	12,169,103	34
Low	754,148	14	10,863,604	36	11,617,752	33
No-data	452,713	9	2,968,023	10	3,420,736	10

Pronghorn Crossing Site Prioritization

We recently identified pronghorn road crossing sites along the TCH from Brooks, Alberta to Swift Current, Saskatchewan where road mitigation, including wildlife underpasses, overpasses, and associated fencing and jump-outs, could improve pronghorn conservation (Lee et al., 2023). The purpose of this field assessment was to obtain information and recommendations from experts to prioritize the pronghorn crossing sites.

To reduce the number of sites to visit in the field, the original 16 potential pronghorn road crossing locations were first screened. We used a list of criteria, including spatial agreement of pronghorn observations with the connectivity model, AVC clusters, habitat permeability, cumulative effects (captured through human footprint density within a 400 m buffer), and potential for multi-species connectivity benefits (considered mule deer, white-tailed deer, elk, pronghorn). Each criterion was scored from 1 to 3, and criteria weighting was determined in an Analytical Hierarchy Process (AHP) by a working team consisting of provincial transportation and environment agencies, a provincial insurance agency, and conservation non-governmental organizations (Lee et al., 2023). To further refine this prioritization, we organized field visits to six sites with the working team in fall 2023. During the field visit we reviewed the ease of mitigation infrastructure constructability, infrastructure type (overpass or underpass), land ownership complexity, and private land conservation potential. The following sections describe the resulting priority sites to pursue pronghorn road mitigation infrastructure in Alberta and Saskatchewan.

Pronghorn priority crossing sites

During the field visit the working team identified (in order of prioritization) Sites 5, 8, and 3 in Alberta and Sites 13, 10/15 in Saskatchewan (Figure 8). There was clear agreement on the ranking of sites in Alberta, and while there was a clear top rank in priority for sites in Saskatchewan (Site 13), there was a lack of clarity on which of the other two priority sites ranked higher. There was support from the Nature Conservancy Canada and Alberta Conservation Association for pursuing investment in the area, particularly for locations that have high connectivity conservation value (all sites except 15 in SK were very high or high-valued ecological connectivity value). However, it was noted that securing land will be difficult without a commitment for the construction of a wildlife crossing structure at any site.

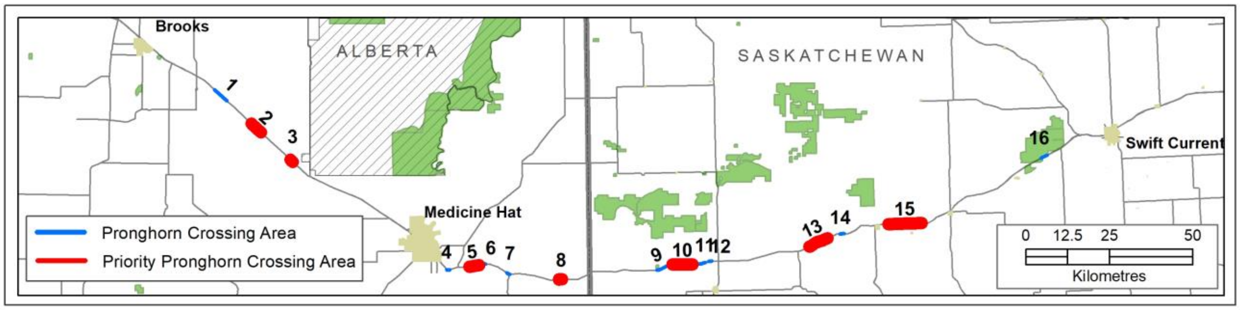


Figure 8: Priority site locations for pronghorn crossing infrastructure on the TCH in Alberta and Saskatchewan.

To guide discussions and planning for road mitigation and development of conservation actions we outlined key characteristics for each prioritized site.

Alberta Site 5

Site 5 is located approximately 17.5 km east of Medicine Hat, Alberta, and is approximately 3 km in length. Assessed against the chosen criteria, it achieved a high score of 14 of a possible 15. The site has the following characteristics that led to the high score:

- Top 10% agreement between pronghorn observations and pronghorn connectivity model.
- AVC recorded, but not an AVC hotspot.
- Native prairie habitat on one side of the TCH, less favorable (i.e., tame pasture) on the other.
- A crossing structure at this location would benefit more than one ungulate species.
- Linear density between 5.0–7.5 km/km^2.

Sites 5 and 6 were both identified as potential priority sites, and due to their close proximity to each other, they were both visited during a site visit by the working team. Site 5 was selected as the most favored site in Alberta to pursue a pronghorn crossing structure. The following site attributes were discussed:

- Railroad tracks occur very close to the TCH (north side) at the length of the site. This would require an overpass with three tunnels to clear the eastbound and westbound TCH and the railroad.
  - While favorable for pronghorn connectivity, removing both barriers to movement, it creates additional complexity in realizing the build due to increased infrastructure cost and need to gain support from Canadian Pacific Railway.
- The eastern portion of Site 5 had one transmission line present near the TCH, as opposed to two transmission lines (one double circuit) on the western portion.
  - This makes constructability potentially easier on the eastern portion as only one set of transmission lines needs to be considered.
- Site 5 is close to Medicine Hat and Dunmore.
  - AVCs are higher in these developed areas and it presents an opportunity to gain community support for wildlife crossing structures.

- The Nature Conservancy of Canada (Alberta Branch) prioritizes protection of native prairie through private land conservation, however, often supports tame pasture as well, as restoration is possible.
- There is already privately conserved land in the area—to the east and south of the site.

Alberta Site 8

Site 8 is located approximately 46 km east of Medicine Hat, Alberta, and approximately 10 km east of Irvine, Alberta. The site is approximately 1 km long. Assessed against the chosen criteria, this site resulted in a score of 12. The site has the following characteristics that led to this score:

- Top 25% agreement between pronghorn observations and pronghorn connectivity model.
- AVC recorded, but not a hotspot.
- Native prairie habitat on both sides of the TCH.
- A crossing structure at this location would benefit more than one ungulate species.
- Linear density between 5.0–7.5 km/km^2.

Site 8 was selected as a possible site in Alberta to pursue a pronghorn crossing structure, preferably an overpass during a site visit by the working team. The following site attributes were discussed:

- Topography works well for an overpass at this site. Pronghorn would have a clear line of site across the highway (or potential crossing structure) as they approach from either the north or south across the TCH.
- A single transmission line on the north side of the highway would not be difficult to accommodate during construction.
- Crown land on both sides of the highway, which may be favorable for securing land for future development.

Alberta Site 3

Site 3 is located approximately 41.5 km east of Brooks, Alberta and 69 km west of Medicine Hat, Alberta. The site is approximately 1 km long. Assessed against the chosen criteria, this site resulted in a high score of 14. The site has the following characteristics that led to the score:

- Top 20% agreement between pronghorn observations and pronghorn connectivity model.
- No AVC recorded.
- Native prairie habitat on both sides of the TCH.
- A crossing structure at this location would benefit all four ungulate species (pronghorn, mule deer, white-tailed deer, elk).
- Linear density between 5.0–7.5 km/km^2.

Site 3 was selected as a possible site in Alberta to pursue a pronghorn crossing structure, preferably an overpass, during a site visit to Site 2 and drive by Site 3. Sites 2 and 3 were originally considered together due to their close proximity; however, Site 3 was chosen as preferable to Site 2. The following site attributes were discussed:

- There is a development permit for a large gas station just east of Site 3, where the historic Highway 1 meets with the current TCH.

- The transmission lines are further away from the highway than at site 2.
- The topography has more slope than at Site 2, which is likely better for an overpass constructability and pronghorn visibility.

Saskatchewan Site 13

Site 13 is located approximately 3.6 km east if the intersection of the TCH with Highway 614, and is approximately 6 km long. Assessed against the chosen criteria, this site resulted in a score of 11. The site has the following characteristics that led to the score:

- Not within the top 25% agreement between pronghorn observations and pronghorn connectivity model.
- Unstable (not statistically significant) AVC hotspot.
- Native prairie habitat on both sides of the TCH.
- A crossing structure at this location would benefit more than one ungulate species.
- Linear density between 5.0–7.5 km/km2.

Site 13 was selected as a clear favorite to prioritize a crossing structure in Saskatchewan. The following site attributes were discussed:

- While overpasses are most suitable for successful pronghorn crossing, Saskatchewan Highway Services is not likely to entertain an overpass due to concern for transportation of oversized agricultural equipment. For this reason, underpasses will be pursued at each Saskatchewan site. Raising the highway to create an open-span bridge span would be more desirable for pronghorn visibility and likelihood of using the crossing structure, however, will be more expensive.
- The railroad is close to the TCH at the length of this site, requiring a longer stretch of underpass. This would require a wider underpass to accommodate risk-adverse pronghorn.
- Land ownership is primarily private on either side of the highway; however, the working team noted that they believe there is crown land as well.
- Both north and south sides of the TCH has been identified by the Nature Conservancy of Canada as priority for conservation in their Natural Area Conservation Plan for the “Southwest Sandhills” area. The majority of parcels are identified as priority 1.

Saskatchewan Site 10

Site 10 is located approximately 8 km west of the intersection of the TCH with Highway 21 and is approximately 6 km long. Assessed against the chosen criteria, this site resulted in a score of 11. The site has the following characteristics that led to the score:

- Top 20% agreement between pronghorn observations and pronghorn connectivity model.
- AVC recorded but not an AVC hotspot.
- Native prairie habitat on one side of the TCH, less favorable (i.e., tame pasture) on the other.
- A crossing structure at this location would benefit more than one ungulate species.
- Linear density between 5.0–7.5 km/km^2.

Site 10 was selected as favorable site in Saskatchewan to pursue an underpass during the working team site visit. The following was discussed:

- While some of the working group preferred Site 10 as having greater conservation value to Site 15, others preferred Site 15.
- The topography of the highway may allow for the highway to be raised to accommodate a bridge-span style underpass, which gives more visibility to pronghorn. However, this would be a larger, more expensive endeavor than a culvert style underpass.
- The north side of the TCH includes parcels that the Nature Conservancy of Canada has identified as priority for conservation in their Natural Area Conservation Plan for the “Southwest Sandhills” area. Parcels are identified as Priority 1, 2, and 3.

Saskatchewan Site 9

While Site 9 was not originally chosen as a priority site to assess during the working team site visit, it was discussed during the visit at Site 10. It was revealed that there are considerable ungulate mortalities close to Site 9. Additionally, there is an existing railroad underpass at Site 9 that may already be used by ungulates. Assessed against the chosen criteria, the site resulted in a score of 13. The site has the following characteristics that led to the score:

- Top 20% agreement between pronghorn observations and pronghorn connectivity model.
- AVC recorded, but not an AVC hotspot.
- Native prairie habitat on both sides of the TCH.
- A crossing structure at this location would benefit all four ungulate species (pronghorn, mule deer, white-tailed deer, elk).
- Linear density > 7. 5 km/km^2.

It was determined that Site 9 should be added as a priority to pursue exclusionary highway fencing that would direct pronghorn and other ungulates to utilize the existing railway underpass that crosses under the TCH. The following site attributes were discussed:

- There is pronghorn and deer mortality in this area.
- Mitigation to use an existing railway underpass would be cost-effective and a good addition to a wildlife-road mitigation system.

Saskatchewan Site 15

Site 15 is approximately 10.5 km west of Gull Lake, Saskatchewan, and is approximately 10 km long. Assessed against the chosen criteria, this site resulted in the highest score of 15. The site has the following characteristics that led to the score:

- Top 20% agreement between pronghorn observations and pronghorn connectivity model.
- Unstable (not statistically significant) AVC hotspot.
- Native prairie habitat on one side of the TCH, less favorable (i.e., tame pasture) on the other.
- A crossing structure at this location would benefit more than one ungulate species.
- Linear density of < 5.0 km/km^2.

It was determined that Site 15 is a favorable site to pursue an underpass during the working team site visit. The following was discussed:

- Similar to Site 10, Site 15 has native prairie on one side, and tame pasture on the other. This would still be considered for private conservation.
- Site 15 does not appear to have as strong overlap with the updated pronghorn connectivity models that was based on connections between highly valued pronghorn habitat.
- There are some parcels both on the north and south sides of the TCH that includes parcels identified by the Nature Conservancy of Canada as priority for conservation in their Natural Area Conservation Plan for the "Southwest Sandhills" area. Parcels are identified as Priority 1, 2, and 3.

Wildlife and Motorist Safety Road Mitigation System Assessment

Our goal is to identify areas along the TCH from Brooks, Alberta to Swift Current, Saskatchewan where road mitigation measures would improve motorist safety risk and ecological connectivity for several species of wildlife. We aim to better understand the value of already recommended pronghorn road mitigation sites to support movement of additional species such as mule deer, badger, and rattlesnake. Here we build on past work with an updated AVC analysis and consider new species connectivity models and their intersection with the TCH (Lee et al., 2023, 2020).

We updated our analysis on animal vehicle collision cluster locations by using Alberta Wildlife Watch data provided by the GOA and RCMP data provided by Saskatchewan Government Insurance. In addition, we used the species-agnostic connectivity modeling results provided by Dr. Helene Wagner's lab at the University of Toronto, as outlined in the previous section, to develop a road index of crossing potential based on pronghorn movement.

Methods

Animal vehicle collision analysis

To identify road sections with a high risk to motorist safety we obtained AVC data (2018–2022) from the Alberta Wildlife Watch Program and RCMP reported collisions from Saskatchewan Government Insurance. We used the AVC data to identify road sections with statistically significant AVC clusters and to calculate the cost of AVCs per kilometre of road section.

Alberta Wildlife Watch (AWW) and RCMP collisions data (with GPS locations) were used to identify clusters using Kernel Density Estimation (KDE+) (Chung et al., 2011). We used KDE+ open-source software that analyzes observation clusters with repeated random simulations (Monte Carlo method) to objectively determine their significance (thresholds). Significant clusters can be ranked according to cluster strength (Bíl et al., 2016). A similar method is used by Alberta Transportation and Economic Corridors to identify clusters of provincial significance to guide investment in road mitigation to reduce risks to motorist safety (Alberta Transportation and Economic Corridors, 2023).

To run the KDE+ analysis, we snapped AWW carcass locations to TCH (using 75 m buffer) and ran KDE+ in ArcMap using a 250 m moving window. To display results, we used Bíl et al.'s (2016) KDE+

cluster strength definitions; the strongest and most stable clusters are those with a strength ≥ 0.6 and at least five carcass records per cluster. Weaker clusters are those with a strength < 0.6 and/or 4 or fewer carcass records per cluster.

We used AWW data to identify the number of AVCs per species per kilometre along the TCH. We extracted ungulate species and applied a correction factor to calculate the direct costs associated with AVCs. A correction factor was applied to AVC carcass reports to account for animals that are involved in a collision but die away from the highway right of way and are undetected. A previous research project determined that for every carcass reported on the highway and right of way by highway maintenance contractors, 2.8 carcasses are found off the right of way and not reported (Lee et al., 2021). The correction factor value can be applied to AVC data collected from road surveys to improve estimates of actual ACVs.

We attributed the cost of AVCs with ungulates using values reported by Huijser et al. (2022) (Table 5). Since they did not include pronghorn in their analysis, we applied the costs for deer to pronghorn AVCs.

Table 5: Costs per ungulate collision (extracted from Huijser et al. 2022) in USD. Deer included both mule and white-tailed deer.

Cost category	Deer	Elk	Moose
Vehicle repair	$4,418	$7,666	$9,535
Human injuries	$6,116	$14,579	$26,811
Human fatalities	$3,480	$23,200	$46,400
Total	$14,014	$45,445	$82,646

Alberta Wildlife Watch Program uses a different approach to model costs whereby a standard cost of a collision of $100,000 CDN is applied to the number of collisions/km/year based on AWW data with no applied correction factor (Alberta Transportation and Economic Corridors, 2023).

Intersection of Ecological Connectivity models and TCH

To identify areas where ecological connectivity intersects with the TCH we developed road indices for a series of connectivity models outlined in the previous section. To develop road indices the mean connectivity value was assigned per kilometre of road section and was then standardized into indices from 0 to 1, using the following equation:

$$X\_norm = (X - X\_min) / (X\_max - X\_min)$$

To prioritize areas where different connectivity models intersect with the TCH, we highlighted the top 10% and 20% (percentile) of each index. We also created an index of animal vehicle collisions based on the count per km and identified the top 10% of the AVC index. The AVC index identified similar areas to the KDE + cluster analysis.

To test how other grassland species align with where pronghorn movement intersects with the TCH we also summed all models except pronghorn and then compared to pronghorn to identify areas of alignment.

To create a priority ecological connectivity index to identify areas where grassland species intersect with the TCH we summed pronghorn, badger, mule deer, rattlesnake, and structural connectivity indices and displayed the top 10% of each index. We compared the priority ecological connectivity index to the AVC index to identify areas of alignment.

Results

Animal vehicle collision assessment

There were 362 AVCs (1014 with correction factor applied) reported (annual mean = 71 or 199 with correction factor applied), from 2018 to 2022 along TCH from Brooks, Alberta to Swift Current, Saskatchewan (Figure 9). We only included AVC data for Saskatchewan if it had species information and a GPS location, resulting in removal of 230 records from this dataset. Such record removal, of course, affects the number of AVC reports, reducing our ability to identify clusters for the Saskatchewan section of the study area. At least 11 species were struck over the study period, deer species (81.5%) followed by coyote (7.5%), were the dominant species involved in collisions. Pronghorn accounted for 3.9% of the AVCs and mortalities were recorded in all five years (Figure 10). Peak AVCs occur in October and November (Figure 11).

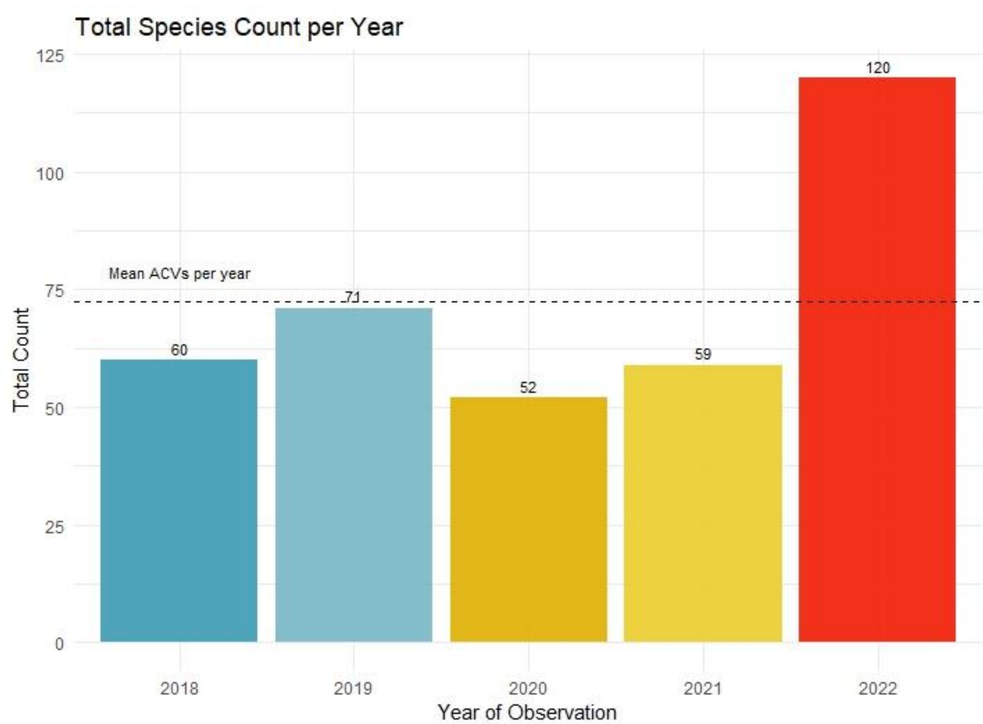


Figure 9: AVCs per year (2018–2022) along TCH from Brooks, Alberta to Swift Current, Saskatchewan.

Table 6: Total AVCs from 2018 to 2022 along TCH from Brooks, Alberta to Swift Current, Saskatchewan.

Species	**AVCs**	**% AVCs**
Unknown deer	139	38.4
Mule deer	136	37.6
Coyote	27	7.5
White-tailed deer	20	5.5
Pronghorn	14	3.9
Badger	13	3.6
Porcupine	4	1.1
Moose	3	0.8
Red fox	2	0.6
Striped skunk	2	0.6
Elk	1	0.3
Raccoon	1	0.3

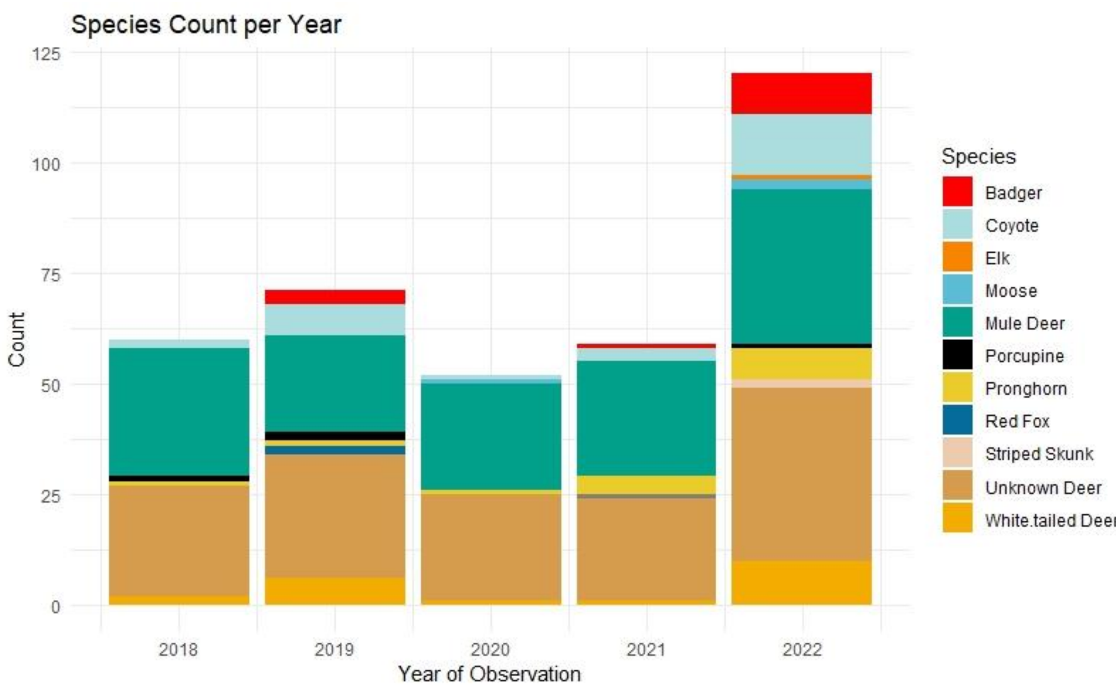


Figure 10: AVCs per year (2018–2022) per species along TCH from Brooks, Alberta to Swift Current, Saskatchewan.

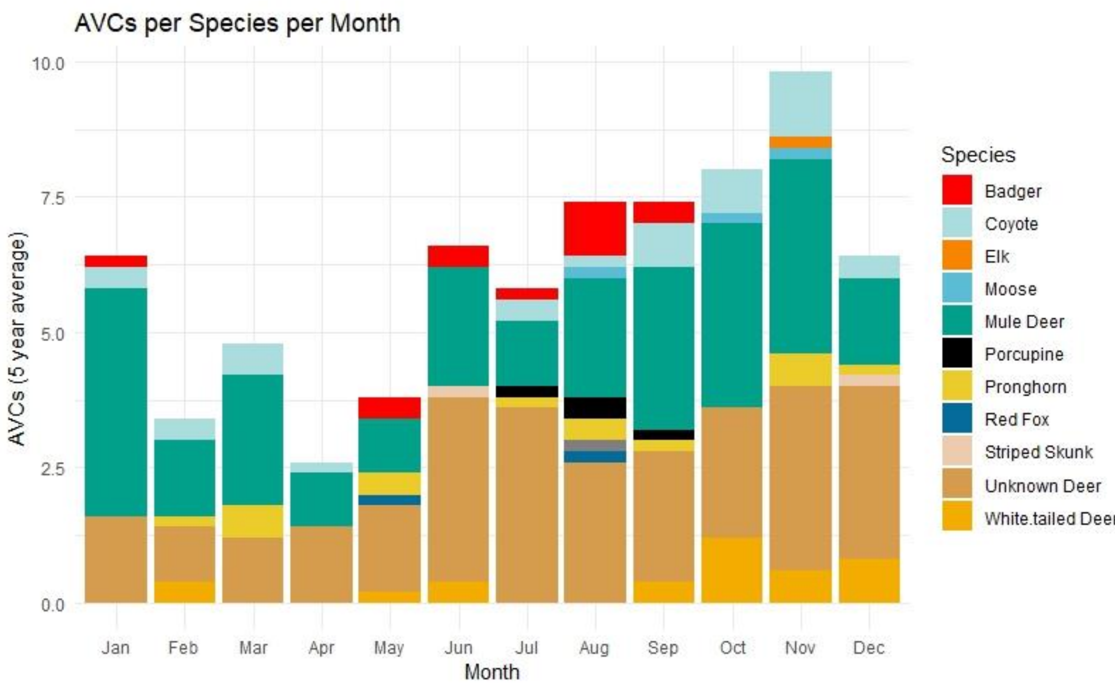


Figure 11: AVCs per month per species based on average over five years (2018–2022) along TCH from Brooks, Alberta to Swift Current, Saskatchewan.

Animal vehicle collisions are an important source of information for species at risk, such as badger and rattlesnake, where road mortality can affect species recovery (Alberta Environment and Parks, 2016). Although rattlesnake modeling predicts movement across the TCH, none were reported in the datasets we accessed. This is unsurprising given that carcass and collision data obtained for this assessment focus on larger mammal species that are removed from highway rights of way due to safety concerns. Smaller species such as rattlesnake tend to degenerate quickly and can be missed during road surveys. There were 13 badger mortalities reported along this stretch of the TCH over the last five years, predominately in the west portion of the study area near Brooks, Alberta. Collision data from Saskatchewan are insufficient to be able to conclude whether either of these species are involved in collisions.

We conducted KDE+ analysis on medium to large mammal AVC data along TCH using a 250 m moving window to detect spatial patterns. Results indicate nine strong clusters (Table 7 and Figure 12). on the Alberta section where road mitigation could be considered to improve motorist safety. The Saskatchewan section would be better informed by improvement to carcass collection data.

Table 7: KDE + results for 250 m moving window along TCH. Clusters are ranked based on strength (high to low) which represents individual motorist safety risk. Other field include, SStr, where 1 highlights best sites for road mitigation, Str_Dens2 which measures the collective impact of strength, and cluster importance. Cluster type identifies if strong (statistically significant) clusters are based on AWW defined strength threshold of >= 0.60 and 5 or more carcasses recorded per cluster or weak clusters (not statistically significant) are based on AWW defined strength threshold of < 0.6 and 4 or less carcasses records per cluster).

FID	Cluster ID	Number of Carcasses	Strength	Cluster Length	Point Density	Strength	S Strength	Cluster Type
0	18	11	0.76	1110	0.99	0.75	1	strong
1	16	14	0.75	1365	1.03	0.79	1	strong
2	11	16	0.73	1641	0.98	0.69	1	strong
3	30	16	0.69	1809	0.88	0.54	1	strong
4	10	5	0.68	426	1.17	0.94	1	strong
5	12	12	0.67	1310	0.92	0.57	1	strong
6	27	15	0.62	1813	0.83	0.42	0	strong
7	2	5	0.62	508	0.98	0.60	0	strong
8	23	6	0.56	746	0.80	0.36	0	strong
9	1	4	0.56	411	0.97	0.53	0	weak
10	34	3	0.48	338	0.89	0.38	0	weak
11	39	3	0.48	335	0.90	0.38	0	weak
12	17	3	0.47	334	0.90	0.38	0	weak
13	7	3	0.46	334	0.90	0.37	0	weak
14	26	3	0.43	333	0.90	0.35	0	weak
15	14	4	0.42	522	0.77	0.25	0	weak
16	15	3	0.41	337	0.89	0.33	0	weak
17	41	3	0.36	354	0.85	0.26	0	weak
18	31	4	0.33	569	0.70	0.16	0	weak
19	28	3	0.33	356	0.84	0.23	0	weak
20	9	3	0.31	384	0.78	0.19	0	weak
21	47	3	0.25	432	0.69	0.12	0	weak
22	25	5	0.25	843	0.59	0.09	0	weak
23	38	2	0.25	252	0.79	0.16	0	weak
24	19	2	0.25	251	0.80	0.16	0	weak
25	49	2	0.25	251	0.80	0.16	0	weak
26	21	2	0.25	249	0.80	0.16	0	weak
27	5	2	0.25	248	0.81	0.16	0	weak
28	20	2	0.25	247	0.81	0.16	0	weak
29	8	2	0.25	247	0.81	0.16	0	weak
30	40	2	0.25	247	0.81	0.16	0	weak
31	44	2	0.24	243	0.82	0.16	0	weak
32	42	2	0.24	241	0.83	0.16	0	weak
33	43	2	0.23	233	0.86	0.17	0	weak
34	13	2	0.22	228	0.88	0.17	0	weak
35	6	2	0.21	222	0.90	0.17	0	weak

36	45	2	0.20	216	0.93	0.17	0	weak
37	22	2	0.20	215	0.93	0.17	0	weak
38	48	2	0.19	211	0.95	0.17	0	weak
39	36	2	0.19	209	0.96	0.17	0	weak
40	3	2	0.18	198	1.01	0.18	0	weak
41	35	2	0.16	190	1.05	0.18	0	weak
42	24	4	0.14	636	0.63	0.05	0	weak
43	46	2	0.13	192	1.04	0.14	0	weak
44	4	2	0.12	196	1.02	0.12	0	weak
45	32	2	0.07	222	0.90	0.06	0	weak
46	29	2	0.06	229	0.87	0.04	0	weak
47	37	2	0.04	237	0.85	0.03	0	weak
48	33	2	0.02	245	0.82	0.01	0	weak

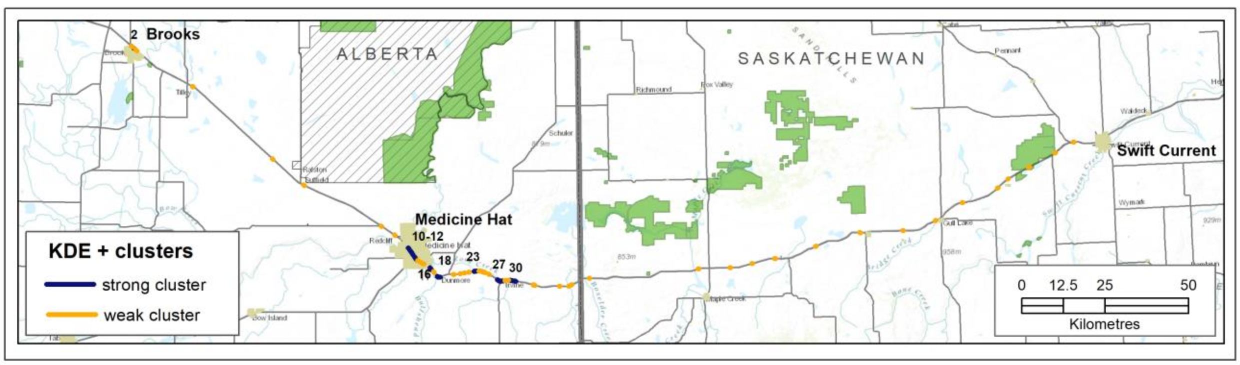


Figure 12: KDE+ analysis depicting strong (blue), and weak AVC clusters (orange) along the TCH from Brooks, Alberta to Swift Current, Saskatchewan. Strong clusters are labeled and match Cluster ID from Table 7.

The average total annual cost of collisions along the TCH in our study area is $924,742 USD ($2,589,277 USD or $3,492,572 CDN with the correction factor) based on five years of available data. The average annual costs of collisions in Alberta is $552,832 USD ($1,547,929.60 USD or $2,087,940 CDN with correction factor) and in Saskatchewan is $371,910 USD ($1,041,347 USD or $1,404,632 CDN with the correction factor). The kilometre sections where AVCs have higher costs are shown in Figure 13. It is important to note that, for the Saskatchewan dataset, collisions that were reported with low accuracy were removed from the analysis and therefore the true cost will be significantly higher.

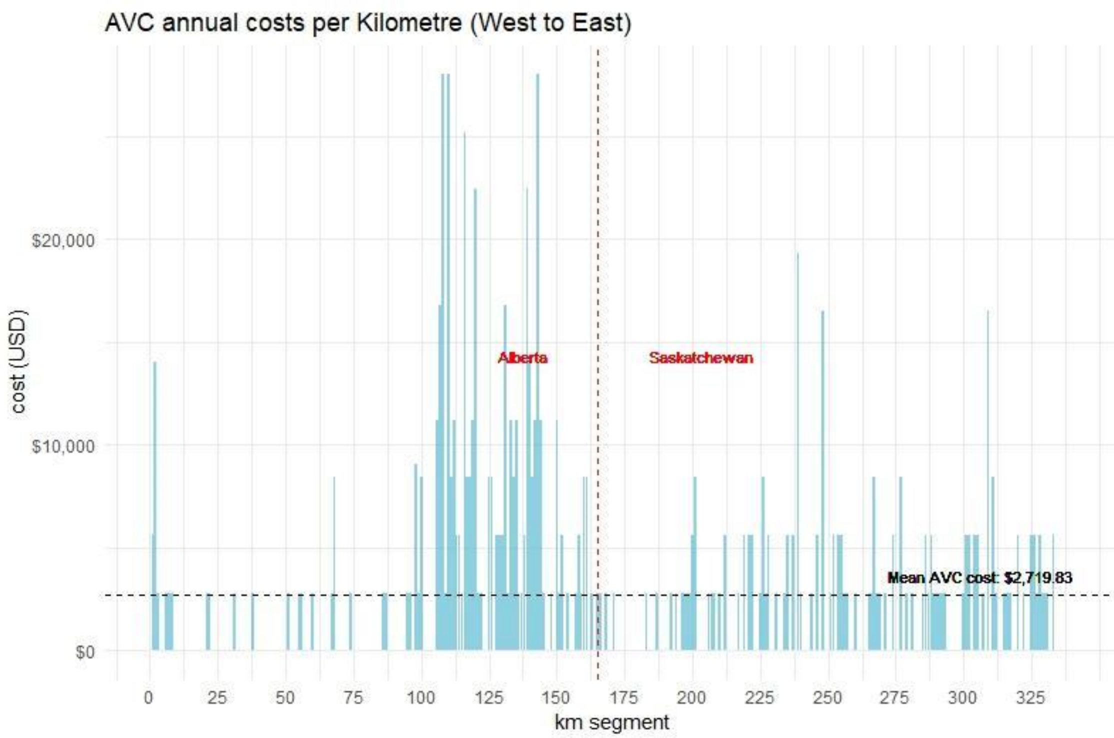


Figure 13: AVC annual costs per kilometre in USD from Brooks, Alberta to Swift Current, Saskatchewan.

Intersection of Ecological Connectivity models and TCH

Using the ecological connectivity models outlined in the previous section (Table 2), we generated road indices for each model, displaying the top 20% (based in percentiles) of each to identify where different connectivity models intersect with the TCH (Figure 14).

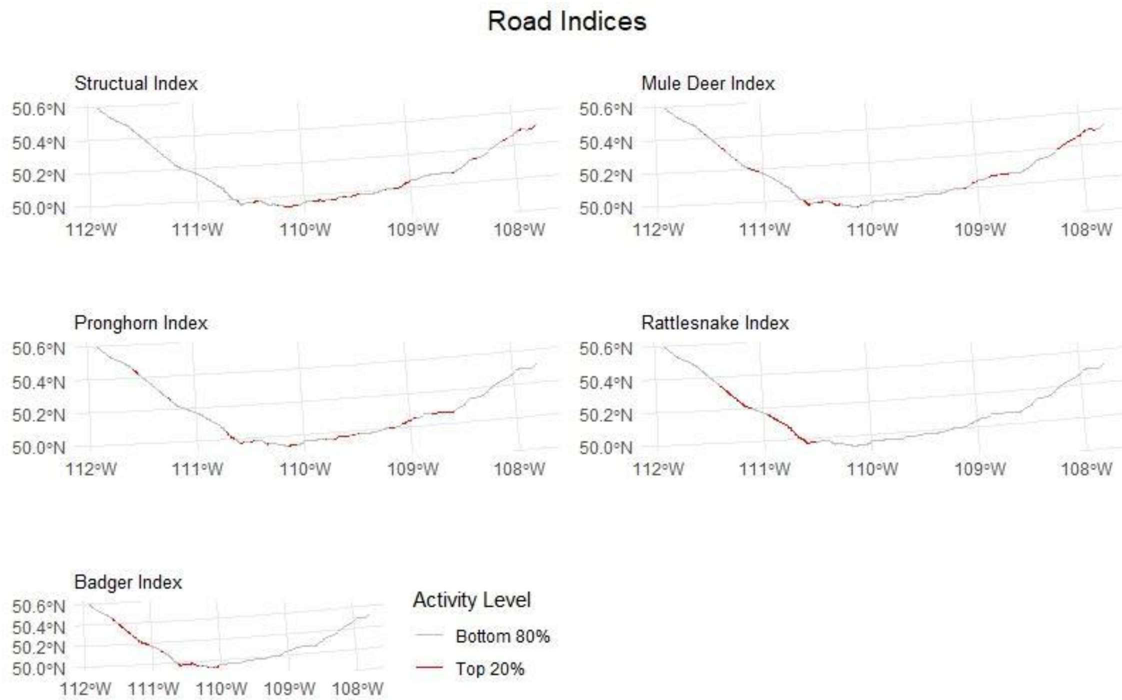


Figure 14: Ecological connectivity indices and AVC index. The top 20% is drawn in red for structural, mule deer, pronghorn, rattlesnake and badger connectivity indices from Brooks, Alberta to Swift Current, Saskatchewan.

Since past studies have focused on identifying pronghorn road crossing sites, we wanted to understand how other grassland species compared to pronghorn. We summed structural, mule deer, rattlesnake (Alberta only), and badger (Alberta only) road indices (referred to as the ecological connectivity road index (EC). We then compared the overlap in the top 20% percentile between pronghorn and ecological connectivity road index Figure 15. We found 34 kilometres of overlap between the pronghorn model and the ecological connectivity index (shown in green), but an additional 34 kilometres (shown in red) do not overlap — an important consideration for road mitigation planning to include wider complements of grassland species.

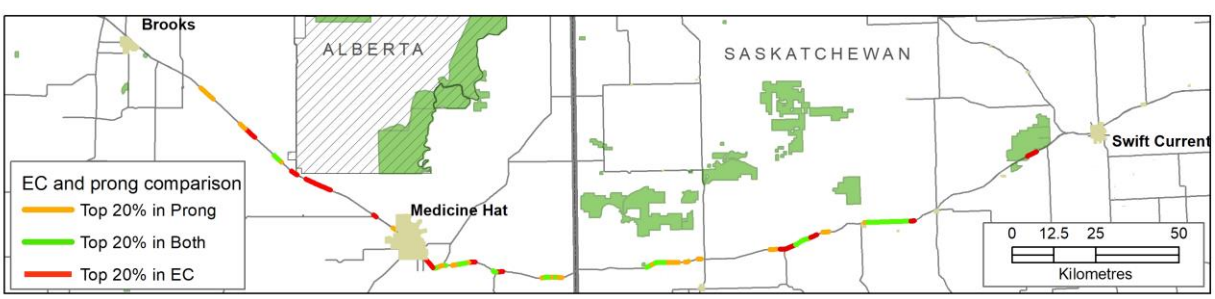


Figure 15: Ecological connectivity index (incudes mule deer, structural, badger, and rattlesnake) models. The top 20% displayed in red, pronghorn index where top 20% is displayed in orange and where the two indices overlap displayed in green from Brooks, Alberta to Swift Current, Saskatchewan.

Ecological Connectivity in Grasslands and ACVs

To further refine prioritization the intersection of animal movement and the TCH we summed structural, pronghorn, badger, mule deer and rattlesnake models to identify areas where road mitigation could better support movement of grassland species across the TCH. We considered different percentiles for prioritization of where the ecological connectivity index intersects the TCH and display the top 10% (Figure 16 top map). To be able to compare the ecological connectivity index to road sections with a high number of ACVs, we generated an ACV index and displayed the top 10% (Figure 16 middle map). Finally, we compared the ecological connectivity summed index to the AVC index to identify areas where there is alignment between AVC clusters and animal movement needs along the TCH in (Figure 16 bottom map). We only identified 1.5 kilometres where priority road sections for animal movement need overlap with motorist safety risk (Table 8).

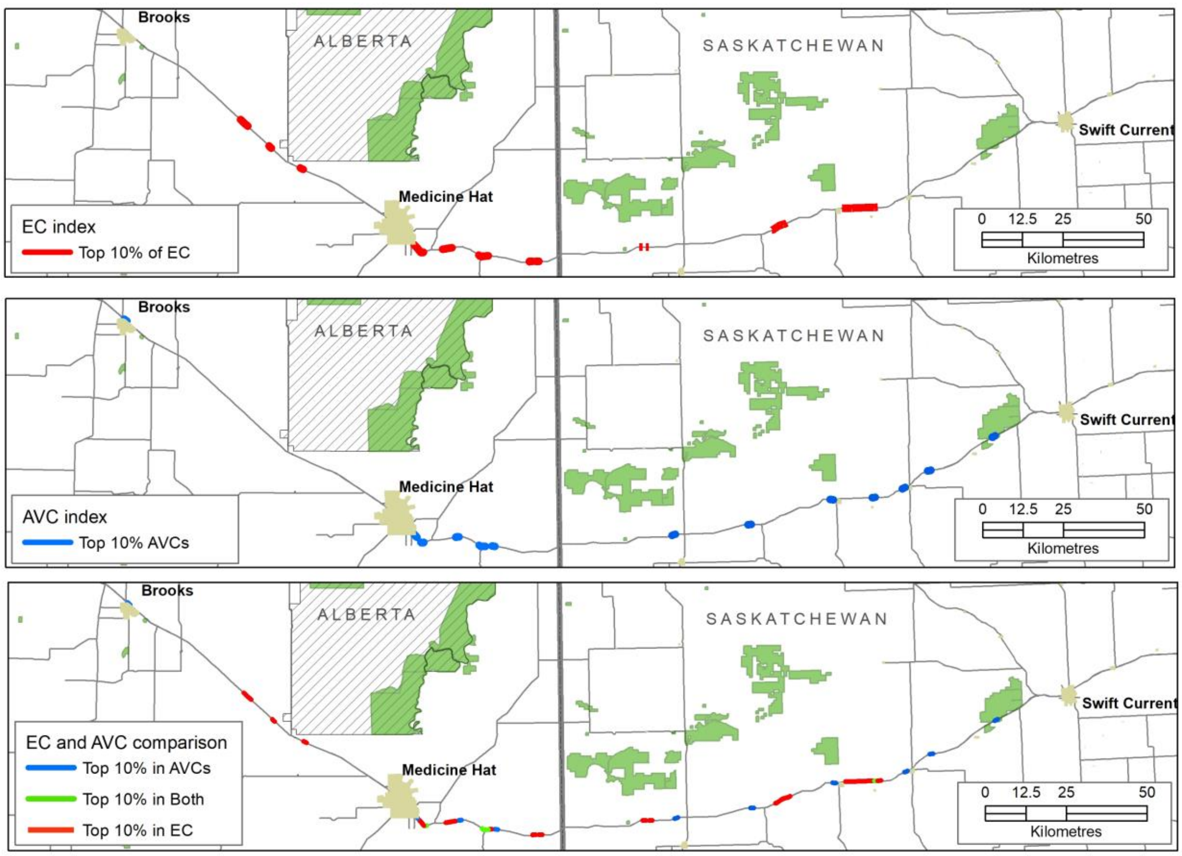


Figure 16: Ecological connectivity summed index. The top 10% is shown in red from Brooks, Alberta to Swift Current, Saskatchewan.

Table 8: Crossing priority areas for ecological connectivity, AVCs (motorist safety), and their overlap.

Top 10%	Num. of km	% of TCH
both EC and AVC	5	1.5
only AVC	14	4.1
only EC	30	8.8
neither EC nor AVC	291	85.6

To summarize this assessment, we identified potential road mitigation sections along the TCH to address road and motorist safety risk (Figure 17) and outline in Table 9 the purpose of each site, ecological connectivity and/or motorist safety risk. In addition, for ecological connectivity we outline which grassland species may cross at each section to inform the future design of road mitigation infrastructure.

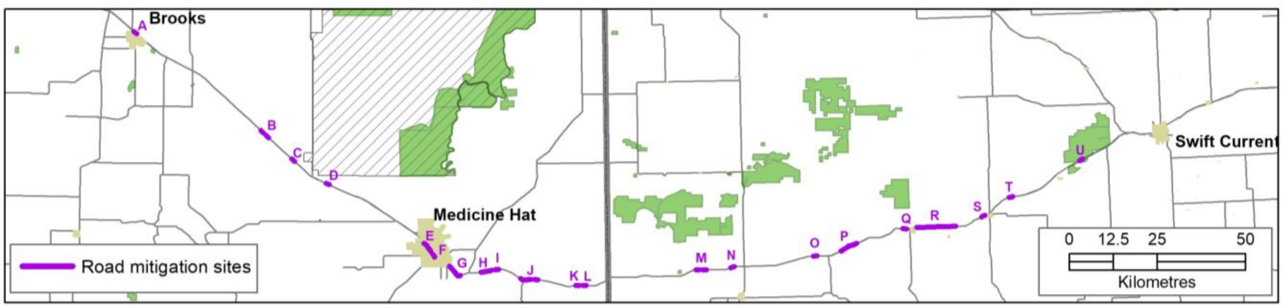


Figure 17: Road sections along TCH where road mitigation is recommended from Brooks, Alberta to Swift Current, Saskatchewan.

Table 9: Road mitigation areas (RS_ID – align with road sections locations on Figure 17) and identification of each areas purpose, grassland species movement and/or motorist safety risk along the TCH from Brooks, Alberta to Swift Current, Saskatchewan. For ecological connectivity sites we identified specific grassland species (rattlesnake, mule deer, badger, pronghorn) or structural connectivity associated with the site.

RS_ID	Province	Num. of km	Ecological Connectivity					Motorist Safety Risk	Notes
A	Alberta	1	⊗					[car]	
B	Alberta	3	[rattlesnake]	[mule deer]	[badger]	[pronghorn]		⊗	pronghorn site 2
C	Alberta	1	[rattlesnake]	[mule deer]	[badger]	[pronghorn]		⊗	pronghorn site 3
D	Alberta	1	[rattlesnake]	[mule deer]	[badger]	[pronghorn]		⊗	
E	Alberta	3	⊗					[car]	
F	Alberta	1	⊗					[car]	
G	Alberta	5	[rattlesnake]	[mule deer]	[badger]	[structural connectivity]		[car]	
H	Alberta	3	[rattlesnake]	[mule deer]	[badger]	[pronghorn]	[structural connectivity]	⊗	pronghorn site 5
I	Alberta	4	[rattlesnake]	[mule deer]	[badger]	[structural connectivity]		[car]	
J	Alberta	1	⊗					[car]	
K	Alberta	1	[mule deer]	[badger]	[pronghorn]	[structural connectivity]		⊗	Pronghorn site 8
L	Alberta	1	[mule deer]	[badger]	[pronghorn]	[structural connectivity]		⊗	
M	Saskatchewan	1	[mule deer]	[pronghorn]	[structural connectivity]			⊗	Pronghorn site 10
N	Saskatchewan	1	⊗					[car]	
O	Saskatchewan	1	⊗					[car]	
P	Saskatchewan	5	[mule deer]	[pronghorn]	[structural connectivity]			⊗	pronghorn site 13
Q	Saskatchewan	1	⊗					[car]	
R	Saskatchewan	11	[mule deer]	[pronghorn]	[structural connectivity]			⊗	Pronghorn site 15
S	Saskatchewan	1	⊗					[car]	
T	Saskatchewan	1	⊗					[car]	
U	Saskatchewan	1	⊗					[car]	

Discussion

This section of the TCH intersects wildlife movement pathways leading to animal vehicle collisions (AVCs) and resulting in direct mortality for wildlife and/or an increased risk to motorist safety. Additionally, wildlife may avoid crossing the TCH due to traffic volumes reducing their access to resources. Depending on the species, direct mortality from vehicle collisions or avoidance behaviour can have a direct impact on population persistence. For many species (e.g., deer sp., coyote) collisions may not have population-level effects, illustrating how important it is to understand which species and how many individuals of those species are involved in AVCs. In our study area, we identified three species of concern where road mortalities and/or avoidance may have population-level impacts: badger, rattlesnake, and pronghorn.

Badger is listed on Schedule 1 of the Species at Risk Act (SARA) as Special Concern and as a sensitive species in Alberta. Past status reports noted mortalities associated with roads as one of the concerns for recovery (Scobie, 2002). In our study area, 13 badger mortalities were reported, identifying a need to provide safe passage for badgers across the TCH to reduce mortality risk from vehicle collisions.

Prairie rattlesnake also occur in our study area and modeling predicts the possibility of movement across the TCH. Prairie rattlesnake are listed on Schedule 1 of SARA as Special Concern and a species of special concern in Alberta. The COSEWIC (Committee on the Status of Endangered Wildlife in Canada) status report identifies road mortalities as having population-level impacts on the species recovery (COSEWIC, 2015). Interestingly, a genetic study of prairie rattlesnake that examined possible genetic impacts of the TCH on their populations found genetic exchange is still occurring. They suggested that movement is likely occurring along river valleys where movement does not need to cross over the TCH (Weyer et al., 2014). The authors state that movement over the TCH is rarely successful, noting possible longer-term issues related to inbreeding due to habitat fragmentation, like that caused by highways, reducing movement between populations.

There were 14 pronghorn mortalities reported in carcass or collision data over the five-year period of our assessment, which likely does not have population-level impacts on the species. Other studies indicate pronghorn sensitivities to traffic on roads with increasing vigilance and reduced foraging (Jones et al., 2022). Migratory species fitness levels can be challenged by anthropogenic features that reduce their time foraging and/or their ability to move freely across the landscape. The TCH imposes a barrier to effective movement, exacerbated by increasing traffic volumes.

We can alleviate road effects on wildlife and improve motorist safety by investing in crossing infrastructure (such as underpasses and overpasses with fencing and jump-outs) to facilitate the safe movement of wildlife while also reducing motorist safety risk. Species exhibit strong preference for the type (over or under the highway), and size of crossing infrastructure. Pronghorn, for example, have been shown to prefer overpasses while mule deer prefer underpasses (Seidler et al., 2015). Although in Alberta we have seen an increase in investments for crossing infrastructure, the need for crossing infrastructure across both provinces is great, likely owing to its relatively high price. It is therefore important to prioritize areas for investment. Based on the carcass data, Transportation and Economic Corridors (Alberta) has developed thresholds for defining strong AVC clusters to prioritize road mitigation investment. In Alberta, TEC considers AVC costs to society to establish a cost-benefit analysis of investment in road mitigation that includes the monetary cost of crossing infrastructure projects. We are not aware of this approach being taken in Saskatchewan. The consideration of high AVCs clusters is important as it is currently the only programmatic approach (in Alberta) for investment in crossing infrastructure not associated with a highway upgrade. To the best of our knowledge, there are no program triggers in Saskatchewan for investing in road mitigations for wildlife.

Using TEC thresholds to identify road sections with high AVC clusters, we identified eight strong clusters (all in Alberta) and 40 weak clusters. The Saskatchewan dataset is less informative as we used RCMP collision information that had GPS location data and species descriptions. The number of collisions occurring in Saskatchewan is greater than depicted here and likely strong AVC clusters do occur. Deer species represented 82% percent of the carcass and collisions data and therefore the main reason to address strong ACV clusters is to reduce risk to motorist safety.

To better identify where animal movement intersects the TCH, we considered the alignment of road section based on multiple grassland species and a structural connectivity index. The results reinforce past studies and highlight the importance of considering both motorist safety risk and animal movement needs, however, these do not always align (Lee et al., 2023, 2020). We identified 49 km of the TCH representing 14% of the study area where investment in road mitigation would enable safe passage for migrating ungulate species and species at risk (badger and rattlesnake). Only 1.5% of the crossing areas align both motorist safety risk and animal movement needs. Therefore, if road mitigation planning only considers motorist safety risk, migratory ungulates and SAR movement needs will not be adequately addressed. We recommend developing a mitigation system to address both motorist safety and animal movement needs-based and focused on the 49 km that we assessed as high priority. A road mitigation system would include a series of crossing structures (combined with fencing) to facilitate safe movement of grassland wildlife while reducing risk to motorist safety.

Important next steps include:

- Consideration of existing infrastructure and the role it may be able to play in supporting safe movement wildlife.
- Preferences in crossing infrastructure for SAR and migratory ungulate species.
- Design considerations for crossing infrastructure to accommodate different grassland species (badger, rattlesnake, and pronghorn have different needs).

For the next phase of Pronghorn Xing, we recommend considering (design and cost assessment) a road mitigation system from Medicine Hat to Highway 41 in Alberta. This would address a series of strong AVCs clusters as well as pronghorn, badger, and mule deer movement needs, and possibly rattlesnake. In Saskatchewan we recommend consideration of road mitigation for pronghorn at site 13.

Conservation Actions

A workshop was held in January 2024 with the working team members to identify goals, objectives and actions (summarized in the following table) to provide direction on next steps.

Goal	Objectives	Actions	Responsibility
1.0 Implement road mitigation to support pronghorn and other grassland species movement across the TCH			
	Assess Functional Connectivity and confirm road crossing sites		
		Establish a pronghorn collaring project	ACA
		Monitoring mitigation sites for SAR (birds, mammals)	Miistakis
	Develop funding strategy to support road mitigation		
		Identify funding opportunities for building road mitigation infrastructure	Miistakis /CWF
		Design and identify draft costs of mitigation infrastructure systems at priority sites in Alberta and Saskatchewan	Miistakis
		Develop one-pager communication resources for priority sites	Miistakis/CWF
	Share and mobilize knowledge		
		Share road mitigation system recommendation with partners	Miistakis
		Organize field trip with Wyoming DOT and Consulting groups	ACA/Miistakis (funding dependent)
	Build relationships with existing and new collaborators		
		Meeting annually as working team	All/ organizer Miistakis
		Engagement with CP Rail	
		Engagement with counties and rural municipalities	Miistakis
		Engagement with indigenous communities	Miistakis
2.0 Secure private land associated with road mitigation sites			
	Confirm road crossing sites		

	Interview landowners on pronghorn presence and other species of concern	
	Collect pronghorn collaring data	ACA
Engage with landowners near priority road mitigation sites		
	Develop strategy for landowner engagement	
	Share SALTS approach along Alberta Hwy 3	Miistakis
Share and mobilize knowledge		
	Share ecological connectivity models and overlay products with land trusts	Ninon Meyer (UofT), Andrew Jakes, Miistakis
	Share communication materials on priority mitigation sites with land trusts	
3.0 Improve fence permeability in migration corridors and at road mitigation sites		
Invest in fence mitigation projects		
	Ground truth pronghorn fencing permeability model	
	Complete fence mitigation or replacement projects in focus areas	ACA
Education and outreach		
	Share education materials on wildlife-friendly fencing (does not impede livestock movement)	ACA
4.0 Build policy support for ecological connectivity investments		
Engagement with provincial agencies		
	Input into wind and solar directives on pronghorn movement and wildlife-friendly fencing	Miistakis
	Work with EPA to inform transportation planning, crown lands and conservation notations	Miistakis
	Work with Saskatchewan Ministry of Highways and Saskatchewan Environment to support connectivity	Miistakis
Engagement with local counties and rural municipalities		
	Engagement with counties and rural municipalities that have ASP's developed in pronghorn movement areas	Miistakis

		Identify counties and rural municipalities that refer to ecological connectivity in their MDPs	
	Engagement with Federal Agencies		
		Identify contacts for ECCC, Parks Canada, and Infrastructure Canada	
		Meetings to identify opportunities for investment in protecting ecological connectivity	Miistakis
5.0 Build social capital with local communities			
	Develop communication plan for promoting ecological connectivity		
		Identify key audiences	
		Refer to ORRSC/SARM engagement plans as a template	
		Engage Cornell Conservation Films for targeted Pronghorn outreach	
		Review "Science to Solutions" approach for conservation messaging and products	
6.0 Develop milestones and timeline for pronghorn conservation plan			
	Identify milestones for pronghorn connectivity plan implementation		All
	Establish Timelines		All

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Appendix A: Methodology for Mule Deer and Badger Connectivity Models, and structural connectivity for Saskatchewan prepared by Dr. Meyer, University of Toronto.

Methods

A typical method to identify areas with high potential wildlife activity first requires an estimate of resistance surface, i.e., a spatial layer that reflects the degree to which a location in the landscape facilitates or impedes movement of a focal species (Zeller et al., 2012). Resistance surfaces are often derived from habitat suitability values, which can be estimated empirically using occurrence information, for example.

Species data

We modeled the ecological connectivity of two terrestrial mammal species in the Northern Sagebrush Steppe. The mule deer (*Odocoileus hemionus*) occurs in southwestern Canada and the western USA, stretching south into northern Mexico. It uses many types of habitat including grasslands, crops, and forest. The American badger (*Taxidea taxus taxus*) is classified as a species of *Special Concern* under Canada's Species at Risk Act, and *Sensitive* in Alberta. It is dependent on natural grasslands for food and habitat and is particularly threatened by landscape conversion and roads. Both species are frequently subject to collisions with vehicles, and mule deer in particular can pose a significant risk to motorists' safety (Lee et al., 2023).

We used occurrence data from the Fisheries and Wildlife Information System in Alberta (FWMIS, 2023), and from three camera trapping surveys in the Greater Calgary Region. We filtered data to retain species records occurring in the last 10 years to avoid a mismatch between the species-habitat association due to the rapidly changing landscape in Alberta. In Saskatchewan, we used an existing habitat suitability model for mule deer developed for the Saskatchewan Habitat Management Plan (Saskatchewan Ministry of Environment, 2020).

Environmental data

We tested the influence of environmental variables on the habitat use of our focal species. Variables were chosen based on the literature (MULTISAR, 2020) and obtained from the Alberta Satellite Land Cover at a resolution of 25 m. As animals often respond to their neighbouring environment and not just their immediate surroundings, we calculated the proportion of the different land cover categories within a radius of 150 m for each location in the landscape.

Table 10: Variables tested for mule deer and badger.

Species	Variables tested
Mule deer	Grassland, crops and agriculture, development (urban and industrial), shrubs, coniferous trees, deciduous trees
Badger	Shrubs, grassland, crops

Habitat suitability

To quantify the effects of environmental layers on species distribution, we used an inhomogeneous point process model (PPM). This method is similar to a generalized linear model for point data, and is particularly suitable to analyze presence-only data for prediction and spatial mapping (Fletcher and Fortin, 2019) It estimates the intensity, or the expected abundance, of species reports in an area, and can therefore be used to make inferences about relative patterns in species abundance (Renner et al., 2015). Importantly, it accounts for covariates that may influence the intensity of points (Fletcher and Fortin, 2019) The PPM is defined as:

$$\lambda(s) = exp\ (\alpha + \ \beta x(s) + \cdots)$$

where λ is the intensity of the point process at locations s across the study area, x is a covariate at location s, and α and β are parameters to be estimated.

We tested a suite of candidate additive models that incorporated a combination of several covariates, and the best-supported model for each species was chosen based on the AIC. We implemented the analysis with the R package SPATSTAT (Baddeley et al., 2015; Baddeley and Turner, 2005a).

The habitat suitability index for mule deer in Saskatchewan was developed for the Saskatchewan Habitat Management Plan and was based on expert opinion. It included cropland, grassland, shrubland, topographic roughness, forest, and oil well density (Saskatchewan Ministry of Environment, 2020).

From habitat suitability to landscape resistance

We transformed the habitat suitability values into resistance using a negative exponential transformation following the equation developed by Trainor et al. (2013):

$$R \ = 100 - 99\ \frac{(1 - e^{(-3*HS)})}{1 - e^{-3}}$$

Where R is the resistance, HS is the habitat suitability (here the intensity λ is developed above), and the factor "3" is determined the shape of the curve. Using this transformation, we developed species-specific resistance maps ranging from 1 to 1000 in Alberta and Saskatchewan. We used the resulting resistance maps as input in the connectivity analysis.

Ecological connectivity

We estimated ecological connectivity using circuit theory. This method is based on random walk and has the advantage that it does not assume animals have a perfect knowledge of the landscape. The resulting product is a prediction of current density or probability of movement across each pixel of the landscape (McRae et al., 2008). We implemented the analysis using the package circuitscape.julia (Anantharaman et al., 2020). For computational efficiently, we reduced the resolution to 50 m in Alberta. We simulated current density between pairs of points (nodes) that were evenly distributed at 5 km along the outer margin of the study area (each node was randomly connected to four others). This method reduces node location bias compared to randomly selecting nodes within the study area and requires fewer pairwise computations (Koen et al., 2014).

Structural connectivity

Structural connectivity refers to the spatial configuration of the habitat patches in the landscape (unlike functional connectivity that also considers the behaviour of species and their responses to the landscape). If no species data are available, modeling structural connectivity can provide valuable information on where natural elements that provide connectivity for numerous species remain on the landscape. Structural connectivity also takes into account the degree of modification of natural areas by human activities (e.g., transportation corridors, mining, residential development, etc). We used the 1000 m resolution Saskatchewan Human Footprint Spatial Data Product (ver. 1.0) (Saskatchewan Ministry of Environment, Lands Branch) as the input layer to assess connectivity in Circuitscape.julia following the same approach as above. In Alberta, we used the species-agnostic connectivity map (i.e., structural connectivity) developed by (Marrec et al., 2020) with a resolution of 100 m.

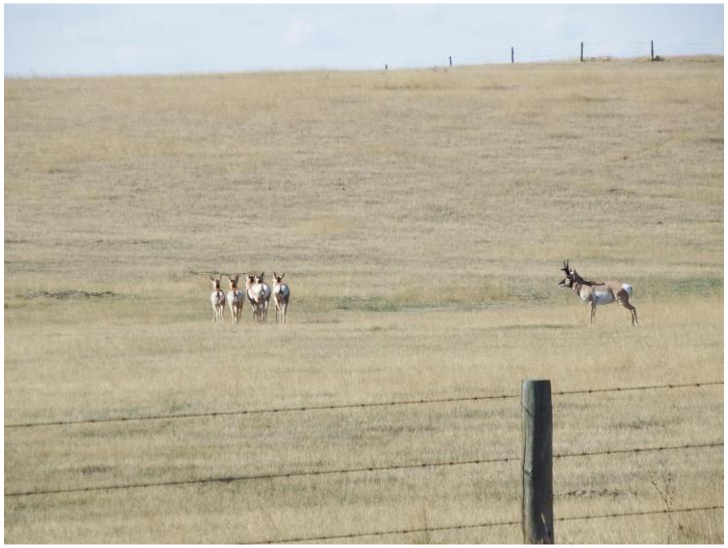
Results

We used 8652 and 498 independent records of mule deer and badger (respectively) in Alberta. The best supported point process models included the following environmental variables:

- For mule deer: coniferous trees, deciduous trees, grasslands, shrubs, crops, development
- For badgers: grasslands, shrubs, crops

The resulting connectivity maps are presented in the report body.

Appendix B: Priority Pronghorn Crossing Site Visit Photos



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