Miistakis Institute

Pronghorn Xing: Improving pronghorn migration through road improvements.

Prepared by: Tracy S. Lee, Sophia Sulimov and Ken Sanderson

September 2021

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Executive Summary

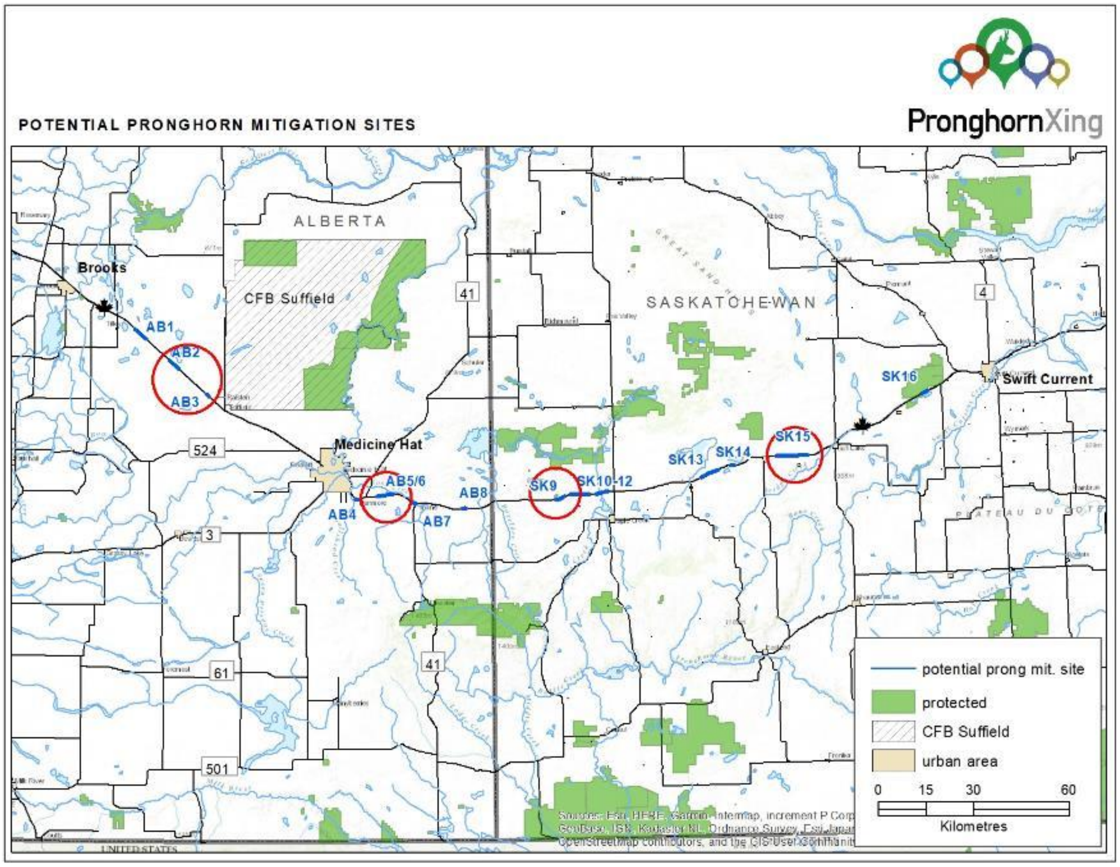
In the Canadian Northern Sagebrush Steppe (NSS), pronghorn *(Antilocapra americana)* move both daily to find food and local habitats and annually, migrating to meet their seasonal needs. Roads crisscross the NSS, causing two key issues for pronghorn: direct mortality from vehicle collisions and habitat fragmentation as crossing risk triggers avoidance behaviour reducing pronghorn fitness and dividing populations.

We set out to identify places along the Trans Canada Highway (TCH) from Brookes, Alberta to Swift Current, Saskatchewan where road mitigation, including underpasses, overpasses, and associated fencing and jump-outs, could improve pronghorn conservation by reducing collisions and improving landscape permeability. We considered three data sources: a pronghorn connectivity model, pronghorn observations reported by citizen scientists, and animal vehicle collision (AVC) data reported by highway maintenance cleanup crews (Alberta) and the RCMP (Saskatchewan). We created road section indices for each data source and identified locations where they agreed that pronghorn were likely to cross. We identified 16 potential pronghorn road mitigation sites along the TCH. Not only did our results identify areas of alignment between pronghorn observations and connectivity, we also found misalignments that will need to be further investigated. In general, pronghorn observations and connectivity do not match well with AVC data, which is dominated by deer incidents.

We focused on the TCH because of high traffic volumes (>5,000 vehicles per day) and an concern of pronghorn avoidance behaviour. Pronghorn movement also intersects with secondary highways and those with higher traffic volumes should be further considered, for example Highway 3 has traffic volumes exceeding 3,500 vehicles per day. We identified areas where pronghorn observation and connectivity aligned along secondary roads in the NSS to highlight areas for further scrutiny.

To further refine potential pronghorn road mitigation along the TCH, we assessed the 16 sites against a list of criteria agreed on at an expert workshop including pronghorn road crossing, AVC cluster, multi-species benefits and cumulative effects. Other criteria identified as important in next steps include better understanding of future land use, impact of fencing, and ease of constructability of mitigation infrastructure. To help prioritize pronghorn road mitigation sites, workshop participants rated criteria in an Analytical Hierarchy Process (AHP) to determine criteria weightings.

Based on pronghorn road mitigation site prioritization we identified four priority potential pronghorn road mitigation sites (red circles on map, AB2-3, AB4-5, SK9-10 and SK15) for further consideration along the TCH.



As next steps we recommend site visits with transportation engineers to determine if existing infrastructure can be integrated into a crossing network (i.e., existing bridges over rivers, railway underpass) and to identify the most appropriate locations for mitigative infrastructure.

More discussion is needed on strategies to implement road mitigations that will improve pronghorn and human safety. Research indicates pronghorn strongly prefer overpasses; there is no evidence pronghorn will consistently use an underpass. Overpasses are more expensive than underpasses, decreasing the number of sites where pronghorn road mitigation will be achievable. In addition, pronghorn do not necessarily cross where deer cross. Yet deer crossing site have the highest risk to motorist safety based on AVC data. These complicating factors require further discussion with agency personal to develop implementation strategies and point to the need for a mitigation system designed to address both motorist safety and ecological connectivity and different species preferences for crossing roads.

Progress will also include understanding road mitigation sites in relation to landownership and governance, fence ecology, and identification of migration paths along secondary roads, specifically those with over 2,000 vehicles per day.

Introduction

In the Canadian Northern Sagebrush Steppe (NSS), pronghorn move daily and complete seasonal migratory movements to meet their short- and long-term life needs (Jakes 2015; Jakes *et al.* 2018). Across the NSS, highways fragment pronghorn habitat resulting in direct mortality and/or disrupted movement (Jones *et al.* 2020). We set out to identify areas along the Trans Canada Highway (TCH) and on secondary highways where road mitigation, including underpasses, overpasses, and associated fencing, could improve pronghorn conservation by reducing collisions and fragmentation effects on pronghorn movement.

We developed Pronghorn Xing (PX) — a citizen science program designed to ground truth seasonal migratory pinch points identified by connectivity models across highways in the NSS (Jakes 2015) and improve public participation in pronghorn conservation. Wildlife observations collected by the public enabled us to understand where pronghorn and other wildlife are commonly crossing, involved in collisions, or staging along highways in the NSS. Ultimately, this will help improve pronghorn conservation by informing strategies to reduce pronghorn vehicle collisions while also ensuring the safe passage of pronghorn across highways. The generated information will be shared with government agencies in Alberta and Saskatchewan.

We report on the program's research results to:

- compare connectivity models and PX observation data to identify locations where they agree pronghorn are crossing roadways;
- compare pronghorn connectivity and PX observations with a motorist safety risk assessment based on cluster analysis of ungulate collisions; and
- identify potential pronghorn road mitigation sites that consider possible motorist safety risks and benefits to multiple species.

Methods

Study Area

Our study took place in the Canadian Northern Sagebrush Steppe (NSS), where pronghorn move daily and seasonally to meet life requirements (Jakes *et al.* 2018). Across this region provincial highways fragment the landscape and cause direct mortality and/or may disrupt movement patterns reducing pronghorn survivability

(Jones *et al.* 2020). Our assessment included the TCH from Brooks, Alberta to Swift Current, Saskatchewan and six secondary roads, Highway 3, 41, 61, 501, and 524 in Alberta and Highway 4 in Saskatchewan (Figure 1). Traffic volumes vary across the study area with higher volume roads, Highway 3 and the TCH, supporting between 5,000 and 10,000 vehicles per day and exceeding 10,000 daily around Medicine Hat (Figure 2; Alberta Transportation 2017b).

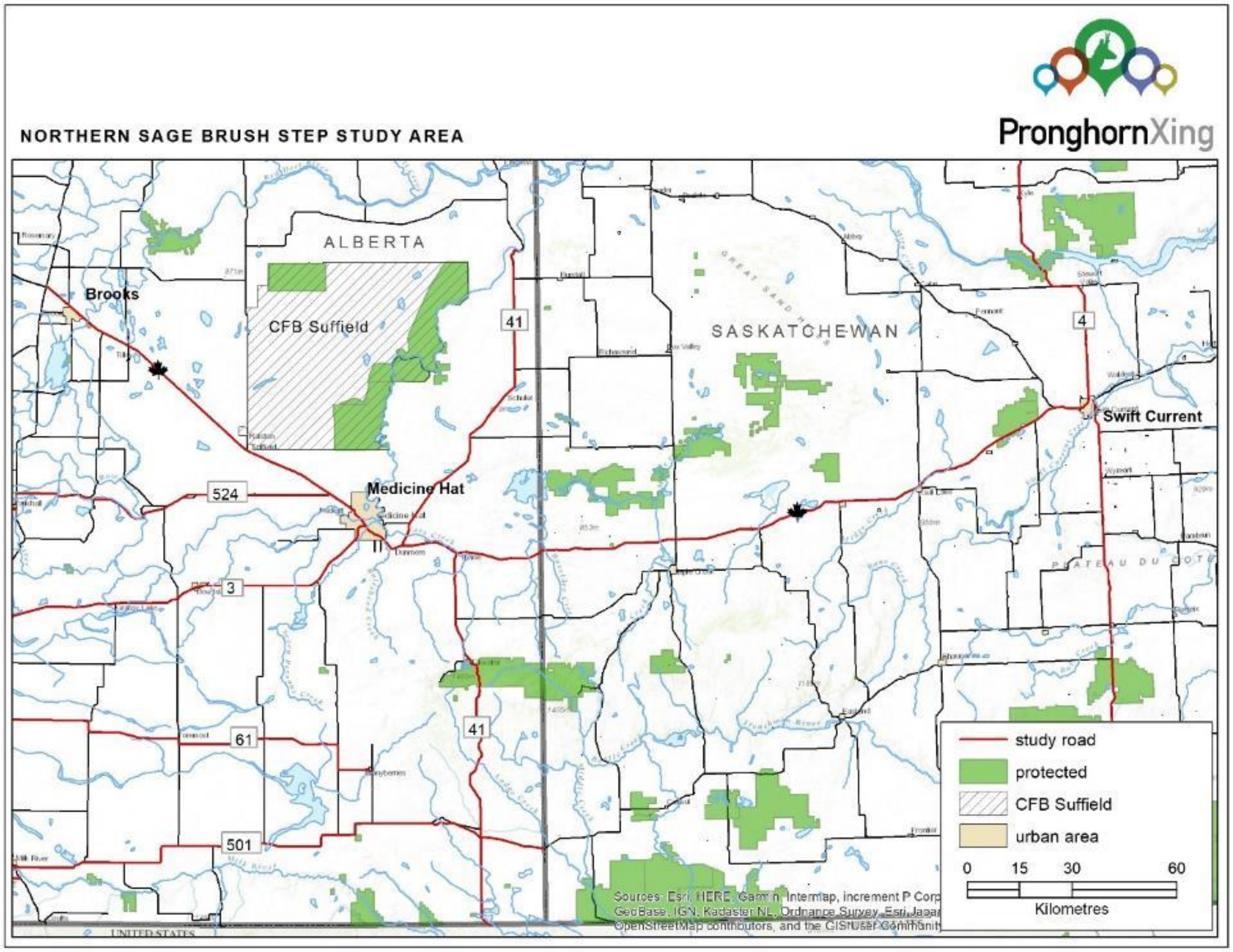


Figure 1: Highway network in Canadian Northern Sagebrush Steppe, roads surveyed marked in red.

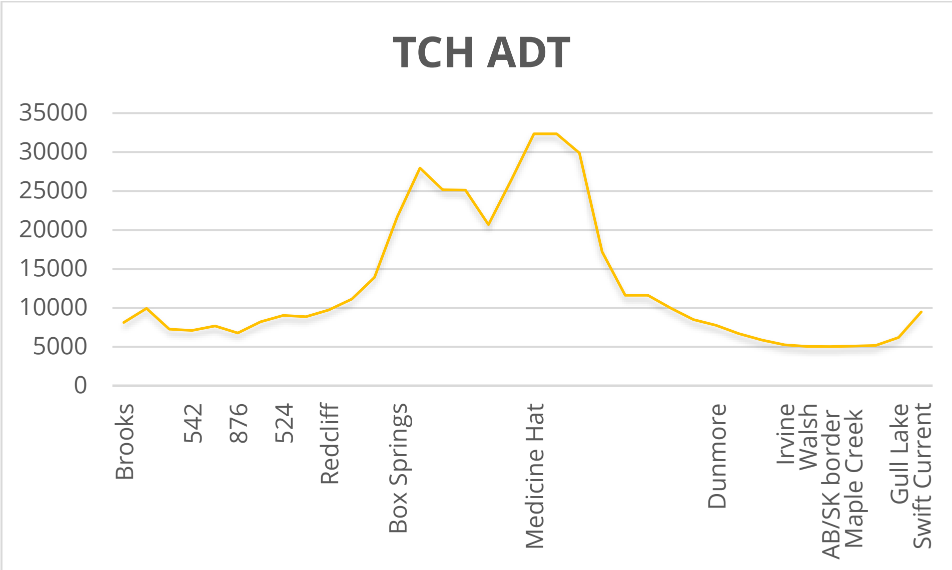


Figure 2: Average Annual Daily Traffic Volume for 2019 along the TCH from Brooks, Alberta to Swift Current, Saskatchewan.

Data sources

To identify road sections for mitigation to improve pronghorn movement we considered three different datasets:

1. Pronghorn Xing: pronghorn observations reported by citizen scientists along the provincial road network in Canadian NSS.
2. Pronghorn Connectivity: model developed by Dr. Andrew Jakes for spring and fall pronghorn migration in the Canadian NSS.
3. Motorist safety: composed of two datasets. For Alberta, data were provided by the Alberta Wildlife Watch Program, from reports by highway maintenance contractors of carcass observations. For Saskatchewan, we used vehicle collision data reported to RCMP. Hereafter, we use animal vehicle collision (AVC) to refer to both the Alberta and Saskatchewan collision datasets.

Pronghorn Xing

Pronghorn Xing data were collected from October 2017 to December 2020. Volunteers reported animal sightings while out driving, using a freely available smartphone application. Information collected included species, number of animals observed, and the animal status (adjacent, crossing the road, or dead). The smartphone application automatically recorded the date, time, and location. In addition, observers were able to start a driving route in the smartphone application to track road sections driven during a survey. This route function enabled data to be standardized to observer effort which was not necessarily consistent across the study area.

Submitted data were screened and classified. Duplicated observations were identified and removed based on a series of rules. If two observations of the same species occur on the same day within 1 kilometer of each other, and with same status (crossing, adjacent, mortality), duplicate records were removed. Verified pronghorn data were identified to road section, defined using one kilometer markers from Alberta Transportation and Saskatchewan Highways and Infrastructure. We determined (using the route function in the app) that observer effort varied among road sections with more routes closer to towns such as Medicine Hat (Figure 3). All road sections with <5 routes were classified as data deficient and excluded from the analysis. This occurred on small sections of secondary highways. To address inconsistency in observer effort, we calculated a pronghorn observation index by dividing pronghorn observations per road section by the number of times a kilometer-long section had been driven by an observer. The pronghorn observation index was used in all analysis.

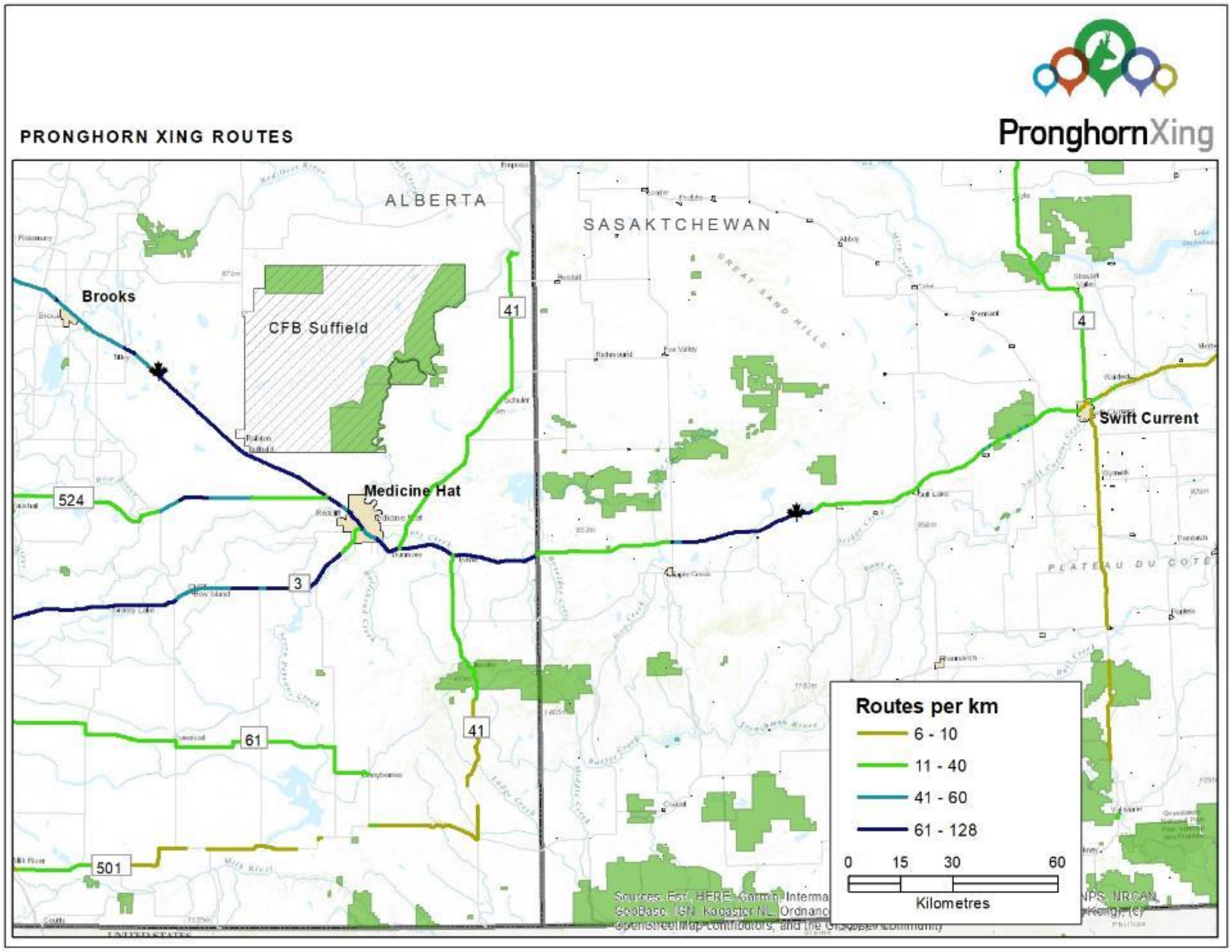


Figure 3: Routes per road section (km) along provincial highway network used to normalize Pronghorn Xing data that accounts for observer effort.

Pronghorn Connectivity Model

We used a functional pronghorn connectivity model developed for spring and autumn by Dr. Andrew Jakes (Jakes 2015; Jakes *et al.* 2018). In our analysis, pronghorn spring and autumn connectivity models were averaged to generate one model for analysis. One kilometer road sections were assigned the mean observation/km value for that section, and all pixels touching the road network were included in the index of pronghorn connectivity. The pronghorn connectivity index was used for all further analyses.

Animal Vehicle Collisions (AVCs)

A key motivation to mitigate wildlife crossing is to improve motorist safety. To identify road sections with a high risk to motorist safety we obtained animal carcass data (2017–2020) from the Alberta Wildlife Watch Program and RCMP Collision data (2016–2019) from Government of Saskatchewan Insurance (Alberta Transportation

2017a). We prepared the dataset both as point AVC locations and an AVC index to enable direct comparison with the other datasets.

AVC point data were used to identify hotspots 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). The strongest and most stable clusters are those with a strength value ≥0.6, while weaker or unstable clusters are those with strengths <0.6. Stable clusters are consistently observed over time and won't change strength if one or two animals are added or have gone unreported (Alberta Transportation 2017a).

Alignment of Indices

First, we determined where the pronghorn connectivity model and observations align to identify movement paths across roadways. Where we found strong alignment, we used these paths to prioritize and recommend potential road mitigations. To analyze datasets, we compared the indices (Table 1) using linear regression. This gives us both correlation significance and strength. We converted each index to percentiles and summed the indices to identify road sections with strong agreement (top 10%, 20%, and 25%). We used the same approach to relate the pronghorn observation index to the AVC index and the pronghorn connectivity index to the AVC index.

Table 1: Road Indices

Index	Source Data	Process Description
Pronghorn Observation Index (Prong Obs).	Developed from the Pronghorn Xing dataset collected by citizen scientists.	Pronghorn observations (adjacent, crossing and mortality) were enumerated to road sections (1 km), normalized to road section length, and observer effort. The index ranged from 0 to 1, where 1 is an observation with high confidence.
Pronghorn Connectivity Index (Prong Con.)	Developed using average value from spring and fall connectivity models developed by Dr. A. Jakes.	Road sections (1 km) were assigned mean connectivity based on all pixels associated with the road network. The index ranged from 0 to 1 where 1 represents sections with high connectivity.
AVC index (AVC)	AB: Alberta Wildlife Watch Program (2017–2020), includes highway maintenance cleanup crew carcass observations reported via a smartphone application. SK: RCMP Collision data (2016–2019); animal collisions that cause damage are reported to RCMP and Government of Saskatchewan Insurance (SGI).	AVCs were enumerated per road section (1 km). The index ranged from 0 to 1, where 1 are locations with high incidence of wildlife collisions.

Identification of potential pronghorn road mitigation sites

To identify road sections for mitigation consideration along the TCH, we identified areas where two indices agreed (we used summed index values of 1.5–2.0 or top 25% of alignment). For comparisons with the AVC index, we only considered alignment where KDE identified a cluster along the road segment (i.e., a stable (statistically significant) cluster or an unstable cluster).

For secondary highways, we identified road sections with a high level of agreement between the pronghorn observation and connectivity indices. We also plotted AVC clusters based on the Alberta Wildlife Watch data on secondary roads in Alberta but did not prioritize potential pronghorn mitigation sites on these roads at this time.

To prioritize pronghorn mitigation sites, we developed a set of criteria (Table 2) at a program workshop with representatives from provincial government agencies, NGO's, and land trust organizations working in the area. Workshop participants contributed to prioritization of pronghorn mitigation sites using an Analytical Hierarchy Process (AHP). Eleven individuals compared each criterion to another using pairwise comparisons and weighting of how much more important one was. These were amalgamated using open-source software[1], which determined weightings.

Table 2: Criteria for Identifying Pronghorn Mitigation Areas

Criteria	Definition
Pronghorn road crossing	The spatial alignment agreement between the pronghorn connectivity model and pronghorn observations reported via pronghorn crossing. Factor classified based on the top 10%, 20% and 25% spatial alignment.
AVC cluster	Use of cluster analysis to identify stable (statistically significant) and unstable AVC clusters based on Alberta wildlife watch and Saskatchewan RCMP collision data. This value determines the risk to motorists.
Habitat Permeability	The density of less favorable land and pronghorn habitat on either side of the mitigation site.
Constructability	The ease of implementing road mitigation (underpass, overpass) from an engineering perspective, including factors such as local topography, distance to railway, and presence of existing infrastructure that can be modified into a mitigating structure.
Multi-species benefit	The number of ungulate species along with pronghorn that would benefit from mitigation.
Cumulative effects	The density of the human footprint (including fencing, roads, oil well sites, housing, and other anthropogenic disturbances) within a 400 m buffer around the mitigation site (Jones et al. 2019).

Results

Pronghorn Xing

Over the three-year period, 934 pronghorn observations were reported using the PX program. A total of 81.5% of observations were animals beside a road, 10.9% unknown, 4.8% crossing, and 2.5% mortality (Figure 4). On the TCH, 419 pronghorn observations were reported while 515 observations were reported on secondary

[1] https://bpmsg.com/ahp/

roads (Figure 5A). We also plotted pronghorn observations reported during the spring (March 20 – June 21) or autumn (September 22 – December 21) migration periods (Figure 5B). For the pronghorn observation index, we grouped all three statuses and time periods into one dataset.

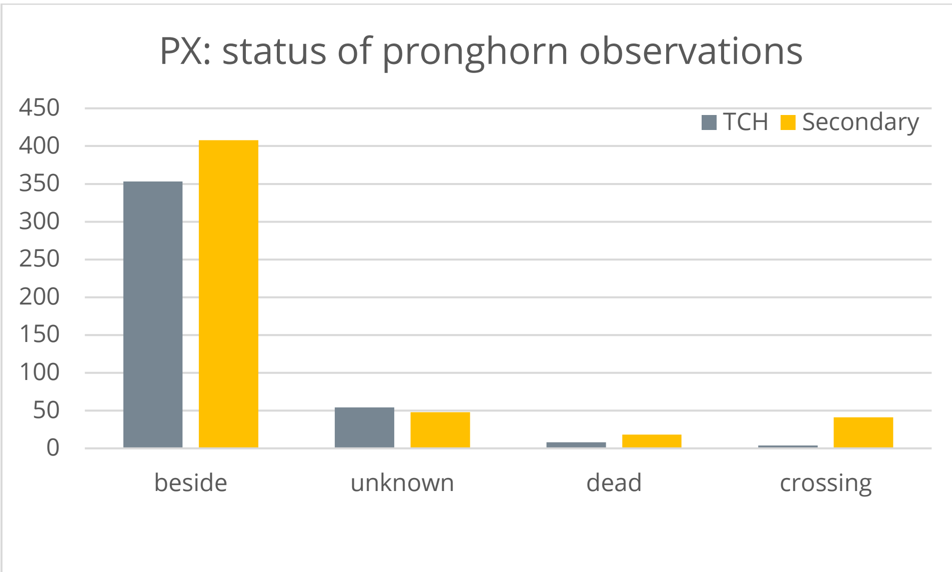


Figure 4: PX observations of the number of pronghorn (y-axis) and status (beside the road, unknown, dead, or crossing) along the Trans Canada Highway and secondary highways.

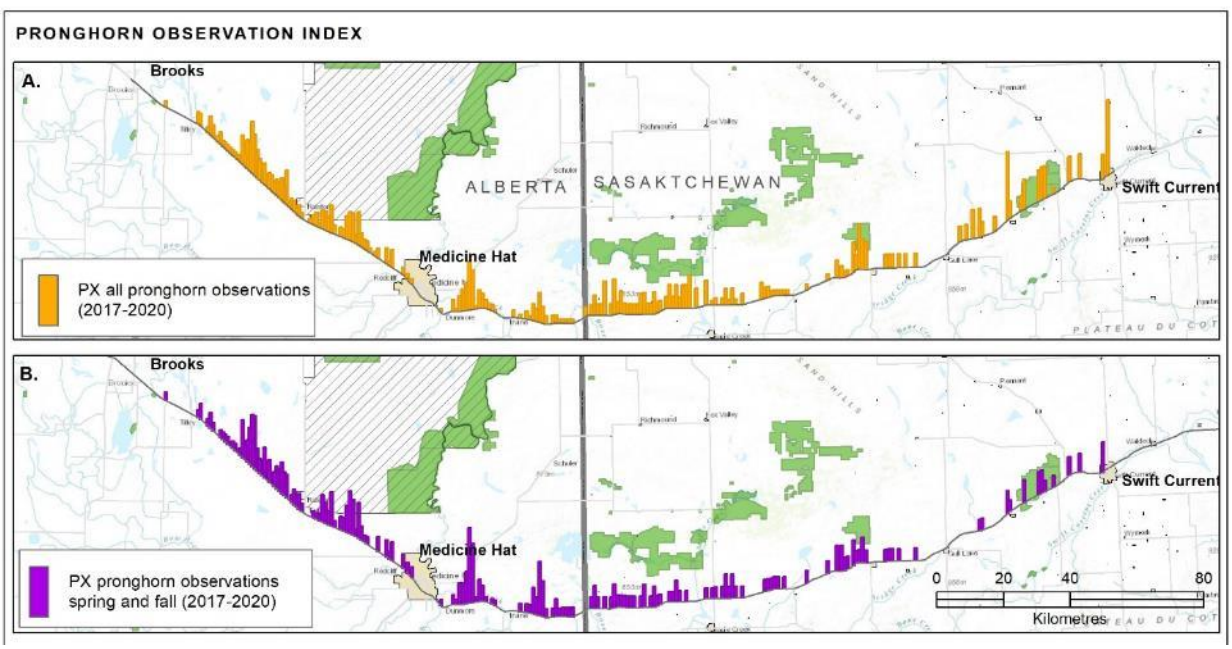


Figure 5: Pronghorn observation index in 1 kilometer road segments in southern Alberta and Saskatchewan. Bar height is relative index strength with higher bars depicting a higher number of overall pronghorn observations (Panel A), and pronghorn observations occurring during the spring and fall migration periods (Panel B).

Pronghorn Connectivity

The pronghorn connectivity index (Figure 6) identified road sections where pronghorn migration corridors intersect with the TCH. Eighty kilometres of the TCH falls within the top 25% of the pronghorn connectivity index.

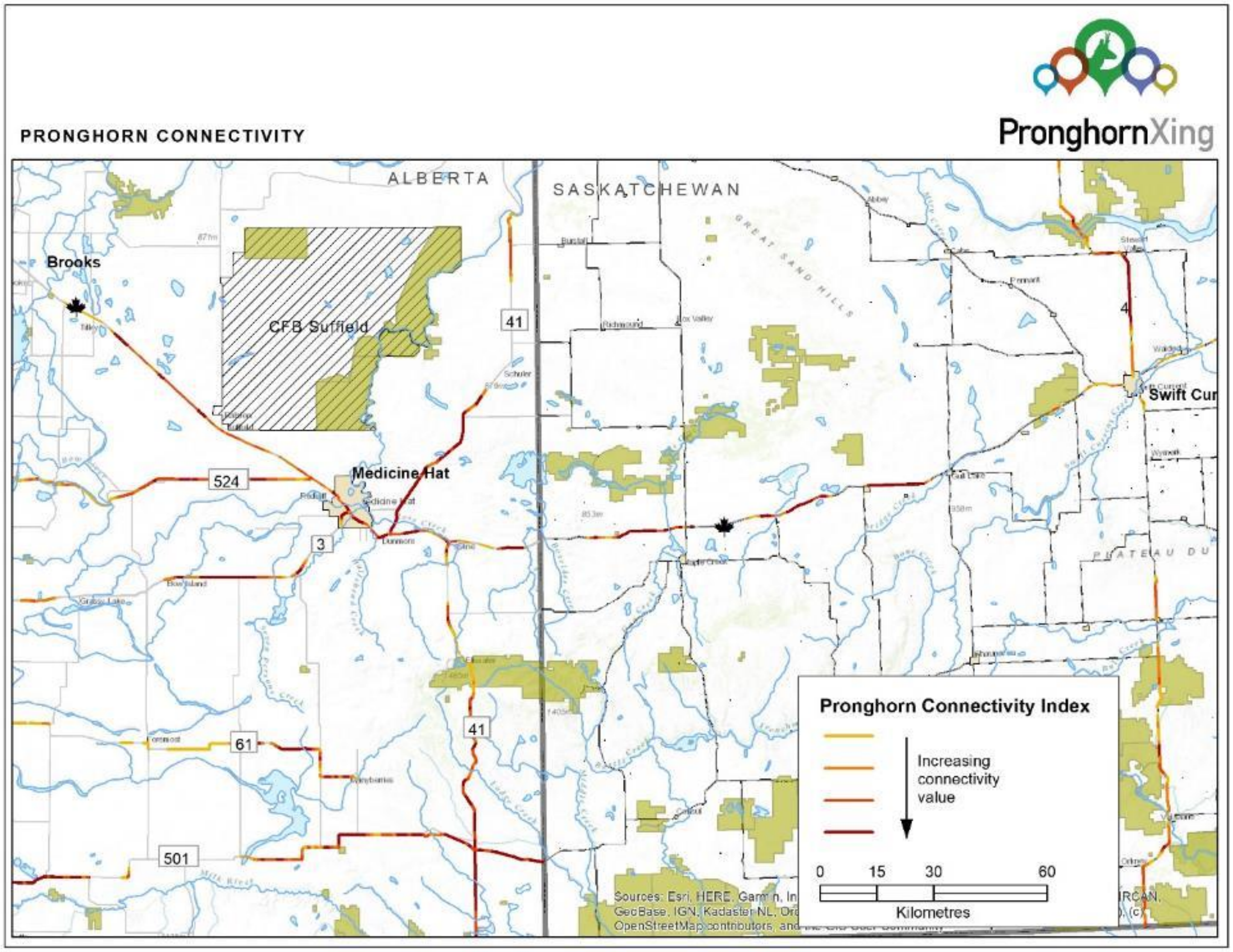


Figure 6: Pronghorn connectivity index along the Trans Canada Highway and secondary highways.

Animal Vehicle Collisions

Our data sources reported 152 animal vehicle collisions along the TCH (mean = 38/year) from carcasses reported on the Alberta section from 2017 to 2020, and 371 (mean = 93/year) on the Saskatchewan section of the TCH from 2016 to 2019. In Alberta, 98% of the animals were deer, and only 2% were pronghorn over the three-year period. In Saskatchewan AVC data are limited in that species information is not recorded (domestic animals may be included) and the location accuracy is inconsistent, with some records having GPS coordinates (48%) and others estimated to a km nearest marker (52%).

The KDE+ analysis of transportation defined control and TCH sections (one section at 250 m diameter search radius) identified five locations with statistically significant clusters of animal vehicle collisions along the TCH (Figure 7). These were near Brooks, through Medicine Hat, west of Dunmore, at the junction of TCH and Highway 41 south, and at the Alberta / Saskatchewan border. These are areas where transportation agencies could effectively install road mitigation to reduce risk to human safety and enable wildlife crossing.

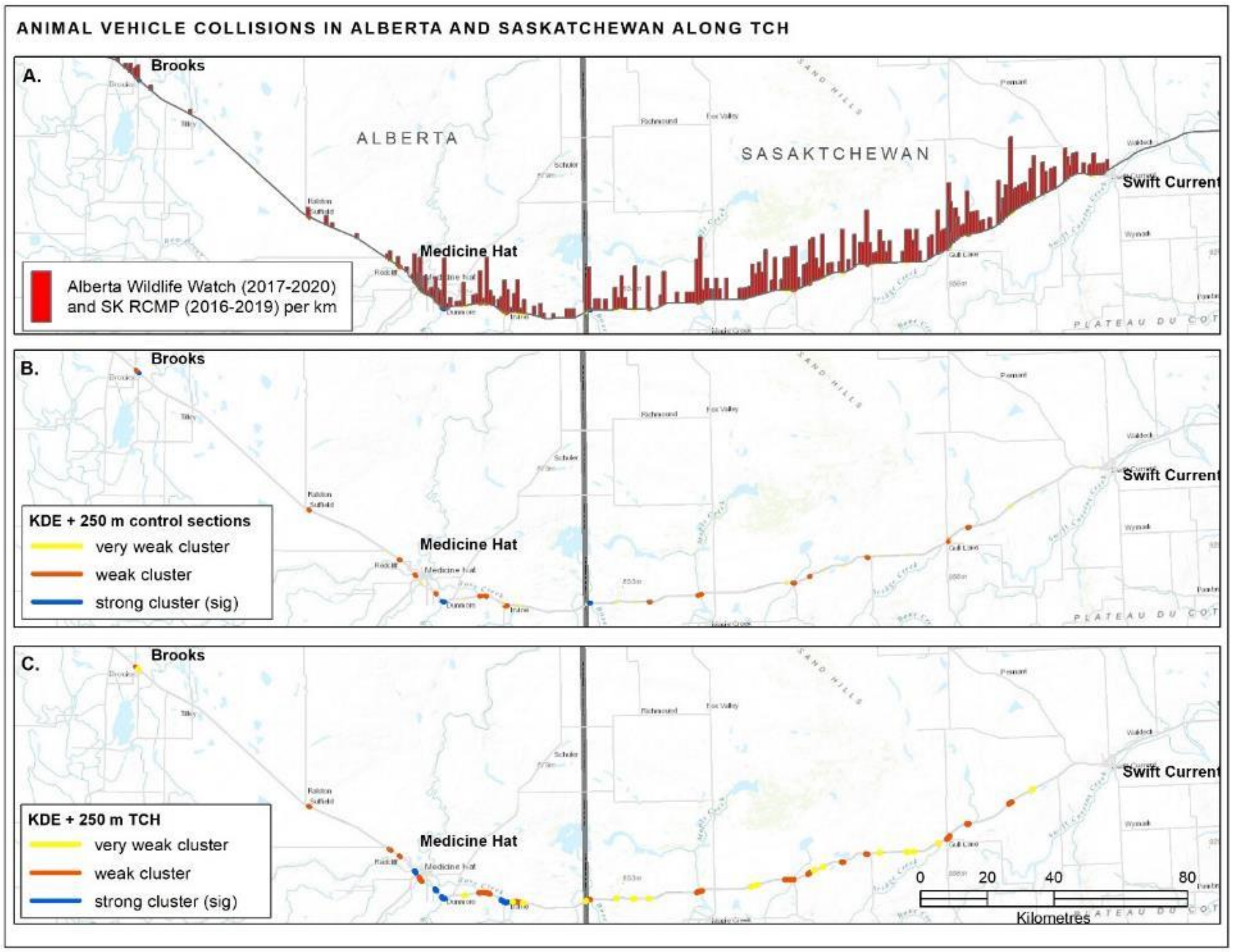


Figure 7: Motorist safety risk, including animal vehicle collisions per 1 kilometer road section (Panel A) displayed as AVC index (red bars). Wildlife collision clusters per highway control section using a 250 m diameter window (Panel B) and on the Trans Canada Highway using a 250 m diameter window (Panel C). Statistically significant clusters are shown in blue, weak non-significant clusters in red and very weak non-significant clusters in yellow.

Animal vehicle collisions involving pronghorn were reported in both the Pronghorn Xing and Alberta Wildlife Watch datasets. In total, 56 pronghorn were involved in collisions over the four years (mean = 14/year in the Alberta portion of the NSS), 11 on the TCH and 45 on surveyed secondary roads.

Alignment between different datasets

We plotted road section indices (Table 1) to find agreement among datasets. The pronghorn connectivity index and pronghorn observation index are very weakly and positively related along the TCH (Figure 8) and secondary highways. AVC data are negatively related to both Pronghorn Observations and Pronghorn Connectivity value along the TCH (not displayed).

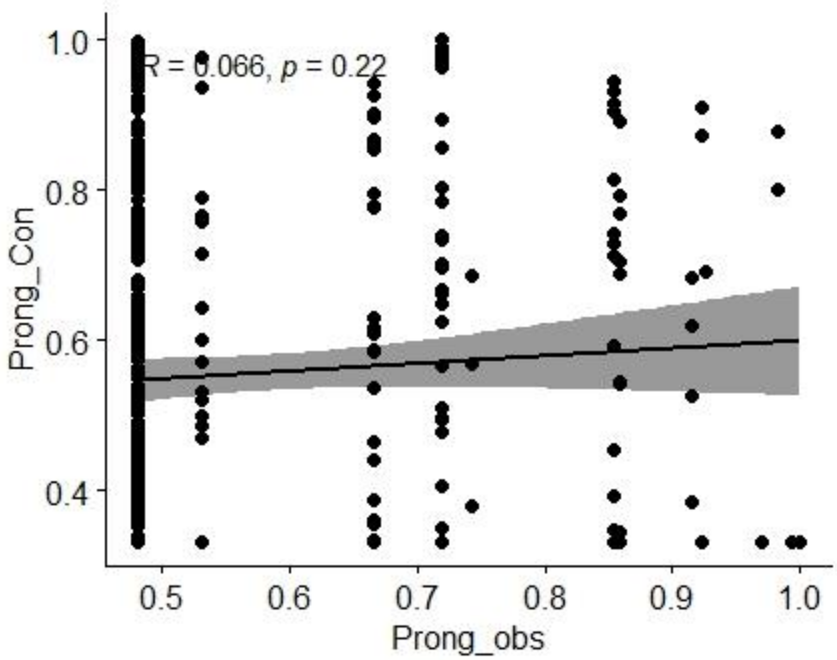


Figure 8: Linear regression (R=0.066, p=0.22) between pronghorn connectivity and PX pronghorn observation indices along the Trans Canada Highway. Positive index agreement increases from left to right and from bottom to top.

We summed the indices to identify road sections with strong spatial agreement, represented as values closer to 2 on the histogram (Figure 9) and displayed top 10%, 20%, and 25% agreement (Figure 10).

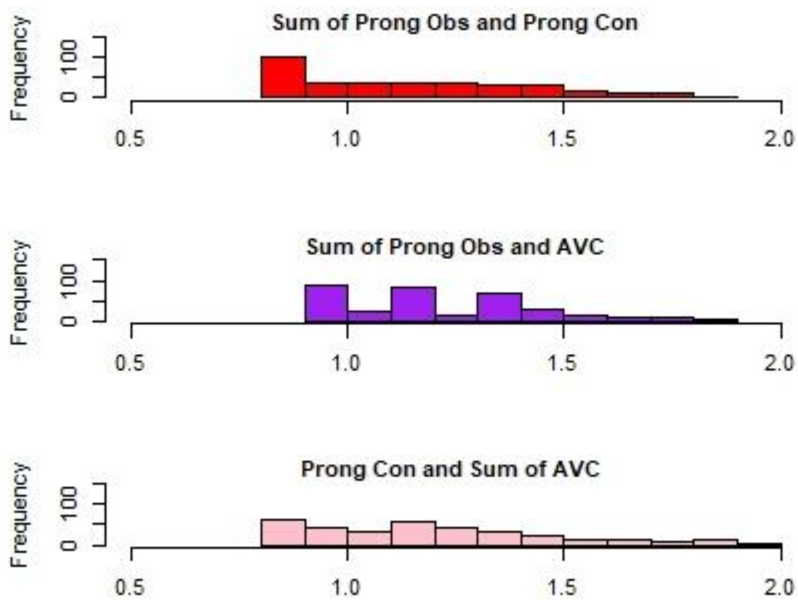


Figure 9: Frequency histograms of summed indices for pronghorn observations and pronghorn connectivity value (red), pronghorn observations and AVCs (purple) and AVCs and pronghorn connectivity value (pink). Higher index sums indicate greater agreement and values between 1.8 and 2.0 represent top 10% of agreement between datasets.

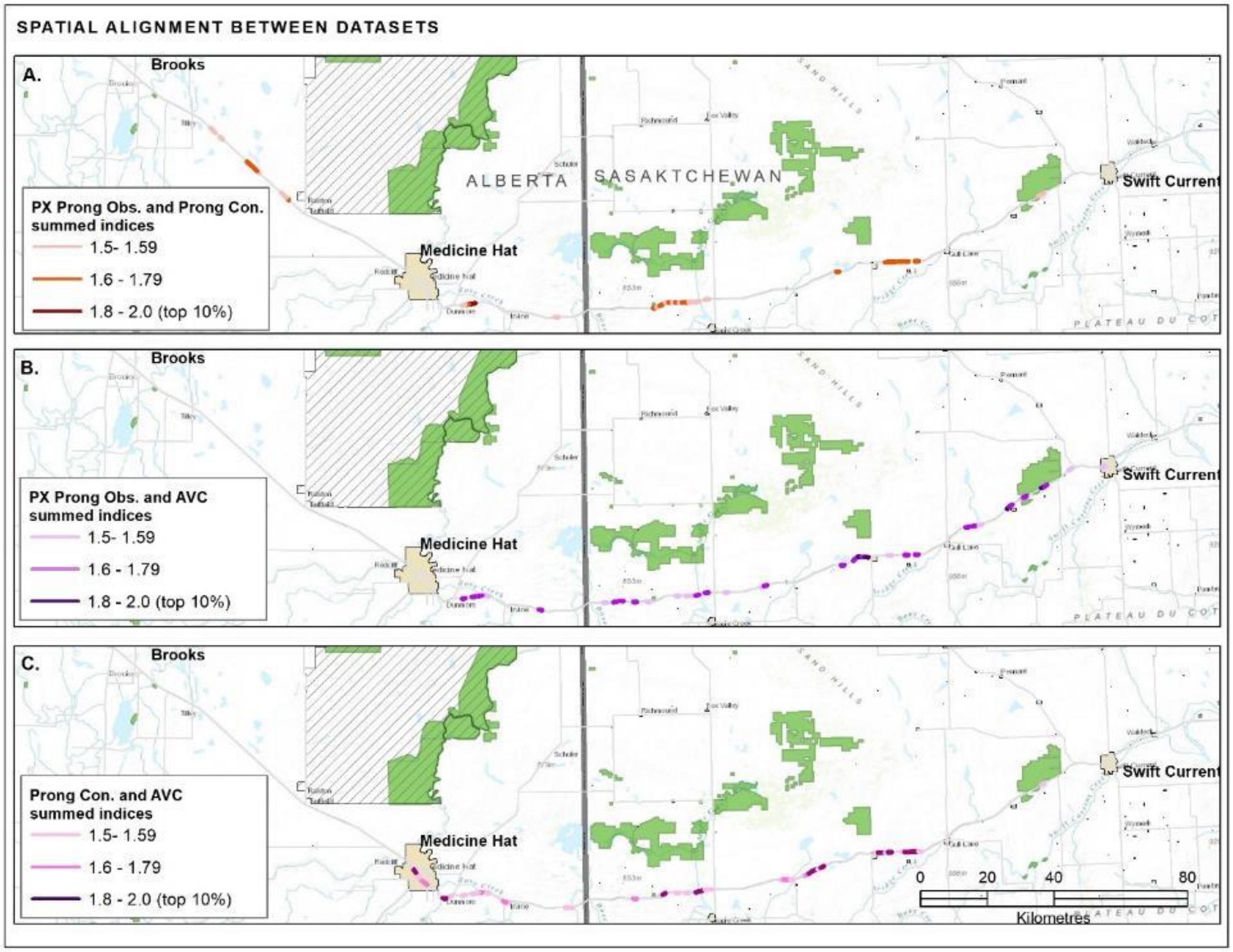


Figure 10: Spatial agreement of summed indices for pronghorn observations and pronghorn connectivity value (panel A), pronghorn observations and AVCs (Panel B) and AVCs and pronghorn connectivity (Panel C). Values between 1.8 and 2.0 represent top 10% agreement between datasets (shown in dark red, dark purple and dark pink); 1.6 to 1.79 represent top 20% of agreement between datasets; and 1.5 to 1.59 represent top 25% of agreement between datasets.

Identification and prioritization of potential pronghorn road mitigation sites

We identified 15 potential sites along the TCH in Alberta and Saskatchewan where road mitigation could improve pronghorn movement. An additional site was added along TCH near Crane Lake based on recommendation of workshop participants resulting in 16 potential pronghorn mitigation sites.

We then applied a set of criteria to each site (Table 2) and further refined the list based on weighted results from an AHP (Figure 11). Criteria with low weights (fence permeability) or ones that might be difficult to rate (constructability) were removed from the criteria list to prioritize road mitigation sites and weights were recalculated (Table 3). These criteria although important will be considered in later phases of the project. Each potential pronghorn road mitigation site was scored using a rating system of 1-3 (Table 4) where higher values represent more important road mitigation sites. Weighing derived from the AHP were applied to the criteria (Table 5).

Decision Hierarchy

Level 0	Level 1		Glb Prio.
Pronghorn Road Mitigation Criteria	pronghorn road crossing	0.176	17.6%
	AVC cluster	0.113	11.3%
	habitat permeability	0.151	15.1%
	fence permeability	0.091	9.1%
	constructability	0.113	11.3%
	land-use intent	0.099	9.9%
	multi-species benefit	0.112	11.2%
	cumulative effects	0.144	14.4%
			1.0

Figure 11: AHP results and criteria weights.

Table 3: weighted criteria included in prioritization

Criteria	Weighting
Pronghorn road crossing	25.3
AVC cluster	16.2
Habitat Permeability	21.7
Fencing Permeability	0.0
Constructability	0.0
Land use intent	0.0
Multi-species benefit	16.1
Cumulative effects	20.7

Table 4: Criteria and scores used to assess potential road mitigation sites.

Criteria	Score
Pronghorn Road Crossing	
top 10%	3
top 20%	2
top 25%	1
AVC KDE +	
stable cluster	3
unstable cluster	2
mortality but no cluster	1
Permeability	
Habitats (natural cover) both sides	3
habitat one side/less favourable matrix other side	2
less favourable matrix both sides	1
Multi-species benefit	
all four [2]species presence	3
more that one species	2
pronghorn only	1
Cumulative Effects	
linear density <5.0 km/km2	3
linear density between 5.0-7.5 km/km2	2
linear density km/km2 >7.5 km/km2	1

[2] White tailed deer, mule deer, elk and pronghorn

Table 5: Potential pronghorn road mitigation sites criteria assessment score

Site	Pronghorn road crossing	AVC (KDE+)	Habitat Permeability	Multi-species benefit	Cumulative Effects	Scores (20 top value)
AB1	1	0	3	2	2	11
AB2	2	0	3	3	2	14
AB3	2	0	3	3	2	14
AB4	0	3	1	2	1	8
AB5	3	1	2	2	2	14
AB6	0	2	2	2	3	11
AB7	0	3	3	2	2	12
AB8	1	1	3	2	2	12
SK9	2	1	3	3	1	13
SK10	2	1	2	2	1	11
SK11	1	2	3	2	1	12
SK12	1	1	3	2	1	11
SK13	0	2	3	2	2	11
SK14	2	1	3	2	1	12
SK 15	2	2	2	2	3	15
SK 16	1	1	3	2	2	12

Potential pronghorn road mitigation sites (Figure 13) with the highest score in Alberta included sites AB 2,3 and 5 along the TCH (Figure 14), and in Saskatchewan SK9-10 and SK15 (Figure 15). Some of the sites include two potential road mitigation sites due to site proximity and to enable greater flexibility during on the ground assessment of identifying location for site infrastructure.

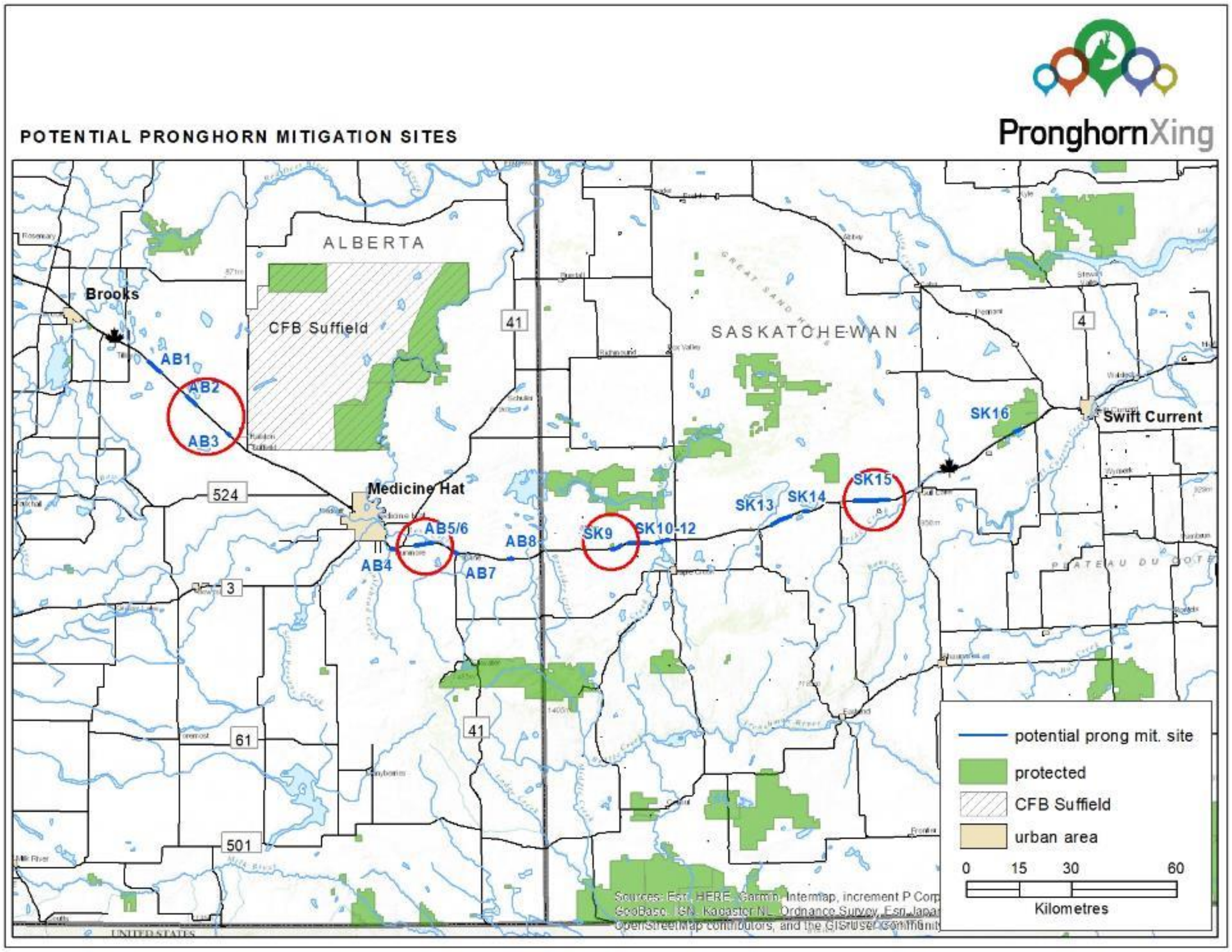


Figure 13: Sixteen potential pronghorn road migration sites (displayed in blue) along Trans Canada Highway in Alberta and Saskatchewan. The red circled area (Alberta AB2-3, AB5-6, Sk9-10 and SK15) represent priority potential pronghorn road mitigation sites.

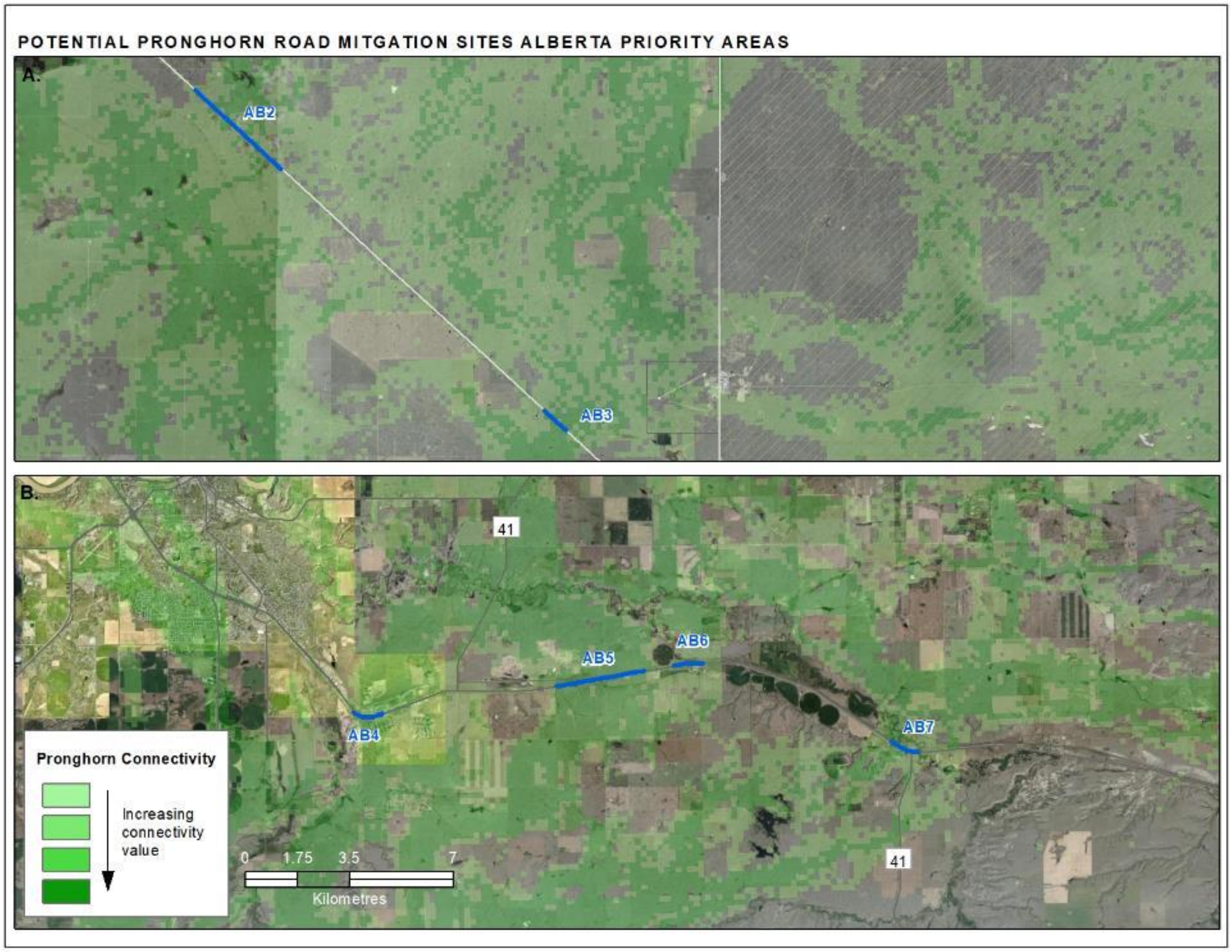


Figure 14: Priority potential road mitigation sites for pronghorn along a 20 km stretch of the Trans Canada Highway in Alberta highlighting sites AB2-3 (Panel A) and sites AB5-6 (Panel B).

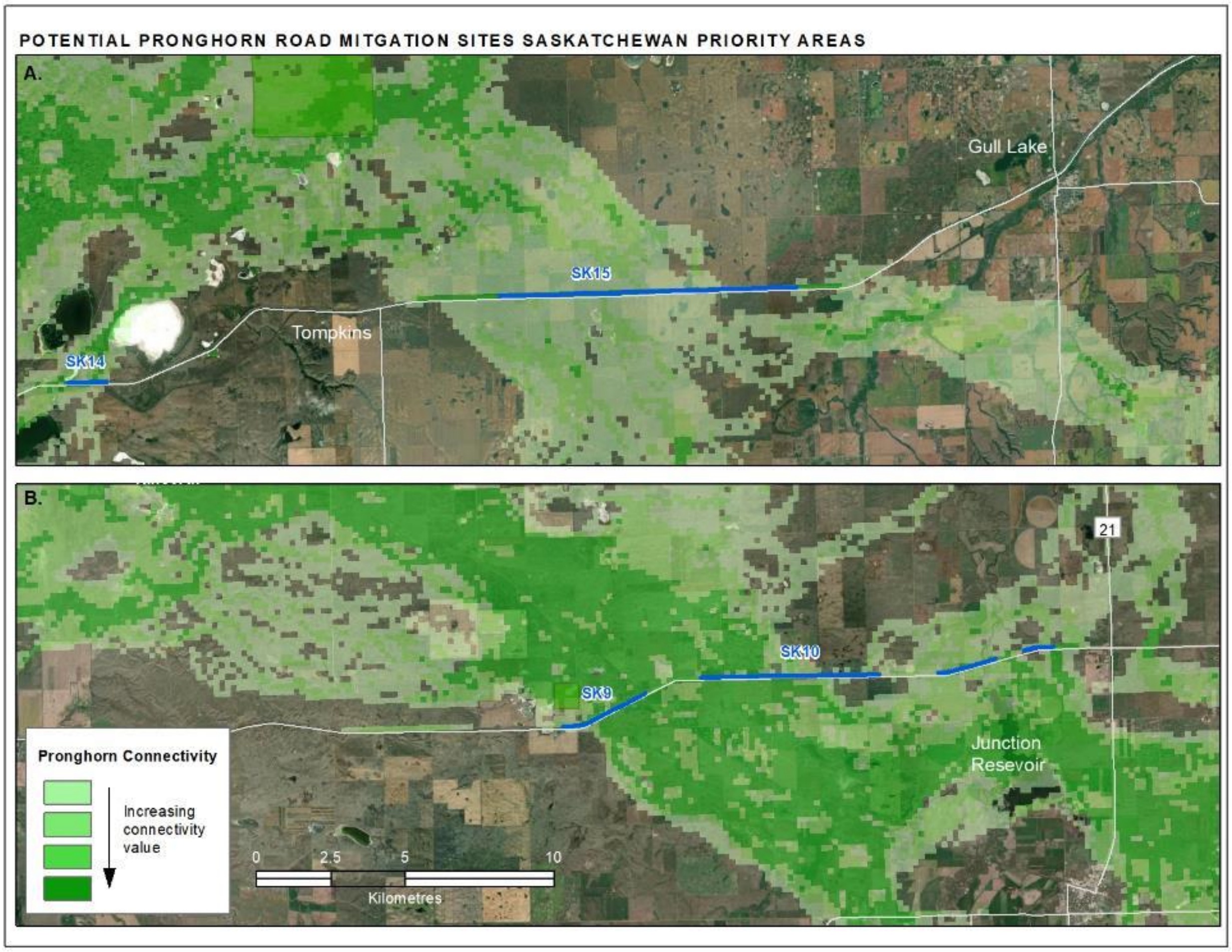


Figure 15: Priority potential road mitigation sites for pronghorn along a 16 km stretch of the Trans Canada Highway in Saskatchewan highlighting sites SK15 (Panel A) and SK9-10 (Panel B).

Secondary highways

We reviewed where there was strong agreement (top 10%) between pronghorn observations and pronghorn connectivity on all secondary highways, and where there were strong animal vehicle collision clusters on Alberta secondary highways (Figure 16). We did not prioritize these areas in this analysis. There is not agreement between AVC stable clusters and pronghorn movement on secondary highways.

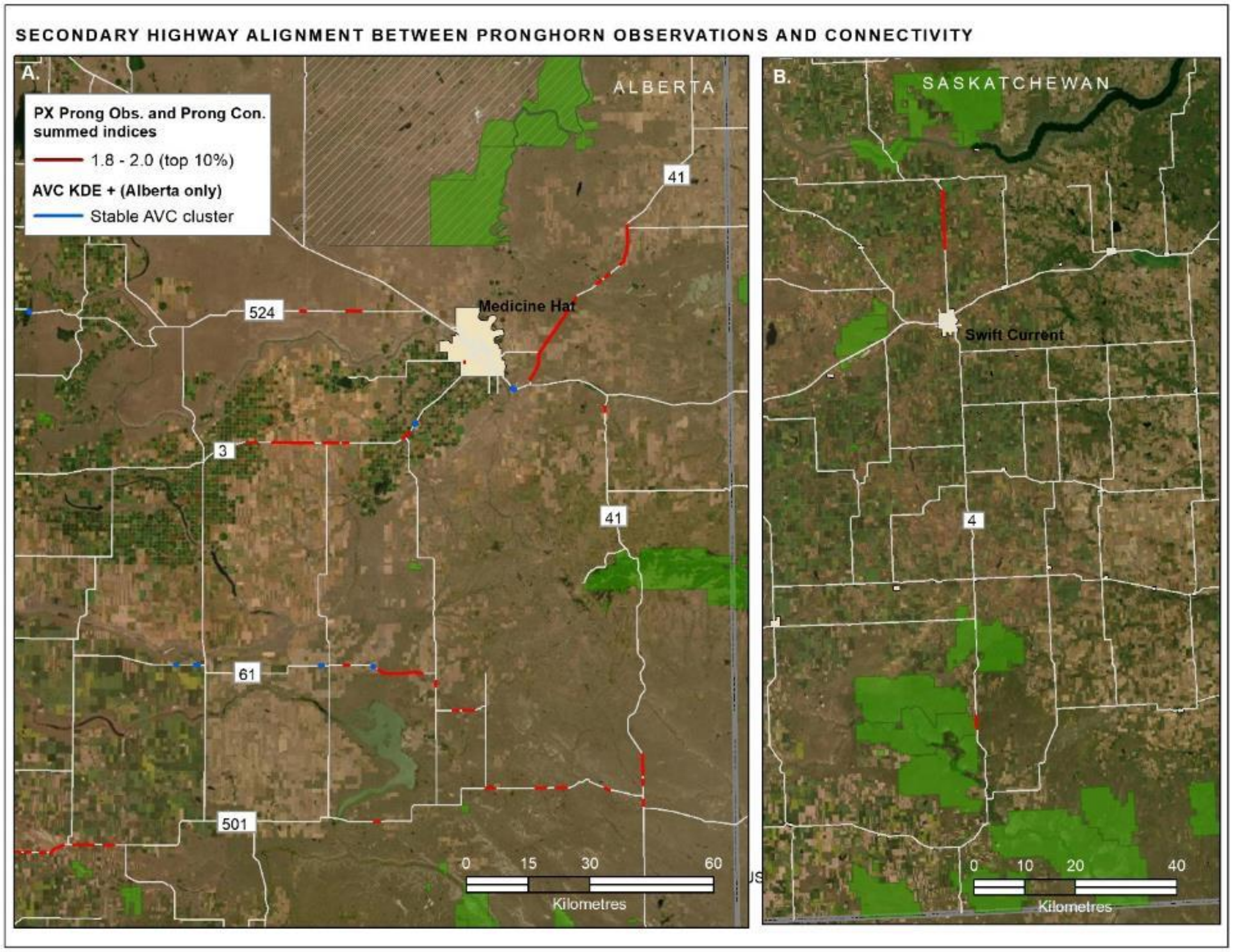


Figure 16: Secondary roads with agreement between pronghorn observation index and pronghorn connectivity index (red) and AVC stable clusters (blue).

Discussion

The Pronghorn Xing project was developed to identify road sections where mitigation could improve pronghorn conservation by enabling safe passage of animals across the highway through mitigation measures. A component of the pronghorn population in southeastern Alberta and southwestern Saskatchewan are migratory and move long distances each spring and autumn to meet life requirements (Jakes 2015). Roads cause two key issues for pronghorn: direct mortality from collisions with vehicles and habitat fragmentation due to road avoidance, potentially reducing pronghorn fitness (Gavin and Komers 2006, Jones *et al.* 2020). To maintain migratory populations of pronghorn, we will need to find ways for them to move safely across high volume roads in the Canadian portion of the NSS (Jones *et al.* 2020).

Pronghorn vehicle collisions

Pronghorn mortalities from collisions are rare (2%) compared to deer (98%), a consistent finding with other areas (Sawyer *et al.* 2016). There were 56 pronghorn vehicle collisions reported in the Alberta portion of the study area over the four-year study period, not accounting for animals that were hit and died away from the road right-of-way. A recent study in the Canadian Rocky Mountains reported an additional 2.8 carcasses off the right-of-way for every carcass reported on the road through traditional road surveys (Lee *et al.* 2021). Applying this correction factor to our study adds approximately 39 pronghorn mortalities from AVCs in the Alberta portion of the NSS. This pronghorn mortality estimate does not include information from roads in Saskatchewan or railways where pronghorn have been associated with large mortality events particularly during severe winters (Jones *et al.* 2020). Direct pronghorn annual mortality from vehicle collisions is unlikely to be a limiting factor for pronghorn populations in "normal" years. However, during severe weather events pronghorn may be more susceptible to road mortality (Jones *et al.* 2020) and the behavioural inhibition caused by high traffic volumes may have strong indirect effects on pronghorn populations.

A key conclusion is that road sections with stable AVC clusters and where motorist safety is at risk, are dominated by deer, not pronghorn, collisions in the NSS.

Pronghorn Avoidance of Roads

Current traffic volumes along the TCH range from between 5,000 to over 10,000 vehicles a day near Medicine Hat. Research indicates that traffic volumes can start to have negative effects on ungulates at 2,000 vehicles per day, and have strong barrier effects when they exceed 10,000 vehicles per day (Charry and Jones 2009). There is evidence that pronghorn may already be avoiding roads (Gavin and Komers 2006). Although it is difficult to determine the effect of roads on pronghorn behaviour, there is concern that the TCH is fragmenting pronghorn populations and reducing fitness of migrating animals. A GPS collared pronghorn spent three days one side of the TCH, walking along the edge of the road, before finally crossing. Lost foraging opportunities due to switching to vigilance behaviour can potentially reduce fitness during the migration (Gavin and Komers 2006). Road avoidance is particularly concerning during winter storms when pronghorn may be unable to escape extreme conditions (Christie *et al.* 2015).

An example from the American west offers additional support for the need to invest in road mitigation. Highway 191 in Wyoming has lower traffic volumes (on average 2,758 vehicles / day) than the TCH. However, the State Department of Transportation invested in a series of road mitigation projects (6 underpasses and 2 overpasses) over a 20 km section of this 2-lane highway to ensure the safe movement of migrating mule deer and pronghorn and secondarily to reduce AVCs. Overpass and underpass mitigations reduced animal vehicle collisions by approximately 81% (Sawyer *et al.* 2016).

Furthermore, a study of pronghorn in southeastern Alberta measured vigilance and foraging behaviour along road sections and found that they increase vigilance near all roads and forage less near high volume roads (defined as > 300 vehicles per day)(Gavin and Komers 2006). This study highlights the potential need for mitigation along the TCH and some secondary highways in the NSS as even lower volume roads can reduce foraging effort.

Where the Pronghorn Migration and Roads Intersect

Based on current traffic volumes we believe road mitigation along the TCH will improve pronghorn migration and survival in the NSS. To identify road sections for pronghorn mitigation we assessed three datasets: a pronghorn connectivity model, pronghorn observations reported by citizen scientists, and AVC data reported by highway maintenance cleanup crews (Alberta) or the RCMP (Saskatchewan). Our analysis determined where these datasets agreed on locations that wildlife frequently cross. We identified 16 of these potential pronghorn road mitigation sites along the TCH. When using AVC data, we only compared areas where there was agreement between stable AVC clusters identified using KDE+ software; sites where transportation departments are most likely to invest in road mitigation to improve motorist safety. Motorist risk is key in road mitigation decision-making.

Our results show the benefits of including fine scale movement data in conjunction with connectivity modelling. Of the 80 kilometers found to have high connectivity value, 38 kilometers also had frequent pronghorn observations. The remaining 42 kilometers include two mitigation corridors identified in the Saskatchewan connectivity models that did not agree with pronghorn observations and road sections with a high number of pronghorn observations but low connectivity values. Model agreement may be affected by shifts in animal movements as landscape conditions change over time. This is the case in AB4, where connectivity is high (based on a 2015 landscape), but recent imagery indicates new developments and a gravel pit. In addition, the connectivity model indicates movement to the west of Medicine Hat which is also no longer feasible given development activity (Paul Jones, pers com). These appear to have changed pronghorn behaviour

Disagreements in other areas are more difficult to explain. In some cases, pronghorn observations and connectivity were both high but did not overlap. Here, we only recommended road mitigation where there was alignment with *clusters* (for example AB4, and AB7). These results highlight that road sections with high AVCs are not necessarily aligned with pronghorn movement behavior. Similar to other studies, the two stable AVC clusters along TCH are dominated by deer vehicle collisions and are not associated with pronghorn migratory routes (Lee et al. 2020). Despite this, both AB4 and AB7 could be strategically integrated into a mitigation system that includes under- and overpass, associated fencing and signage all linked together to improve both pronghorn and deer movement while accounting for motorist safety.

Potential Pronghorn Road Mitigation Sites along the TCH

To further refine a potential pronghorn road mitigation system, we assessed the 16 identified sites against a list of criteria. Four key areas were identified for further consideration where road mitigation could improve both human safety and pronghorn movement across the TCH (Figures 14 and 15). For these sites we recommend site visits with transportation engineers to determine if existing infrastructure (i.e., existing bridges over rivers, railway underpasses) could be incorporated into the network and to identify the most appropriate locations for new infrastructure.

Transportation departments are investing in infrastructure, including underpasses, overpasses and wing fencing to both improve motorist safety and landscape permeability for wildlife (Forman *et al.* 2002; Kociolek *et al.* 2015, Sawyer et al. 2016). Underpasses are more common and tend to be significantly less costly than overpasses. Wyoming built a road mitigation network, including 2 overpasses and 6 underpasses along a 20 km stretch of Highway 191 to ensure safe movement of mule deer and pronghorn. Monitoring found that pronghorn preferred to use overpasses (92%) and mule deer preferred to use underpasses (79%) (Sawyer et al. 2016). They speculate that the preference for overpasses by pronghorn may be due to their use of long-distance sight detection of predators. Regardless, this is an important consideration along the TCH where overpasses will be needed to ensure safe movement of migratory pronghorn, and underpasses will benefit deer. There will be distinct disadvantages to motorists on road sections deemed high risk unless a diverse mitigation system is implemented. Effective road crossing research, mitigation, and monitoring are intimately linked to driver safety.

Considerations for Moving Forward

Secondary Roads

We did not identify potential pronghorn road mitigation sites along the secondary roads in the study area. Instead, we recommend reviewing secondary roads with transportation personal to identify opportunities where road mitigation could be considered. For example, Highway 3 in Alberta might be a priority for consideration for road mitigation given that its average annual traffic volumes are exceeding 3,500 vehicles / day and there are plans for twining portions of the highway. In addition, Highway 41 north intersects the key migratory pathway of pronghorn between CFB Suffield (and north) and the north side of the Trans Canada highway. Mitigation measures for Highway 41 should be considered as the loss of this migratory pathway would negate any benefit of installing an overpass along the Trans Canada Highway on the east side of Medicine Hat.

Fencing

A complicating factor influencing pronghorn movement is fencing. Pronghorn rarely jump fences, preferring to creep under them (Jones 2014; Yoakum *et al.* 2014).In the NSS, fences inhibit pronghorn movement as the lowest wire may be too low to crawl under and / or is barbed. An important conservation strategy is to build fences with a double-stranded smooth bottom wire that is at least 45 cm off the ground (Jones *et al.* 2018; Paige 2020). We do not currently understand how fencing is influencing movement within the study are and specifically along the TCH, but we expect areas with high connectivity and few pronghorn observations during our study could result from inappropriate fencing. Identifying fencing as a barrier is an important next step in our research (Xu *et al.* 2021).

Land Use Intent

Land use intent and zoning can nullify efforts to implement mitigation infrastructure. The future intended development of land may render any structures built ineffectual as these developments may increase the human footprint in the area, or further fragment the landscape around the structure, driving pronghorn away from the site. Understanding the current municipal zoning around the potential pronghorn road mitigation sites and consulting

Area Structure Plans will help determine if investment in mitigation infrastructure is an effective strategy.

Land Ownership

We have not considered the jurisdictional complexity of landownership and governance in this analysis. Road mitigation infrastructure requires land on both sides of the highway; either public land or private land with conservation easement or conservation ownership that permits free animal movement. The next step in our analysis is to complete a landownership assessment associated with the proposed mitigation sites and propose recommendations or refinement to the mitigation sites as needed.

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