# The impact of wildlife friendly fences on ungulate crossing behaviour at the Wainwright Dunes Ecological Reserve

Prepared for Alberta Environment and Parks
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February 23, 2016

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# 1 Summary

Fences are an ubiquitous feature of agricultural landscapes and they have the potential to reduce landscape connectivity for resident ungulate populations. Unsuccessful crossing of fences by wildlife has the potential to cause damage or even death to the crossing individual, as well as causing costly (in terms of both time and money) damage to the fence itself. Wildlife friendly designs for fences may provide landowners and ungulate managers the opportunity to mitigate damages that can arise with wildlife crossings. Using remote cameras along the perimeter fence of the Wainwright Dunes Ecological Reserve we quantified species specific crossing behaviour at standard 4 strand fences and 3 strand wildlife friendly fences, by visual inspection and a newly developed semiautomated program. We found that elk were the most abundant and problematic (had the most difficulty) fence crossers with seasonal and diurnal patterns of fence crossing. A temporal shift in crossing behaviour in and out of the reserve was noted and appears to be matched in time with the onset of human disturbance via hunting. We found that by raising the lower strand to 21 inches and lowering the top strand to 38 inches, wildlife friendly fences increased the behavioural opportunities for elk to cross. We observed a shift from crossing through the standard fence to crawling under the new wildlife friendly fences. While difficult crossings made up a proportionally small amount of crossing, the sheer number of crossing we observed suggest any modification that increase fence permeability to ungulates, elk in particular, should result in less damage to the fence and wildlife.

# 2 Introduction

All over the world sections of fence criss-cross and fragment the landscape, especially those associated with agriculture (Gadd 2012). Though necessary for the containment of livestock or the exclusion of people from different areas, these structures can also serve as a barrier to movement and a health hazard to native wildlife (Paige 2012). Fences fragment already disturbed habitats, limiting areas accessible, and suitable, for foraging or dispersion of wildlife, and posing a significant risk of entanglement resulting in injury or even death (Olson *et al.* 2009). A wide variety of species can be affected by fences, even birds and bats (Maclean 2006), however, the species most universally affected by fences are those most closely related to the domesticated hoofed mammals these structures are designed to contain, the ungulates (Rey *et al.* 2012).

In North America this is especially the case, where dead ungulates can be found along the many miles of fence, and untold numbers experience serious injuries such as strains, sprains, cuts and subsequent infections (Paige 2012). The native ungulates, including elk, deer, antelope, sheep, and moose, all of which can be found in various regions of Alberta, are capable as adults of jumping over common agricultural wire fences (Gates *et al.* 2012), yet some prefer not too, instead electing to crawl under or through (Paige 2012). The height of a fence, how close it comes to the ground, and the space between strands are significant factors in determining both the method of passage and ease with which wildlife can cross different fences (Hanophy 2009). Across the different species the demographic most heavily impacted by fences is juveniles, who have been found to be eight times more likely to die in fences than adults (Paige 2012). In addition, young are also easily separated from mothers when the adult crosses the fence, leaving them alone and susceptible to abandonment and predation (Gates 2006).

Despite the problems that rangeland fences cause for wildlife, the essential role they play in the agriculture industry cannot be dismissed (Halbritter 2013). However, the inability of fences to facilitate safe passage by wildlife may result in an economic cost through damage to fences. This damage is expensive and time consuming for landowners, as they must repair and maintain their fences (Hanophy 2009). Fence damage (loose or broken wires) or inadequate repairs potentially compound the problems associated with wildlife damage. Not only do damaged fences reduce their effectiveness for containing domestic species, they also increase the chances of further wildlife entanglement (Hanophy 2009).

Clearly, any improvements made to fence design that promote landscape connectivity in ungulates through safe fence passage, while also reducing the economic cost associated with fence repairs, will be beneficial to both wildlife (and their managers) and agricultural landowners. Mitigative measures have been proposed to facilitate fence crossing and thereby enable animal dispersion, reducing the number of fence related injuries and deaths, while maintaining the fence's effectiveness at containing livestock (Dolan & Mannan 2009). These typically consist of a reduction in the number of total strands, a reduction in height of the highest strand, and an increase in height of the lowest strand. Fences built with wildlife in mind and designed with mitigative measures (number of strands and their placement) are termed wildlife friendly fences. Unfortunately, there is not much awareness of wildlife friendly fences, and the culture surrounding agriculture has been somewhat resistant to suggestions of change. This is largely due to a lack of awareness on the whole subject of fencing with wildlife in mind, the ease with which it can be done, and the great benefit it can have for all parties (Paige 2012). Likely the lack of adoption is an indication that utility and efficacy of wildlife friendly fences has not been fully proven and requires continued research. This study was designed to address that need. In collaboration with Alberta Environment and Parks at the Wainwright Dunes Ecological Reserve we examined the crossing behaviour and frequency of four ungulate species (elk, mule deer, white-tailed deer, and moose) at fence sites with standard and modified (wildlife friendly) fencing using motion activated cameras.

# 3 Methods

## 3.1 Fence characteristics and camera locations

Wainwright Dunes Ecological Reserve (hereafter WDER) is located approximately 250km southeast of Edmonton in the Parkland Natural Region of Alberta. The 2821ha reserve is located within an agricultural matrix and has an ongoing history of being used seasonally, as rangeland for free roaming cattle by a local grazing association. In 2011, it was noted that some fences at the perimeter of WDER required replacement. The original fences consisted of four strands of barbed wire placed at 16, 22, 32 and 42in off the ground. Wildlife friendly fences were proposed for the replacement fence line as an alternative. Suggested fence specifications were based on an extensive review of existing literature and with the target ungulates species in mind (GOA 2011, Hanophy 2009, Paige 2008, Amesbury 2007, Karhu 2004, JHWF. n.d.).

Wildlife friendly fences were constructed in the late summer 2011 after negotiating their specifications with the affected grazing association. They were constructed with three barbed wire strands, initially placed at 21, 32 and 42in. This was done to facilitate the permeability of the fence to animals crawling under the fence. The installation of the new wildlife friendly fence in conjunction with the remaining standard four-strand fence provided the opportunity to assess the efficacy of wildlife friendly fence for retaining cattle while promoting safe passage to resident wildlife who often travel between the WDER and the surrounding agricultural matrix. Further modifications were then applied within the three year period to both the new and the old fences to assess their ability to further improve fence permeability for wildlife (see Appendix I for further details). They included the following:

a) lowering the two top wire strands on new fences to 28 and 38in of the ground, to enhance the ease of jumping over the fence;

b) placing of PVC pipes around the top and bottom barbed wires on the gates in the new fences for enhanced visibility and smoothness;

c) replacing two bottom strands on the old fence line with one, placed at 18in of the ground, to enhance the ease of crawling under the fence;

d) adding vinyl siding trim pieces to the top and bottom wires on gates in old fence line for enhanced visibility.

Twelve Reconyx motion activated cameras for remote mass image data collection were installed in fall 2011 at locations along both the new wildlife friendly and existing standard fences (six along each fence type). These sites were selected based on evidence that wildlife used these locations for moving into and out of the reserve. Cameras were located on or near fences to best capture animal crossings. Of the six cameras allocated to both the standard and wildlife friendly fences, half (three for each) were located at gate sites that could be opened as required, which typically occurred seasonally when domesticated animals were no longer in the vicinity (Figure 1). Biologists from Alberta Environment and Parks maintained the cameras and downloaded images on a monthly basis from September 2011 until November 2014.


Figure 1: Map of camera locations along the perimeter fence (green) of the Wainwright Dunes Ecological Reserve. Colours of the camera symbols indicates whether the camera was located at an old (standard) or new (wildlife friendly) fence or gate. Map courtesy of Drajs Vujnovic.

## 3.2 Manual data collection

Once the data had been downloaded from the cameras located on fence lines along the park boundary (Figure 2) and compiled the individual pictures were viewed and manually sorted, classified, and summarized using the Reconyx MapView Professional program by tagging the image with appropriate metadata. Image metadata was assigned according to events captured in the images using a set of specific predefined keywords. These keywords were applied to each picture through the use of a toolbar in the viewing window. They were designed to tag relevant information such as species, demographics, crossing events, methods of crossing, behaviours, and other noteworthy data. Images that contained domesticated animals, humans, or species of non-interest were removed from subsequent analysis. Additional information (date and time etc.) was recorded by the camera itself and incorporated into the image's metadata. The completed metadata was then exported and further summarized and analyzed by site, fence type, and ungulate species.


Figure 2: Reconyx camera and placement on the fence, in this case a wildlife friendly fence. Photo courtesy of Drajs Vujnovic.

## 3.3 Automated data collection

In addition to identifying crossing events and classifying images (based on species, sex and crossing type) by hand, we developed a semiautomated method to reduce the time spent by operators identifying crossing events and classifying images. The semiautomated method was then tested against $\approx$ 480,000 manually classified images to determine the efficacy of the method in removing non-target images, while retaining all the images in a sequence, containing a crossing event. How the program is used and functions is given, in depth, in Appendix III & IV.

### 3.4 Landscape context

Lidar data for WDER was obtained from Alberta Environment and Parks to investigate a local landscape context within which the fence crossings were occurring. These data provided a raster based estimate of vegetation height across the reserve. Using ArcGIS we used these data to classify the reserve into grassland (≤60cm vegetation height), treed (≥2m vegetation height), and shrub (>60cm and <2m) cover types (ESRI 2011). From this we calculated the nearest distance in meters from the camera to sufficient cover (treed patch of at least 5m by 5m). We calculated this distance in both the direction into and out of the reserve. This generated cover layer was also used to characterize the immediate vicinity of the camera based on concentric circular buffer distances of 10, 50, 100, 200, and 500 meters from the camera. In particular, we extracted the proportion of this area that was treed as an estimate of overall cover. Using generalized linear models (GLMs) of a Poisson type we modelled the number of crossings at each camera based on fence type (standard or wildlife friendly and fence or gate), distance to cover in and out of the reserve, and the proportion of treed cover within a set buffer distance. We used an AIC model selection procedure to compare models and test the hypothesis that the inclusion of landscape context variables was an improvement over the null model which contained only fence variables (Burnham & Anderson 2002). All analyses and figures were produced in R (R Core Team 2013).

## 4 Results

### 4.1 Semiautomated method

We found that the semiautomated program was able to reduce the total number of images that must be classified by hand by over half (54.8% of images were removed). The retained images, those in category 1, 2, or 3 (those with the highest crossing probability, see Appendix III for details) contained 72.6% of crossing events. The remaining crossing events were contained within the category 4 and 5 images (those with the lowest crossing probability, see Appendix III for details), which were not retained for manual processing. We did not find a significant bias in retained crossing between the day and night, suggesting the method is adequate for night without further adjusting the input parameters. The reduction in the number of images that require manual processing following identification from the semiautomated method resulted in a reduction in operator time by approximately 4. For a full explanation of various image categories, please refer to Appendix III.

## 4.2 General crossing behaviour

Once individual crossing events had been identified and classified, either through the manual or semiautomated method, we quantified a total of 14,623 crossing events. Nearly all of the fence crossing events were attributable to elk ($\approx$ 80%; Figure 2). While crossing events by each species varied between sites, elk remained the most prevalent species observed crossing at all sites. Following elk the two deer species (White-tail deer and Mule deer) were the most common crossing ungulate with $\approx$ 10% and $\approx$ 8% of the crossings, respectively. Moose were the least common ungulate (1.5% of crossings) to be found crossing fences and their activity seems to be highest in proximity to David Lake. Unknown ungulates, where the individual could not be identified, account for $\approx$ 1% of the total number of crossings. It should be noted that elk are an order of magnitude more common than the other species and account for most of the fence interactions (crossing or otherwise) observed and as such the report and statistics that follow will focus primarily on elk. While crossing data are not a stand-in for habitat selection there appears to be habitat segregation, in terms of which species cross where, among the ungulates, however this trend requires further investigation.

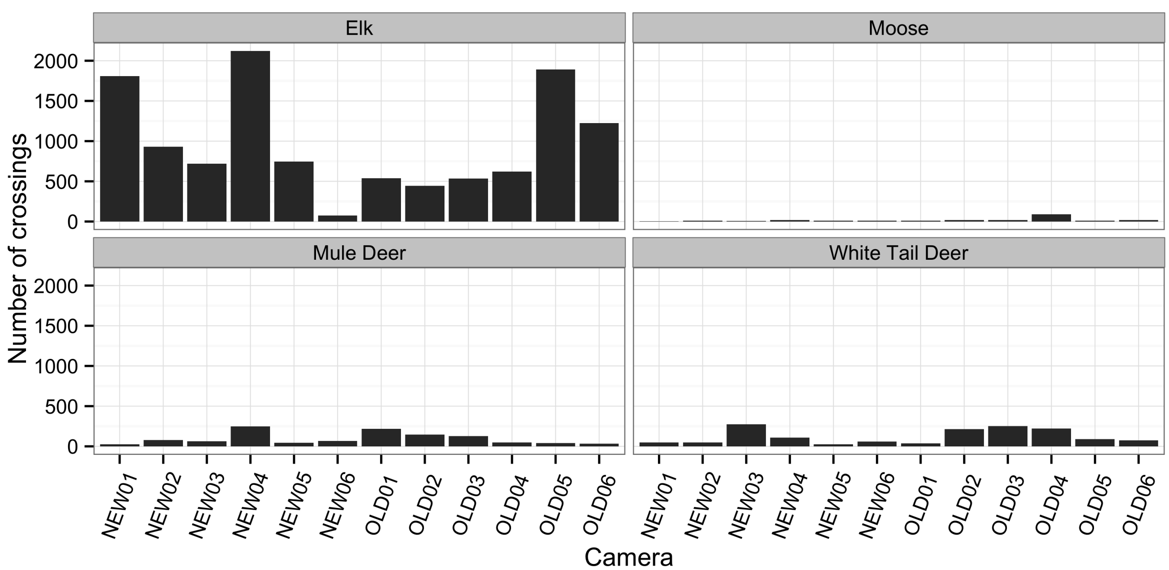


Figure 3: The number of crossing events recorded for each species by motion trigger cameras at each camera location. Please note the y-axis is the same for all species, highlighting the contribution elk make to the dataset.

Among the four species there was a fairly even spread of crossings for the different demographic groups (Figure 3). The highly gregarious nature of elk is clearly seen by the large number of groups observed crossing the fence. The group classification denotes when a crossing captured also had members of other demographics in the image frame; this includes mother and young (cow-calf) groups and included the relatively minor category for individuals of unknown demographics. It seems likely that additional damage to the fence can be the result of the passage of groups, regardless of their composition.

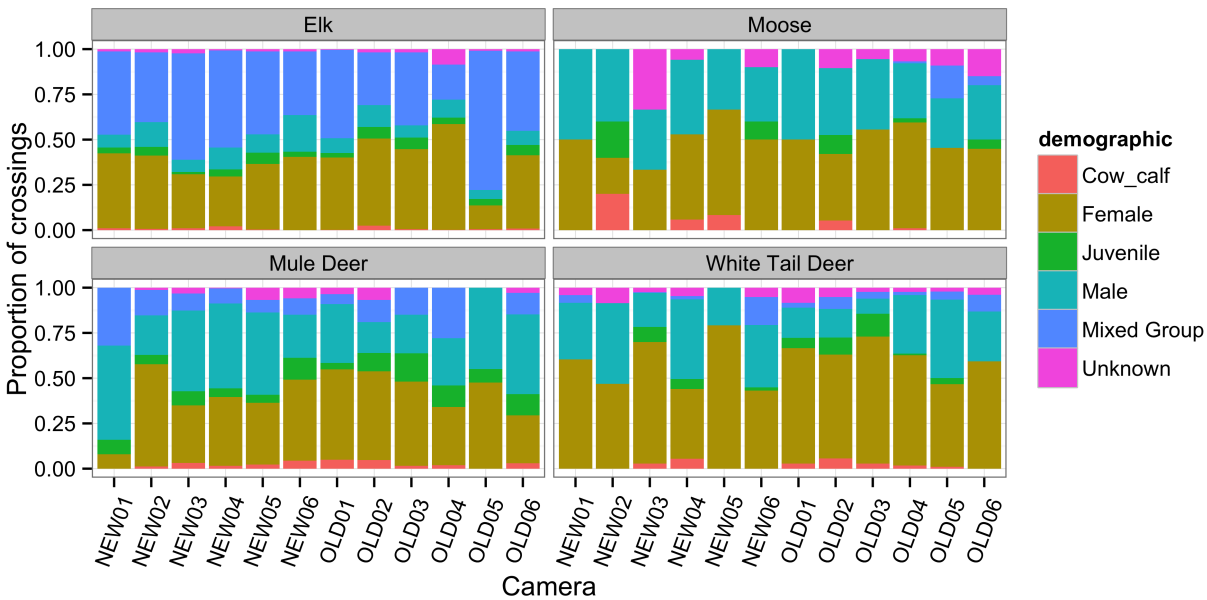


Figure 4: Proportional demographic breakdown of crossing individual(s) by ungulate species and camera location. Note that group consisted of more then one individual but group composition was not recorded or may be unknown.

## 4.3 Temporal patterns in crossing behaviour and refuge effects

After determining the species and demographic patterns of crossing individuals we quantified the temporal (both seasonal and diurnal) trends in crossing events. Seasonally all ungulates observed (to some extent) displayed increases in crossing events during and around the period of the rut (October, November and December) and to a lesser extent during the spring calving season (Figure 4). This trend is particularly striking for elk, but no doubt would hold for the other species if they were as prevalent as elk. The autumn increase in crossing events, and overall activity, also corresponds to the onset of hunting season in the surrounding land (WMU 234; Archery = September 1 until October 31 and General rifle = November 1-30 for most species and additionally December 1- 20 and January 1-20 for elk), which may be a disturbance for individuals and increase their movement into the reserve.

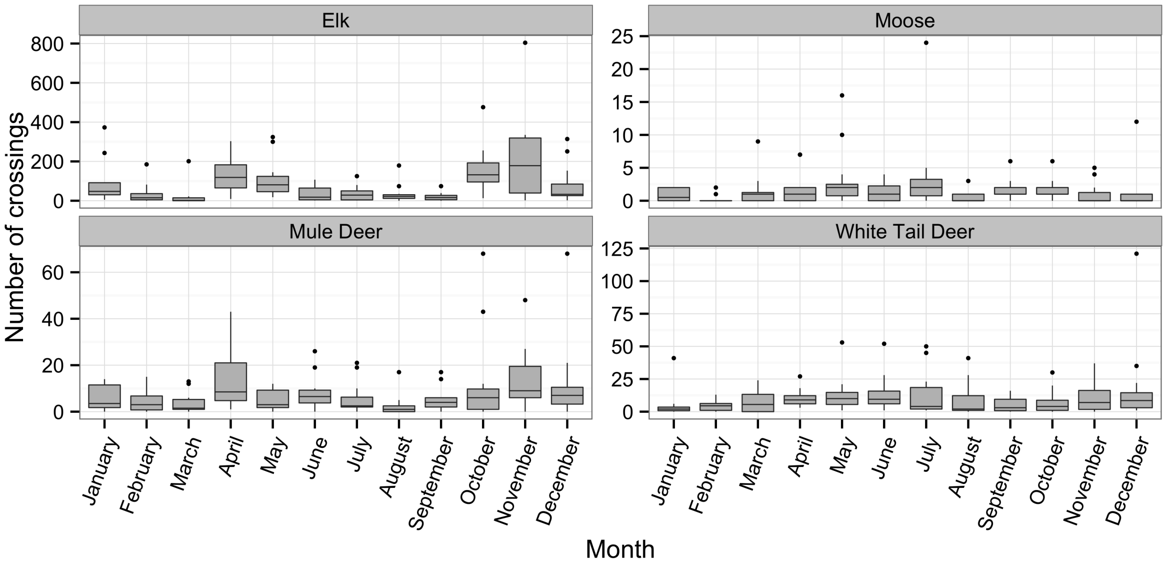


Figure 5: Species specific frequency of fence crossing by month. Note that the y-axis varies for each species.

It is well established that ungulates are crepuscular, most active and mobile at times around dawn and dusk. We found that trends in crossing time for all species are consistent with this understanding of ungulate behaviour (Figure 5). Temporally, we found that crossings to and from the WDER were concentrated around dawn and dusk. The dusk crossing activity tended to be more temporally spread out relative to the dawn crossing events. Because of sample size constraints all subsequent results on the temporal shift in the use of the reserves is focused on crossing behaviour of elk.

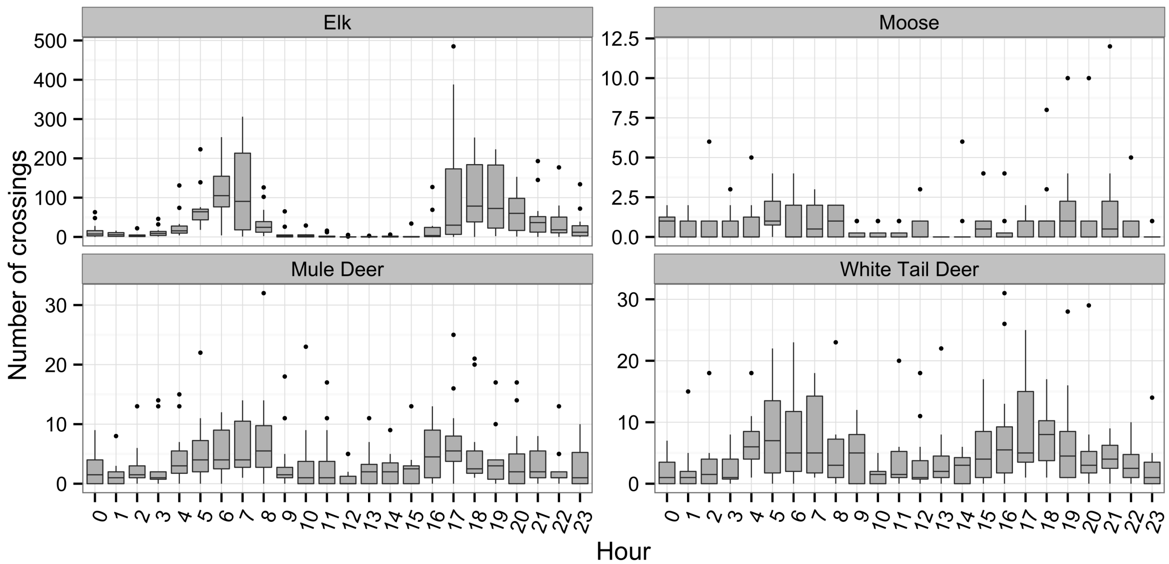


Figure 6: Crepuscular trends in the number of crossing events by hour (using a 24 hour clock) across all sites by species. Note that the y-axis varies for each species.

An interesting behaviour comes to light when we investigated elk crossings further. By dividing the crossing events into those entering and leaving the reserve we can clearly see a trend that elk in the vicinity of our cameras leave the park during the evening, presumably to forage in the surrounding agricultural matrix, before returning to the safety of the reserve at dawn (Figure 6). This trend was consistent across all months. We found that the temporal distribution of the direction of travel in crossing event was significantly different ($\chi^2$=19471.7, df=23, p<0.001), a majority of elk crossing events were out of the WDER in the evening and back into the reserve in the morning.

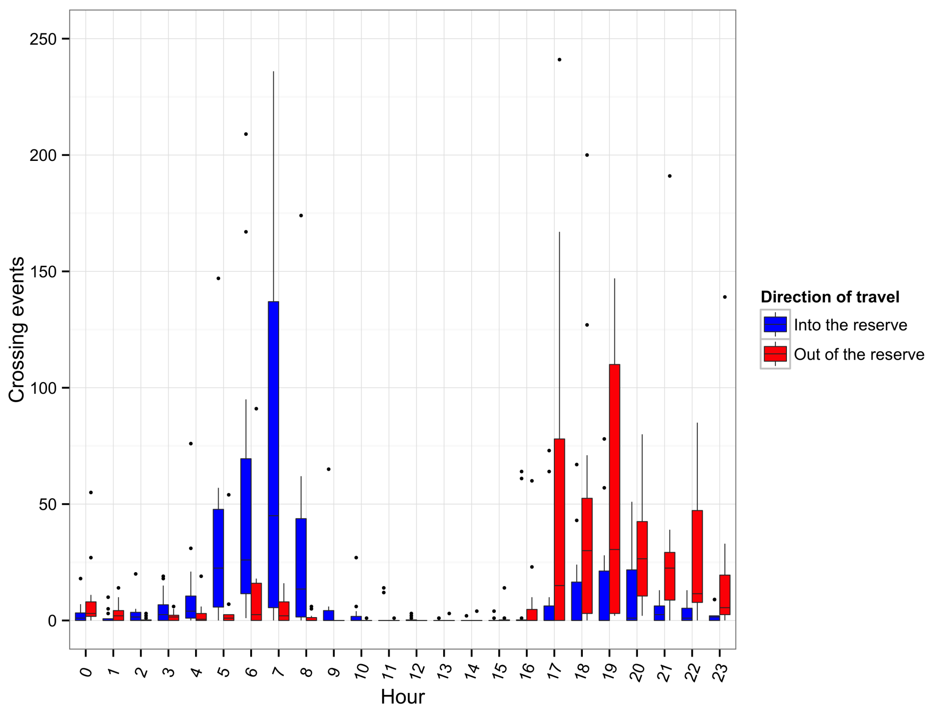


Figure 7: Directionality of crossing events by hour (using a 24 hour clock) of elk across all sites and months. Elk appear to leave the reserve at dusk and return to the reserve at dawn.

Further, when we matched the crossing into and out of the WDER with sunrise and sunset, respectively, we observed a fine scale temporal shift in the timing of crossings in and out of the WDER with the onset of hunting. In August and September (pre-hunting) crossings into the reserve occurred post sunrise 45% of the time and crossing out of the park occurred pre sunset 42% of the time. Conversely in November, coinciding with the onset of rifle season, only 6% of crossing occurred post sunrise and less then 1% of crossing occurred pre sunset, suggesting a shift to more nocturnal behaviour (Figure 7). This nocturnal shift was significant, using a nonparametric permutation t-test for differences in means, both at dawn corresponding to the return of individuals to the reserve ($t=68.73$, $p<0.001$) as well as at dusk and the movement of individuals out the reserve ($t=-99.55$, $p=0.06$).

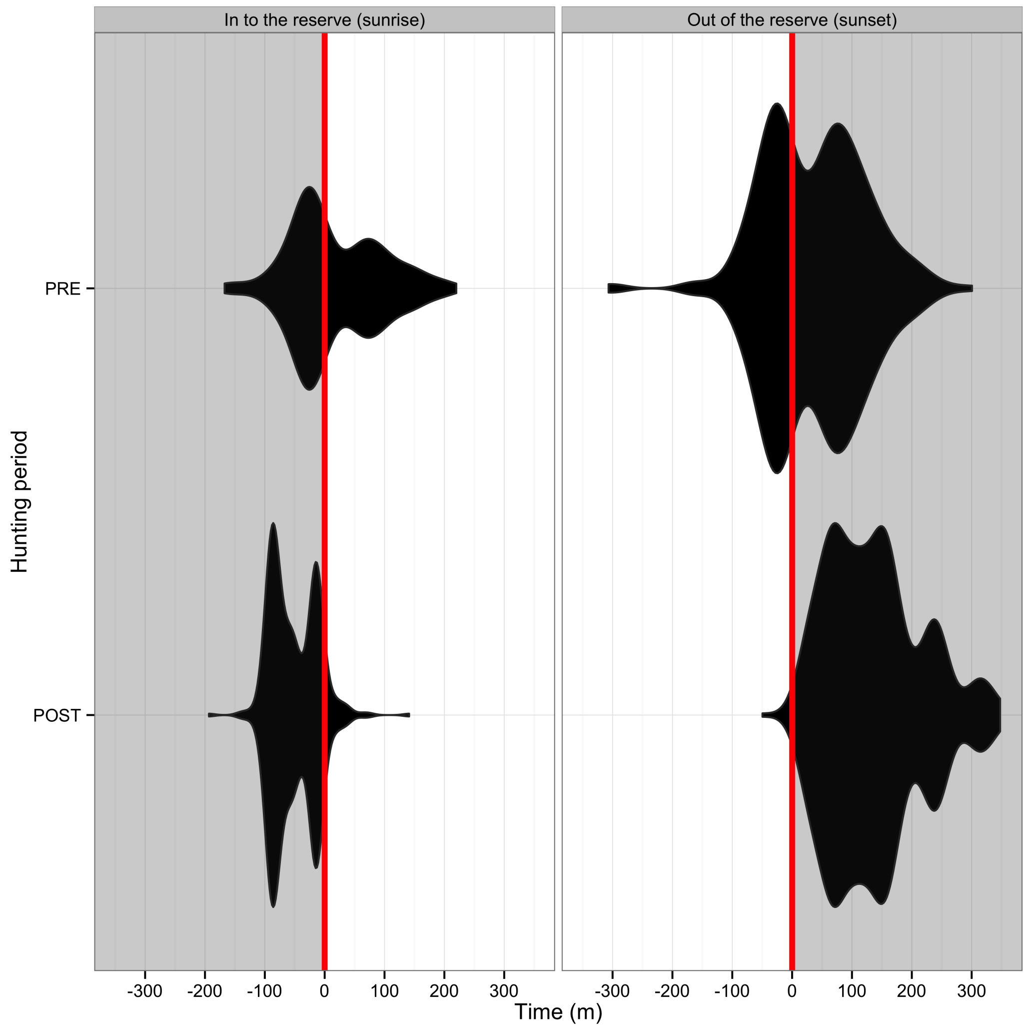


Figure 8: Violin density plots of the temporal shift in elk crossing times into and out of the reserve in minutes relative to sunrise and sunset, respectively. The vertical line indicates sunrise and sunset and the shading highlights the periods of the day when the sun is down. Note that in the pre-hunting months ("PRE"; defined as August and September) individuals enter and leave the reserve in the daylight time periods, while following the onset of hunting ("POST"; November 1- 30) there is a behavioural shift to entering and leaving the reserve during nocturnal periods.

## 4.4 Impact of fence type

### 4.4.1 Standard 4 strand and wildlife friendly 3 strand fences

We quantified trends in how ungulates crossed the fences, what difficulties they had, and how fence modification may influence fence permeability. Most readily apparent is the fact that when a gate is open animals are most likely to use this interruption in the fence as a movement corridor if they are in the vicinity (Figure 8). The data recorded by the camera at OLD04 is especially noteworthy as it was open throughout the study period and was used almost exclusively, with a few exceptions for moose and deer. If no open gate was available the most frequent method of crossing was jumping over the fence. However, the proportion of crossing events over the fence showed a statistically significant declined from being $\approx 90\%$ of crossings at standard four strand fences to $\approx 73\%$ at new wildlife friendly fences ($\chi^2$=789.81, df=2, p<0.0001). Difficulty in crossing can arise when animals get hind feet caught up in the top strands. While over the fence crossings were common for both old and new style fences, there were proportionally fewer for new wildlife friendly fences as different crossing options became available due to strand placement.

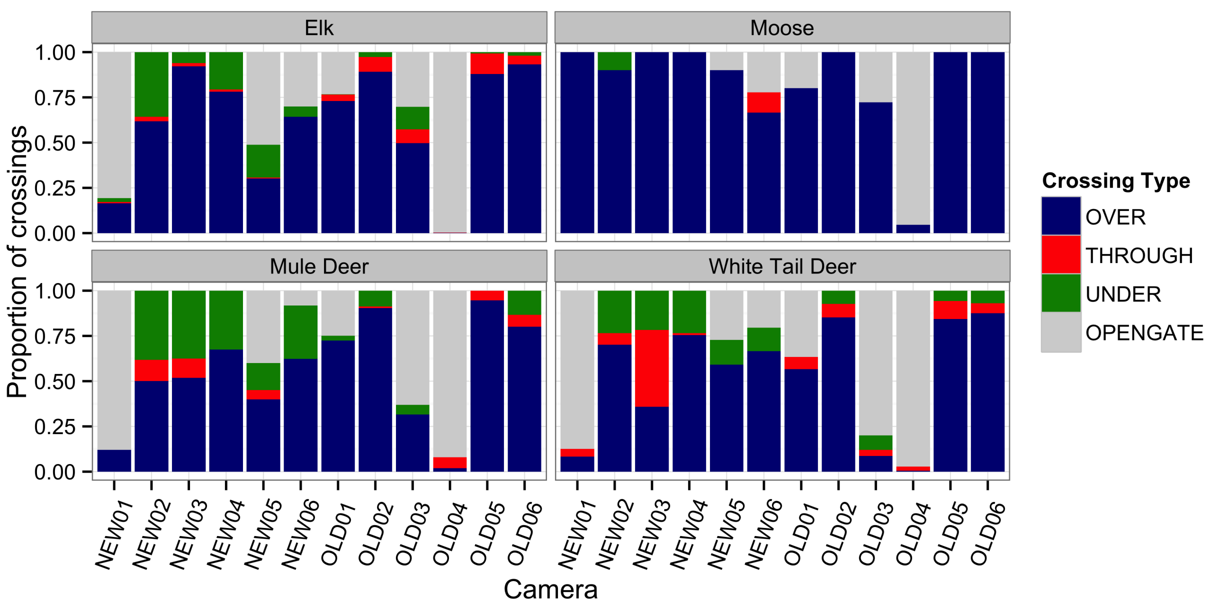


Figure 9: Proportion of crossing events for each species based on how the crossing event occurred in relation to the fence (over, under, through, or via an open gate).

Certain individuals, particularly juveniles, may not be comfortable, or capable of, jumping over the fence and must therefore crawl under or through the strands. This is one area where fence modifications can make a big difference. There was a statistically significant difference in how elk crossed fences when we compared standard and modified fences (not including open gates), with elk preferentially passing under modified fences rather than going through as they did with standard fences ($\chi^2$=789.81, df=2, p<0.0001). At standard (old) fences only

2.7% of elk crossing attempts were under the fence, because bottom strands were too low to the ground, forcing animals instead to go through roughly 8.2% of the time. In comparison, crossing events at modified (new) fence sites, had an approximately eight fold increase in elk crossing events under the fence, increasing to be 22.1% of the total crossings (Figure 3). At modified fence sites the percentage of attempts going through the fence drops to a negligible 1.8%. This trend is consistent, though less obvious, in both the deer species indicating the modified fence truly causes a change in fence crossing behaviour by providing attractive alternatives to going through the fence (a damaging and dangerous crossing type). For representative images of theses types of crossing please see Appendix II.

It appears that individuals are preferential in how they choose to cross, and modifications to fences facilitate these options, however, it is unclear whether wildlife friendly fences decrease the proportion of crossing events that result in an individual having difficultly or failing to successfully cross the fence (Figure 9). When we define a difficult crossing as the crossing individual being impaired by the fence, or a failure, as the crossing individual being impaired by the fence to the point of abandoning the crossing attempt we see that these events appear limited, proportionally. It is clear that elk are much more likely to have difficulty or failed attempts relative to the other ungulate species. We found that roughly 6% of elk crossing result in failure or difficulty, this corresponds to nearly 700 instances (through the years and across sites) where there was potential damage to both the fence and crossing individual. These data could only be determined from images that were analyzed by hand as a failed crossing (where the individual attempted to cross, was impaired, and retreated) was not differentiated from a non-crossing event by the semiautomated method.

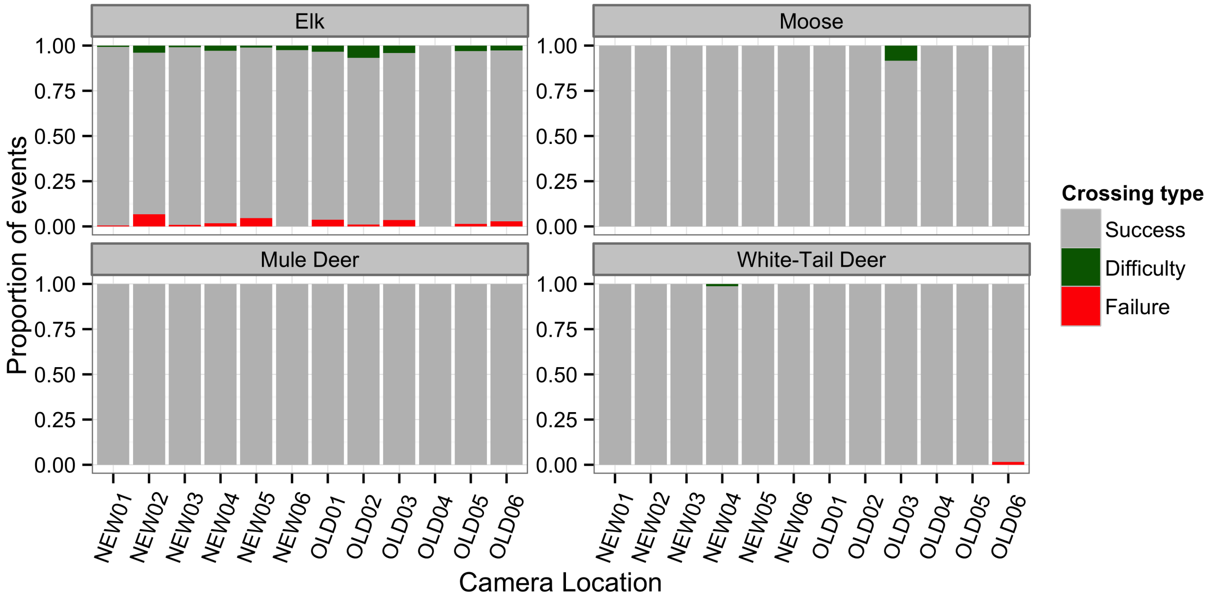


Figure 10: Species specific proportion of crossing events that resulted in a successful crossing, difficult crossing (where the crossing individual was impaired by the fence), or a failure (where the crossing individual was impaired by the fence to the point of abandoning the crossing attempt).

Crossing events are not the only time during which damage might arise to the fence or animal, crossing events comprised approximately 2.5% of images of the target species. Of the data which we classified all images, not just crossing events, (i.e. by "hand" and not the semiautomated method), the presence of the fence (and camera to a lesser extent) resulted in individuals from all species to spend considerable time in the vicinity of the fence (Figure 10). Generally the more an individual was bothered by the fence the more they would pace along it or mill around its vicinity, thus being captured in a greater number of pictures that didn't include a crossing event. When viewing the pictures it was noted that, specifically for juveniles, individuals would often run back and forth along the fence many times before crossing. Interestingly, despite their apparent ease of crossing the moose display similar levels of behavioural impediment, however this could be attributed to smaller sample size. In this context fences appear to alter animal movement behaviour by eliciting a response that would not occur in the absence of the fence.

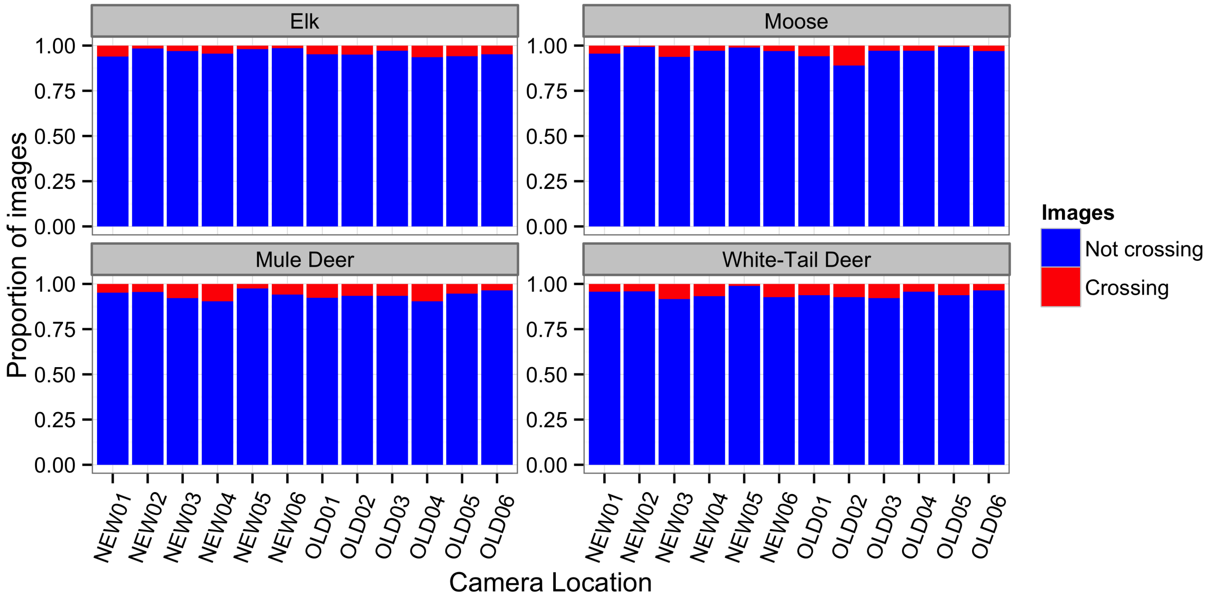


Figure 11: Species specific crossing efficiency as indexed by the proportion of crossing events relative to the number of images captured (not crossing). During this time individuals may be engaged in behaviours associated with the fence but not with the intent on crossing.

### 4.4.2 Further modifications to fences and gates

Additional modifications applied to both standard and new wildlife-friendly fences (as described in the methods) had varying levels of success in modifying fence crossing behaviour. The success or failure of modification to have the desired effect of facilitating fence crossing was in part due to the modifications themselves, and in part due to sampling issues. The lowering of the top strands on new fence lines did significantly encourage individuals to cross over the fence ($\chi^2$=117.43, df=2, p<0.001, $\phi$=0.09). However, the raising of the bottom strand on the old four-strand fences from 16 to 18in did not appear to facilitate individuals in moving under these fences, as would be expected (in fact, we observed a slight negative correlation, $\phi$=-0.02). We were not able to fully evaluate the addition of PVC pipes to the gates of the wildlife friendly (three strand) fences or vinyl trim clips to the gates in the standard (four strand) fences. In both cases the observed crossing events happened almost exclusively at the gates when the gates were open. It is also worth noting that, as opposed to the first sampling year (2011/2012), weather conditions (especially deep snow during winter months) affected the behaviour of studied animals in the following two years, resulting in far fewer animal-fence interactions at studied locations during this time. This affected our ability to draw conclusions based on the statistical analyses. We did, however, note an anecdotal preference to cross on the fence sections adjacent to the modification suggesting their efficacy may depend on their ubiquity.

## 4.5 Landscape context of fence crossing behaviour

The particulars of crossing events exist in the larger scale of animal movement patterns and behaviour over the landscape. We investigated the influence of the landscape in two ways. First we examined the directionality of individual crossing movements at each site. While previously we noted, in elk, the tie between directionality and the timing of crossing (see Figure 6 above, for example), here we found that certain camera sites and locations were preferred for travel in a single direction. This trend was most clear in elk, as evidenced by substantial deviations for 50% (0.50) for certain camera locations (Figure 11). This trend is also noticeable in moose but may be due to the relatively small sample sizes for that species. Deer have relatively balanced use in terms of directionally. It is uncertain what environmental variables might prompt these differences in crossing directionality.

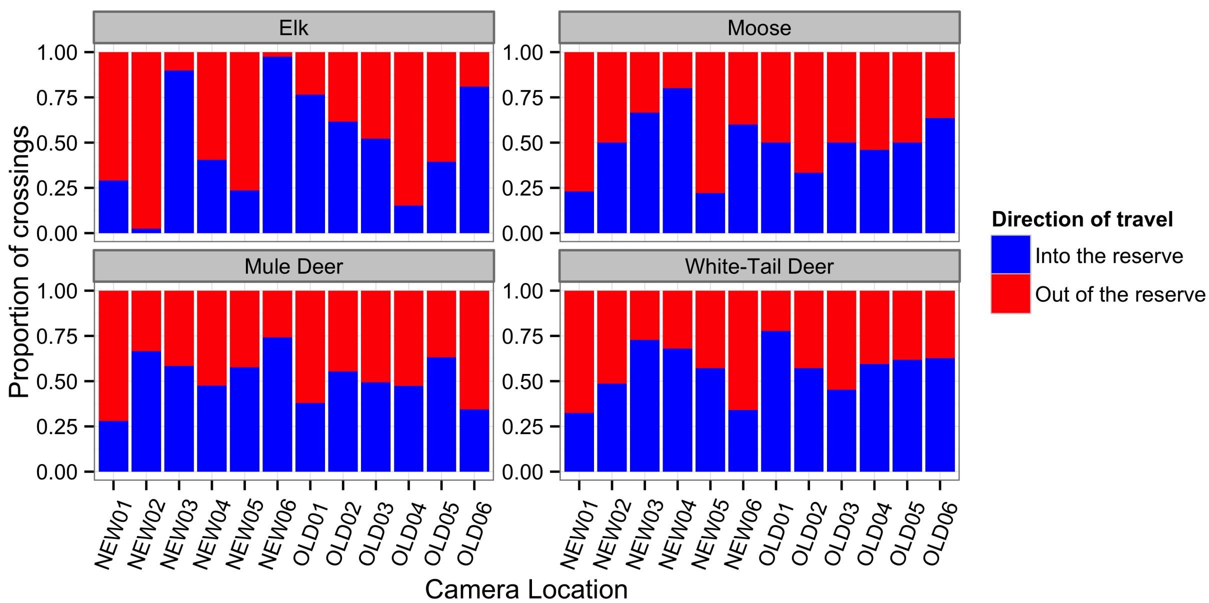


Figure 12: Site specific crossing direction (into or out of the reserve) by species. Preference for using a site for crossing in a specific direction can be seen as a deviation from 0.50.

Secondly, we used a generalized linear model of a Poisson type to model the number of crossing at each camera (n=12) based on fence type (standard or wildlife friendly and fence or gate), and landscape context. Landscape context was incorporated as both the local scale (distance to cover in and out of the reserve and the proportion of treed cover within a set buffer distance) as well as the larger scale (UTM northing location of the camera). Model selection suggests that the best model from our candidate set represented the hypothesis that both small and large scale landscape context variables improve the model over and above fence characteristic variables (Table 1 and 2). Additionally the most support was found for using a buffer size of only 10 meters to represent local landscape context (AIC $w_i$=1). However, care should be taken when utilizing these models based on the small sample size (n=12) and number of parameters in the model (k=9).

| Model | K | LL | AIC$_c$ | $w_i$ |
|---|---|---|---|---|
| fence+local+landscape | 9 | -302.95 | 713.90 | 1.00 |
| fence+local | 7 | -1436.36 | 2914.72 | 0.00 |
| fence | 4 | -1993.86 | 4001.44 | 0.00 |

Table 1: Model selection of the candidate models which represent hypothesis about which features best explain the number of elk fence crossings observed via motion activated cameras. Fence characteristic, as categorical variables, refer whether the fence was old (4 strand standard) or modified to be wildlife friendly and whether the camera was situated at a fence or gate site. Local landscape characteristics include the distance to cover in meters both inside the reserve and out of the reserve and the proportion of forest cover within a set buffer distance.

| Variable | Estimate | Std. Error |
|---|---|---|
| Intercept | 7835107.4 | 372434.1 |
| UTM northing | -2.6886 | 0.1278 |
| UTM northing$^2$ | 0.0000002 | 0.00000001 |
| Forest in 10m buffer | -5.5328 | 0.2598 |
| Distance to cover (in) | -0.0438 | 0.0022 |
| Distance to cover (out) | 0.0100 | 0.0004 |
| Gate | -1.7775 | 0.0596 |
| Old | 1.1655 | 0.0450 |
| Gate*Old | 1.8343 | 0.0990 |

Table 2: Model coefficients of the best candidate model (fence+local+landscape) as selected by AIC. Note that the coefficient values and standard errors are in the log form (as specified by the Poisson model) and need to be exponentiated for natural units.

# 5 Discussion and Management Implications

Fences clearly form barriers to movement and impede landscape connectivity, however, the degree to which management and fence design may mitigate some of the negative effects, namely damage to crossing individuals and the fence itself, is not well studied. Using remotely captured images of wildlife fence crossings at WDER, our study uncovered a number of trends in the data that may help focus future work and provide insight into the ways in which wildlife friendly fences may mitigate the barrier effect fences may pose.

Firstly, it is clear that at the WDER the primary concern for managers with regards to fences is developing strategies for dealing with elk crossings. Elk are by far the most abundant ungulate species observed crossing fences, have the most difficulty in crossing, and often do so in groups. All these factors, including their relatively large body size compound the potential they have for causing damage to fences. In Colorado and Utah, Harrington & Conover (2006) found that pronghorn had the highest mortality rates related to crossing fence lines, followed by mule deer and finally elk, however they did not quantify abundance of these species. While elk may be less likely to die from fouled crossing attempt, their size and abundance suggests that poorly executed crossings may result in damage to the fence, requiring regular surveillance and repairs. By incorporating wildlife-friendly design into WDER fences managers may be able reduce potential damage to the fence as well as reduce the harm to the animals themselves.

Other studies on wildlife friendly fences typically do not consider how ungulates cross the fence, however, they did suggest that wildlife friendly fences increase the behavioural options available to crossing individuals (Bauman *et al.* 1999, Knight *et al.* 1997). When faced with the need to cross standard four-strand fence, most of the ungulates we observed choose jumping over the fence as a preferred option, consistent with findings elsewhere (Harrington & Conover 2006). However, incorporating wildlife friendly designs into fence construction has the opportunity to present the crossing individuals with an increased number of options for crossing. We observed an important shift in how crossings were conducted between standard and wildlife friendly fences. There was a distinct trend, most clear in elk, for individuals to switch from going through or over a standard fence to crawling under a wildlife friendly fence. Clearly, raising the lower strand offers an increased opportunity for crossing under the fence. This advantage may be most significant for improving the ability of juvenile individuals to cross the fence. Juveniles are particularly susceptible to fence related mortality, being eight times more likely to die than adults (Harrington & Conover 2006). In addition, the reduction in height of the top two strands of wildlife friendly fencing makes the most common crossing type, jumping over the fence, a less difficult task with more room for error. The reduction in strands from 4 to 3 should reduce to potential for ungulates to become fouled in the fence during crossing.

Further reduction in height of the top strand additionally modify crossing behaviour, further facilitating crossing by jumping the fence. The same effect was not noted in raising and combining the bottom two strands on standard 4 strand fences, and we found no bias in small (deer) and large (elk) body sized individuals in their willingness to crawl under the modified traditional fences. Conversely, there was a significant shift to movement under the wildlife friendly fences relative to standard 4 strand fencing by elk, suggesting the height of the bottom strand may be limiting in this modification. We therefore suggest that there may be a higher minimum height of the lowest strand, which could be tested for in the future.

Our observations suggest that fouling of the rear leg was the most common crossing difficulty, consistent with the findings of Harrington & Conover (2006). This fouling may be contributed to by the space between the two top wires, which was kept at 10 inches throughout the study. Increasing the separation to 12 inches may help, but was not tested. Finally, the safest passage through the fence, and most preferred crossing was through an open gate. While managers may be logistically limited due to grazing constraints to when gates may be left open, they would ideally be left open whenever possible. Despite the anecdotal claims by local ranchers that ungulates do not care much for open gates, our study clearly demonstrates that these locations will be sought out and used by ungulates in their vicinity, when available. Managers employing wildlife friendly fencing and active management of gate sites have the potential to provide increased behaviour option for crossing to the widest demographics of all ungulate species. Additionally, locating gates at known ungulate crossing sites may further increase the utility of gates in mitigating landscape connectivity.

Fences not only impede movement behaviour, but also result in animals spending additional time in the vicinity of the fence. This additional time and fence oriented behaviours that did not involve crossing have the potential to be a source of damage to the fence just due to inquisitive nature of the animals. These non-crossing events and behaviours were investigated and we were surprised to find that all species had proportionally the same ratio of crossing images to non-crossing ones. We had hoped that looking at the data in this way would have given us some insight into the crossing efficiency of the different species. We had thought that elk appeared to spend more time lingering at the fence prior to cross than the other species. However, this observation was not supported by the data. Further refinement of a "crossing efficiency" metric to include a temporal aspect and additional study of the behaviours associated with non-crossing individuals at the fence may also be required.

Anecdotally, we noted increased curiosity with the additional modifications done to the gates when PVC pipes and vinyl trim clips were added to the wire strands. These additions were implemented in order to increase the visibility of the fence strands (clips and pipes) and mitigate the effect of barbs on animals moving over and under the fence (pipes only). Individual animals approached and sniffed at the additions suggesting they did increase the visibility of individual strands. However, this interest may have been due to the novelty of the additions and the effect may wear off as individuals habituate to the pipes and clips. Individuals at these sites exclusively made use of the open gates, making it difficult to make any conclusions as to their effectiveness in modifying crossing behaviour. Also, when an open gate was not available, crossing individuals appeared to preferentially cross the fence on the sections adjacent to the additions (and were thus not counted as crossing at the modifications). We did not quantify this effect further. This suggests that the effectiveness of these additions to facilitate crossings or change crossing behaviour may only occur if a vast majority of the fence has been constructed in the same fashion.

Clearly, there are large amounts of variation in which sites the animals choose to cross the fence. The landscape context within which the fences exist is important for determining the selection of crossing sites over and above the characteristics of the fence. While our statistical analysis regarding the influence of spatial context was limited by sample size (the number of sites) and is "overfit", we feel that resident individuals clearly know where they are going and are mostly likely drawn to the large agricultural fields outside the southeastern portion of the WDER much more then the mixed use and smaller fields on the north side of David Lake. Agricultural activity in these fields probably changes their attractiveness seasonally and between years. The behavioural pattern we observed in elk was to use WDER as a daytime refuge while leaving the reserve at night, presumably to forage, seems to indicate that this larger landscape scale vegetation patterns play a role in the selection of crossing sites. With sufficient data (more camera sites) it may be possible to model the location of fence sites most likely to be used for crossing prioritizing them for conversion to a wildlife friendly design. Additionally, identified crossing "hotspots" locations would also make excellent gate sites, removing the barrier when domestic grazing was not present.

The temporal shift in behavioural use of the WDER, as evidenced by the timing of crossing events, suggests that the presence of refugia within agriculturally dominated landscapes provides ungulates with the behavioural flexibility to reduce their exposure to the risks associated with human activities, particularly hunting. This may become a concern if these individuals are spatially or temporally unavailable for management through hunting or contribute to crop damage or depredation (Walter *et al.* 2010, Hegel *et al.* 2009, Burcham *et al.* 1999). It appears that individuals are able to subtly shift their temporal use of refugia rather quickly in response to the onset of increased human disturbance, hunting in the case of our study. This suggests that elk have the behavioural flexibility to adapt to risky human activities if given the opportunity both spatially, through the presence of refugia and temporally, through nocturnal shifts in activity patterns of locations which pose a risk.

In total, a single cow (a calf) was observed crossing under the fence at a wildlife friendly fence gate site, which had the addition of plastic tubing. Considering the number of crossing images and the many more (orders of magnitude more) images of cows at the fence, we are confident that the fence was adequate for it's first intended purpose, to contain livestock. We feel that the data presented in this report suggest that the purpose of excluding livestock is not mutually exclusive from facilitating increased permeability to native ungulates. In particular, correctly implemented wildlife friendly fences provide a viable means of meeting the requirements of a fence to contain livestock, while further facilitating the permeability of the fence relative to traditional fences for native ungulates.

Managers tasked with maintaining the ecological function of ungulates within WDER will have to consider the role fences play in potentially impeding the connectivity of the reserve to the surrounding agricultural lands. Ungulates, and elk in particular, appear to use the surrounding agricultural land for foraging returning daily to the reserve. Any management actions that promote additional behavioural opportunities for fence crossing or provide more space for passage under and over the fence will mitigate the barrier aspects of the fence. Wildlife friendly fence (three strand) designs with decreased top strand height and increase bottom strand height provide these opportunities. Seasonal increases in movement rates and fence crossing could be accounted for by strategically opening gates, however, obligations to cattle grazing may make this unfeasible. Fences are a necessary feature of agricultural landscape, but wildlife friendly designs may provide an opportunity to mitigate their effect on landscape permeability for ungulates, while also reducing the potential cost associated with fence damage incurred during crossing attempts.

Lastly, this project also demonstrated the potential for a semiautomated program to reduce the investment of time and money in human cataloging of images. The level of accuracy we demonstrated for retaining crossing events was acceptable (≈73%) and did not differ between day and night. However, recording fence crossing events is a unique question suited to automation, further we did have the luxury of a vast number of events within the data collected, which may not be the case in studies detecting the presence of rare and elusive species (Arzoumanian 2005, Caorsi 2012, Quiroga 2013, Yu *et al.* 2013). Our accuracy was determined by running the program against a test data set with known and identified events. We used generic program inputs for each camera and our reported accuracy is conservative and could increase with the division of the data set into smaller and more similar units with unique program inputs. This increased accuracy will, however, come at cost of increased operator involvement. Where we noted reduced accuracy of the semiautomated method additional accuracy may be achieved by suitable camera placement relative to the stated goals of the project (i.e. centre the fence in the image). Anecdotally, cameras whose image had the fence (for some or all of the study period) far to one side had the lowest accuracy as it became difficult to divide the image into a pre- and post-crossing region. The behaviour of animals towards the camera (i.e. licking and breathing on the lens) itself reduced the ability of the semiautomated program to identify crossing events. In more general terms the program we produced reduced the data set by ≈55% by removing images that were captured as the result of the trigger of the camera by non-target sources (i.e. not animals) such as moving clouds and waving vegetation. In fact, this percentage may be higher, as some non-target images were "pre-cleaned" from the dataset before we received them. This reduction in the number of images required to be processed manually, is a general result not unique to this study that may be an important contribution to other studies that use remote cameras.

# 6 Acknowledgements

We thank Alberta Environment and Parks, in particular Ksenija Vujnovic and Drajs Vujnovic, for providing the data, financial support required for this project, helping with reducing the total number of images to target species, and for comments and edits. We also thank The King's University for providing logistical support. This work was completed as part of undergraduate research projects by Ian MacLeod, Kaitlyn Visser, and Alexander Lekas. Phil Walker is thanked for editing previous versions. Special thanks to the Buffalo Park Grazing Association and landowners surrounding the WDER for their support. This final report relies heavily on the structure and content developed for the interim reports submitted to Alberta Parks for this project and is meant to replace those documents, as this contains the most updated data.

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# 8 Appendix I

## 8.1 Study design

| | **New** Fenceline | | | | | |
|---|---|---|---|---|---|---|
| | 2011/12 | | 2012/13 | | 2013/14 | |
| | W[2] | S[3] | W | S | W | S |
| N1 (gate) | B1[4]/O[5] | B1/C[6] | B1/C | M3[7]/C | M3/C | M3/C |
| N5 (gate) | B1/C | B1/C | B1/O | M3/C | M3/C | M3/C |
| N6 (gate) | B1/C | B1/C | B1/O | M3/C | M3/C | M3/C |
| N2 (fence) | B1 | B1 | M1[10] | M1 | M1 | M1 |
| N3 (fence) | B1 | B1 | M1 | M1 | M1 | M1 |
| N4 (fence) | B1 | B1 | M1 | M1 | M1 | M1 |

| | **Old** Fenceline | | | | | |
|---|---|---|---|---|---|---|
| | 2011/12 | | 2012/13 | | 2013/14 | |
| | W | S | W | S | W | S |
| O1 (gate) | B2[8]/C | B2/C | B2/O | M4[9]/C | M4/C | M4/C |
| O3 (gate) | B2/C | B2/C | B2/O | M4/C | M4/C | M4/C |
| O4 (gate) | B2/O | B2/O | B2/O | M4/O | M4/O | M4/C |
| O2 (fence) | B2 | B2 | M2[11] | M2 | M2 | M2 |
| O5 (fence) | B2 | B2 | M2 | M2 | M2 | M2 |
| O6 (fence) | B2 | B2 | M2 | M2 | M2 | M2 |

Table A.1: Study design for fence and gate construction and modification across the three study years.

[2] Winter or time outside of the grazing season (≈ end of October to mid June)
[3] Summer or the grazing season (≈ mid June to the end of October)
[4] Baseline 1 (B1), wire strands at 21in/32in/42in
[5] Gate is open
[6] Gate is closed
[7] Modified 3 (M3), top and bottom strand made visible and smooth using PVC pipe
[8] Baseline 2 (B2), wire strands at 16in/22in/32in/42in
[9] Modified 4 (M4), top and bottom strand made visible with vinyl siding trim
[10] Modified 1 (M1), top two strands lowered from baseline to 21/**28**/**38**
[11] Modified 2 (M2), bottom two strands combined to **18**/32/42

# 9 Appendix II

## 9.1 Representative pictures


Figure A.1: An example of a juvenile white-tail deer crossing under a wildlife friendly fence. The increased height of the lower strand allows for easy passage.


Figure A.2: Elk passing through a standard 4 strand fence (lower strand is in the snow). Notice the degree to which the wire strands bend, resulting in loose wire. Loose wire may increases the potential for fouling during crossing.


Figure A.3: An example of the fouling that can happen during crossing (categorized as a crossing with difficulty), often when strands are loose. In this case the elk is crossing a standard design gate. This type of difficultly (hind leg getting hung up) was the most common difficultly in elk crossing over a fence.


Figure A.4: Elk group passing through a standard 4 strand fence. The increased pressure of multiple elk, with less individual space to manoeuvre during crossing, may result in more damage to the fence and as a result increase the potential for fouling during subsequent crossings.


Figure A.5: The only recorded cow crossing observed at a wildlife friendly gate with the addition of plastic tubing.

# 10 Appendix III

## 10.1 Automated data collection

We developed a semiautomated method to reduce the time spent by operators to identify crossing events and classify images. The desired parameters for each step can be placed in an instruction file, where the program will read and process each of the image sets accordingly. The sections below will explain in depth how the program functions in seven main steps. Following these seven steps, an operator manually inputs the desired metadata from the files containing the most probable events (crossing events in our case).

### 10.1.1 Division of images into manageable sets

Initially, the photos are broken into sets based on temporal adjacency, we defined a set to contain all images that do not have more than a 5 second time difference between images in a sequence (e.x. Figure A.7). This value may be modified by the user at run time depending on the estimates of temporal independence between events. Each camera was (user) configured to take photos in burst of 3, therefore each set has a minimum of 3 images. The date and time for each image was found by the program by either the image name, or the metadata assigned to the image by the Reconyx camera. Day and night images were distinguished by whether or not the camera's flash was deployed. All the images were processed together until the "histogram analysis of fragments" step (see below), where the night images are processed differently.

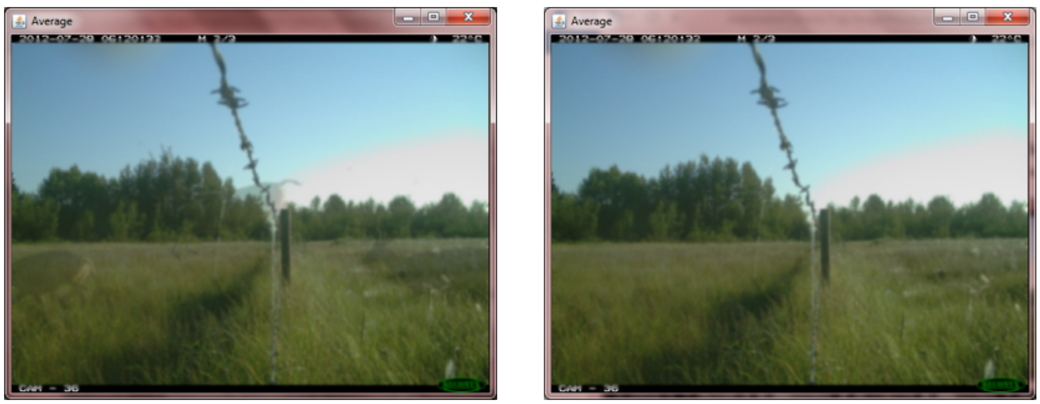
Figure A.6: An example crossing sequence.

### 10.1.2 Reducing the size and blurring the images to reduce background noise.

The number of pixels in each image are cut in half twice to increase processing speed, and to reduce the effect of small background noise in any one pixel. Then a 3x3 and 7x7 Gaussian Blur, in addition to a Box Blur, were applied. Blurring helps to reduce the noise in the image and reduce the effect of slight changes in movement and lighting between pictures, which could trigger unwanted differences later in the program. The sequence and type of blurs are customizable by the user.

### 10.1.3 Production of an average image

A background (average) image was created, to which each of the images was compared to detect movement. Two ways of creating an average image were developed (Figure A.8). The first was to take the average value of a particular pixel across the images in a set. However, this led to ghosting of the animal in the average picture, which is not desired as the ghosting itself can be detected as movement. The second method, which we used for the remainder of the project, removed most of the ghosting by applying a second step which compared the standard deviation of an individual pixel in the background (average) image to the same pixel across each of the images in the set. Pixels were retained if they were within one standard deviation of the average image.




(a) (b)

Figure A.7: Figures of (a) the created background image with ghosting, as evidenced by the faint presence of the crossing deer, using the standard average method for developing the background image and (b) the preferred method to create a background image by taking a pixel average and determining if it is within one standard deviation of the average in the set, which reduced ghosting.

### 10.1.4 Region selection

The images were then partitioned into regions using the implicit definition of two lines to delineate the fence for the purpose of determining if a crossing event occurred (Figure A.9). The centre region was selected to fully encompass the fence, with extra space so that movement of the fence, caused by crossing individuals, is not detected as movement in either the right region or the left region. Camera placement at this step plays a key role in the ability to clearly identify crossing events.

Figure A.8: The created average image and the region selected to determine if a crossing event occurs. The regions roughly divide the right and left side of the fence, corresponding to the approach and retreat of the crossing individual. The centre fence region is blocked in order to minimize the effect of moving fence strands on image processing during the crossing event.

### 10.1.5 Production of difference image and thresholding

Each of the pixels in the original images are compared to the pixels in the average image. In each image within the set, the red, green and blue pixel values were compared to the average image and the difference calculated. A maximum difference of 765 (255 for each colour) is possible. All pixels with a difference above a threshold are retained as significantly different, and the pixels below the threshold difference are set to 0 and presumed to be noise. The threshold value is user defined and the value we used (60) was determined based on trials with our particular images and appeared to optimize the balance between keeping the most relevant fragments while reducing fragments appearing from background noise.

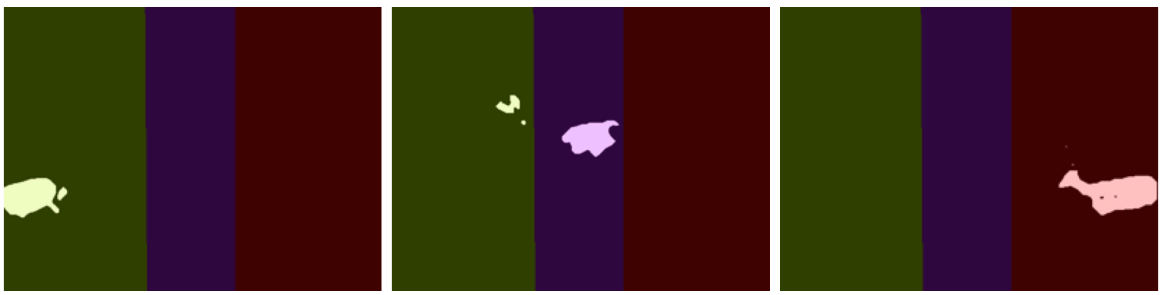


Figure A.9: The example crossing sequence difference images following thresholding, erosions and dilation.

### 10.1.6 Histogram analysis of fragments

Each of the fragments then goes through a series of erosions and dilations to eliminate small noise fragments (Figure A.10). This procedure causes the larger fragments to join together and fill in, making a more complete picture. At this point, day and night (when the flash was engaged by the camera, which included dusk and dawn) images go through separate processes. Each fragment in the day images has a histogram created showing the distribution of the red, green and blue pixels. This histogram can be compared to a list of set rules, which can differentiate between most backgrounds and animal fragments based on colour distribution. The fragments that are due to noise are deleted, while the animal fragments are kept. The rules are not comprehensive due to the propensity of animals to have similar colouring as their environment. The rules for histogram comparison are user defined and may depend on the general colours in the images background and help differentiate the focal animal from the image background. Images where the flash was employed could not be differentiated based on histogram analysis, this is an area for possibly future research. When the flash is used, the red, green, and blue pixels are equalized to different shades of grey. Contrast is reduced to lighting conditions and no discernible variation could be found between noise fragments and animal ones (Figure A.11).

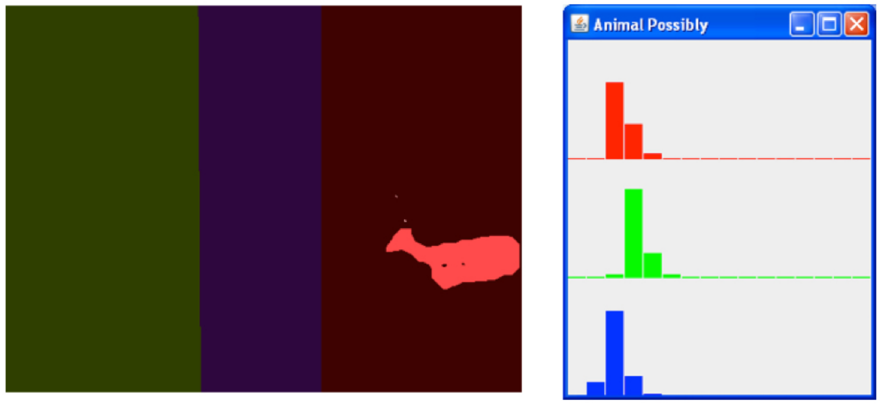



Figure A.10: The average image with the large deer fragment highlighted, the histogram of red, green, and blue value for the pixels in the fragment are also displayed.

Following histogram analysis, each region of the image is then analyzed for fragments. The number and size of the fragments, as well as the percent of the region the fragments take up, was detected and recorded. The fragments that are detected in the middle region are disregarded, due to the propensity to be from movement of the fence and animal movement. All photos that have a region containing a fragment that covers over 65% of the region are also disregarded in the analysis. These value may be (are most often) caused by animals breathing near the camera or by being too close to the camera, possibly with their head extended over the fence, which could trigger a crossing. These images are removed to reduce the chance of a false positive occurring.

### 10.1.7 Categorization of images based on crossing confidence

Identifying and tracking the animal fragments, as it moves through the defined regions of the image within the set of images, allows us to distinguish whether or not a crossing event occurred. Based on the pattern of animal fragments detected over the set of images, a categorical value of 1 through 5 is assigned to the image set. A value of 1 indicates a very high confidence of crossing and that an animal is detected in the left region and then in the next photo or two is detected in the right region, or vice versa. A classification of 2 is assigned to a set where there is only three images and movement is detected in only one or two of the images but not in the remaining image(s). This category is needed because many animals move so quickly that they are only detected once by the camera, and have exited the camera frame by the time the other two photos are taken. Normally this would be detected as no crossing, however the deer can often be visually seen crossing the fence in one photo, so a value of 2 indicates the images should be gone over manually. A classification of 4 is given to all the photos that have detection of movement in all regions of all images, or when there is nothing detected in any of the regions. This is caused by background which is continuously detected in all regions, or the images where nothing significant is detected in any region. These photos have a very small chance of being a crossing and therefore are given a lower value. A category of 5 is given to a set when there is movement that is solely detected on one side of the fence. Animals milling or the movement of cows on a single side of the fence can cause this. Finally, any set that does not fit into the other four categories is assigned a 3, which are also gone over manually. The value that is assigned for a particular crossing event is given to all the images in the set, including the ones that were previously disregarded for having a region which had a greater than 65% coverage.

The photo location and the assigned classification, are then exported in a CSV file. Once the program has completed running on all the user defined images, all of the CSV files are combined into one file and the intermediary CSV files are deleted. These steps are done by the classification program. The second part of the program is called the "Picture Mover", where this program uses the CSV file and created folders to move the photos into the assigned folder based on their crossing confidence. Photos with a confidence of 1 and 3 were placed in a folder together, as they both contained the most crossing, 2 was in another folder, and 4 and 5 were also placed together. The photos in these folders can then be selectively uploaded into an image viewer (i.e. Reconyx Map View) to be tagged with metadata, for further analysis. Folders 1-3 were viewed for crossing events and the images tagged with the relevant metadata by hand following the procedure in the previous section. To assess the accuracy of the semiautomated program the classification of images by the semiautomated method was compared to a test set of data that had be classified by hand.

# 11 Appendix IV

## 11.1 Semiautomated program operation

This Appendix explains the step by step method for how to use the program used in this study.

### 11.1.1 Part 1- "Start Find Animal Program"

This step is used to manually assign regions that will be used for setting the automatic instruction for the next steps.

1. Open "Start Find Animal Program" (Figure A.12)

   Caution: clicking the exit button on any of the photos or the control panel will close all the windows and end the program.

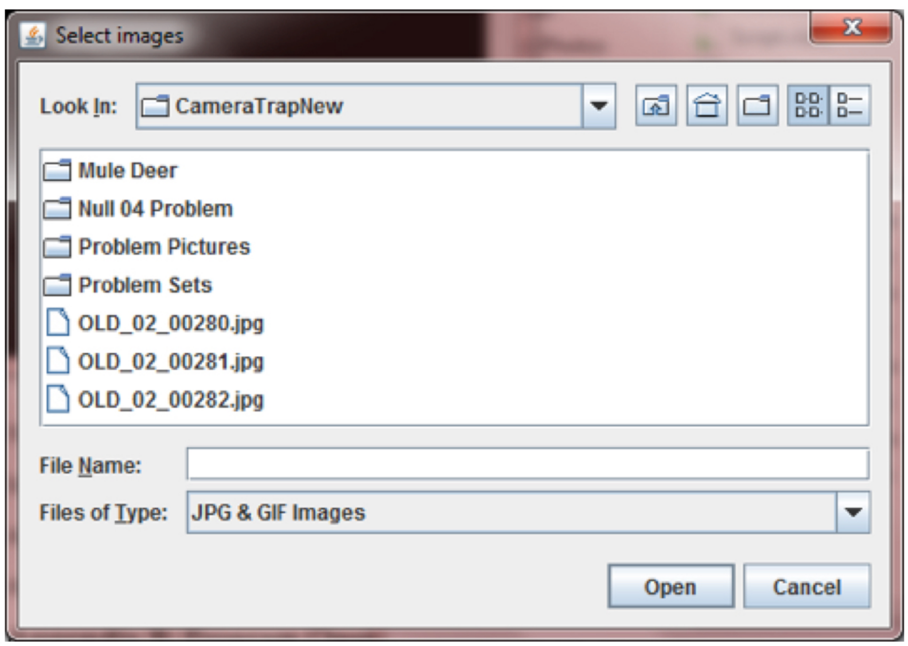



Figure A.11: "Start Find Animal Program" start screen.

2. Select desired pictures and press "open".

3. Half the resolution of the images twice, then make the background image. On the background image the regions can be selected by clicking the image in horizontal lines (top and bottom). The command prompt will indicate the values of the lines that were selected (Figure A.13).

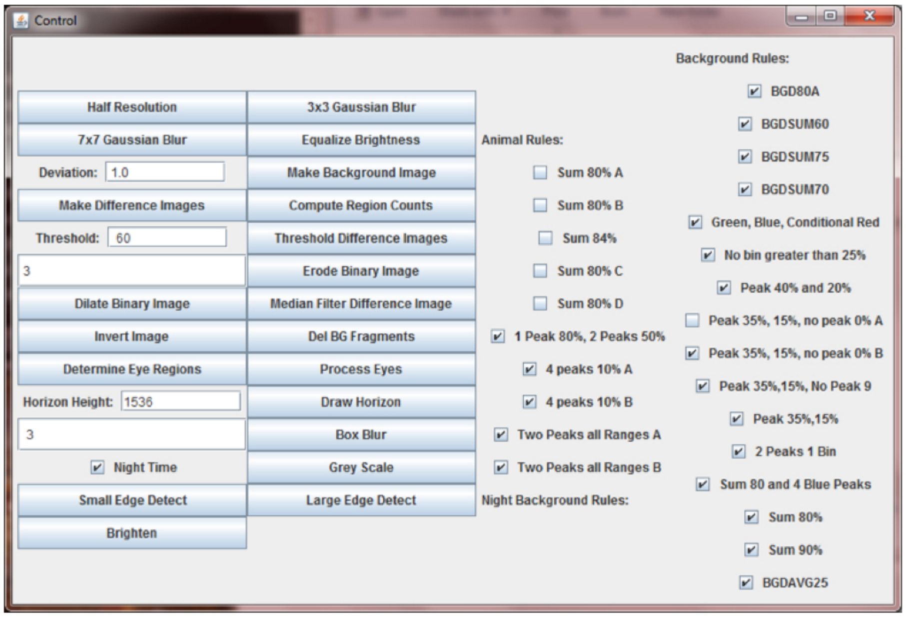



Figure A.12: Control screen.

4. Return to the main folder for the program, right click on "Template" and click "edit". Find the below lines:

```
<MouseClick><X>1</X><Y>0</Y></MouseClick>
<MouseClick><X>1</X><Y>0</Y></MouseClick>
<MouseClick><X>1</X><Y>0</Y></MouseClick>
<MouseClick><X>1</X><Y>0</Y></MouseClick>
```

Enter in the X and Y locations from the program, from the command prompt where the 1s and 0s are. Other commands can be added or deleted to adjust the rule list as desired.

Save the file, using the name of the set that is being run followed by `.xml` i.e. `New01_2014_01.xml`. This list will be used by the next program to automatically process the images.

Note: Each camera will need its own instruction set. Depending on the movement of the camera between the files for each camera, individual instructions may be needed for each file.

### 11.1.2 Part 2- "Animal Image Processor"

This step sorts all the photos by time, runs through the program and assigns them a value and then exports the data into individual CSV. Files are then combined into a larger CSV file, the smaller files are then deleted.

1. Open "Animal Image Processor" (Figure A.14)

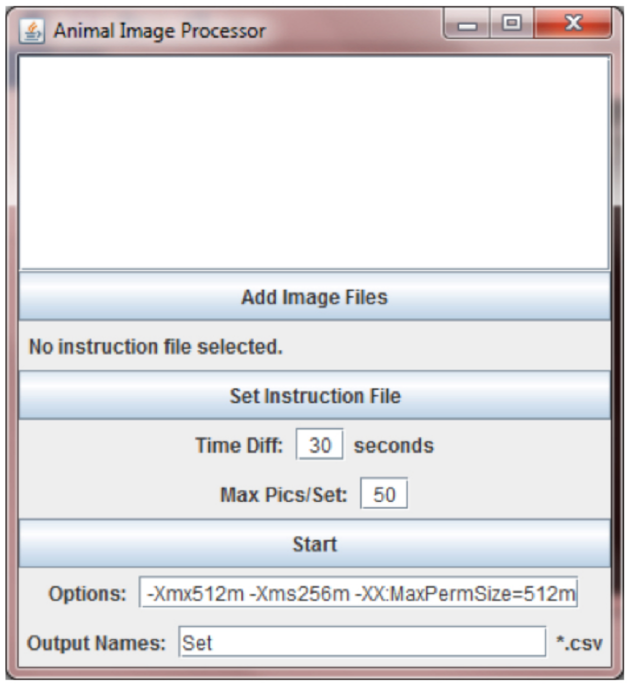



Figure A.13: "Animal Image Processor" start screen.

2. Click "Add Image Files". Select all of the images to be run.
3. Click "Set Instruction File". Select the instruction file that was created in Part 1.
4. Set the Time Diff as 5 seconds. This indicates the maximum amount of time that can be between photos before they are considered to be from different sets. Max Pics/Set can be left at 50.
5. Change the Output Name to the desired name for the set. Using the name of the File plus a extra underscore, ie. `New03_2014_01_` is recommended.
6. Press Start. For detail instruction of how the program works please see Methods section.

### 11.1.3 Part 3- "Picture Mover"

For this part, folders are created that the images are sorted into based on the assigned ranking from the previous part.

1. Create a folder labeled after the file name. Create sub folders for the five directories. Directory 1 and 3 can be joined together, as can 4 and 5.

2. Open "Picture Mover" (Figure A.15)

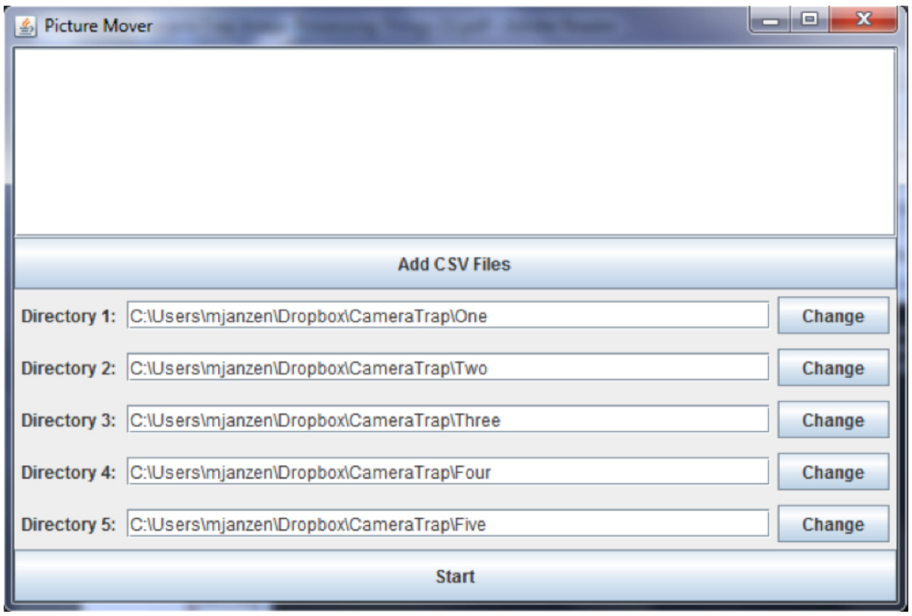



Figure A.14: "Picture Mover" start screen.

3. Click "Add CSV Files". Select the final CSV file that was created in the last part.

4. Click "Change" to select the subfolders created in step 1.

5. Select "Start". The pictures will be moved into their selected files. The photos are then ready to be moved if needed to a computer that has the Reconyx software and analyzed.