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### To Jump or not to Jump: Mule Deer (*Odocoileus hemionus*) and White-tailed Deer (*Odocoileus virginianus*) Crossing Decisions

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April 27, 2016  
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Burkholder et al. • Deer negotiating Fences

**To Jump or not to Jump: Mule Deer (*Odocoileus hemionus*) and White-tailed Deer (*Odocoileus virginianus*) Crossing Decisions**

**ABSTRACT**

There have been recent efforts to enhance ungulate movement through modified fencing structures. Ungulates such as mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*) typically negotiate fences by either jumping over fencing or going under. Here we examine crossing success and crossing decisions of mule deer and white-tailed deer and determine factors that influence crossing success and the impending decision to jump over or crawl underneath fencing. Using a BACI (Before-After-Control-Impact) design, we deployed remote cameras along fence lines in three study areas; Canadian Forces Base (CFB) Suffield and OneFour research center in Southeastern Alberta, Canada, and The Nature Conservancy's Matador Ranch in North-central Montana. We used logistic regression to model the probability of deer successfully crossing a fence and of deer crossing under a fence versus jumping over it based on important fence and environmental characteristics. We collected 499 crossing attempts with 326 successful crosses. We found that crossing success was influenced by sex, season, snow presence, number of attempts, site types and bottom wire heights. We found that crossing decision, in contrast, was influenced by species, sex, season, and bottom and top wire heights.

**KEY WORDS** mule deer, fence, barrier, white-tailed deer, ungulates

Wildlife need to move, whether daily or seasonally, to find food and other resources, and consequently if hindered, overall fitness can be hampered directly and/or indirectly (Alexander 1991). Both anthropogenic and topographic features can act as barriers to movement, which limit an animal's ability to move freely across a landscape (Seidler 2014). A common anthropogenic linear feature that may act as a barrier to wildlife movement are fences (Harrington and Conover 2006).

Fences have been a part of landscapes since people made the switch from hunter and gatherers to farmers and ranchers. Fences have been used in farming and ranching to keep domestic livestock in designated pastures and to delineate ownership boundaries but were an expensive cost to landowners in areas where no local fencing materials existed until the introduction of the barbed wire (Hornbeck 2010). From 1880-1900, hundreds of thousands of tons of barbed wire fencing was produced and erected across western North America to establish property lines and rights (Hornbeck 2010). By the mid 1880's at the peak of production, 643,000-965,000 km of barbed wire was being produced annually (Hayter 1939).

Fences can act as an impermeable or semi-permeable barrier to wildlife. For example, eight-foot page wire fences act as a complete physical barrier to larger wildlife because it prevents them from crossing over, through or under, forcing the animals to cross somewhere else (Reference – Huijser?). On the other hand, common barbed wire fences are often semi-permeable because they allow some form of negotiation (Vercauteren 2006). Recent wildlife – fence interactions have shown that fences make movement more difficult, but not always impossible, through fragmentation of the landscape (Harrington and Conover 2006). This fragmentation can indirectly affect an animal's fitness by limiting daily and seasonal movements thereby preventing

the attainment of necessary resources. For example, Seidler et al. (2014) found a stretch of non-wildlife-friendly fencing that completely impeded radio-collared migrating pronghorn from crossing the fence-road complex on U.S Highway 191 near Farson, WY. However, 11% of the radio-collared pronghorn used a stretch of wildlife-friendly fencing to continue migration across this fence-road complex.

Fencing can also directly influence an animal's fitness if it leads to mortality (Harrington and Conover 2006). Harrington and Conover (2006) found that mortalities were most often caused by ungulates becoming caught between the top two wires. Mule deer experienced the highest fence-mortality rate compared to pronghorn and elk with 0.08 mule deer mortalities/km. Mule deer crossed more frequently and spent more time in road "right-of-ways" and is one explanation for higher mortality rates in mule deer compared to pronghorn and elk. Additionally, Harrington and Conover (2006) found that the mule deer, pronghorn, and elk juveniles were eight times more likely to become caught and die in fencing than adults.

To move successfully through anthropogenically fragmented landscapes, wildlife, including ungulates, must decide upon a cost-effective mode to successfully negotiate barriers (Shepard 2013). The decisions an animal makes attempting to negotiate a barrier and the outcome of that decision (success/failure) can be influenced or constrained by various internal and external factors. Internal factors include species type, age, and sex while external factors include environmental gradients and variation (i.e. season, snow presence) along with the barriers themselves.

Across western North American, for example, pronghorn (*Antilocapra americana*) are often more limited on their ability to negotiate barriers successfully compared to other ungulates like mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*). Pronghorn

have been observed to typically cross under fences as opposed to jumping over them and are known for their reluctance to jump (Lubinski 2000, Harrington and Conover 2006). This mode of negotiating fences is probably because pronghorn have adapted to prairie landscapes with low groundcover so were rarely required to jump over anything taller than sagebrush (Lubinski 2000). Mule deer and white-tailed deer, however, have adapted to a wide variety of habitats and so are not as often constrained in their ability to negotiate fences. They have been observed jumping over and crawling under fences successfully (Harrington and Conover 2006).

Differences in internal factors such as species, age and sex may influence an animal's locomotion or behavior. White-tailed deer, for instance, have smaller body sizes (Hobbs 1989) and different innate behaviors compared to mule deer such as their different behavioral responses to predators (Lingle 2001). These behavioral differences between species could lead to differences in locomotion. For example, in response to predation by coyotes, mule deer were observed standing their ground and often attacking the coyote while white-tailed deer were observed fleeing (Lingle 2001). Fawn locomotion could differ from adults due to their smaller body size and because they might still be learning successful ways to negotiate barriers from their mothers (Riley 1984, Vercauteren 2006). Females locomotion could differ from males because they are smaller than males and because males have antlers. Antlers may have a larger influence on locomotion than body size due to the antlers becoming entangled in the barbed wire. Environmental factors, including seasonality and snow presence can also affect mule deer and white-tailed deer locomotion. For example, it has been shown that season and weather can influence behavior of mule deer movement decisions (habitat selection) at multiple scales (Nicholson 1997). In part, this could be due to the varying annual requirements corresponding to the changing seasons. For deer, spring is associated with spring migration, fawning, and

lactation. Summer is associated with overabundant resources and a post-fawning period. Fall is associated with fall migration, mating and gestation and winter is associated with scarce resources and continued gestation (Ullrey 1970, Worden and Perkins 1995, Perkins et al 1998). Snow depth is another variable that can affect the movement and mobility of ungulates (Parker 1984). As snow depth increased so did the energetic costs to mule deer and elk (Parker 1984). The characteristics associated with a fences such as bottom and top wire heights on barbed-wire fencing, could also alter ungulate mobility. In one wildlife-fence interaction study, fence height increased the deterrence rate of white-tailed deer jumping over progressively until it reached 100% deterrence at 2.4 m (Vercauteren 2010). Private landowners are finding success in decreasing wildlife mortality caused by fences by implementing various fence enhancement types to allow for easier wildlife access. These enhancements range from replacing barbed wire with smooth wire, PVC pipes, seasonal electrical fencing, or suspension fences, installing visible markers; and/or raising the bottom wire to the same level as the second wire from the ground (Paige 2012).

Here, we aimed to determine factors that influence fence crossing success and fence crossing decisions of both mule and white-tailed deer (Figure 1a). Specifically, we tested whether individuals from two deer species (mule deer and white-tailed deer) were successful or unsuccessful at negotiating barbed wire fences and, if successful, how the individuals chose to negotiate the barrier (jumped over or crawled under). We hypothesized that deer would successfully cross more at enhancement sites (goat bar, smooth wire, and clips) than at historic, known-historic or control sites once the enhancement was added. We also hypothesized that if the deer successfully crossed, it would select to cross under a fence rather than jump over it only

if it is the most cost-effective decision based on the same measured physical and abiotic attributes.

We expected to see differences in crossing decisions based on internal and external factors due to the variations associated with each. In reference to internal factors, we expected to see a difference between fawns and adults with adults having higher crossing success because fawns have less experience with crossing barriers (Vercauteren 2006). We did not expect to find a difference in crossing success between the different species and sexes. We expected to find differences between these internal factors in the actual crossing decision or individual behavior. We expected white-tailed deer to cross under a fence more often than mule deer because they are generally smaller in size with different innate behaviors (Lingle 2001). We expected fawns to cross under a fence more than adults due to their smaller size and lack of experience jumping. We expected females to cross under a fence more than males because females are generally smaller in size and males have antlers that can become entangled in the barbed wire.

In reference to external factors we expected to find higher crossing success in all enhancement sites compared to the control sites because of the raised bottom wire height allowing ease of access for deer. We also expected to see crossing success increase as top and bottom wire increased. We did not expect there to be a difference in crossing success between summer, fall and spring. However, we did expect winter to have the lowest crossing success because of snow presence and the need to conserve energy under limited resource availability. Regarding crossing decisions, we expected to see more deer cross under a fence during winter, fall and spring.

During the summer, there is a net surplus of available resources with lowered energetic costs required in obtaining them. Therefore, we would expect to see the highest rates of jumping over fences during this period. We also expected that deer would choose to jump over more when

snow was present and so may affect crossing decisions particularly in the winter. Finally, we expected deer to cross under fencing more often when the bottom and top wire has been raised or a fence modification has been added because fence enhancements and raising the bottom wire are supposed to allow animals ease of access.

Further understanding deer -fence interactions is important because it can provide insights into the factors determining where, when and how deer negotiate fencing and potentially how these species' energetic requirements plays a role in these interactions.

## **STUDY AREA**

We studied mule deer and white-tailed deer fence interactions in a transboundary region of Southeastern Alberta (AB) and North Central Montana (MT), deemed the Northern Sagebrush Steppe (NSS) (Figure 2). The two study sites in AB included Canadian Forces Base (CFB) Suffield and OneFour Research Center. Field work in MT was conducted at The Nature Conservancy's Matador Ranch (Figure 2). The NSS is characterized by flat open plains and rolling hills as a result of "glaciation recession and deposits" and dramatically fluctuating annual temperatures (Mitchell 1980). Badlands and deep coulees exposed and created by rivers and other waterways makeup this region (Mitchell 1980). The NSS is considered semi-arid receiving, on average, 327 mm of precipitation annually as measured by the agricultural Canada research substation at OneFour research center from 1940-70 (Barret 1984). All three study sites are native sagebrush steppe habitats which include western wheatgrass (*Agropyron smithii*), blue grama (*Boutelova gracilis*), needle-and-thread (*Stipa comate*), June grass (*Koeleria cristata*), silver sagebrush (*Artemisia cana*), big sagebrush (*Artemisia tridentata*), western snowberry (*Symphoricarpos occidentalis*), cactus (*Opuntia polyacantha*), and rose (*Rosa spp.*) (Barret 1984, Poor et al 2012).



## **METHODS**

### **Experiment Design**

Digital images from remote trail cameras (predominately Reconyx PC650, PC800 or PC900) were collected and analyzed from a current camera trap study that assesses pronghorn interactions with fences. The project used a BACI study (Before-After-Control-Impact) design to collect images from trail cameras on deer interactions with fencing. A BACI study design is a powerful method for evaluating the effect of an “impact”, which in this case was our fence modifications. Specifically, the design allows for the comparison (of animal-fence interactions before and after fences were modified) between pre-modification data and treatment data. Without such a study design, it would be difficult to conclude that differences were associated with fence modification rather than some additional, unmeasured variable present in the treatment population (Hebblewhite 2008). Incorporating a control to compare to the treatment allows for the researcher to determine whether differences were due to the treatment or other unmeasured factors (Hebblewhite 2008).

### **Study Sites**

Trail cameras were deployed during specific time periods in groups of three (described as a site), centered around a historic crossing location (Figure 3) Historic crossing locations were determined through pre-camera deployment surveys by identifying ungulate crossing locations from fecal pellets, hair strands observed on fencing and where the ground had been continuously trampled. Each site included a historic crossing fence panel, a control fence panel and an enhancement fence panel with a camera positioned at each separate panel for consistency, the area of view for each camera image included the area from the camera to the adjacent post and extended 2-3 meters on each side of the fence line. There were eight sites from OneFour research

center, forty study sites from CFB Suffield and sixteen sites from the Matador Ranch. Following the BACI approach, a “before” period was used to collect data when no fence panels were modified. Bottom and top fence wire height was measured. During the “after” period, the lowest barbed wires at historic crossing locations were lowered so animals could not cross underneath. In addition, fence enhancements were put in place (either a “goat bar” (12’ PVC pipe, carabineer clip, or smooth wire) at each enhancement fence panel. Each enhancement fence panel’s bottom wire was set at 18” from the ground. The top wire height was not modified at the enhancement fence panel.

Camera trapping was initiated in AB in 2010 and expanded into MT in 2015. Camera trapping at CFB Suffield began in November 2010 and is ongoing through April 2016. Camera trapping at OneFour Research Center occurred from July 2012 to July 2014. Camera trapping in MT began in March 2015 and is ongoing. Once images were collected, we used a photo classification protocol developed by Alberta Conservation Association (ACA) to standardize various deer behaviors when interacting with fences (Appendix 1).

### **Database and Analysis**

We constructed a database to compile measured continuous and categorical explanatory variables to determine fence crossing success and decisions of deer (Table 1). We analyzed data using logistic regression to evaluate crossing success [successfully crossing the fence (1) or unsuccessfully crossing the fence (0)] and crossing decision [going under a fence (1) or jumping over a fence (0)]. We first screened variables for collinearity using Pearson’s product-moment correlation index, with  $r > 0.6$  as the threshold cut-off value. We then further screened variables for modelling efforts using univariate analysis of each variable. Variables which had  $p$ -values  $> 0.05$  were deemed insignificant and discarded for further analysis, with the remaining variables

considered as my global model. We then ran generalized logistic regression and used forward and backwards stepwise Akaike's Information Criteria (AIC) to identify the top model(s) by eliminating insignificant variables with  $p$ -values  $> 0.05$  in influencing crossing success and decision (Burnham and Anderson 2002). We then re-ran generalized logistic regression on the top model for both crossing success and decision. We took the exponential of each beta coefficient to standardize the results to interpret. We also ran odds ratios for both crossing success and decision. Finally, we used K-fold cross validation analysis to test the performance of my top model (Boyce et al. 2002). All analysis was conducted using R 3.2.3 (R Core Team 2013).

## **RESULTS**

We evaluated 499 occurrences of individual mule deer and white-tailed deer fence interactions using camera traps across AB and MT. Of those 499 occurrences, 326 individuals crossed the fence successfully with 163 individuals choosing to jump over and 163 individuals choosing to cross under. Of these images 308 were mule deer and 191 were white-tailed deer (most of which were observed in Canada sites). We assessed 311 females, 148 males, 40 fawns and 2 unknown adults.

### **Crossing Success**

Pearson's product-moment correlation analysis revealed that the bottom wire and the top wire coefficients were slightly correlated with one another, but not great enough to be significant. Otherwise, the remaining variables were not correlated (Table 2a). Univariate analysis on categorical and continuous variables identified significance and influence (positive/negative) on deer crossing success (Table 3a). Factors that were determined insignificant ( $p > 0.05$ ) on crossing success of deer included the before/after variable and the age of each individual (adult

or fawn) and were not included in further analysis (Table 3a). We ran a global model and used an AIC step-wise forwards and backwards test to determine the best model (Table 4a). Using this procedure, only species was found to be insignificant. The top model for crossing success of deer included sex, bottom wire and top wire heights, season, site type, snow presence, and the number of attempts (Table 4a).

We found that males were 0.75% less likely to cross successfully in reference to females. Both species were found to be 3.12 times more likely to cross successfully during fall by a factor, 3.41 times during summer, and 1.82 times during winter but the winter estimate had a  $p$ -value  $> 0.05$  and so was not statistically different from spring. Deer were 5.76 more likely to cross successfully when snow was absent and we found that the number of attempts had a negative influence on crossing success by 0.61%. This means that as the number of attempts increased, the likelihood of the deer crossing successfully decreased by 0.61%. We found that as bottom and top wire increased deer were 0.07% and 0.05% respectively more likely to cross successfully, however top wire height was found to be statistically insignificant ( $p$ -value  $> 0.05$ ). Finally we found no statistically significant difference in crossing success in known and known-control sites in reference to control sites. We did, however, find that deer were 0.40% less likely to cross successfully when using smooth wire and 0.93% less likely to cross successfully when using goat bars. They were 3.75 times more likely to cross successfully when using clips, but the smooth wire estimate was found to be statistically insignificant (Table 5a).

Finally, we ran a K-fold cross validation on our final model to validate model performance. Values range from -1 to +1 with values closer to +1 exhibiting better predicting performance (Table 7a). The  $p$ -values in this case are the probability of seeing the observed correlation or stronger if no correlation exists. Our best model performs well: the mean Spearman's rank

correlation coefficient is 0.954 and a p-value of 1.788e-05 (Table 7a). These values indicate our results were not due to chance alone.

### **Crossing Decision**

Pearson's product-moment correlation analysis revealed that the bottom wire and the top wire coefficients were slightly correlated with one another, but not great enough to be significant.

Otherwise, the remaining variables were not correlated (Table 2b). Univariate analysis on categorical and continuous variables identified significance and influence (positive/negative) on deer crossing decisions (Table 3b). Factors that were determined insignificant ( $p > 0.05$ ) on crossing decisions made by deer included the number of crossing attempts by individual, the enhancement type (smooth wire, clips and goat bar) and the age of each individual (adult or fawn) and were not included in further analysis (Table 3b). We ran a global model and used a AIC step-wise forwards and backwards test to determine the best model (Table 4b). The top model for crossing decisions of deer included sex, bottom wire, top wire, season, and species, eliminating the before/after variable, site type and snow presence (Table 4b).

We found that males were 0.97% less likely to cross under compared to females. White-tailed deer were 0.92% less likely to go under in reference to mule deer. During the summer and fall deer were 11.75 and 2.99 times more likely to cross under respectively in reference to the spring. During the winter deer were 0.92% less likely to cross under a fence in reference to spring, however it is not statistically different from spring ( $p$ -value  $> 0.05$ ). The top and bottom wire heights have 0.26% and 0.17% positive influence on deer respectively. As the bottom and top wire distance increases deer were 0.26% and 0.17% more likely to cross under a fence (Table 5b).

Finally, we ran a K-fold cross validation on our final model to validate model performance. Values range from -1 to +1 with values closer to +1 exhibiting better performance (Table 7b). The *p*-values in this case are the probability of seeing the observed correlation or stronger if no correlation exists. Our best model performs well: the mean Spearman's rank correlation coefficient is 8.75 and a *p*-value of 0.0009 (Table 7b). These values indicate our results were not due to chance alone.

## **DISCUSSION**

Our study looked at whether individuals from two deer species (mule deer and white-tailed deer) were successful or unsuccessful at negotiating barbed wire fences with different modification types and, if successful, how the individuals chose to negotiate the fence (jumped over or crawled under). We hypothesized that deer would successfully cross more at enhancement sites (goat bar, smooth wire, and clips) than at historic, known-historic or control sites once the enhancement was added. We also hypothesized that if the deer successfully crossed, it would select to cross under a fence rather than jump over it only if it is the most cost effective decision based on the same measured physical and abiotic attributes. We expected to see differences in crossing decisions based on internal and external factors due to the variations associated with each.

We found that clips had the highest crossing rate out of all modification types with 0.93% crossing success compared to the control site with 0.80% crossing success (Table 6a) Mule deer and white-tailed deer were 0.14% more likely to cross successfully when a clip enhancement had been added compared to the control. Smooth wire and goat bars had the opposite effect with 0.37% less likely to cross successfully when smooth wire had been added compared to the control and 0.63% less likely to cross successfully when a goat bar had been added compared to

the control (Table 6a). We believe the increased crossing success is due to the raised bottom wire height and the inconspicuousness of the clips themselves. All enhancements, however, were found to be statistically insignificant in crossing decision compared to the control sites.

The site type variable was insignificant for predicting crossing decision. Additionally, the top wire height had little influence on the crossing success, however the bottom wire height showed a slight positive influence on crossing success. As the bottom wire increased the likelihood of crossing increased 0.07% (Table 5a). even if the top wire is too high for deer to jump over it, they still have the option of crawling under the fence. This means that, in terms of crossing success, the bottom wire height is more important than the top wire height.

Top wire and bottom wire heights, however, were both found to have a positive influence on crossing decision. As the top and bottom wire heights increased the likelihood of crossing under the fence also increased by 0.18% and 0.26% respectively (Table 5a and Table 5b). Deer are not as constrained by fences as other ungulates, such as pronghorn. And while they can successfully jump over a fence less than 2.4 meters (Vercauteren 2010) we believe if the bottom wire is raised enough for them to go under it is the more energetically beneficial (easier) choice and they will therefore choose to cross under.

Goat bars compared to clips on the other hand had the lowest crossing rate with 0.16% crossing success (Table 6a). Mule deer and white-tailed deer were 0.63% less likely to cross successfully if they used a goat bar compared to the control site even though the bottom wire was raised to 18" allowing easier access (Table 5a). We suggest that the goat bar is actually deterring ungulates before even attempting to cross because of its unnatural, anthropogenic quality. We only had eight individuals attempt to cross using a goat bar modification. We propose that deer were not even attempting to cross at goat bars but, instead, choose to cross at the control, known

or another site altogether (Figure 1b). It would be interesting to continue and record wildlife-goat bar interactions and see whether, over time, ungulates become habituated to it. Boroski 1998 looked at water use patterns for mule deer and found that human disturbance did not particularly preclude or seriously impede the use of water by deer. Goat bars have been used in other types of projects as a method to keep animals moving across overpass structures (Reference M. Huijser work). Currently, goat bars are recommended as a method for continuing wildlife movement, particularly pronghorn through fences (Paige 2012). Our findings could hold in other systems and it would be important to determine if goat bars, across the board, deter ungulates.

Presently, more research is required to compare mule deer and white-tailed deer fence-interaction behavior between wildlife overpass use and pasture sites due to compounding factors like roads. Deer may behave differently near high speed and high vehicle use highways versus low use dirt roads. As an example, the wildlife overpass situated on Highway 93 in Western Montana sees approximately 3,800 vehicles per day (Arment 2014). The difference in traffic volume between the roads in each area could account for the difference in behavior between the mule deer and white-tailed deer in each area. In contrast, our three study sites have very few roads with present roads maintaining low traffic volume. Regarding underpass use and behavior, mule deer were found to be less likely to cross overall and exhibited nervous and wary behavior while crossing (Reed 1981 and Dodd and Gagnon 2011, and Robert 2009) Their wary behavior did not change over a ten-year study (Reed 1981). White-tailed deer “passage” rates on the other hand had no relationship with traffic volume (The Dodd and Gagnon 2011). Robert (2009) also found that white-tailed deer and mule deer exhibit different behavior while crossing a highway. White-tailed were more likely to cross a highway than mule deer. This could be due to the fact



that mule deer are normally found further away from the highway and therefore cross less. White-tailed deer could also be more adaptable to anthropogenic influences.

We measured behavior by the site chosen to cross at and the number of attempts each individual needed trying to cross. We found that as the number of attempts per individual increased the likelihood of that individual crossing successfully decreased by 0.39% (Table 5a). We believe this could be due to increased energetic costs potentially associated with crossing fences (Shepard 2013). In this study we were unable to actually measure energetic requirements associated with crossing fences but we infer how our results could potentially relate to energetic differences effecting movement decisions. As the number of attempts increase, energy is being used so the most cost effective decision is to cross the fence somewhere else where the odds of successfully crossing with the lowest amount of energy needed are higher. If the individual could not cross successfully the first time they were more likely to find another place to cross. We also observed a difference in crossing success and crossing decision in relation to seasonality, sex and species. We found that deer were 3.41 times more likely to cross successfully and 11.75 times more likely to cross under during the summer compared to the spring (Table 5a and Table 5b). The observed increase in crossing success during the summer could be due to the seasonal change in forage nutrition and availability (Mautz 1978). Deer go through an annual cycle of “feast and famine” where in the winter months they decrease their food consumption by almost 50% where approximately 30% of winter browse is actually digested (Mautz 1978). Because browse is poorly digestible, deer spend half their time foraging and the other half ruminating and by spending more time ruminating there is less time to forage (i.e. movement). During the summer on the other hand, where resources are abundant and browse is of higher quality, deer digestion efficiency reaches 50-80% and food consumption

increases (Mautz 1978). Deer spend most of their time foraging with little ruminating time. This increase in foraging simultaneously leads to an increase in movement which could account for the higher fence crossing success rates.

Deer were found to cross under 11.75 times more often during the summer in reference to spring (Table 5b). With increased movement causing increased crossing rates, increased energy expenditure follows and while there is little difference in energetic costs between crawling under a fence and jumping over it (Hanely 1989) fine-scale daily energetic costs add up over time and could therefore significantly affect deer fitness (Hanely 1989). If deer increase foraging bouts during summer in relation to spring, then they are crossing fences more. We interpret this as during the summer, females with fawns are teaching offspring how to successfully negotiate barriers.

Deer were 3.12 times more likely to cross successfully during the fall (Table 5a). The rut could account for higher crossing success in the fall. The rut forces males and females alike to move more (Pekins 1998, and Relyea 1994). With this kind of stressor, deer have more incentive to cross whether to find or avoid a mate, depending on sex (Relyea 1994). Increased crossing rates could lead to increased energy expenditure and, as discussed above, may influence the crossing decision. Deer were found to cross under 2.99 times more often during the fall in reference to spring (Table 5b) due to the rut and gestation taking place during the fall (Pekins 1998). Both species and sexes experience higher daily energetic demands during the fall when food availability starts to decrease (Pekins 1998). To keep energetic costs and consumption in balance deer must increase food consumption and reduce other activities to allow for fetal growth and development (Hobbs 1989). The maintenance energy expenditure of pregnant females was found to be 16.4% above non-pregnant females (Ullrey 1970). This could mean

choosing to cross under a fence instead of jumping over it as a fine-scale energy saving mechanism.

Winter was found to be statistically indifferent to spring for both crossing success and crossing decision, however, snow presence was found to influence crossing success. Snow absence was found to have a positive effect on crossing success. Compared to the other internal and external factors, snow presence had one of the largest influences on crossing success with deer crossing 5.53 times more in the absence of snow (Table 5a). This result coincides with other studies looking at the effect of snow depth on ungulate mobility (Parker 1984). Snow depth is considered to be the most significant variable that affects the movement and mobility of ungulates and was normally seen to decrease the mobility of ungulates (Parker 1984).

Sex influenced crossing success and decision, where males were found to cross 0.75% less and were 0.97% less likely to cross under in reference to females (Table 5a and Table 5b). A male's antlers can impede their ability to negotiate fences successfully by crawling under because they can become entangled and in addition, their larger body size could deter associated movements. If they are too large to cross underneath the wire but try anyways they may have a higher chance of becoming caught so the most cost effective decision would be to jump over the fence.

Species type did not significantly affect crossing success but did affect the decision. Fences affect both deer species equally, however there was a skew in recorded species between the MT site and the AB sites which may have affected crossing success results. MT observed 20 white-tailed deer while, both sites in AB observed 171 white-tailed combined. We also observed 308 mule deer in all three sites compared to the 191 white-tailed deer observed in all three sites. Regarding crossing decisions, white-tailed deer were 0.92% less likely to crawl under a fence in

reference to mule deer (See Table 5b), based on different innate behaviors belonging to each species like their response to predators (Lingle 2001). It was interesting that we did not observe a difference in crossing success between mule deer and white-tailed deer but we did observe a difference in the actual crossing decision.

## **MANAGEMENT IMPLICATIONS**

Movement is one of the most important energetic costs for animals because it allows them to locate food and other resources (Alexander 1991). When movement is impeded, an animals' overall fitness can be directly or indirectly affected. Understanding ungulate-fence interactions and the factors that may influence their ability to navigate these semi-permeable or complete barriers has important management implications for future wildlife-friendly fence construction and modification. Results could also further our knowledge and potentially provide insight as to why deer make certain decisions about where, when and how to move. Based on results discussed here, we recommend clips as opposed to goat bars when implementing wildlife friendly fencing for deer species.

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FIGURES

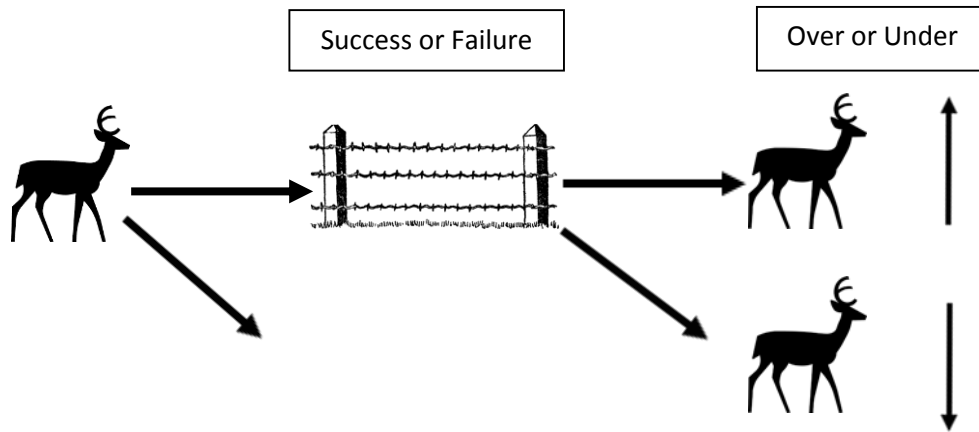


Figure 1a: Hypothesis 1 and 2. Showing crossing success and crossing decision

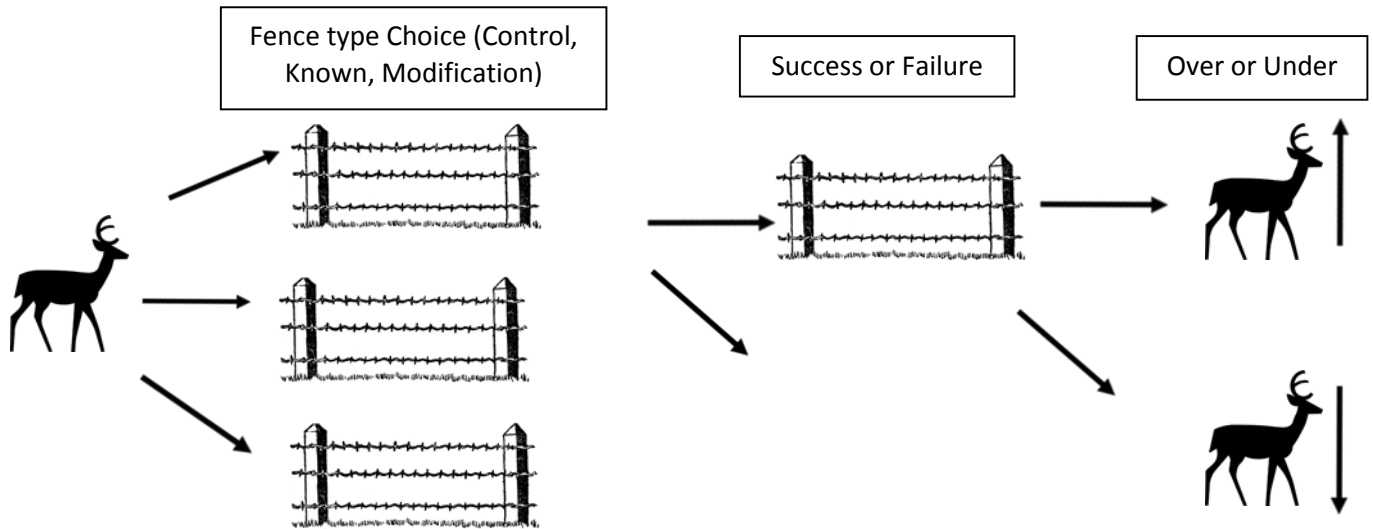
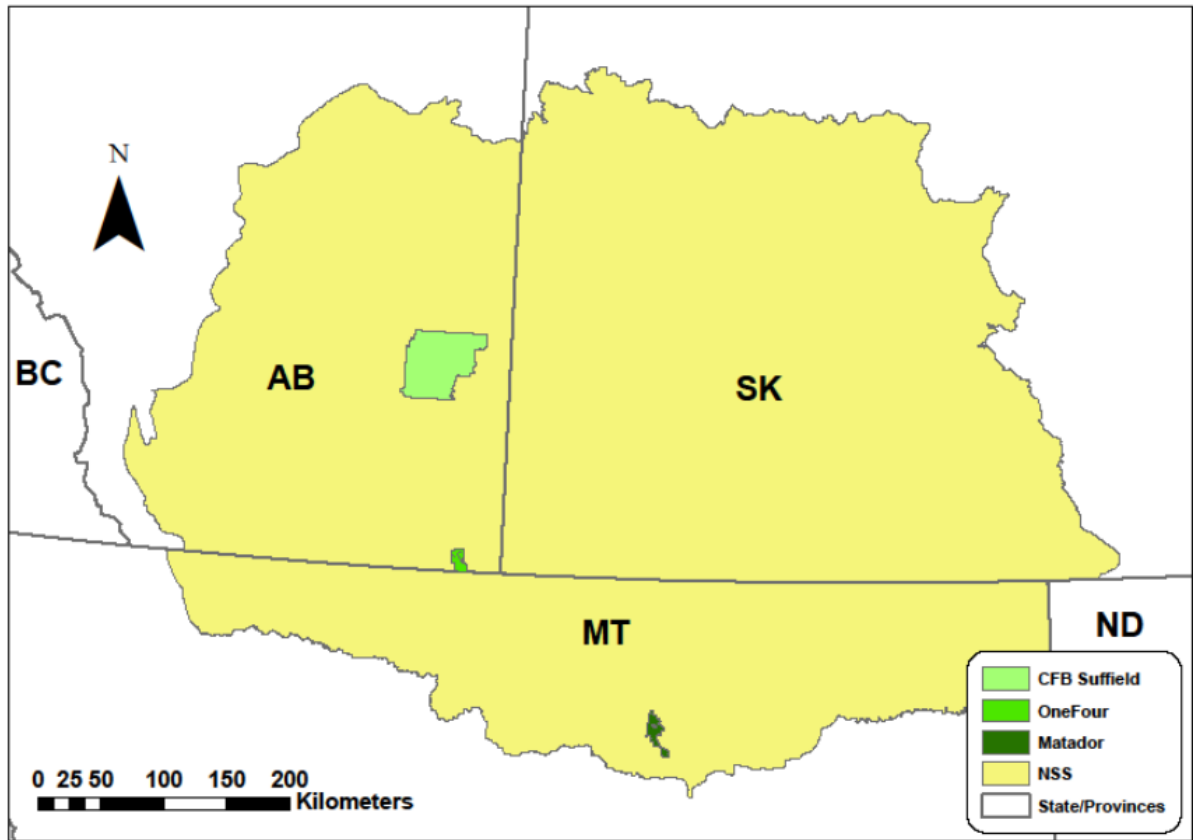
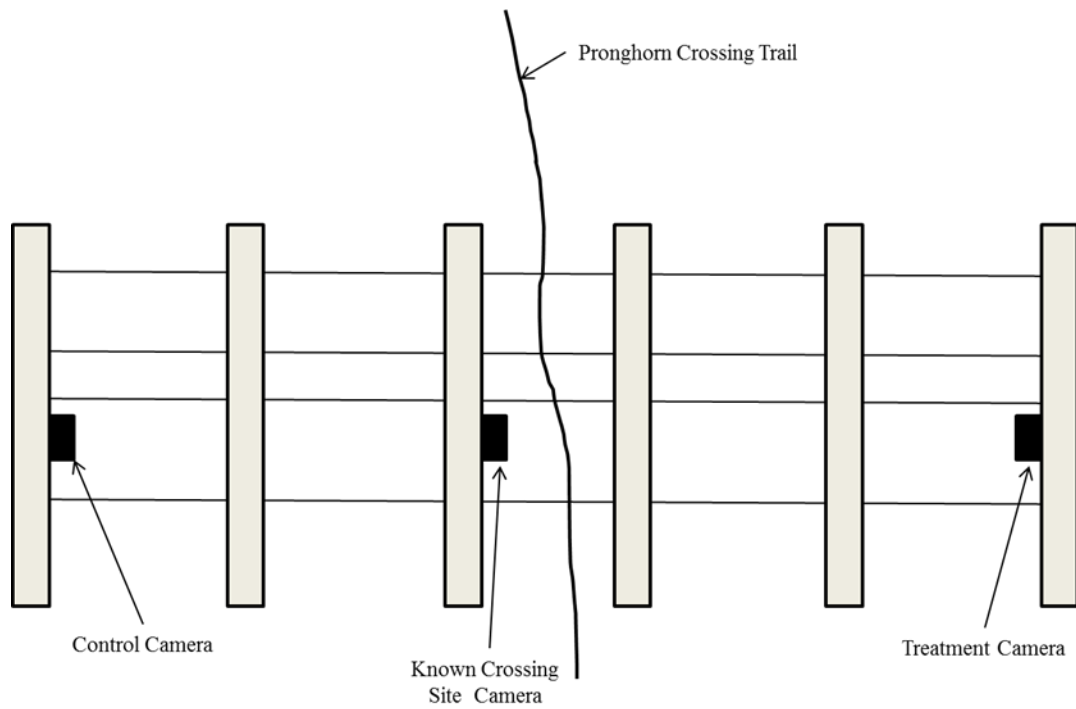


Figure 1b: Making a decision before attempting to cross and then crossing success at specific fence type and crossing decision made

## Study Areas within the Northern Sagebrush Steppe



**Figure 2:** A map made through Global Imaging System software to show the three sites; two study sites in AB included Canadian Forces Base (CFB) Suffield and OneFour Research Center. Field work in MT was conducted at The Nature Conservancy's Matador Ranch



**Figure 3:** A depiction showing the general placements of camera's and treatments at fences with a centered historic (known) location and the control and treatment panels to the right or left of the historic crossing location.

**TABLES**

**Table 1: A priori explanatory variables for modelling crossing decisions made by deer**

Continuous Variables	Categorical Variables
Attempts	Age (fawn or adult)
Bottom Wire Height (cm)	Season (spring, summer, fall, winter)
Top Wire Height (cm)	Sex (male or female)
	Enhancement Type (goat bar, clips, smooth wire)
	Species (mule deer/white-tailed deer)
	Time period (before/after)
	Fence Panel type (historic, enhancement, control)
	Snow (Presence or Absent)

**Table 2a. Pearson's product-moment Correlation results for continuous variables for deer crossing success**

	Attempt	Bottom Wire	Top Wire
Attempt	1.000	-0.011	-0.021
Bottom Wire	-0.011	1.000	0.514
Top Wire	-0.021	0.514	1.00

**Table2b. Pearson's product-moment Correlation results for continuous variables for deer crossing decision**

	Attempt	Bottom Wire	Top Wire
Attempt	1.000	-0.016	-0.070
Bottom Wire	-0.016	1.000	0.546
Top Wire	-0.070	0.546	1.000

**Table 3a. Univariate Analysis for Each Internal and External Variable in Crossing Success**

<b>Variables</b>	<b>Estimate</b>	<b>P-value</b>
Species 1 (int. mule deer)	0.456	2.34e-12
Species 2 (white-tailed deer)	0.143	.001
Age (int. fawn)	0.840	7.67e-08
Age (adult)	-0.096	0.225
Sex (int. female)	0.694	2.00e-16
Sex (male)	-0.154	0.001
Sex (fawn)	0.055	0.484
Season1 (int. spring)	0.403	7.33e-13
Season2 (summer)	0.181	0.037
Season3 (fall)	0.292	2.66e-06
Season4 (winter)	0.350	9.66e-07
Snow Absent (int.)	0.300	2.69e-06
Snow Present	0.249	3.86e-09
Attempt (intercept)	0.897	2.00e-16
Attempt	-0.165	2.00e-16
Before (intercept)	0.606	2.00e-16
After	0.034	0.428
Top Wire (intercept)	0.046	0.820
Top Wire	0.013	0.002
Bottom Wire (intercept)	0.400	3.42e-08
Bottom Wire	0.016	1.00e-04
Site Type1 (int. control)	0.690	2.00e-16
Site Type2 (known)	-0.073	0.202
Site Type3 (known-control)	0.036	0.665
Site Type4 (smooth)	-0.083	0.384
Site Type5 (clip)	0.205	0.025
Site Type6 (goat bar)	-0.40	0.011

**Table 3b. Univariate Analysis for Each Internal and External Variable in Crossing Decision**

<b>Variables</b>	<b>Estimate</b>	<b>P-value</b>
Species 1 (int. mule deer)	1.082	2.00e-16
Species 2 (white-tailed deer)	-0.406	4.01e-14
Age (int. fawn)	0.640	6.24e-04
Age (adult)	-0.073	0.445
Sex (int. female)	0.603	2.00e-16
Sex (male)	-0.400	4.35e-10
Sex (fawn)	-0.022	0.807
Season1 (int. spring)	0.380	8.14e-06
Season2 (summer)	0.406	7.44e-04
Season3 (fall)	0.252	0.005
Season4 (winter)	-0.233	0.017
Snow Absent (int.)	0.887	2.00e-16
Snow Present	-0.330	4.74e-06
Attempt (intercept)	0.448	1.49e-10
Attempt	0.044	0.402
Before (intercept)	0.930	2.00e-16
After	-0.300	4.39e-08
Top Wire (intercept)	-1.090	1.84e-05
Top Wire	0.035	6.26e-10
Bottom Wire (intercept)	-0.391	2.25e-05
Bottom Wire	0.054	2.00e-16
Site Type1 (int. control)	0.136	0.027
Site Type2 (known)	0.458	3.34e-10
Site Type3 (known-control)	0.540	8.51e-08
Site Type4 (smooth)	0.233	0.061
Site Type5 (clip)	0.394	1.20e-04
Site Type6 (goat bar)	0.364	0.281



**Table4a. Step-wise AIC Score for Crossing Success**

Start: AIC=496.01 Decision ~ Sex + BotWire + TopWire + Season + SiteType + Species + Snow + Attempt

Variables	Df	Deviance	AIC
Species	1	464.24	494.24
<none>		464.01	496.01
TopWire	1	466.21	496.21
BotWire	1	469.55	499.55
SiteType	3	475.40	501.40
Season	5	481.51	503.51
SiteType	2	493.28	521.28
Snow	1	493.78	523.78
Attempt	1	515.06	545.06

Step: AIC=494.24 Decision ~ Sex + BotWire + TopWire + Season + SiteType + Snow + Attempt

Variables	Df	Deviance	AIC
<none>		464.24	494.24
TopWire	1	466.80	494.80
+Species	1	464.01	496.01
BotWire	1	470.02	498.02
Season	3	475.41	499.41
SiteType	5	481.74	501.74
Sex	2	493.96	519.96
Snow	1	497.36	525.36
Attempt	1	515.13	543.13

Initial Model:

Decision ~ Sex + BotWire + TopWire + Season + SiteType + Species + Snow + Attempt

Final Model:

Decision ~ Sex + BotWire + TopWire + Season + SiteType + Snow + Attempt

	Step	Df	Deviance	Resid. Df	Resid. Dev	AIC
1				483	464.01	496.01
2	Species	1	0.237	484	464.24	494.24

**Table4b. Step-wise AIC Scores for Crossing Decision**

Start: AIC=244.64 Decision ~ Sex + BotWire + TopWire + Season2 + BeforeAfter + SiteType + Species2 + Snow

Variables	Df	Deviance	AIC
SiteType	5	218.90	240.90
BeforeAfter	1	213.94	243.94
Snow	1	214.15	244.15
<none>		212.64	244.64
BotWire	1	222.97	252.97
TopWire	1	224.02	254.02
Season	3	229.61	255.61
Species	1	236.29	266.29
Sex	2	275.71	303.71

Step: AIC=237.69 Decision ~ Sex + BotWire + TopWire + Season2 + Species2

Variables	Df	Deviance	AIC
<none>		219.69	237.69
+Snow	1	218.96	238.96
+BeforeAfter	1	219.52	239.52
Season	3	231.09	243.09
+SiteType	5	215.65	243.65
TopWire	1	232.59	248.59
BotWire	1	241.94	257.94
Species	1	247.98	263.98
Sex	2	282.12	296.12

Step: AIC=240.9 Decision ~ Sex + BotWire + TopWire + Season2 + BeforeAfter + Species2 + Snow

Variables	Df	Deviance	AIC
BeforeAfter	1	218.96	238.96
Snow	1	219.52	239.52
<none>		218.90	240.90
+ SiteType	5	212.64	244.64
Season	3	230.97	246.97
TopWire	1	232.48	252.48
BotWire	1	237.59	257.59
Speices	1	246.42	266.42
Sex	2	280.99	298.99

Step: AIC=238.96 Decision ~ Sex + BotWire + TopWire + Season2 + Species2 + Snow

Variables	Df	Deviance	AIC
Snow	1	219.69	237.69
<none>		218.96	238.96
+BeforeAfter	1	218.90	240.90
+SiteType	5	213.94	243.94
Season	3	230.98	244.98
TopWire	1	232.59	250.59
BotWire	1	237.75	255.75
Species	1	247.31	265.31
Sex	2	281.10	297.10

Initial Model:

Decision ~ Sex + BotWire + TopWire + Season2 + BeforeAfter + SiteType + Species2 + Snow

Final Model:

Decision ~ Sex + BotWire + TopWire + Season2 + Species2

	Step	Df	Deviance	Resid. Df	Resid. Dev	AIC
1				308	212.64	244.64
2	SiteType	5	6.2623	313	218.90	240.90
3	BeforeAfter	1	0.0578	314	218.96	238.96
4	Snow	1	0.7306	315	219.69	237.69

**Table 5a. Final Model Using Generalized Logistic Regression for Crossing Success**

Variables	Estimate	Std. Error	Z value	Pr(> z )	e <sup>β</sup>
Intercept	-4.127	1.413	-2.921	0.003	0.016
Sex 2(Male)	-1.360	0.275	-4.951	7.36e-07	0.256
Sex 3 (Fawn)	0.482	0.493	0.977	0.328	1.619
Season 2 (sum)	1.227	0.491	2.499	0.012	3.411
Season 3 (fall)	1.140	0.367	3.099	0.002	3.124
Season 4 (win)	0.601	0.482	1.247	0.212	1.824
Attempt	-0.927	0.165	-5.612	2.00e-08	0.396
Snow	1.751	0.326	5.376	7.61e-08	5.760
Bottom Wire	0.073	0.031	2.366	0.018	1.076
Top Wire	0.052	0.033	1.588	0.112	1.053
SiteType2 (K)	-0.460	0.370	-1.245	0.213	0.631
SiteType3(KC)	-0.130	0.524	-0.247	0.805	0.878
SiteType4 (S)	-0.501	0.511	-0.979	0.328	0.606
SiteType5 (Cl)	1.324	0.762	1.736	0.082	3.758
SiteType6 (G)	-2.567	0.952	-2.696	0.007	0.076

**Table 5b. Final Model Using Generalized Linear Regression for Crossing Decision**

Variables	Estimate	Std. Error	Z value	Pr(> z )	e <sup>β</sup>
Intercept	-8.093	2.093	-3.866	1.11e-04	3.06e-04
Species (WTD)	-2.302	0.512	-4.497	6.89e-06	0.100
Sex 2(Male)	-3.542	0.559	-6.333	2.40e-10	0.029
Sex 3 (Fawn)	-0.186	0.698	-0.266	0.790	0.830
Season 2 (sum)	3.058	0.942	3.246	0.001	21.285
Season 3 (fall)	1.258	0.550	2.286	0.022	3.518
Season 4 (win)	-0.106	0.659	-0.161	0.872	0.899

Bottom Wire	0.200	0.058	3.429	6.05e-04	1.221
Top Wire	0.152	0.051	2.972	0.002	1.164
SiteType2 (K)	1.163	0.653	1782	0.074	3.199
SiteType3(KC)	1.197	0.813	1.472	0.141	3.310
SiteType4 (S)	0.330	0.912	0.361	0.718	1.391
SiteType5 (Cl)	0.865	0.830	1.042	0.297	2.375
SiteType6 (G)	1.581	2.097	0.754	0451	4.860

**Table 6a Odds Ratio Table After Enhancements Crossing Success**

	Total	# Not Crossed	# Crossed	P(cross)
Control	54	11	43	0.796
Known	91	42	49	0.538
Known-Control	11	0	11	1.000
Smooth	14	8	6	0.428
Clips	32	2	30	0.937
Goat Bar	6	5	1	0.167
Total	208	68	140	0.673

**Table 6b Odds Ratio Table After Enhancements Crossing Decision**

	Total	# Over	# Under	P(cross)
Control	43	37	6	0.139
Known	49	37	12	0.245
Known-Control	11	6	5	0.454
Smooth	6	2	4	0.667
Clips	30	12	18	0.600
Goat Bar	1	0	1	1.000
Total	140	94	46	0.328

**Table 7a: K-fold cross validation results crossing success**

	Correlation Values	P-values
<b>1</b>	0.818	3.785e-03
<b>2</b>	0.975	1.499e-06
<b>3</b>	0.906	2.959e-04

<b>4</b>	0.895	4.639e-04
<b>5</b>	0.895	4.639e-04
<b>(meanfreq)</b>	0.954	1.788e-05

**Table 7b: K-fold cross validation results crossing decision**

	<b>Correlation Values</b>	<b>P-values</b>
<b>1</b>	0.500	0.1414
<b>2</b>	0.616	0.0577
<b>3</b>	0.752	0.0120
<b>4</b>	0.646	0.0434
<b>5</b>	0.774	0.0085
<b>(meanfreq)</b>	0.875	0.0009