EFFECTIVENESS OF MODIFYING EXISTING FENCES TO DETER DEER AND ELK FROM CROPS AND HIGH-VALUE PASTURES

by

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Lastly, to all graduate students, remember: “It’s not just a job, it’s an adventure”!

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ABSTRACT

Big game can damage crops and compete with livestock for valuable forage. Ranchers have reported their tolerance for big game would increase if the animals could be prevented from using key areas critical for livestock use. Likewise, some farmers have high value areas and crops that must be protected. Fences provide the most consistent long term control compared to other deterrent methods, but are costly to erect. Traditional complete construction of game fences cost more than $9,000 per kilometer for materials. Costs of erecting deer proof fencing can be greatly reduced if an existing fence is modified instead of being replaced entirely. The objective of this study was to investigate the possibility of modifying existing fences to prohibit deer (*Odocoileus spp.*) and elk (*Cervus elaphus*) crossings. Forty exclosures were constructed to test 4 different fence modifications across southwest Montana. Exclosures were baited and monitored for two winters to determine how well they detered ungulate crossings. Results indicate effective modifications can be made to existing fences for $827 - $2187 per kilometer for materials. Different designs proved to have varying levels of effectiveness, with 1.8 m woven wire being 100% effective. These fences are a cost-effective way to fence out wildlife in many high-value areas where traditional fences are not practical. If farmers and ranchers can keep big game out of important foraging areas, their tolerance for these animals on the rest of their property may increase as depredation losses decrease.

CHAPTER 1

INTRODUCTION

Wildlife damage is a major concern for many farmers, ranchers, and wildlife professionals throughout the United States. In the western U. S., much of this concern is centered upon deer (white-tailed deer, *Odocoileus virginianus* and mule deer, *O. hemionus*) and elk (*Cervus elaphus*) consuming forage meant for livestock. Deer and elk cause considerable monetary losses as perceived by some farmers and ranchers (Conover 1994; Wywialowski 1994; Irby et al. 1997). Big game animals caused an average monetary loss of $5616 in forage consumption per landowner in southwest Montana in 1993 (Lacey et al. 1993). Mule deer depredation of alfalfa fields has been estimated between 2.2 and 2.6 kg/deer per night (Austin et al. 1998). Financial losses due to wildlife depredation lower landowner tolerance of wildlife on their property (Conover 1998). Compensation programs exist in some areas to replenish losses accrued by ranchers due to wildlife forage consumption, but these programs are costly and do not satisfy all producers (Van Tassel et al. 1999; Wagner et al. 1997).

Although many methods of deterring ungulates to prevent depredation have been used, fencing is the most reliable long-term method (Craven 1983; deCalesta 1983). Unfortunately, fence is expensive to build, sometimes more costly than the commodity being protected. Many designs of woven wire and electric fences are currently used. These include slanting electric fences, double fences, and L shaped overhead designs. One of the most common designs used today is an eight foot high woven wire fence such as the one built for the Starkey Experimental Forest and Range in Oregon in 1987. Total costs for materials to build that fence were $6521.41/km based on 1992 prices (Bryant et al. 1993). The cost of material to build the same fence in 2006 would be $9393.97/km.

By reducing costs of fence construction, more high value crops and pastures can be protected from ungulates in a cost-effective manner. Modifying existing fences instead of constructing new fences would greatly reduce materials cost. Having the ability to use cost-effective fencing to reduce ungulate depredation in key areas will allow farmers and ranchers to reduce forage losses without having to rely on state reimbursement programs or other retroactive solutions. Tolerance for wildlife on private lands can be increased if damages caused by wildlife are reduced or wildlife can be directed to less critical areas. By fencing only key areas subjected to high economic losses from ungulates, wildlife migrations and daily movements will not be interrupted, and crucial habitat is provided by the rest of the ranch at a reduced overall cost to the producer. Increased tolerance for deer and elk on private lands is an important consideration today and in the future of wildlife management, as more historical range for these animals is overtaken by human development.

Many pastures and crops in Montana are already fenced to contain or exclude cattle and sheep. The typical ranch in southeast Montana has 58 km of livestock fence (Williams et al. 1996). This study investigated the possibility of modifying existing livestock fences to prohibit deer and elk entry. Previously, there were no formal evaluations on the effectiveness of such fences at deterring deer and elk.

Four modification designs using combinations of woven and smooth wire were tested across southwest Montana over two winters. The four tested modifications used rebar post extensions and were each 1.8 meters high. All designs were developed to cost as little as possible, while still being potentially effective at stopping deer and elk. The goal was to create a barrier that an animal would not be willing to cross under normal circumstances, although the capability of a deer or elk to penetrate even the most expensive design tested certainly exists.

The hypothesis tested was: each of four selected fence modifications will successfully deter deer and elk more often than the control.

CHAPTER 2

LITERATURE REVIEW

Wildlife Depredation

Deer and elk in southwest Montana and other areas of the intermountain west cause considerable monetary losses as perceived by some farmers and ranchers. Wildlife professionals agree that wildlife are causing economic losses to farmers and ranchers at an increasing rate (Conover and Decker, 1991). In 1994, 27.9% of field crop producers in this region reported wildlife losses caused by hoofed mammals (Wywialowski, 1994). A different 1994 nationwide survey of farmers reported that 89% of farmers had wildlife cause damage on their farm, with damage from deer being reported by 67% (Conover, 1994). Over 66% of farmers in northern Utah and southwest Wyoming have experienced wildlife damage, and deer are perceived as the greatest source of wildlife damage (McIvor and Conover, 1994). In Montana, 51% of landowners reported consumption of forage as the most common type of wildlife damage, with elk being the major cause in the southwestern portion of the state (Irby et al. 1997). In a statewide survey of agricultural producers conducted in 1993, 81% of respondents reported white-tailed deer on their land, 76% reported mule deer, and 29% reported elk (Irby et al. 1996).

Big game animals caused an average monetary loss of $5616 in forage consumption per landowner in southwest Montana in 1993 (Lacey et al. 1993). Of that forage, elk accounted for 40% and mule deer accounted for 30%. When offered in a mixed diet, daily intake of alfalfa hay by penned mule deer and elk averaged 1.49 kg/100 kg body weight (Austin and Urness, 1987). When considering consumption, effect of grazing on growth, and trampling effects, mule deer depredation of alfalfa fields has been estimated between 2.2 and 2.6 kg/deer per night (Austin and Urness, 1993; Austin et al. 1998).

Financial losses due to wildlife lower landowner tolerance of wildlife on their property. A survey of producers in New York found the majority of farmers losing more than $1,000 annually to deer depredation felt the loss was unacceptable (Brown et al. 1978). Conover (1998) found that 80% of farmers with annual losses of less than $500 from wildlife damage considered their losses to be acceptable. Only 31% of respondents with losses greater than $500 considered losses acceptable, and 24% of respondents in the survey stated that wildlife losses on their farms or ranches was so severe that it reduced their willingness to provide habitat for wildlife on their land. This is consistent with a 1994 survey in which 56% of agricultural grass-roots leaders reported losses higher than they were willing to tolerate (Conover, 1994).

In some areas where damages occur, compensation programs exist to replenish losses accrued by ranchers to wildlife forage consumption, but these programs are increasingly costly and do not satisfy all producers. Major problems with compensation programs are that they do not address the root of the problem and states get into a pattern of paying out reimbursements over long periods. Nineteen states had some form of wildlife depredation compensation program in 1997, most of which were established to reimburse losses from ungulates (Wagner et al. 1997). Mule deer and elk were responsible for most of the depredation claims in Wyoming in 1995, but 50% of producers who submitted claims felt that settlements were not fair and equitable (Van Tassel et al. 1999).

Methods of Deterring Ungulates

Preventing wildlife damage from occurring is generally more beneficial to landowners than trying to compensate for damages later. Many methods of preventing damage by ungulates have been used, with varying results (Craven 1983; deCalesta 1983). Propane gas exploders, fireworks, gunfire, and dogs have all been used to frighten deer, although these are considered short-term solutions to depredation. Formal testing of frightening devices with deer has shown them to be ineffective at reducing crop damage for long periods of time, although they may be an effective short term solution (Belant et al. 1996; Gilsdorf et al. 2004). Propane exploders and aircraft have been used to haze elk, but are also considered short-term solutions. Combining audible cues with a negative stimulus has also been tried, but did not deter white-tailed deer (Gallagher and Prince, 2003). Repellents such as human hair, bone tar oil, mothballs, hot pepper sauce, blood meal, cat feces, soap, coyote urine, and fermented egg solids have been used to deter white-tailed and mule deer, with some temporary success (Craven 1983; Conover, 1984; Swihart and Conover, 1990; Andelt et al. 1991; Andelt et al. 1994). Few of these are effective with elk (Andelt et al. 1992). Most repellants are more suited for orchards, vineyards, and ornamental planting, where potential damage is concentrated in a small area. High costs and limitations on use make repellents unpractical for most row crops, pastures, and other large areas (Craven 1983). Shooting deer or elk through special damage hunts or trapping animals and relocating them temporarily reduces the local population and can alleviate damages, but when herds rebuild damage will likely occur again in crops or pastures (deCalesta 1983).

Fences provide the most consistent long term control compared to other deterrent methods, but can be costly to erect (Craven 1983; deCalesta 1983). Many designs of woven wire and electric fences have been tried and are currently used (VerCauteren et al. 2006b). The most commonly accepted design used today is a 2.4 m woven wire fence (Ray 1984). This style of fence is considered nearly 100% effective, but expensive. The Starkey Experimental Forest and Range in Oregon used this style of fence at a cost of $6521.41/km for materials based on 1992 costs (Bryant et al. 1993). The purchase price of material to build that same fence in 2006 is $9393.97/km, based on prices in the Bozeman, Montana area. A similar woven wire fence 2.6 m high was constructed on the Stephen F. Austin Experimental Forest in Texas (Halls et al. 1965). This fence included a single strand of smooth wire above the woven wire, and a 1.2 m wide section of woven wire was placed along the ground to discourage dogs and other animals from digging under the fence, and cost $840.16/km in 1964 (Halls et al. 1965). Fences 2.3m high have been used to deter deer from highway right of ways in Utah (Lehnert and Bissonette, 1997). Slanting designs constructed of woven wire fencing have also been used with effective results (Messner et al. 1973). Inverted L-shaped woven wire and double woven wire fences have also been briefly tested, but no extensive formal examination of effectiveness has been performed (Goddard et al. 2001). Plastic net fencing 2.4 m high is considered effective for fencing small areas in an urban settings, but has not been tested on large scale applications (Rosenberry et al. 2001).

Many electric varieties of fencing have also been used to deter deer and elk. A recent evaluation of ElectroBraid^{TM} fence found it to be an effective barrier at a cost of $9,000/km for materials and installation labor (Seamans and VerCauteren, 2006). A vertical 5 wire electric design developed by Pennsylvania State University has been effective at deterring deer (Craven 1983). Derivations of a slanting 7 wire electric fence have been used to prevent deer and elk from consuming haystacks (Onstad and Knight, 2001). A single strand of electric wire baited with peanut butter has proven effective at reducing deer depredation in cornfields, although this is not a practical permanent control (Hyngstrom and Craven, 1988). Woven wire 1.2 m high with an electric offset was tested briefly and failed (Goddard et al. 2001). Electric offsets have also been designed using 3 electric wires with some success (Craven 1983). All of these fence designs are focused on new construction.

Wildlife Movements

Using fencing to control wildlife depredation can sometimes interfere with daily wildlife movements and migration routes. For this reason, daily movements of ungulates must be considered when evaluating fencing as a wildlife control method.

Deer and elk have been documented to travel significant distances in a day's time. Fall movements of elk in a 1973 study averaged over 1.5 km per day (Craighead et al. 1973). Mean daily movements of elk in Michigan were measured at over 1200 m when human activity was occurring (Knight 1981). Summer and fall home ranges for elk in Wyoming have been measured between 250 and 3988 hectares (Rudd 1982).

White-tailed deer have been found to move up to 18.6 km per day, with average hourly movements of 1.5 km (Nelson et al. 2004). One study of dispersing white-tailed deer recorded daily movements of up to 9.4 km (Nelson and Mech, 1992). In the Missouri River Breaks area of Montana, mule deer buck average home range size is 27 square km, and for white-tailed bucks near the Yellowstone River, average home range is 5.2 square km (Mackie et al. 1998).

CHAPTER 3

METHODS AND MATERIALS

Pilot Study

In 2002, pilot study and demonstration sites were chosen near Billings and Ennis, Montana, in areas where damage to crops traditionally occur. To identify fence designs deserving more formal evaluation, 50 m sections of existing fences were augmented with high-tensile wire, woven wire, or polypropylene mesh. On all of these existing four-strand barbed-wire fences, fence posts were extended with fiberglass rods to achieve a height of 1.83 m. Three designs were installed. Design 1 used 3 strands of high-tensile wire alternating with existing barbed wire, plus two strands were extended above the existing fence and were attached to the fiberglass post extensions. Design 2 used 1.19 m Max-Flex woven wire mesh (5 cm X 10 cm) plus 3 strands of high-tensile wire on the extended fence posts. The 3rd design was simply 1.83 m high polypropylene mesh. Strength and durability were monitored periodically. Fence modification designs were considered adequate and acceptable if fence sections withstood environmental conditions after 6 months. From this effort, 4 variations of high tensile wire and woven wire designs were developed for further testing and evaluation in this project.

Formal Evaluation

Test Sites

Formal testing of 4 configurations of the high-tensile and net-wire designs has taken place on private ranches in central and southwestern Montana. Specific designs were selected to minimize cost of material to increase cost-effectiveness potential. Materials used in this study were selected based on the results of the pilot study. Procedures used during this project were approved by the Montana State University Institutional Animal Care and Use Committee, protocol number 52-05.

Testing was conducted to show effectiveness of each fence design at deterring deer and elk separately so results would not be confounded. The main criteria for site selection was a history of relatively high winter use of the area by deer or elk, but not both species concurrently. Four ranches were chosen for the study where ungulate numbers were relatively high (Fig. 1). On each ranch, two individual study areas were selected, giving a total of 4 replication sites for deer and 4 for elk. The Sun Ranch, LLC., which is located approximately 20 miles south of Cameron, MT, and the Galt Ranch, approximately 10 miles west of White Sulfur Springs, MT, were used for testing fences as elk barriers. The American Fork Ranch, located approximately 15 miles northeast of Melville, MT, and the Lane Ranch, approximately 10 miles east of Livingston, MT, were used for testing with deer. The American Fork Ranch had predominately white-tailed deer at both sites, with mule deer occasionally seen. At the Lane Ranch, one site was visited predominately by white-tailed deer, the other site mostly by mule deer.

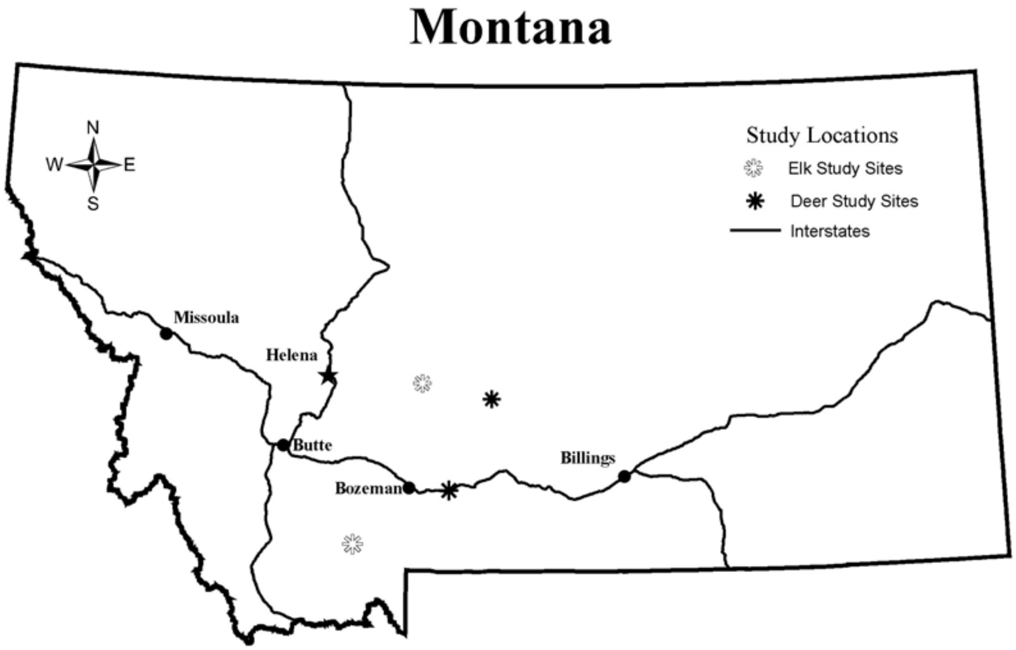

Figure 1. Study Site Locations

Sites on each ranch were separated to eliminate the likelihood that the same animals would visit both sites during any given week. Site separation at testing locations for deer was approximately 10 km, and for elk, sites were separated by approximately 14 km and 60 km on each ranch. Specific site selection criteria included relatively level ground, as little rock as possible, and a history of ungulate use during winter in the specific location. The study period was from October through March during 2004 - 2005, and repeated in 2005 - 2006.

Fence Designs

All 4 fence designs were modifications of an existing 4 strand barbed wire fence. In all designs, 1 cm rebar was used to extend the height of wooden posts to 1.90 m. A 1 cm hole was drilled into the center of the post to a depth of 15 cm, and a 75 cm section of rebar was driven into the hole with a hammer. Corner posts were extended to a height of 1.9 m using a 120 cm long piece of 4 cm by 4 cm by 3 mm angle iron, which was wired to the post in 2 locations. Wires were attached to wood posts using 38 mm barbed fencing staples, and attached to steel extensions using 16.5 gauge tie wire.

Design 1 (Fig. 2) consisted of adding a single strand of 12 gauge smooth wire between each existing barbed wire and between the bottom barbed wire and the ground. Three strands of 12 gauge smooth wire were added above the existing barbed wire to bring the fence height to a total of 1.83 m. Vertical fence stays were placed on the wires between posts to hold the bottom 8 wires at a consistent spacing. Wire spacing was 15 cm for the bottom 8 wires, and 20 cm for the top 3 wires. Rebar extensions were bent at a 45 degree angle to the outside of the fence.

Figure 2. Design 1

The second design (Fig. 3) was identical in wire configuration to the first; the only difference was 4 strands of additional smooth wire were electrified with a portable charger producing a minimum of 4 Kv of electricity. The lowest additional strand of smooth wire was not electrified so vegetation would not ground the fence. The next 4 additional wires were electrified, leaving the top two additional wires non-electric. All barbed wires and the bottom strand of smooth wire were connected to a ground rod driven 30 cm into the soil. Tube insulators were used on electrified wires on wooden posts, and corner insulators were used in each corner. Rebar extensions were bent outward at a 45 degree angle. No fence stays were used.

Figure 3. Design 2

Design 3 (Fig. 4) had 1.19 m high woven wire (15 cm x 15 cm) placed over the barbed wire, with the bottom at ground level. Three strands of 12 gauge smooth wire were strung above the barbed wires to bring the total height to 1.83 m. Wire spacing for the 3 smooth wires were 20 cm. Once again, rebar extensions were bent at a 45 degree angle towards the outside of the fence.

Figure 4. Design 3

The fourth design (Fig. 5) had 0.99 m woven wire placed over the barbed wire, with the bottom at ground level. Then, 0.81 m woven wire was strung above to bring the total height to 1.80 m. Woven wires were tied together using 16.5 gauge tie wire. Due to the stiffness of the woven wire, rebar extensions were left straight in this modification.

Figure 5. Design 4

Study Design

At each of the 8 study sites, 5 individual standard 4 strand barbed wire fence exclosures were constructed. Each square exclosure was 9.75 m by 9.75 m. Wooden posts measuring 10-13 cm in diameter were driven into the ground 60 cm using a tractor mounted hydraulic post driver. Aboveground height of each post was 1.37 m. Corner H braces were assembled, with 5 m spacing between each. Four strands of 12.5 guage twisted barbed wire were attached to the posts, with equal spacing of 30 cm between each wire, to bring the total height of the top wire to 1.2 m. Fence stays were used to insure equal wire spacing between corner assemblies.

Exclosures were constructed in a line parallel to nearest available cover with 10 m between each exclosure (Fig. 6). Four exclosures were then randomly selected to recieve 1 of the 4 selected fence designs, with the 5th left as a control. Since the study compared modifications to a 4 strand barbed wire fence, a non-modified 4 strand barbed wire fence was used as the control. Six small square bales (approximately 200 kg total) of high quality alfalfa hay were then stacked on edge inside each exclosure in a 2 wide by 3 high pattern as bait.

Figure 6. Baited Site.

Exclosures were monitored once weekly from October through March to determine if deer or elk entered them. All exclosures were monitored for 22 weeks during 2004-2005, and for 24 weeks during 2005-2006. The study was conducted during winter so that animals could be baited with a food source into exclosures. Each exclosure was considered to be breached if there was evidence of any deer or elk entering, including tracks, scat, or consumed hay. Necessary repairs were made to all fences on a weekly basis, restoring them to original condition. Alfalfa hay was replenished as needed every week. By repairing each study site to original condition every week, independence among treatments was maintained. If an exclosure was breached, it was counted as a failure for that period of one week, and unbreached fences were counted as a success. Any exclosure that was breached and had all hay consumed for three consecutive weeks was determined to be a failure for that site for the remainder of the winter, and was no longer repaired or replenished with fresh hay. Controls were baited continuously throughout the study season.

Analysis

Statistical analysis of differences between fence designs was calculated using a z test of proportions. Data collected were count data and met the assumption for normality, with large enough sample sizes to make a *z* test the most appropriate. Analysis was conducted separately for deer and elk. Data from all 4 sites through both years for each species was pooled in the final analysis. The total number of breaches of the control exclosure was used to determine *n* in the calculation. Use of the control assured that deer or elk were in the area and conditions were such that they were attracted to the alfalfa bait. Differences were considered significant at $P \leq 0.1$. The treatments in this study were the fence designs. The experimental unit was each individual exclosure. The observational unit was each individual fence modification.

CHAPTER 4

RESULTS

Deer

Pooled data for sites testing efficacy with deer yielded a total of 184 weeks where fences were baited and being actively monitored. Of these, the control was breached a total of 126 times, which was the corresponding n for calculating z values for proportions.

Differences between all fence designs and the control for deer were considered statistically significant at $P \leq 0.1$, with $P \approx 0$ for all designs compared to the control. Design 4, 1.8 m woven wire, was the most consistently effective design for deterring deer throughout the study, with zero failures (Fig. 7).

Significant differences between the designs when compared to each other were also found (Table 1). Numbers of deer breaches by month for each site are provided in Appendix A.

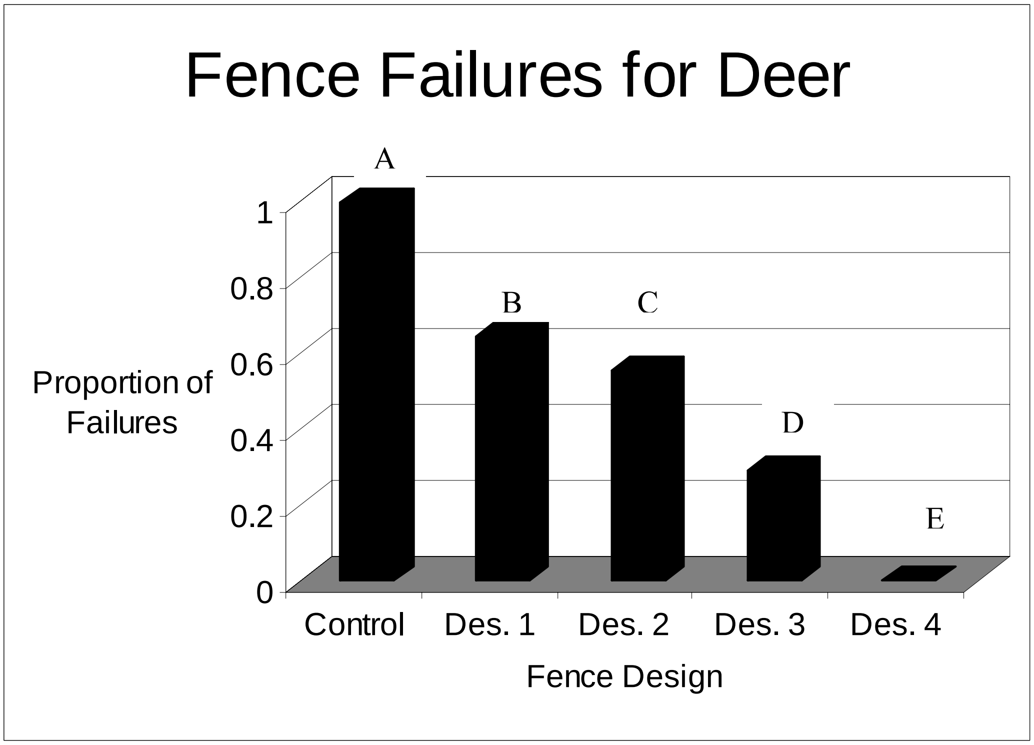

Fig. 7. Proportion of Fence Failures for Deer

Table 1. Differences in Breaches Between Designs for Deer

	n	# Breaches	Proportion of Breaches	*z**	Sample Variance	*P*-value
Control	126	126	1	153.39	0.095	≈ 0
Design 1	126	81	0.675			
Design 1	126	81	0.675	1.41	0.061	0.079
Design 2	126	70	0.555			
Design 2	126	70	0.555	4.21	0.06	< 0.001
Design 3	126	37	0.294			
Design 3	126	37	0.294	6.58	0.041	≈ 0
Design 4	126	0	0			

Elk

Pooled data for sites testing efficacy with elk yielded a total of 150 weeks when sites were baited and being monitored. Snow drifts greater than 1 m deep caused 3 sites to be temporarily removed from the study during year two. Since the effective height of the fence was less than 1 m, and not a valid test of the designs under normal conditions, these weeks were not included in the analysis, resulting in a difference between total number of weeks tested for deer and elk. To be consistent, breaches of the control exclosure were still the factor to determine n calculated into the analysis. The control for elk sites was breached a total of 61 times, which was the corresponding n for calculating z values for proportions.

All designs were significantly different from the control, with $P \approx 0$ for all designs when compared to the control. Design 4, 1.8 m woven wire, was the most consistently effective design for deterring elk throughout the study, with zero failures (Fig. 8).

Comparing among designs, differences between design 1 and design 3 were not considered to be statistically different. All other designs were statistically different from each other considering $P \leq 0.1$ (Table 2). Numbers of elk breaches by month for each site are provided in Appendix B.

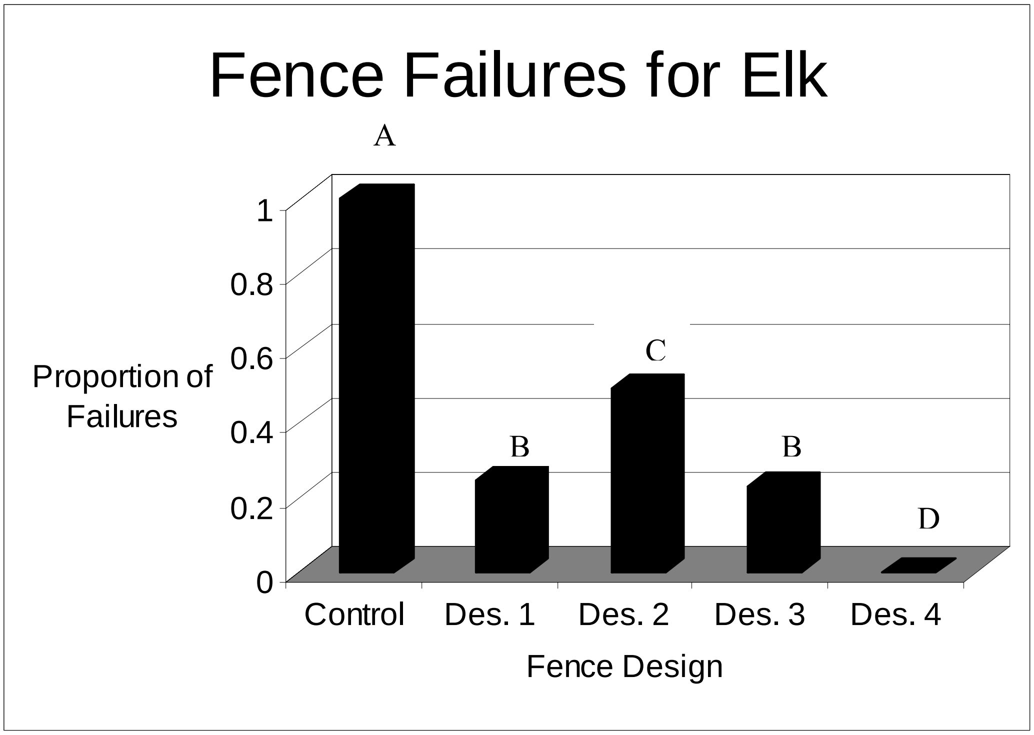

Fig. 8. Proportion of Fence Failures for Elk

Table 2. Differences in Breaches Between Designs for Elk

	n	# Breaches	Proportion of Breaches	*z**	Sample Variance	*P*-value
Control	61	61	1	8.59	0.055	≈ 0
Design 1	61	15	0.246			
Design 1	61	15	0.246	-2.82	0.084	< 0.003
Design 2	61	30	0.492			
Design 2	61	30	0.492	3.02	0.083	< .002
Design 3	61	14	0.229			
Design 3	61	14	0.229	3.97	0.053	< 0.001
Design 4	61	0	0			
Design 1	61	15	0.246	0.21	0.077	0.4161
Design 3	61	14	0.229			

Material Cost

Cost of materials for design 1 was approximately $812/km. Design 2 cost $937/km, using a portable, battery operated fence charger. Design 3 cost $1625/km, and design 4 cost $2187/km. Cost for all designs exclude the initial 4 strand barbed wire fence. All prices are for materials only, and were calculated from retailers in the Bozeman, MT area at the time of construction in August, 2004. Costs of fencing have traditionally been broken down into materials and labor for installation (Halls et al. 1965; Bryant et al. 1993; Seamans and VerCauteren, 2006; VerCauteren et al. 2006b). In this study, labor was not included in determining cost of fence construction. Labor expenses for fencing are highly variable depending on location, landscape features, type of fencing, and contractors involved. Therefore, only material cost has been calculated for these designs, and should be compared to other fences accordingly (Fig. 9).

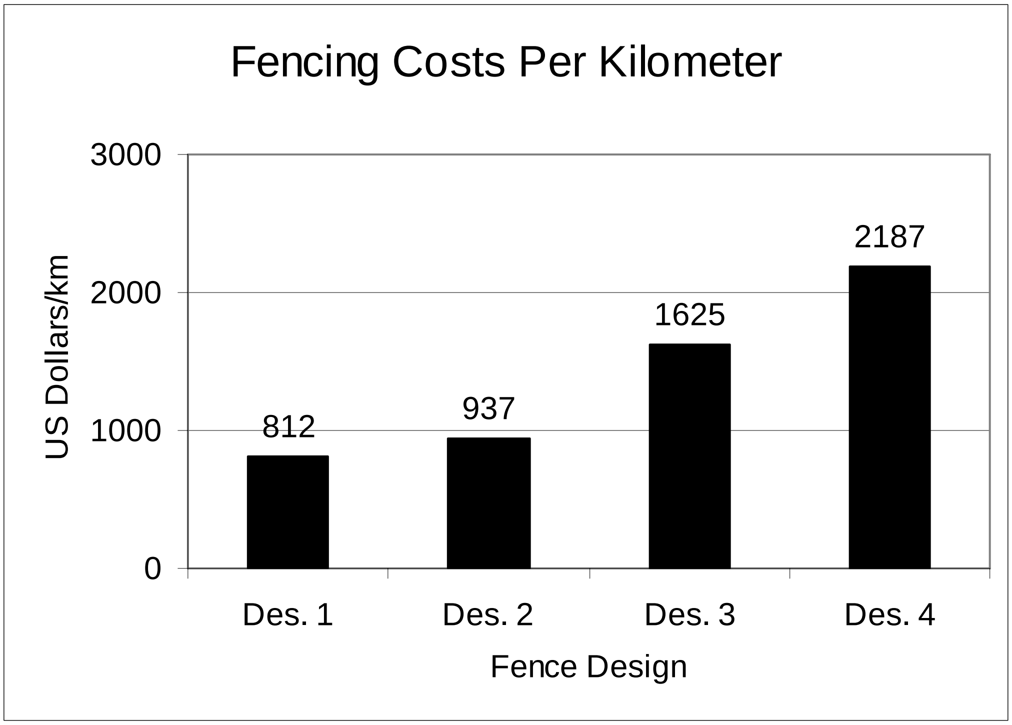

Figure 9. Fence Costs for Material

CHAPTER 5

DISCUSSION

Modifications

All tested designs were more effective than controls, so the hypothesis that each of four selected fence modifications will successfully deter deer and elk more often than the control was not rejected. There were differences among designs, with some being more effective than others. The 1.8 m woven wire design was the most effective for deer and elk, but other designs showed some ability to deter ungulates.

Design 1 was the modification most often breached by deer during the study. Deer were consistently able to crawl between the lower wires in this design, despite the use of a fence stay to hold the wires together. No deer were observed attempting to jump into this exclosure, and damage to the exclosures indicated that jumping in did not occur. However, deer frightened by approaching humans were often observed jumping out over the top wire of the exclosure. The angle at the top of the fence may have facilitated this behavior, as documented by Jones and Longhurst (1958).

Design 1 was more effective at deterring elk than deer. Designs 1 and 3 were the 2nd best designs for repelling elk. The fence stay held the lower wires close enough together to make it difficult for the larger elk to crawl through. When breaches did occur, evidence indicated that elk crawled through the fence instead of jumping over it.

Design 2 was the 3rd most effective design for deer and the poorest tested modification for elk. Crawling through the lower wires was the method of entry noted for design 2, even though 4 of the bottom 9 wires were electrified. The electrified wires easily tangled with the grounded barbed wires, effectively grounding the fence charger. Deer were observed crawling through the fence at times when the fence was known to be charged. Their heavy winter coat may have insulated deer from the electric charge. This has also been speculated in other electric fencing studies for deer, although not formally tested (Seamans and VerCauteren, 2006). Even when ties were added to maintain the spacing of the electric wires to increase pressure against the hide, deer were seen crawling through with no apparent shock. Evidence from damage indicated that elk also crawled through this design. The lack of a fence stay likely allowed the wires to stretch when elk pushed against them, allowing them to breach the fence. The electric charge apparently had little if any effect on elk or deer in this study.

Design 3 was the 2nd most effective design at deterring deer. The woven wire base made it impossible for deer to crawl through, and there was no evidence of deer jumping over the top wire of the fence. Instead, it appeared that when deer entered, it was by jumping between the woven wire and lowest strand of smooth wire. Another wire placed directly above the woven wire may have stopped this, although this was not tested. When deer left this exclosure, it appeared that they jumped out over the top, likely due to the angle of the top 3 wires. Design 3 tied for the 2nd best modification for elk. Similar to deer, elk appeared to enter by walking over the woven wire and beneath the smooth wires. Being taller, elk were able to get their head inside the exclosure directly over the woven wire, and then pushed their way through. This type of behavior when elk approach fences has been documented in previous research (Bauman et al. 1999). When elk entered, they typically pushed the woven wire down to a height of 30 – 60 cm. Elk were seen jumping out of this exclosure over the top wire when frightened by humans, but damage and tracks also indicated they crawled back out through the hole created upon entry.

Design 4 was the most effective for both deer and elk. Deer never breached this design during the course of the study; elk only breached it when snow drifted deeper than 1 m and developed a solid crust, reducing the effective height of the fence to 0.8 m. At all study locations, deer and elk left a heavily rutted trail all the way around exclosures with this design, but did not jump over it, even when the exclosure was the only one containing alfalfa hay.

Fence Damage

In all designs that were breached, considerable damage was sometimes done to the fence. Rebar post extensions were often bent to the outside of the exclosure, presumably from attempts to jump out. However, no rebar ever broke, and extensions were easily straightened by hand. Angle iron corner extensions were also bent regularly, and use of a heavier angle iron or a tall wooden post could have prevented this. Smooth and barbed wires were often broken during this study, although this is not as likely to happen when fencing over a longer distance, which will allow wires to stretch rather than break. Deer and elk also snapped several wooden posts during the study, and this is also less likely to happen on longer expanses of fence.

Benefits of Modifying

The effectiveness of using 1.8 m fence height is an important finding from this study. Previously, the most commonly accepted fences for deterring ungulate crossings have been constructed with woven wire 2.4 m in height (VerCauteren et al. 2006b). Deer and elk have the ability to jump over fences higher than 1.8 m (Craven 1983). However, this did not occur during this study using a food resource as bait during winter conditions. This indicates that a desire for food is not enough motivation for an ungulate to jump over a fence of this height. It is reasonable that the drive to obtain food inside an exclosure will be less if resources are sufficient outside the exclosure. The results of this study indicate that a fence higher than 1.8 m is not necessary to protect a food source from ungulates, even during harsh winter conditions. This lower height is necessary for modifying an existing fence as opposed to construction with all new materials.

Many pastures and crops in Montana and other areas of the west are currently fenced with 4 strand barbed wire or woven wire fences to control domestic livestock, particularly cattle and sheep. Few of these fences are higher than 1.2 m, which allows for passage by deer and elk. In the past, deer and elk proof fences typically involved construction of 2.4 m fencing using wooden posts 3.35 m long, set into the ground to a depth of 90 cm. To construct this high fence around a field already fenced to control livestock, the existing fence posts were replaced with the longer posts. The cost of material and labor due to this was very high.

Extensions to wooden fence posts with an above ground height of 1.2 m were successful in this study at supporting wires in a durable fashion for an additional 60 cm of height. By using fence posts already in the ground instead of replacing, cost of the fence was reduced greatly. Posts described by Bryant et al. (1993) in the construction of the fence around the Starkey Experimental Forest and Range in Oregon currently cost $23.10 each in the Bozeman, MT area. The 1 cm steel rebar extensions used in this study cost $0.41 each. Approximately 145 posts are necessary to construct 1 km of fence, yielding a savings of $3290 per km on posts alone. If steel T-posts are in place instead of wood posts, they can also be extended by welding rebar on or using modifications described by Onstad and Knight (2001).

Another benefit of using an existing fence is that some of the wires already in place can be used in the modification design. Although this study focused on modifying 4 strand barbed wire fences, fences for controlling domestic sheep are often constructed using 0.8 m – 1.2 m of woven wire. This woven wire can be used as part of the modified design, reducing purchase cost of wire.

Labor cost was not calculated for any designs in this study, but will be reduced by using materials already in place as well. Modifications can be made to posts with considerably less equipment and effort than setting a new post. Some wire already in place may be used, reducing labor for stringing wire. Existing fences will not have to be removed to allow for new construction, further lowering labor costs.

Cost – Benefit

Not all designs tested in this study should be considered adequate at providing relief from ungulate depredation in all situations. A fence must be cost-effective to produce a desired savings over time, and each individual producer will have to make decisions based on their unique situation. The results of this study show that design 4, a 1.8 m woven wire fence, will be sufficient in most situations for protection of high value crops and pasturelands. Although it was the most expensive, the cost is low enough to be cost effective in many situations. Individual landowners may find, however, that a lower cost design would be beneficial in their particular situation, despite the lower expected efficacy. Areas where pressure on crops is limited by abundant nearby resources may not require expensive fencing to deter ungulates. Particular pastures that have been set aside for spring livestock forage, for example, may not require expensive fencing to keep elk from foraging if similar resources are available nearby.

Cost of fencing is perhaps the most important factor for a landowner deciding whether or not to implement fencing as an ungulate depredation control method. In order to be cost-effective, the cost of the fence can not exceed damage losses expected over the lifespan of the fence. Cost to benefit ratios should be calculated considering the expected lifetime of the fence used. This requires estimation of future damage losses, and landowners should have a thorough understanding of local game patterns and value of losses before investing in fence as a control method. Using more expensive designs such as the 2.4 m woven wire described by Bryant et al. (1993) to exclude wild ungulates from livestock forage production areas will often prove to be more costly than the depredation by ungulates. By reducing initial cost with designs tested in this study, fencing will become an efficient mechanism for certain producers to lessen depredation losses on forage and cropland.

To determine whether a fence will save a producer money or not, the cost of replacing lost forage for the entire time the fence will be in place should be compared against the initial cost of the fence. Austin et al. (1998) reported mule deer consume and trample 2.4 kg of alfalfa per deer per night. If 50 deer forage on a 100 hectare alfalfa field for 90 nights during the growing season, they will eat or trample 10,800 kg of alfalfa that could otherwise have been used as livestock forage. The cost to replace this forage at $88 per 1000 kg would be $950. A woven wire fence constructed on treated wooden posts has an expected life-span of approximately 30 years. Considering $950 per year for 30 years, the total losses to the producer will be $28,500. A 100 hectare square field will require 4 km of fence to enclose. Based on this study, modifying a fence to make it repel deer costs $2,187 per km. The material to fence this field will cost $8,748, which will yield a savings of $19,752 minus labor. This example shows the potential benefit of using a modified fence to reduce losses from ungulates.

A producer must also calculate maintenance cost when considering whether or not a fence will be cost effective. Maintenance will vary highly depending on terrain, weather conditions, and vegetation in the area, and should be considered on a case by case basis. Additionally, future conditions must be anticipated, and changing ungulate populations or patterns, different crops and changing commodity prices will all need to be considered before choosing to fence an area to prevent wildlife depredation. In 2006, a computer program was developed that producers can use as a model to determine cost effectiveness of using fence to control wildlife depredation (VerCauteren et al. 2006a). Tools such as this should also be used by ranchers before deciding whether or not to implement fencing to prevent ungulate depradation.

Areas Suited to Fence Modification

Modified fencing for deer and elk should be considered only for areas that receive a loss in production that justifies the expense of fence construction. Fencing should be limited to specific portions of ranches that receive high economic losses, and not be applied to large expanses of land. Examples of areas that may be beneficial to protect if they are heavily used by deer or elk include grain crops, hay crops, and irrigated, fertilized, or otherwise improved pastures. Large-scale application will likely reduce the economic benefit to a point that makes the control unpractical from an economic sense.

Another consideration for producers using fencing is wildlife passage through their property. Fences should not be constructed in such a manner to interrupt seasonal wildlife migrations or daily movements. Areas less than 400 hectares would be appropriate. The length of the fence on any side of a square exclosure this size would be 2 km, leaving a deer or elk with a maximum distance of 1 km to travel to circumvent the excluded area around the nearest side of the fence. Both deer and elk are capable of traveling this distance in a day. Craighead et al. (1973) found that fall movements of elk were an average of over 1.5 km per day. Migrating deer have been found to move 2.1-

18.6 km per day, with hourly average movements of 1.5 km (Nelson et al. 2004). Limiting sizes of fenced areas will allow deer and elk access to necessary habitat throughout the property, while still protecting the landowner's valuable interests. The objective of using these modified fence designs is to reduce monetary damages caused by wildlife, not reduce wildlife numbers on private lands. Landowners have expressed that wildlife damages below $1000 annually are tolerable, but above that is unacceptable (Brown et al. 1978). In a more recent survey by Conover (1998), 80% of farmers indicated that annual losses less than $500 from wildlife were acceptable. By reducing damages done by deer or elk in areas of high value, levels of damage may be reduced to the acceptance threshold. This should increase tolerance for deer and elk on the rest of the farm or ranch.

Situations Not Suited to Fence Modification

The fence designs tested in this study should not be applied to all situations where deer or elk need to be excluded. These designs were developed to maintain low material cost, so they could be economically practical for agricultural producers. Although no animals penetrated the 1.8 m woven wire design in this study, it is certainly possible for deer and elk to jump over fences 1.8 m high. In cases where few animals could cause large losses in a short time, more expensive fencing may be justified. Higher value interests increase the amount of money that can be spent cost-effectively on ungulate control. Game farms or airports, where zero tolerance for deer crossings is demanded under all circumstances, are examples where woven wire fences 2.4 m high are justified.

Designs tested in this study may be ineffective during winter in areas where deep snow will accumulate and crust. Due to the lower height of these designs, hard packed deep snow allows animals to cross more easily. During the second year of the study, snow up to 1 m deep drifted around 3 study sites, and elk were able to breach all designs. Because of this, these fences may not be ideal for protecting forages where snow drifts are expected to regularly form around the fence. Other methods of fencing or control may be better suited for situations where snowdrifts are anticipated.

Another case where these designs may be less effective are agricultural areas surrounded by very few other food sources. Highly motivated deer or elk have the ability to jump over fences 1.8 m high. In most areas, spring and summer conditions will provide ample natural food supplies for wild ungulates outside cultivated areas. In cases of extreme drought, during severe winters, or areas with little natural vegetation, motivation for ungulates to cross exclusion fences will increase, and fences that otherwise provide adequate control may fail.

Adjacent habitat, other available food sources, the commodity being protected, level of control desired, and cost should all be considered when choosing whether or not to use fencing to deter ungulates, and what style of fencing should be used to attain desired results.

Future Research

Future research involving low-cost fencing to deter ungulates could be beneficial to agricultural producers. Designs using only additional high-tensile wire may be effective under circumstances not tested during this study. Varying adjacent habitat, including both foraging areas and cover, may influence the persistence of deer and elk to reach crops or improved pastures. Density of ungulates in an area, local weather conditions, and time of year may also influence pressure these ungulates put on fences. Fence designs in this study were tested under relatively extreme ungulate pressure when compared, for example, to alfalfa fields on summer range. Therefore, future research should be conducted in crop or rangeland settings, using various adjacent habitats and ungulate densities to determine if less expensive wire configurations will deter deer and elk as well as woven wire designs in various situations. By basing future studies on the modification recommendations made through this research, perhaps modifications can be further refined to allow more landowners access to a cost effective tool to reduce depredation losses.

Another potential area for future research is investigating the use of these fence designs to deter ungulates from crossing highways. Reducing wildlife-vehicle collisions is a major concern for highway safety in areas of high ungulate density. Most highway right of ways are currently fenced to control livestock, and these designs could be a low cost alternative to constructing new fences to discourage deer and elk crossings. By reducing cost, more highway miles could be fenced with current budgets. These designs may be particularly effective for short spans where a blind hill, roadside vegetation, or other factors limit motorist visibility, and ungulates can be routed to cross the highway in an area less likely to cause a collision with a vehicle. It is also possible that the height of these designs will allow deer frightened by an oncoming vehicle to jump over, instead of being trapped on the road system.

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APPENDICES

APPENDIX A

NUMBER OF DEER BREACHES EACH MONTH PER SITE

Lane Ranch Pivot

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	1	0	0	0	0
November	2	0	0	0	0
December	0	0	0	0	0
January	4	2	1	0	0
Feburary	1	0	0	0	0
March	4	2	0	0	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	1	0	0	0	0
December	3	2	1	0	0
January	3	1	0	0	0
Feburary	3	0	0	0	0
March	4	1	1	1	1

Lane Ranch Feedlot

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January	0	0	0	0	0
Feburary	0	0	0	0	0
March	0	0	0	0	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January	0	0	0	0	0
Feburary	3	0	1	0	0
March	4	0	0	0	0

American Fork Ranch East

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	1	1	0	0	0
November	4	4	0	0	0
December	5	4	3	0	0
January	4	4	0	0	0
Feburary	3	3	3	0	0
March	5	5	5	3	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	2	0	0	0	0
November	4	4	4	0	0
December	5	5	5	5	0
January	4	4	4	4	0
Feburary	4	4	4	4	0
March	5	5	5	5	5

American Fork Ranch West

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	1	0	0	0	0
November	4	0	0	0	0
December	5	0	0	0	0
January	4	2	2	1	0
Feburary	3	3	3	0	0
March	5	5	5	0	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	2	0	0	0	0
November	4	1	1	0	0
December	5	5	5	2	0
January	4	4	4	4	0
Feburary	4	4	4	4	0
March	5	5	5	5	0

APPENDIX B

NUMBER OF ELK BREACHES EACH MONTH PER SITE

Galt Ranch Black Butte

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January	3	0	0	0	0
Feburary	1	0	0	0	0
March	5	0	0	0	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	2	0	0	0	0
November	4	0	0	0	0
December	5	0	5	0	0
January	4	1	4	0	0
Feburary	4	0	4	0	0
March	5	1	5	0	0

Galt Ranch Lingshire

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	0	0	0	0	0
January	0	0	0	0	0
Feburary	0	0	0	0	0
March	0	0	0	0	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	3	3	3	3	0
January	0	0	0	0	0
Feburary	0	0	0	0	0
March	0	0	0	0	0

Sun Ranch Pearson

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	1	0	0	1	0
January	2	0	0	0	0
Feburary	1	0	0	0	0
March	2	0	0	0	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	0	0	0	0	0
December	5	5	5	4	0
January	2	2	2	2	0
Feburary	1	1	1	1	0
March	2	2	2	2	0

Sun Ranch Snowball

2004-2005	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	2	0	0	0	0
December	0	0	0	0	0
January	1	0	0	0	0
Feburary	1	0	0	0	0
March	2	1	0	1	0

2005-2006	Control	Design 1	Design 2	Design 3	Design 4
October	0	0	0	0	0
November	3	0	0	0	0
December	3	2	2	2	0
January	0	0	0	0	0
Feburary	0	0	0	0	0
March	0	0	0	0	0