Wyoming Cooperative Fish and Wildlife Research Unit

Biological Science Building, Rm. 419, University of Wyoming, Laramie, WY 82071-3166
Phone: (307) 766-5415 Fax: (307) 766-5400

EVALUATION OF HIGH TENSILE ELECTRIC FENCE DESIGNS ON BIG GAME MOVEMENTS AND LIVESTOCK CONFINEMENT

Final Report

RORY KARHU and STANLEY ANDERSON

April 2003

ACKNOWLEDGEMENTS

The Wyoming Department of Transportation, Bureau of Land Management, Wyoming Game and Fish Department, and Rocky Mountain Elk Foundation provided funding for this research. M. Renner, and M. Chandler with Gallagher Group, J. Randall and K. Mcpherson with Speedrite and T. Wadley provided valuable advice about electric fence concepts and construction. Gallagher Group loaned us a Joule meter. Both Gallagher Group and Speedrite donated fencing materials. We thank J. Haschke, A. Johnson, R. Stevens, and C. Sazma for their help collecting and analyzing data. We are indebted to numerous Wyoming landowners, one Colorado landowner, and the staff at the Sybille Wildlife Education and Research Unit for providing test animals and allowing us access to monitor their electric fences.

EXECUTIVE SUMMARY

We used infrared activated video to evaluate the effects of 2, 3, and 4-wire electric fence designs on elk, mule deer, and pronghorn movements. In addition, electric fences were tested for their effectiveness at containing cattle and bison. Two-wire fence consisted of a ground wire at 20 inches and a hot wire at 30 inches with fiberglass posts spaced 60 feet apart. Post spacing and the use of stays varied between location for 3-wire designs, but wire spacing of 22, 32, and 42 inches and a hot, ground, hot wire configuration remained constant. Four-wire fence consisted of hot wires at 22, 32, and 52 inches and a ground wire at 42 inches with fiberglass posts spaced approximately every 50 feet.

All three wildlife species were physically capable of traversing all of the fence designs, however the difficulty in crossing the fences varied between species and design. With 2-wire electric fence, elk and deer easily crossed, but pronghorn had relatively high aversion rates. Four-wire fences were relatively easy for mule deer and pronghorn to traverse, but were difficult and potentially hazardous for elk to traverse. None of the designs appeared to seriously impede mule deer movements. Electric shock did not appear to be a factor effecting the reaction of elk, mule deer, or pronghorn to electric fences that carried a charge of 0.5-4.5 J. Less than 2% of these species (9 elk, 2 deer, 0 pronghorn) were shocked when interacting with electric fence. There was no apparent pattern between animals shocked and the number of Joules on a fence.

In calf weaning and bull separation tests of domestic cattle, both 2 and 3-wire fences proved to be effective barriers. Contrary to popular belief, we found 3-wire was just as effective at containing bison as 4-wire electric fence.

We provide specific fence design and construction recommendations as well as a construction and maintenance cost comparison between 3-wire electric fence and Wyoming Department of Transportation, 4-wire Type F barbed fence. Of the designs examined in this study, we contend a 3-wire electric fence is the best design to meet the goals of both the livestock producer (cattle and bison) and the wildlife manager.

TABLE OF CONTENTS

Chapter **Page Number**

1 INTRODUCTION…… 1
1.1 Background…….. 1
1.2 Study Areas…….. 1
1.3 Fence Designs…….. 2

2 RESEARCH METHODS…….. 6
2.1 Infrared Activated Video…….. 6
2.2 Wildlife Data Collection…….. 7
2.3 Cattle Data Collection…….. 8
2.4 Bison Data Collection…….. 8
2.5 Electric Pulse Meter……. 9
2.6 Statistical Analysis …….. 11

3 RESULTS AND DISCUSSION…… 12
3.1 Wildlife…….. 12
3.1.1 *Elk*……. 12
3.1.2 *Deer*…….. 15
3.1.3 *Pronghorn*…….. 15
3.2 Livestock……. 16
3.2.1 *Cattle*…….. 16
3.2.2 *Bison*…….. 17

4 DESIGN RECOMMENDATIONS……... 20
4.1 Design Recommendation……. 20
4.1.1 *Fence Flexibility*…… 20
4.1.2 *Fence Stays*…….. 20
4.1.3 *Wire Spacing*…… 21
4.1.4 *Wire Tension*…… 21
4.1.5 *Grounding*…… 21
4.1.6 *Gates*…… 21

5 CONCLUSIONS AND RECOMMENDATIONS…… 23
5.1 Conclusions……. 23
5.2 Recommendations…… 23

REFERENCES…….. 24

APPENDICES…… 25
A. Wyoming Construction Cost Comparison Between 3-Wire Electric Fence and Wyoming Department of Transportation Type F, 4-wire Barbed Fence in May 2002……... 25
B. Maintenance cost comparison between 3-wire electric fence and Wyoming Department of Transportation, 4-wire Type F Barbed…….. 26

LIST OF TABLES

Table		Page Number
1	Chi-Square tests of design x reaction and design x outcome for elk, mule deer, and pronghorn…….……	13
2	Chi-Square tests of design x result for cattle (calf separation and bull separation) and bison……..…….	17

LIST OF FIGURES

Figure		Page Number
1	Study Area Locations…..……...……...…….…….	2
2	Electric Fence Design Detail…...……..…..	3
3	Typical Video/Passive Infrared Monitoring System Setup……..……...	7
4	Shock Energy Released by the Energizer Indicated by Volume of the Electrical Pulse……	10

CHAPTER 1

INTRODUCTION

1.1 Background

Standard barbed wire and barbed/woven wire fences in Wyoming were designed to control livestock, yet minimize impacts on big game movements (Spillett et al. 1967, Reed et al. 1974). However, pronghorn (*Antilocapra americana*) (Sundstrom 1967, Oakley 1973, Yokum et al. 1980) deer, (*Odocoileus hemionus*) (Falk et al. 1978, Ward et al. 1980) and elk (*Cervus elaphus*) (Adams 1982) still have difficulty crossing standard fence designs.

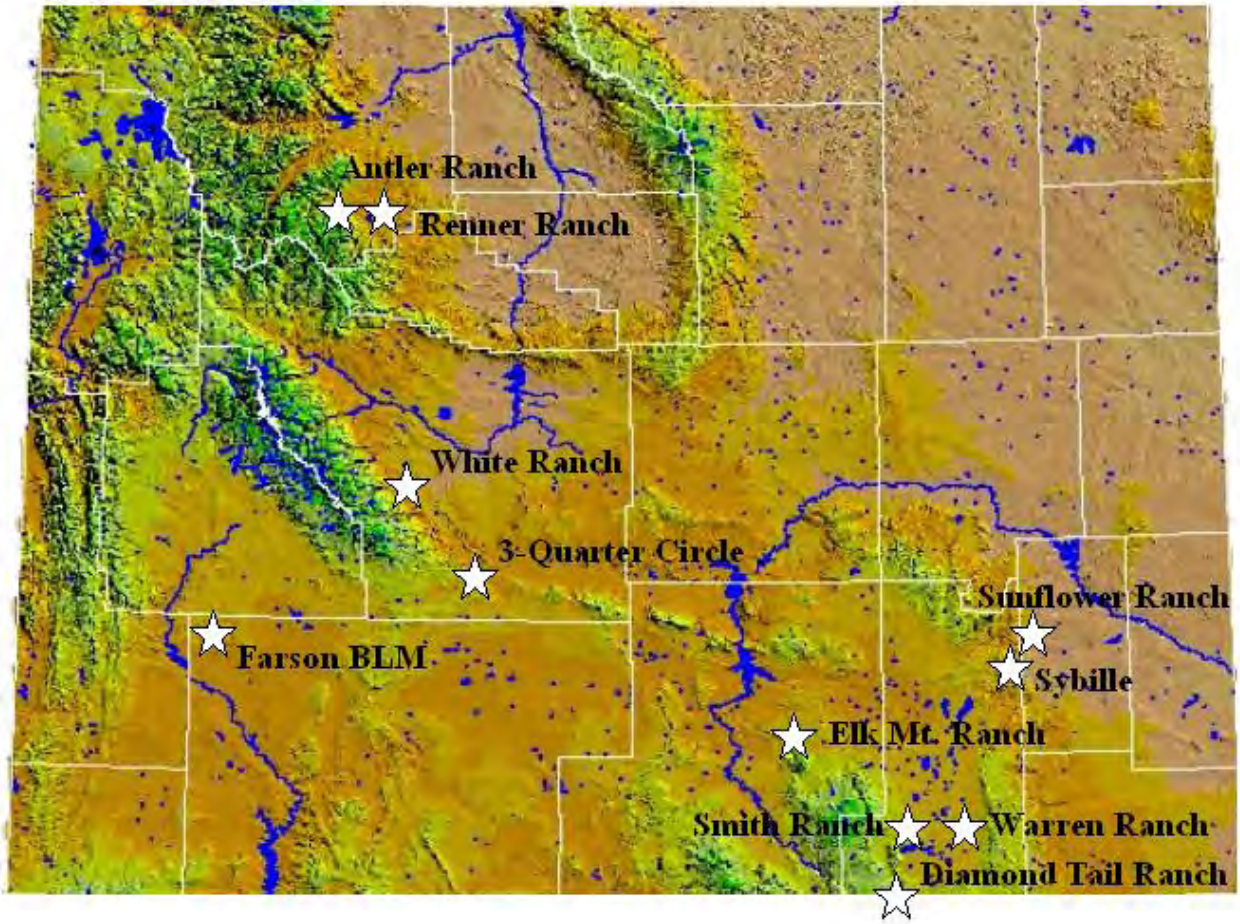
Since the early 1980's, high tensile electric fence has become available and popular in Wyoming. Many private landowners currently use a variety of different designs to accomplish everything from containing bison (*Bison bison*) to discouraging overuse of riparian habitats by cattle (*Bos tarus*). A preliminary phone survey of 20 Wyoming ranches during the winter of 1999 indicated that electric fences are being used in every region of the state and in habitats important for elk, deer, and pronghorn. Additionally, the Bureau of Land Management (BLM) in Wyoming employs electric fence to exclude feral horses from sensitive habitats and as a grazing management tool on rangeland (USDI BLM 2000). The Wyoming Game and Fish Department uses electric fence to exclude cattle from habitat treatment areas. With the increased popularity of electric fence, there is a need to examine the effects of electric fences on wildlife movements and their effectiveness at containing livestock.

Our objective was to determine the reaction of elk, mule deer, pronghorn, bison and domestic cattle to the 3 most common electric fence designs currently used in Wyoming.

1.2 Study Areas

In 2000-2002, data were collected at 8 private ranches in Wyoming (Antler Ranch, Elk Mountain Ranch, Renner Ranch, 3-Quarter Circle Ranch, Medicine Creek Ranch, Warren Ranch, Sunflower Ranch, and White Ranch), 1 research facility (Sybille Wildlife Research Unit), 1 private ranch in Colorado (Diamond Tail Ranch) and 1 BLM fence located near Farson, Wyoming (Figure 1). Habitat types represented at these sites ranged from high elevation grassland to sagebrush steppe and montane forest. All but 2 fences that were monitored for wildlife reactions during this research project had been in existence for a minimum of 3 years. The exceptions were the BLM fence constructed on a federal grazing allotment in conjunction with this research and a fence newly constructed on the 3-Quarter Circle Ranch. All fences monitored for cattle reactions were new construction (White Ranch, Warren Ranch, and Medicine Creek Ranch). Three fences built to monitor bison reactions were also new construction (Sybille Wildlife Research Unit, and Sunflower Ranch).

Figure 1. Study Area Locations

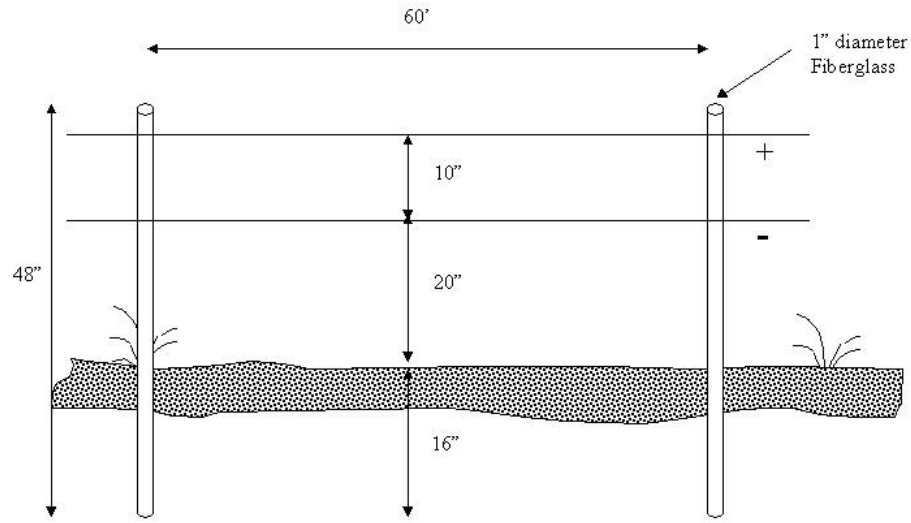


1.3 Fence Designs

Three different fence designs were tested (Figure 2). These designs were selected because they were relatively common in Wyoming and conversations with ranchers and wildlife biologists indicated that these designs held the most promise of allowing wildlife to cross, but still contain cattle and bison. The 2 and 3-wire fence designs are similar to design specifications for 3-wire cross-cattle fence and 2-wire cross-cattle fence (Gallagher™, San Antonio, TX). Three-wire post spacing and the use of stays varied between locations and terrain. We did not separate out these variations for analysis because the overall fence flexibility remained relatively constant. The 4-wire fence primarily used to contain bison did not follow Gallagher design specifications, but most were made with Gallagher products. When we constructed fences to test under pressured conditions with cattle, Gallagher products and designs were used to maintain consistency.

Figure 2. Electric fence design detail. All fences use ¾" - 1" diameter solid fiberglass line posts. Wire is 12.5 gauge, Class III galvanized with a maximum tensile strength of 170,000 PSI and maximum breaking strength of 1308 Ibs. Wires are connected to line posts and stays using metal clips.

1) 2-Wire



2) 3-Wire Type A

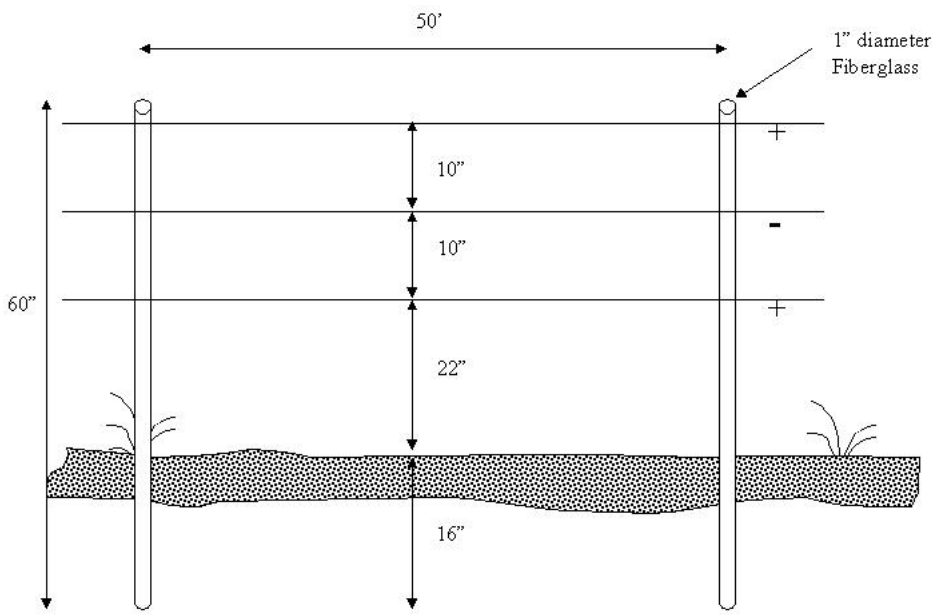
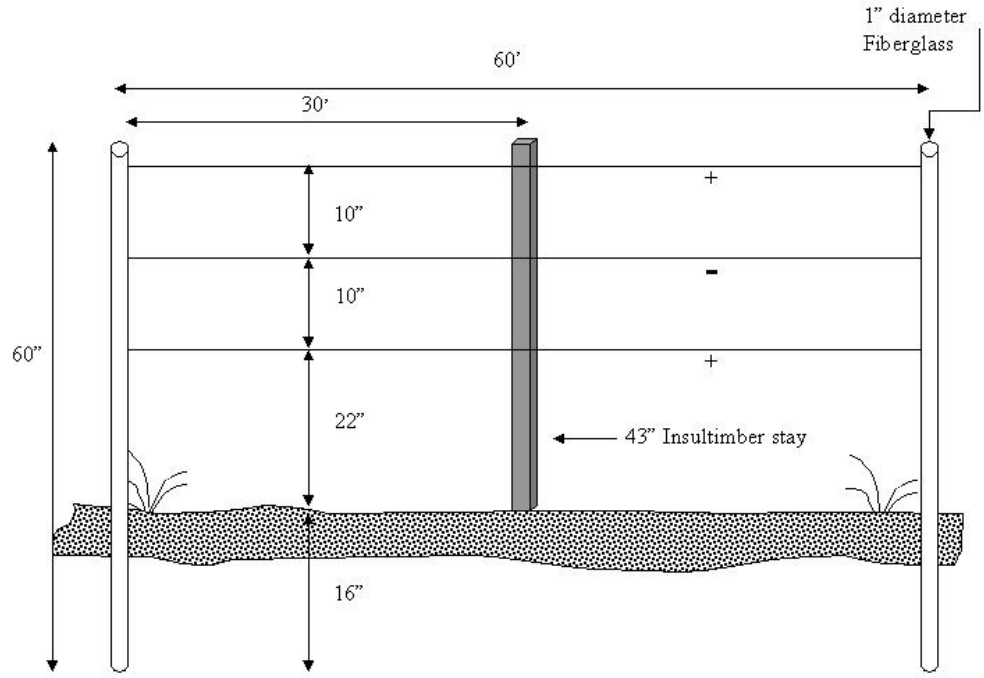


Figure 2. Electric fence design detail cont.

3-Wire Type B



3-Wire Type C

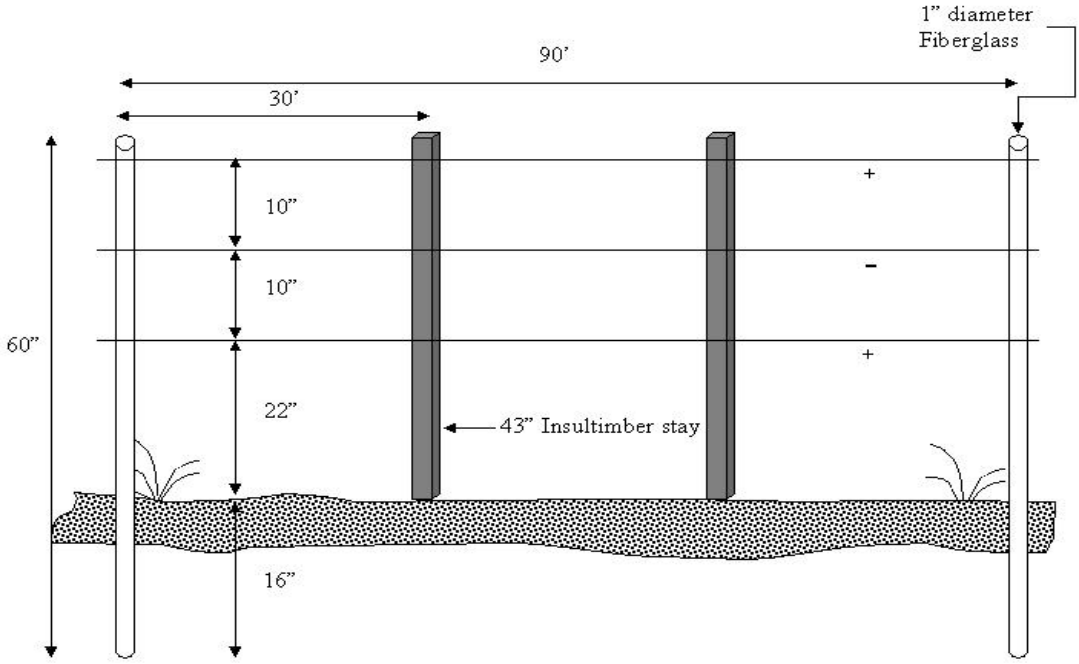
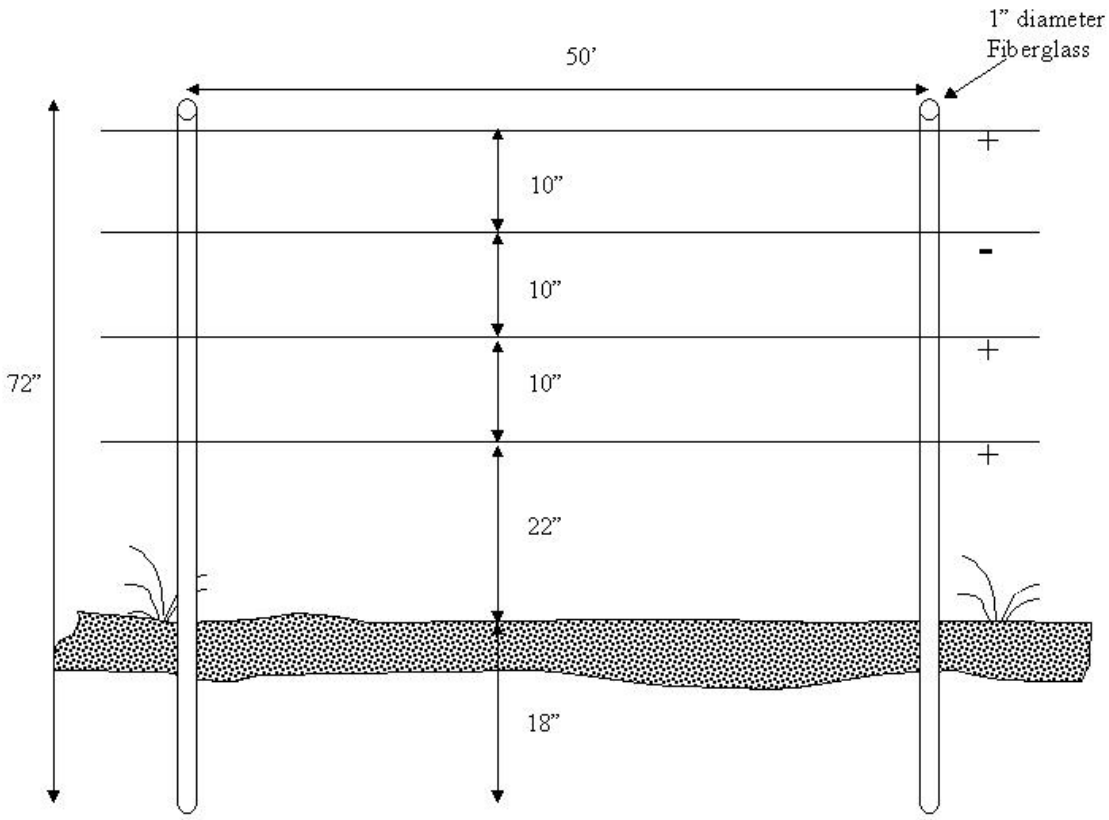


Figure 2. Electric fence design detail cont.

3) 4-Wire



CHAPTER 2

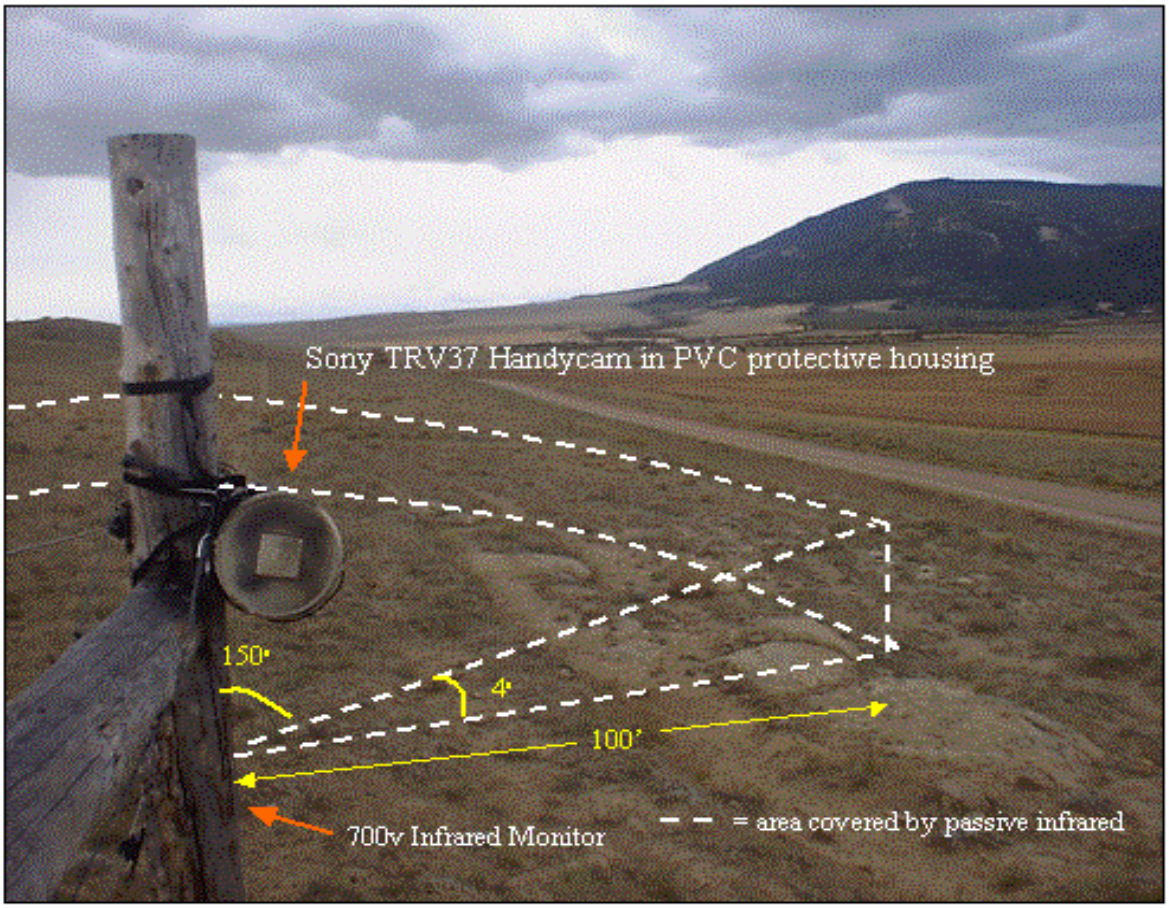
RESEARCH METHODS

2.1 Infrared Activated Video

We used 10 battery-powered video cameras (Sony, New York, NY) in combination with 10 Trailmaster® 700v passive infrared game monitors (Goodson and Associates, Lenexa, KS) to record wildlife and livestock reactions to electric fences.

The monitor was strapped to either a wood brace post within the fence line, a nearby tree, or a post that we set. The least sensitive setting (P=5 and pt=2.5) was used to minimize false activations. The video camera, which was protected by a 6-inch polyvinyl chloride (PVC) pipe housing, was strapped to the post or tree just above the infrared monitor. In theory, the camera was to be activated when heat and movement were detected within the coverage area (Figure 3). Although these systems were adequate for collecting our data, and were activated by the monitors when target species were present, many false hits caused by wind-blown grass, debris, and wind-caused movement of the fence wires were recorded. On average we collected approximately 5 minutes of target footage for every 2 hours of videotape. Cameras were checked and film and batteries were replaced approximately every 14 days.

Figure 3. Typical video/passive infrared monitoring system setup. The area within the dashed white lines indicates TM700v monitor coverage.



2.2 Wildlife Data Collection

Elk, deer, or pronghorn captured on videotape were only considered data points if they approached the fence with an apparent desire to cross. Animals that approached a fence and were turned away more than once were considered an "avert", regardless if they eventually crossed the fence or not. Animals that approached and crossed after being turned away no more than once were recorded as "over" if they jumped over the top wire, "through" if they crossed between any two wires, and "under" if they crossed below the bottom wire. We also recorded and analyzed the final outcome of the interaction with the fence, regardless of attempts, as either "succeed" if an animal was able to get to the other side of the fence while on camera, or "fail" if they did not. We made a distinction between reaction and outcome because we wanted to determine the stress involved when animals

interacted with the different fence designs. We assumed stress levels were positively correlated with avert classifications.

2.3 Cattle Data Collection

Cattle data were only collected on the 2 and 3-wire fence designs that we constructed for controlled tests. We did not test the 4-wire design because we felt it was unnecessary to use this type of fence to contain cattle. To create a situation where cattle would be motivated to challenge a fence we separated calves from cows in the fall and separated bulls from cows and calves in late spring. The calves and cows had a strong desire to get back together having never been separated and the bulls were motivated to cross the fence to breed with the cows that were coming into their first estrus after calving in early spring. In all cases, only the test fence separated the study groups. Cattle at the White Ranch were black angus/limousin cross, on the Warren Ranch, charolais and on the Medicine Creek Ranch, black angus and coriente. Data were collected at each fence location and ranch for one week after animals were first exposed to the fence. If an animal stayed on the correct side of the fence for the week while monitoring took place, we considered it a "contain". If the animal was sighted or recorded on the other side of the fence at any time during the 7-day monitoring period we recorded it as an "escape". Ear tag numbers of escaped animals were recorded to avoid recounting the same animal.

2.4 Bison Data Collection

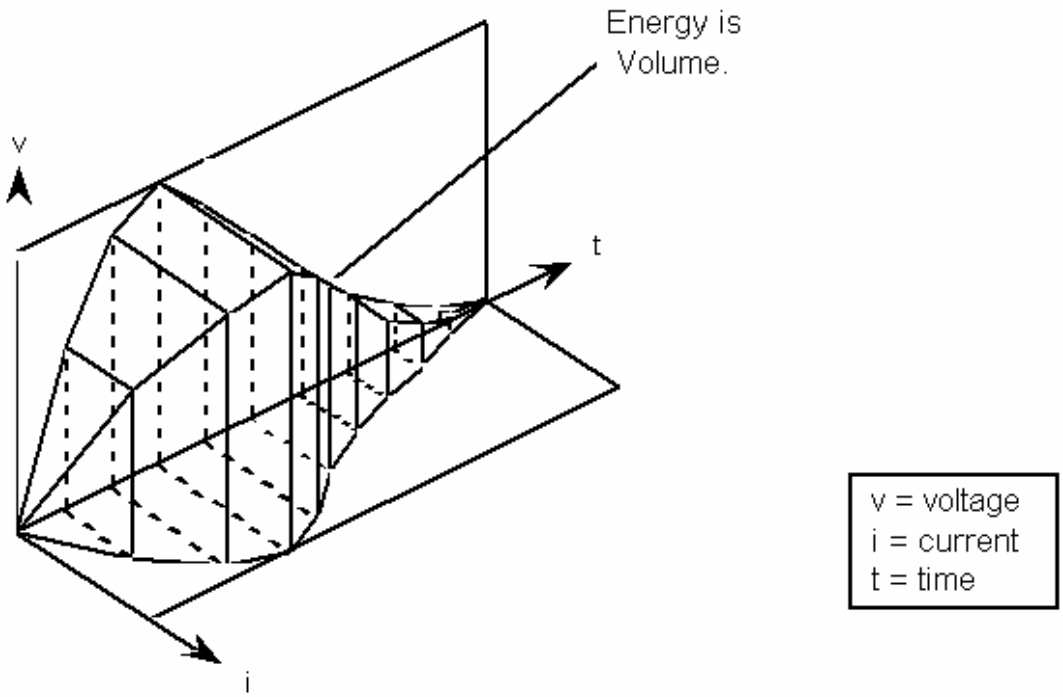
In addition to the data collected on pre-existing 4-wire fences and one pre-existing 3-wire fence, we collected data on 2 newly constructed 3-wire fences (1 Type A and 1 Type C). The new construction took place at the Sunflower Bison Ranch (Type C) and the Sybille Wildlife Research and Education Unit (Type A). Sixteen bison at the Sunflower Ranch were in a 100-acre pasture enclosed by a 5-wire electric fence that had been poorly constructed and the animals were accustomed to traveling through the fence. We constructed and ell shaped study fence that tied into a 72 inch metal stock panel fence on one side and the 5-wire electric fence on the other. The problems with the 5-wire fence were corrected before the bison were released into the newly created 4-acre enclosure.

There were only 3 bison available at Sybille Wildlife Research Unit, however the animals were habituated to one another and the 10-year-old bull had never been separated from the 2 cows. A 1-acre enclosure was constructed and the 2 cows were placed in the enclosure. The 3-wire fence was the only barrier that separated the bull from the cows during the test period. The tests lasted for 7 days at each location. If a bison was observed outside a test pasture or enclosure during the monitoring period, it was considered an "escape". All animals that stayed within the test pasture during the monitoring period were counted as "contain".

2.5 Electric Pulse Meter

A voltmeter is an effective tool for determining if a fence is maintaining desired voltage and for identifying shorts. However, a voltage measurement alone is not adequate for measuring the shock energy available on a fence or for comparing shock energy between different fences. To determine the shock energy or Joules available at any point on a particular fence, you need to know not only voltage, but also current, pulse shape, and pulse length (Figure 4). In essence, the higher the voltage, the higher the current, and the longer they both exist, then the greater the energy (Hancock 1995). The best tool available to measure the shock energy of an electric fence is a Joule meter. Joule meters allow the operator to estimate the resistance in the system and program the meter accordingly. We used a standard resistance of a mature cow, 500 ohms, for all Joule meter readings because this was the only resistance setting available on the meter that was close to the body size of our test subjects. In order to compare wildlife and livestock reactions between fences we needed to have a measure of the pain potential of any particular fence and a Joule meter was the best tool available. We measured the Joule output of every fence at each camera location every time we checked the cameras (approximately every 14 days).

Figure 4. Shock energy released by the energizer is indicated by volume of the electrical pulse. v=volts, i=current, and t=pulse length or time.



Energy figure from Hancock 1995.

2.6 Statistical Analysis

To evaluate the impact of fence designs on wildlife we used a 3 x 4, design x reaction, Chi-Square analysis to test the null hypothesis: 1) the proportion of individuals for each species that jump over (over), go between wires (through), go under the bottom wire (under), or are turned away by the fence more than once (avert) does not differ between electric fence designs. We used a 3 x 2, design x outcome, Chi-Square analysis to test the null hypothesis: 2) the proportion of individuals of each species that successfully cross the fence (succeed) or do not cross the fence (fail) does not differ between electric fence designs.

In the case of bison we used a 2 x 2, design x result, Chi-Square analysis to test the null hypothesis: 1) the proportion of individuals that are held by the fence (contain) or not held (escape) does not differ between fence designs. For cattle we used the same Chi-Square design to test the following 2 hypotheses: 1) the proportion of weaned calves and cows that are held by the fence (contain) or not held (escape) does not differ between fence designs and 2) the proportion of bulls that are held by the fence (contain) or not held (escape) does not differ between fence designs.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Wildlife

A total of 635 data points were collected for elk (322), mule deer (81), and pronghorn (232) (Table 1). Less than 2% of the 635 individuals received a shock when interacting with the electric fences. Of those 11 animals, 3 were shocked by fences charged with 0.5 – 1.5 J, 6 by fences charged with 1.6 – 3.4 J, and 2 by fences charged with 3.5 – 4.5 J. No apparent pattern existed between shock energy and frequency of animals shocked, thus we concluded that, within the range tested (0.5 – 4.5 J), shock energy was not an important factor limiting wildlife movements across electric fence.

We did not collect a large enough sample size for each of the 3-wire fence variations (Figure 2) to analyze them separately for each species. Thus, all 3-wire data for each species was combined for statistical analysis.

3.1.1 *Elk.*

We collected 322 total elk reactions to electric fence. A significant difference (X^2=59.2, df=6, P<0.001) occurred between elk reaction and fence design, but no difference occurred between outcome and design (X^2=3.7, df=2, P=0.2). These results indicate that elk are physically capable of traversing all 3 electric fence designs if given enough time and motivation, but aversion rates and associated stress levels are elevated as the top wire height is increased. On 2-wire fences, none of the elk were averted compared to 20% aversion on 3-wire fences and 58% aversion on 4-wire fence. Three percent of elk (9/322) were shocked by electric fences. Of those, 2 were branch-antlered bulls, 2 were spike bulls, 4 were mature cows and 1 was a calf. Both branch antlered bulls on 3-wire fences and one cow on a 4-wire fence were shocked when they pushed their chest against a ground wire and a hot wire. In doing so, they forced the wires close enough to their skin that the electricity was able to arc the gap from the wire to the animal. The other 6 elk were shocked when they touched a hot wire with their wet nose and grounded through their hooves. We believe the insulating value of an elk's hollow guard hair is responsible for the relatively low shock rate observed. We did not observe a higher percentage of animals receiving a shock on fences that had the highest shock energy. On the contrary, the highest percentage (11.8) of shocked animals were interacting with fences that had the lowest mean J meter readings (0.5 J). There are a couple of possible explanations for this observation. First, the 2-wire fence where we observed the higher shock rate was a fence built in the fall of 2001. Thus, the elk that were shocked were not accustomed to the fence and were more likely to investigate and touch the wire with their wet nose. In addition, the 2 animals that were shocked were standing in wet snow and thus optimum soil conditions existed for grounding through their hooves. A similar shock rate (9.8%) was seen on 3-wire fences, which had a mean Joule meter reading of 1.1 J. The difference in shock rates

between the less powerful 2 and 3-wire fences and the more powerful 4-wire fences (mean = 2.5 J) may be a factor of observer error or be related to an animals ability to sense an

Table 1. Chi-Square tests of design x reaction and design x outcome for elk, mule deer, and pronghorn.

Species	Design[a]	N	n[b]	%Shocked	Reaction[c]				Outcome[d]	
					%Avert	%Over	%Under	%Thrgh	%Succeed	%Fail
						X^2 = 59.2, P<0.001			X^2 = 3.74, P=0.2	
Elk	2-wire	17	2	11.8	0.0	100	0.0	0.0	100	0.0
Elk	3-wire	51	3	9.8	19.6	60.8	13.7	5.9	90.2	9.8
Elk	4-wire	254	5	0.5	58.5	36.6	3.5	1.4	85.0	15.0
						X^2 = 7.6, P=0.3			X^2 = 0.4, P=0.8	
Deer	2-wire	8	2	0.0	0.0	37.5	50.0	12.5	100	0
Deer	3-wire	54	2	5.4	3.7	42.6	48.1	5.6	96.3	3.7
Deer	4-wire	19	2	0.0	5.2	15.8	79.0	0.0	94.7	5.3
						X^2 = 52.7, P<0.001			X^2 = 33.2, P<0.001	
Pronghorn	2-wire	130	4	0.0	60	6.2	33.8	0.0	50.8	49.2
Pronghorn	3-wire	23	3	0.0	8.7	0.0	91.3	0.0	95.7	4.3
Pronghorn	4-wire	79	4	0.0	8.9	0.0	91.1	0.0	93.7	6.3

[a] Design refers to 2, 3, and 4-wire electric fence configurations. Data from all three 3-wire configurations were combined for this analysis.
[b] n equals the number of data collection sites monitored that contributed to the total sample N and were considered significantly independent.
[c] Animals that approached a fence and were turned away more than once were considered an “avert”, regardless if they eventually crossed the fence or not. Animals that approached and crossed after being turned away one time or less were recorded as “over” if they jumped over the top wire, “through” if they crossed between any two wires, and “under” if they crossed below the bottom wire.
[d] Outcome refers to the eventual success or failure of an animal to get to the other side of a fence while being video taped, regardless of how many attempts were made.

electrical charge. To state that an animal was shocked it had to display an obvious involuntary muscle reaction to the stimulus. This reaction is more apparent when an animal is calm as opposed to stressed or panicked. When groups or individual elk were in the vicinity of 2 and 3-wire fences, they appeared calm and were often feeding or milling around before attempting a fence traverse. That was not the case on 4-wire fences. The majority of our 4-wire study fences were located in areas that received heavy elk migratory pressure and elk that approached a 4-wire fence were generally on the move. Thus, the general attitude of the animals was uneasiness and apprehension. The herd would anxiously bunch up against the fence as they anticipated the crossing. Elk would run up and down the fence for 50 to 100 meters in both directions before a lead cow would attempt the first traverse. After the first few elk were on the other side, the majority of the remaining animals would attempt to jump the fence. When these herds crossed there were always 2 or 3 stragglers at the end that would end up leaving the area by running off down the fence line looking for a different place to cross the fence. Although the majority of the animals would get to the other side of the fence, many would approach and turn away from the fence 2 or more times before they would successfully traverse. We expect that the mental state in which elk approach and interact with the 4-wire fence was a primary factor influencing the different shock rates observed. If elk are calm when they are in the vicinity of the fence and not in a big hurry to traverse, there is a greater chance that the animals will sniff the fence or slowly push into a fence with their chest and get shocked. When an animal is shocked under these conditions it is easy for an observer to witness and record the shock because the involuntary reflex is obvious. Conversely, when animals are anxious and panicked and are crossing the fence in large groups, it is harder for an observer to determine if an animal was shocked when in contact with the wire.

Elk looking for a location to cross a 52" 4-wire electric fence

Cow elk on her back after being tripped up by a 4-wire electric fence

Both the 2-wire and 3-wire fences are relatively easy for elk to traverse and the animals apperar less stressed when interacting with these fences. The 4-wire fences that we monitored have a relatively high aversion rate and elk are sometimes injured (we often found hair and skin where the animals had crossed and recorded 3 animals that flipped 180 degrees and landed on their backs when tripped up by the top wire) when attempting to

cross. All of our video data and direct observations suggest that elk experience elevated stress levels when faced with traversing a 52” 4-wire fence.

3.1.2 Deer

We collected 81 deer reactions to electric fence. No significant difference occurred between fence design and deer reaction (X^2=7.6, df=6, P=0.3) or between fence design and outcome (X^2=0.4, df=2, P=0.8). Of the 81 animals captured on videotape interacting with these fences, only 3 were shocked. One animal bit the fence and reacted by jumping through the wires and successfully traversing the fence. Another was shocked when she contacted both the hot and ground wire with her shoulder while feeding up against the fence. She reacted by jumping away from the fence and did not return. The last animal was shocked when she touched the top wire with her nose, but crossed over the fence. The threat of shock does not appear to be a factor affecting deer reaction to electric fence.

3.1.3 *Pronghorn*

We collected 232 pronghorn reactions to electric fence. A significant difference occurred between fence design and pronghorn reaction (χ^2 = 78, df=4, $P \leq 0.001$) and between fence design and outcome (χ^2 = 51, df=6, $P \leq 0.001$). Pronghorn exhibited low aversion rates at 3-wire (8.7%) and 4-wire (8.9%) electric fence. Surprisingly, pronghorn displayed relatively high aversion rates (60%) and a low overall traverse success (50.8%) on 2-wire fences.

No pronghorn were shocked by the electric fences. Electrical shock does not appear to be an important factor influencing the reaction of pronghorn to electric fences. The insulating quality of pronghorn guard hairs, combined with dry soils, allow the animals to contact the hot wires and feel little or no pain. As with elk and deer, pronghorn are more susceptible to being shocked if they touched a hot wire with their nose or ears or were standing on moist soil.

Pronghorn doe feeding on shrub while in direct contact with hot wire

Compared to standard 4-wire barbed fences with bottom wire heights ranging from 6 to 16 inches, a bottom wire height of 20 (2-wire) or 22 inches (3 and 4-wire) on electric fence is relatively high and should provide plenty of space for pronghorn to traverse under the fence. As expected on 3 and 4-wire fences, all pronghorn that traversed the fence did so by ducking under the bottom wire. Similarly, on 2-wire fences, the majority of animals that successfully traversed the fence (87%) did so by crossing under the bottom wire. However, the overall aversion rate on 2-wire was much higher than expected.

Pronghorn jumping 2-wire fence.

The majority of our 2-wire data was collected at fences that were newly constructed in the spring of 2001. The fences were continually monitored from June 2001 through January 2003. We expected pronghorn to become accustom to the fences, but aversion rates did not decrease over the 20-month monitoring period. Pronghorn may need more time to establish fence-crossing locations before a reduction in aversion is observed or they may simply be confused by the relatively low overall height of a 2-wire electric fence. Typical range fences have top wire heights of 40 inches or more and when confronted with a barrier of that height almost all pronghorn will cross under a fence rather than attempt to jump over (Kie et al. 1994). A 2-wire electric fence with a top wire height of 30 inches is much lower and unlike any other fence that these animals are likely to have encountered and they may consider jumping as a fence crossing option. Because jumping is not the preferred method for traversing fences, the resulting indecision, which was exhibited by pacing the fence line and repeatedly approaching then turning away from the fence, may have resulted in higher aversion rates and fewer successful fence crossings.

3.2 Livestock

The results of cattle and bison tests are shown in Table 2.

3.2.1 *Cattle*

We observed 1764 cattle interactions with electric fence. The 2 and 3-wire electric fence designs used for calf and bull separation tests were extremely effective. There was a difference observed between fence designs for the calf separation test (X^2=11.1, df=1, P<0.01). This difference occurred due to failure of the 2-wire fence when 2 cows jumped the fence at the White Ranch and 9 cows jumped the fence on the Warren Ranch. In practice, however there is very little difference between the fences (100% containment on 3-wire compared to 99% containment on 2-wire). Both fence designs were 100% effective at containing bulls when they were separated from cows prior to breeding season.

If 2 and 3-wire electric fences are properly constructed and maintained, they provide a very effective barrier to domestic cattle. If calves are weaned on the fence, we recommend the 3-wire over the 2-wire design.

Table 2. Chi-Square tests of design x result for cattle (calf separation and bull separation) and bison.

Species	Design[a]	N	n[b]	%Contain	%Escape
X^2 = 11.1, P=0.01					
Calf Separation	2-wire	850	3	99	1
Calf Separation	3-wire	850	3	100	0
X^2 = not applicable					
Bull Separation	2-wire	32	3	100	0
Bull Separation	3-wire	32	3	100	0
X^2 = 0.01, P=0.78					
Bison	3-wire	44	3	100	0.0
Bison	4-wire	1144	4	99.8	0.2

[a] Design refers to electric fence configurations. Data from all three 3-wire configurations were combined for this analysis.
[b] n equals the number of data collection sites monitored that contributed to the total sample N and were considered significantly independent.

3.2.2 *Bison*

We collected 1188 total bison reactions to electric fence. No significant difference occurred between fence design and result (X^2=0.01, df=1, P=0.78). Both 3 and 4-wire electric fences were effective at containing bison. We observed 100% containment on 3-wire fences (N=44) and 99% containment on 4-wire fences (N=1144). Two calves on a 4-wire fence were video taped crossing through a fence. The calves did not appear to purposefully cross through the wires, but were forced through by the remainder of the herd when they bunched up at a fence corner. We are not sure what caused the animals to bunch in the corner, but expect they were attempting to escape biting flies.

Many managers believe that a minimum of 4-wires and 52” top wire height are needed to contain bison. When asked why they used 4 or more wire designs, bison ranchers generally responded with one or more of the following reasons: 1) “because it was recommended by electric fence company representatives”, 2) “that is what has worked for other bison ranchers”, or 3) “ the 52” height is needed to keep the animals from jumping the fence. Most have not used 3-wire fences because they feel that they do not provide a substantial barrier. Our data indicates 3-wire fences are just as effective as 4-wire designs.

To qualify our findings we needed to examine how the tests were conducted. Four-wire fence data was only collected at ranches where bison had become accustomed to the fence and were, in most cases, not under pressure to traverse the fence. Because we found it difficult to find adequate replication of 3-wire designs used to contain bison (we only monitored 1 that had previously been constructed), we constructed two fences ourselves. These 2 fences gave us the opportunity to test the 3-wire design under more pressured conditions than existed on 4-wire fences where the animals had learned to respect the fence. The first fence was built after a rancher challenged us to construct an electric fence that could contain his 16 bison (1 bull, 15 cows/calves). He had previously built a 5-wire (12”, 22”, 32”, 42”, 52”) electric fence with all hot wires and the bison would regularly traverse the fence onto his neighbors pasture. Our 3-wire fence was 100% successful at containing the bison. Why did our fence work and the 5-wire fail? Because the 5-wire fence was improperly grounded and did not effectively shock the animals when they tested the wires (throughout this project we found that the number one cause for failure of electric fence was due to improper grounding).

The second fence was built at the Sybille Wildlife Research Unit. There we only had 3 animals to work with, but they were a good test for our 3-wire fence because they were extremely dependent on one another and had never been exposed to an electric fence. We built a 1-acre exclosure and separated the cows from a mature bull. The 2 cows, realizing they were separated from the bull, immediately tested the fence and were shocked. They then began running up and down the fence line looking for an escape. The bull pushed against the fence and was shocked twice before backing off. Although he stayed near and would occasionally walk the fence line, he did not physically test the fence again. The cows continued their travel of the fence line throughout the 7-day test and wore an obvious 5-inch deep path along the interior of the fence. Although we were only able to test the 3-wire fence under pressured conditions for a relatively small number of animals, these observations strongly support that 3-wire fence is effective at containing bison. The higher top wire on a 4-wire fence is not needed to contain bison if they are trained to electric fence and are managed properly. From our own experience working with bison, as well as knowledge gained from

Bison cow looking for an escape route while running beside a newly constructed 3-wire electric fence.

discussing fencing options with bison ranchers, we believe a bison can cross just about any fence it wants. Thus, the key to bison containment relies more on keeping the animals content by providing them with adequate space, forage, and water than it does on fence design specifics.

CHAPTER 4

DESIGN RECOMMENDATIONS

4.1 Design Recommendation

To meet the objectives of the cattle and bison producer (contain livestock) and the wildlife manager (minimize wildlife impacts), we feel a 3-wire design is the best option. All of the 3-wire fence types monitored in this study had identical wire spacing configurations, but not all had the same post spacing and some used stays while others did not (Figure 2).

4.1.1 *Fence Flexibility*

The key to constructing a 3-wire electric fence that works well for containing livestock, yet still allows wildlife to traverse is physical flexibility of the fence. We contend that any of the three 3-wire fence designs tested will have acceptable flexibility if the following criteria are followed: 1) line posts are fiberglass with a diameter no greater than 1"; 2) fifty feet is the minimum spacing between line posts and the maximum spacing if stays are not used and; 3) if stays are used, they are spaced 30' apart and no more than 2 stays are used between fiberglass line posts (i.e. maximum spacing with stays is 90' between fiberglass posts). If posts are set closer than 50' you likely lose the flexibility needed for young animals to cross through the fence between wires.

4.1.2 *Fence Stays*

Because stays are free floating and not connected to the ground (unless tied down in a depression) they may allow more vertical movement when an animal crosses under the bottom wire. Conversely, stays may make it harder for wildlife to cross between wires because stays decrease the free span distance. The free span on fences with no stays is 50' compared to a 30' on fences that use stays and because the stays effectively hold the wires at the same spacing as the posts, the vertical movement between wires is reduced when stays are used. Stays also increase the maintenance and grounding of electric fences because they sometimes flip 360° when hit by traversing wildlife. On 5 occasions we found stays that had flipped over and twisted the middle ground wire up with the bottom and top hot wires. This grounded out the entire fence and severely reduced its effectiveness for containing cattle or bison. Consequently, while the designs that use stays may be slightly easier for wildlife to go under, they also might make it harder for animals to go between wires. In addition, the increased risk of grounding makes designs that use stays higher maintenance and less effective for cattle and bison control.

Bull elk jumping 3-wire fence

4.1.3 *Wire Spacing*

Wire spacing is an important factor to consider when constructing an electric fence. Since the majority of elk cross over, and the majority of deer and pronghorn cross under it is important to maintain a minimum bottom wire height and maximum top wire height. A 22" bottom wire provides adequate space for both young and adult animals to go under a fence and a 42" top wire height is relatively easy for adult deer and elk to jump over. If ground and hot wires are too far apart they will not effectively shock a cow or bison that challenges the fence. If too close, they increase the chance that a hot wire will contact a ground wire and render the fence ineffective. Ten inches between wires is a good rule of thumb to meet cattle, bison, and wildlife objectives.

4.1.4 *Wire Tension*

Proper wire tension is also extremely important. We recommend the wires be tightened to approximately 150 lbs. Most people over tighten high-tensile electric fences figuring that a tighter fence will contain their cattle or bison better. In reality a fence that is too tight is more likely to break than a fence that is properly tensioned. The name "high-tensile" electric fence can mislead people into believing the name is synonymous with "high tension" fences. The "high-tensile" refers to a high breaking strength, but also to a harder, more brittle wire that is easily broken if tightly bent or kinked. All of our study fences, with the exception of one 4-wire fence, used 12.5 gauge, smooth, Class III galvanized wire with a tensile strength of approximately 170,000 PSI and breaking strength of 1308 lbs. This strength of wire seemed to work well for our purposes and could be hand tied when splicing wire ends or connecting insulators. The 200,000 PSI wire that was used on a 4-wire fence was more expensive because it could not be hand tied and required that some sort of wire sleeve or tie be purchased to splice wires or connect insulators.

4.1.5 Grounding

The number one cause of electric fence failure is improper grounding! It is extremely important to make sure the fence is grounded properly. Always follow fence energizer manufacturer recommendations for proper grounding techniques. When in doubt, add an additional grounding rod to the system. If possible locate ground rods at the end and beginning of every fence and periodically in between. Always place grounding rods in moist or wet soils when possible.

4.1.6 Gates

Electric fences do not require the use of special gates. Any gate used on standard barbed or woven wire fences can be used with electric fencing. In fact, electrified spring gates should be avoided because they are often a point of failure and can easily become tangled and unusable. On all gate openings, specially insulated electric fence wire should be buried to carry the electric charge from one side of the opening to the other. On wire-return-ground systems another insulated wire to return the ground to the energizer via the grounded fence wire, should be buried across the gate opening as well. Household

electrical cable should never be used because it is made to carry a maximum of 440 volts. Indeed, all copper wire should be avoided because connecting the copper wire to the galvanized steel fence wire will cause electrolysis and increased maintenance.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

We examined the effects of 2-wire, 3-wire, and 4-wire electric fence designs on elk, mule deer, and pronghorn movements. All three species were physically capable of traversing all of the fence designs, however the difficulty in crossing the fences varied between species and design. With 2-wire electric fence, elk and deer easily crossed, but pronghorn had relatively high aversion and low crossing success. Four-wire fences were relatively easy for mule deer and pronghorn to traverse, but were difficult and potentially hazardous for elk to traverse. Three-wire fences were very effective at containing cattle and bison and relatively easy for elk, mule deer, and pronghorn to traverse.

Electric shock did not appear to be a factor effecting the reaction of elk, mule deer, or pronghorn to electric fences that carry a charge of 0.5-4.5 J. Less than 2% of these species (9 elk, 2 deer, 0 pronghorn) were shocked when interacting with electric fence. We observed no pattern between animals shocked and the number of Joules on a fence.

5.2 Recommendations

Of the designs examined in this study, we contend a 3-wire fence is the best overall design to meet the goals of both the livestock producer (cattle and bison) and the wildlife manager. Four-wire fence could be used to control bison in areas that do not receive pressure by elk, however we feel the extra expense is not necessary when 3-wire appears to be just as effective. Cheaper 2-wire electric fence is recommended for cattle containment only if the fence will not be used to wean calves and pronghorn do not frequent the area.

This study identifies a 3-wire electric fence design that will effectively contain cattle and bison while still allowing elk, deer, and pronghorn to traverse. As such, the fence meets a goal expressed by both Wyoming Department of Transportation and Wyoming Game and Fish Department of containing cattle, while still allowing wildlife to pass. This study, however, did not examine perceived human safety and liability concerns surrounding the use of electrically charged fences on public right-of-ways. Additional research needs to be conducted that addresses these issues before Wyoming Department of Transportation will consider electric fence as an alternative right-of-way fence.

References

Adams, A.W. 1982. Migration. Pages 301-321 *in* J. W. Thomas and K.E. Toweill, editors. Elk of North America: Ecology and Management. Stackpole Books, Harrisburg, Pennsylvania, and Wildlife Management Institute, Washington, D.C., USA.

Falk, N. W., H.B. Graves, and E.D. Bellis. 1978. Highway right-of way fences as deer deterrents. Journal of Wildlife Management 42:646-650.

Hancock, T. 1995. Energizers and energy: an explanation of electric fence concepts. Gallagher Group Limited Research and Development Laboratory. Hamilton, New Zealand.

Kie, J. G., V. C. Bleich, A.L. Medina, J. D. Yoakum, and J.W. Thomas. 1994. Managing rangelands for wildlife. Pages 663-688 *in* T.A. Bookhout, editor. Research and management techniques for wildlife and habitats. Allen Press, Inc., Lawrence, Kansas.

Oakley, C. 1973. The effects of livestock fencing on antelope. Wyoming Wildlife 37(12):26-29.

Reed, D.F., T.M. Pojar, and T.N. Woodward. 1974. Use of one-way gates by mule deer. Journal of Wildlife Management 38:9-15.

Spillett, J.J., J. B. Low, and D. Sill. 1967. Livestock fences-how they influence pronghorn antelope movements. Utah State University Agriculture Experiment Station, Bulletin 470. Logan, Utah, USA.

Sundstrom, C. 1967. Effects of livestock fencing on antelope. Wyoming Game and Fish Commission Federal Aid Report FW-3-R-14. Cheyenne, Wyoming, USA.

United States Department of Interior, Bureau of Land Management. 2000. Interim Electric Fence Policy for the Rawlins Field office. Rawlins, Wyoming, USA.

Ward, A. L., N. F. Fornwalt, S. E. Henery, and R. A. Hodorff. 1980. Effects of highway operation practices and facilities on elk, mule deer, and pronghorn antelope. Federal Highway Administration Report FHWA-RD-79-143. Washington, D.C., USA.

Yokum, J. W.P. Dasmann, H.R. Sanderson, C.M. Nixon, and H.S. Crawford. 1980. Habitat improvement techniques. Pages 329-403 *in* S.D. Schemnitz, editor. Wildlife management techniques manual. The Wildlife Society, Incorporated, Washington, D.C., USA.

Appendix A. Wyoming construction cost comparison between 3-wire electric fence and Wyoming Department of Transportation Type F, 4-wire barbed fence in May 2002.

Fence Contractor	Materials Cost/linear ft		Total Construction Cost/linear ft (Materials + Labor)	
	Barbed	Electric	Barbed	Electric
A	$0.50	$0.35	$1.25	$0.70
B	$0.47	$0.27	$0.95	$0.52
C	$0.43	$0.29	$0.85	$0.58
D	$0.60	$0.20	$1.30	$0.40
E	$0.50	$0.35	$1.00	$0.75
F	$0.47	$0.33	$1.08	$0.66
Average Cost	**$0.50**	**$0.30**	**$1.07**	**$0.60**

Appendix B. Maintenance cost comparison between 3-wire electric fence and Wyoming Department of Transportation, 4-wire Type F barbed.

While working with various landowners and land managers in Wyoming, we questioned them about the maintenance aspect of electric fencing and how it compared to maintenance of barbed wire fences. Specifically, electric fence users were asked "Compared to 4-wire barbed fence, is your electric fence equal, harder, or easier to maintain?" Of 11 respondents, 7 felt that electric fence maintenance was equal, 3 thought they were easier to maintain, and 1 felt that they were harder to maintain. Most respondents that used battery-operated units without a solar panel felt replacing the battery increased maintenance expense compared to barbed wire. However, they also felt the increased battery maintenance cost was offset by having fewer broken wires. The landowner that felt maintenance cost was higher was using a fence that was improperly constructed. The maintenance costs were higher because the energizer was not correctly grounded and his livestock would move in and out of the fence and occasionally break posts or wire.

A properly constructed electric fence is a psychological barrier that receives very little physical pressure from livestock. When physically tested by livestock or wildlife the fiberglass line-posts, the spacing between posts, and the strength of the high-tensile smooth wire generally allow the fence to "give" instead of break wires or posts. Barbed wire fences with 16.5' spacing between rigid wood posts and 12.5 gauge barbed wire that has less breaking strength than 12.5 gauge high-tensile wire is more likely to give way under physical pressure.

The biggest maintenance concern with electric fence has to do with maintaining a minimum shock energy. In order to be effective, electric fences must maintain a continuous pulse of electrical energy. Any conductive material contacting a charged wire will leak energy out of the fence. Conductive materials that generally pose a threat are wet or green vegetation and snow. A loss of energy is only detrimental however, if the fence drops below a certain energy level deemed acceptable for that particular fence. High voltage, low impedance energizers are fairly effective at dealing with this problem. These energizers have the ability to increase the amount of energy released when a fence is under load. Even if the fence is losing energy because of the increased load, the target energy level is maintained. If the load breaks a certain threshold however, the energizer can no longer keep up and the fence becomes ineffective. In areas with high snow depths that completely cover a hot wire there is no feasible way to maintain an adequate charge. The best option in that case is to disconnect the effected wire so the remaining wires do not lose their shock energy.

Maintaining an adequate electric charge is the main maintenance responsibility that sets electric fence apart from barbed wire fence and is the reason many people shy away from its use. While both barbed wire fence and electric fence must be checked periodically for broken wires or posts, only electric fence requires maintenance of an electric charge. Maintaining a charge requires the user to physically measure the voltage or J on a fence to make sure minimum shock energy is uninterrupted. If the fence has been grounded out, the user must find the source of the short and fix the problem.

Maintaining a charge on an electric fence increases maintenance costs compared to barbed wire fence. At the same time, the superior physical flexibility of a properly constructed electric fence decreases maintenance costs compared to barbed wire fence. For this reason, we contend electric fence and barbed wire fence maintenance is approximately equal.