# PERMEABILITY OF THREE-STRAND ELECTRIC FENCES BY BLACK BEARS AND GRIZZLY BEARS

by

Brittani Justine Johnson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Animal and Range Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2018

# DEDICATION

To my partner Nestor, my mother Jennifer, and my grandmother Karen for supporting me through the many challenges I have faced throughout my undergraduate and graduate career. To my grandfather Charlie, who introduced me to this passion and who taught me the gift and privilege of our public lands and resources.

# ACKNOWLEDGEMENTS

I am very grateful to Dr. Lance McNew and Jamie Jonkel, who initiated and supported this project. Jamie allowed me to serve as an intern for Montana Fish, Wildlife, and Parks as well as work on my graduate project. Dr. McNew gave me the incredible opportunity to start this project with Montana State University and earn my master's degree. My sincere thanks to my graduate committee members Dr. Robert Garrott and Dr. Mike Frisina for their insights and wonderful guidance. I also thank Dr. Seth Wilson for his insights into my writing and career path. I am extremely thankful to George Bettas and Jane Ratzlaff with Montana Outdoor Legacy who supported my internship with Montana Fish, Wildlife, and Parks and subsequently supported me as a graduate student at Montana State University. I am also very grateful to my other sponsors; Blackfoot Challenge, U.S Fish and Wildlife Service, Vital Ground, Defenders of Wildlife, Interagency Grizzly Bear Committee, Yellowstone to Yukon Initiative and Tru – Test for supporting me financially or with materials. Bob Weisner, Mike Johnson, Eric Graham and Barry Gordon were instrumental in assisting me with field work and mentorship. To all my mentors at FWP, I thank for giving me direction and support. I would also like to thank the Montana State University Wildlife Habitat Ecology Lab for their support throughout my graduate school career. To all the landowners in the Blackfoot who allowed me to access their properties several times a week, I thank you. This project would not have been possible without you.

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# ABSTRACT

Electric fencing has been used to deter bears in North America for several decades. Producers have turned to a design of a minimum of five-wire electric fence as their primary solution to reduce livestock depredation and to reduce raids of chicken houses and beeyards. However, these designs are expensive and reducing the number of wires used in a design to three wires would be beneficial. Scientific evaluations of the efficacy of three-wire electric fencing at deterring bears is lacking. In 2015 and 2016, I conducted a study in the Blackfoot Valley of Montana to evaluate the efficacy of rapid-deployment electric fencing designs in deterring bears from baited enclosures. Baited enclosures of two fencing configurations were established at 20 sites in the study area. Each enclosure was systematically energized and unenergized for 3-day periods; and passage into the enclosure was monitored with trail cameras to provide information on effectiveness and permeability. I recorded 134 visits by bears to fenced enclosures during the study seasons of 2015 and 2016. Of these visits, 78 occurred in 2015 and included 57 black bears and 21 grizzly bears. Fifty-six visits occurred in 2016, including 34 black bears and 22 grizzly bears. Black bears and grizzly bears were successful at passing the short fence 48% (95% CI: 32.0 – 63.6) and 23% (5.0 – 53.8) of the time, respectively, when it was not energized. When the short fence was energized, black bears were 7% (0.2 – 33.9) successful in passing, whereas grizzly bears were successful in 25% (5.5 – 57.2) of attempts. When not energized, both species successfully passed the tall fence design in 58% (95% CI: 27.7 – 84.8) of attempts. Black bears and grizzly bears successfully entered energized enclosures with tall fences in 30% (95% CI: 13.2 – 52.9) and 0% (95% CI: 0.0 – 45.9) of attempts, respectively. Both fence types deterred bears from entering baited enclosures and all fences allowed less than perfect access when unenergized, suggesting that even minimalistic configurations of electric fences may act as barriers to black and grizzly bears. Further study evaluating the effects of rapidly increasing construction of electric fencing is needed to assess landscape level effects on bear movement and habitat selection.

# INTRODUCTION AND LITERATURE REVIEW

## Grizzly Bear Population Status

Grizzly bear (*Ursus arctos horribilis*) populations in the United States have an extensive history of management and conservation. An estimated 50,000 grizzly bears occurred in North America during the early 1800's. However the population declined rapidly due to European settlement in the West during the 19$^{th}$ century. Livestock protection, commercial trapping, unregulated hunting, and habitat degradation caused rapid population declines from the 1800's to the mid-1900's (Wild and Brown 1986). Less than 1,000 grizzly bears in the lower 48 states were awarded protection under the Endangered Species Act in 1975. Currently, populations occupy a fraction of their historic distribution (Figure 1).

With the exception of Alaska, the current distribution of American grizzly bear populations occur in 6 designated recovery zones (Figure 2). Of these 6 recovery zones, the Greater Yellowstone Ecosystem (GYE), the Northern Continental Divide Ecosystem (NCDE), the Selkirk Mountains Ecosystem, and the Cabinet-Yaak Ecosystem contain resident populations of bears. Currently, populations of grizzly bears in the YGBE and NCDE are estimated to be 650 and 765 bears, respectively (U.S Fish and Wildlife Service 2014). Populations in the Selkirk Mountains and Cabinet-Yaak Ecosystems are estimated to be 70 and 45 bears, respectively (U.S Fish and Wildlife Service 2014). The YGBE (24,800 km$^2$) includes Yellowstone National Park, Grand Teton National Park, the Shoshone, Targhee, Bridger-Teton, Gallatin, Beaverhead, and Custer National Forests, Bureau of Land Management lands, and state and private lands (U.S Fish and Wildlife Service 1993). The NCDE (24,000 $km^2$) consists of Glacier National Park, parts of the Blackfeet and Flathead Reservations, the Flathead, Helena, Kootenai, Lewis and Clark, and Lolo National Forests, state and private land, Bureau of Land Management lands, and the Bob Marshall, Mission, Great Bear, and Scapegoat Wilderness areas (U.S Fish and Wildlife Service 1993). Individuals have been found in the North Cascades and the Selway-Bitteroot but these transient individuals are not considered a permanent population.

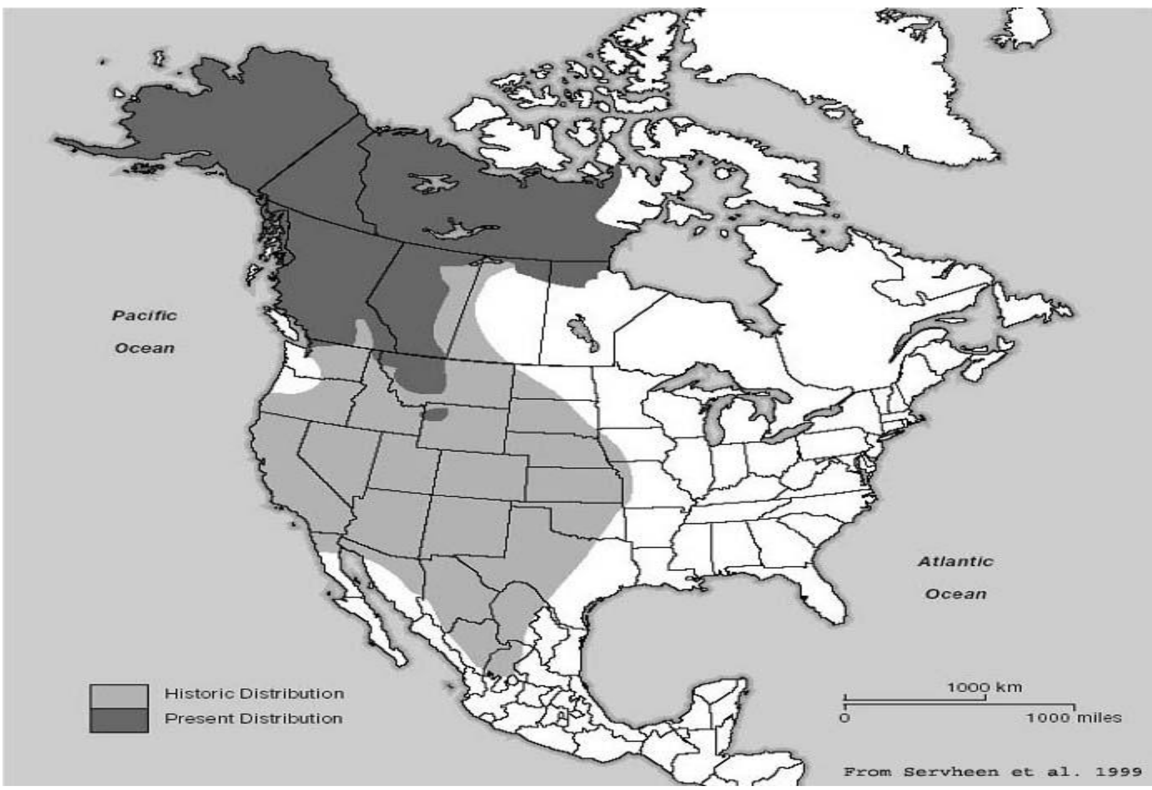


Figure 1. Historic (light gray) and current (dark gray) distribution of grizzly bears in North America (Servheen et al. 1999).


Figure 2. Current recovery zones for grizzly bears in the lower 48 States. These recovery zones are: 1) the North Cascades recovery zone, 2) the Selkirks recovery zone, 3) the Cabinet Yaak recovery zone, 4) the Northern Continental Divide recovery zone, 5) the Selway-Bitterroot recovery zone, and 6) the Yellowstone recovery zone (U.S Fish and Wildlife Service 1993).

Grizzly bears have been protected under the Endangered Species Act since 1975, with the exception of the GYE population which was briefly delisted in 2007, relisted in 2009, and delisted again in 2017. Currently, the U.S Fish and Wildlife Service is in the process of delisting the Northern Continental Divide Ecosystem population and hunting seasons are being discussed. Wyoming and Idaho have established a grizzly bear hunting season for the fall of 2018. Five criteria must be met before populations can be removed from the Endangered Species List (U.S Fish and Wildlife Service 1993):

1) the estimated percent of total mortality of independent aged females cannot exceed 7.6%,

2) the estimated percent of total mortality of independent aged males cannot exceed 15%,

3) the estimated percent of mortality from human causes for dependent young cannot exceed 7.6%,

4) at least 48 females must produce cubs annually, and

5) the population estimate must exceed 500 bears in the recovery area.

Population recovery varies by ecosystem. According to the 1993 Grizzly Bear Recovery Plan (U.S Fish and Wildlife Service 1993), some ecosystems without permanent populations such as the Selway-Bitteroot, and the North Cascades recovery zones will not be recovered for 30–40 years while the GYE and NCDE populations are expected to recover sooner.

In Montana, grizzly bears were classified as a game animal in 1923, prohibition of killing a sow with cubs was reinforced in 1947, and regulated hunting seasons ceased in 1975 when the species was listed as a threatened animal under the Endangered Species Act (Mace and Chilton-Radandt 2011). Since listing, agencies have invested a great deal of effort to conserve grizzly bears. In 1985 the Interagency Grizzly Bear Management Guidelines were established to provide a universal protocol for agencies to follow while attempting to recover populations in the lower 48 states (U.S Fish and Wildlife Service 1993).

Mortality and habitat are priority considerations for grizzly bear management and a focus of recovery efforts. The USFWS Grizzly Bear Management Guidelines list six categories of human-caused mortality: 1) direct human/bear confrontation, 2) attraction of grizzly bears to improperly stored food and garbage associated with towns, subdivisions, farmers, hunter camps, campers, loggers, fishermen, backpackers, and other sources, 3) careless livestock husbandry, including the failure to dispose of dead livestock in a manner that minimizes grizzly bear interactions, 4) protection of livestock, 5) the eroding of grizzly bear habitat for economic values, and 6) lawful or illegal hunting (U.S Fish and Wildlife Service 1993). Estimation of cause-specific mortality rates relative to these categories has been a focus of research since listing. Wakkinen and Kasworm (2004) summarized survival and cause-specific mortality of grizzly bears in the Cabinet-Yaak and Selkirk Mountains recovery zones during 1983 – 2002 and reported survival rates of 0.929 (95% CI = 0.091) and 0.936 (95% CI = 0.064) for adult females in the Cabinet-Yaak and Selkirk Mountains, respectively. Approximately 54% and 80% of total known mortality in the Selkirk and Cabinet-Yaak recovery zones were caused by humans, mistaken species identification while hunting, poaching, and management removal (Wakkinen and Kasworm 2004).

Mace and Waller (1998) found that lower survival and reproductive rates and relatively high mortality rates contributed to decreases in population trend for grizzly bears in the Swan Mountains of Montana. They used capture and telemetry methods to study demography, movements, and population trend and concluded that rural zones were demographic sinks for grizzly bears because of malicious killing and management removal of habituated and food-conditioned bears. Total mortality rates in this area were 13.6%, which is above the recommended rate of 12.5% (Bunnel and Tait 1980). Along the Rocky Mountain Front during the 1980s, 44% of grizzly bear conflicts were livestock depredation related and 40% were property damage reports (Aune and Kasworm 1989, Wilson et al. 2005). During 1991 – 1994, 82% of all human-grizzly bear conflicts were attractant related, including boneyards and beehives, and approximately 55% of conflicts were associated with livestock operations (Madel 1996). Conflicts with humans sometimes resulted in removal of the offending bear, contributing to decreases in population size (Madel 1996). Management removals of grizzly bears due to livestock depredation in the Montana portion of the GYE have more than tripled from 5% during 1994 – 2004 to 17% from 2005 – 2015 (Frey and Smith 2016, Wells 2017). As grizzly bear populations expand into previously unused habitats, human-bear conflicts and mortality rates increase (Madel 1996).

Habitat conservation is the second priority of grizzly bear managers (U.S Fish and Wildlife Service 1993). Craighead and Mitchell (1982) define effective habitat as an environment that provides food, cover, denning opportunity, solitude, and space, and habitat quality and availability are associated with bear demography. Grizzly bear populations appear to be sensitive to small amounts of habitat degradation (Doak 1995), and changes in important habitat components can have disproportionate impacts on demography and population dynamics. Human developments and primary roads affect grizzly bear habitat use in Yellowstone National Park and adult females and subadult males residing closer to developments were trapped because of human conflict at a higher rate than animals of the same class residing farther away (Mattson et al. 1987). Avoidance of human developments sometimes resulted in avoidance of optimal foraging habitat, which in turn resulted in poorer condition of adult females. Viability of grizzly bear populations is in large part contingent on survivorship of adult females (Knight and Eberhardt 1984); when adult females experience an ongoing energetic crisis due to suboptimal forage and stress, their weight and fecundity decrease and chances of mortality increase (Mattson et al. 1987).

## Black Bear Population Status

The black bear (*Ursus americanus*) also has an extensive management history (Jonkel and Cowan 1971, MacHutchon 1989). Historic distribution included most of North America, including Canada and Mexico (Figure 3). The current distribution of black bears includes the Pacific Northwest, the northern Rocky Mountains, the Southwest, the Northern Great Lakes, New England, New York, the Appalachian and Ozark Mountains, and Florida (Figure 3). In the United States, black bear populations are listed as threatened in Texas and Mississippi (Ulev 2007, U.S Fish and Wildlife Service 2013) and endangered in Mexico (Doan-Crider and Hellgren 1996). However, black bears are not threatened in most of the United States and Canada and are considered generally stable over much of their distribution (McCracken et al. 1995). Declines in distribution and population size during the last two centuries has been linked to habitat loss and degradation associated with human settlement and unregulated hunting (Cardoza 1976). Conservation efforts during the past 40 years have allowed black bears to recover to an estimated 600,000 individuals in North America, with 300,000 of those occurring in the United States (Malany et al. 2018).

Black bears in Montana have been managed since 1923 and occur in 6 of 7 administrative regions of the state. Montana Fish, Wildlife, and Parks (hereafter MFWP) further divides these regions into Bear Management Units (BMUs). Management techniques have changed over the decades, but the long-term goal has been to manage black bear populations at a sustainable level of harvest (Mace and Chilton-Radandt 2011). In 1923, the status of black bears changed from a predatory to big game animal, and soon after the harvesting of cubs or a female with cubs became illegal. The use of bait was prohibited in 1948 (Mace and Chilton-Radandt 2011). Nevertheless, black bear harvests remained relatively liberal during the early 20th century. Between 1959 and 1971, hunting was open from March to November and prior to 1967 a hunter could harvest one individual of each species of bear. Human-bear conflict during this period was relatively low as landowners or hunters in possession of a bear license could legally harvest a bear who had become habituated to anthropogenic attractants and posed a potential safety risk to humans.

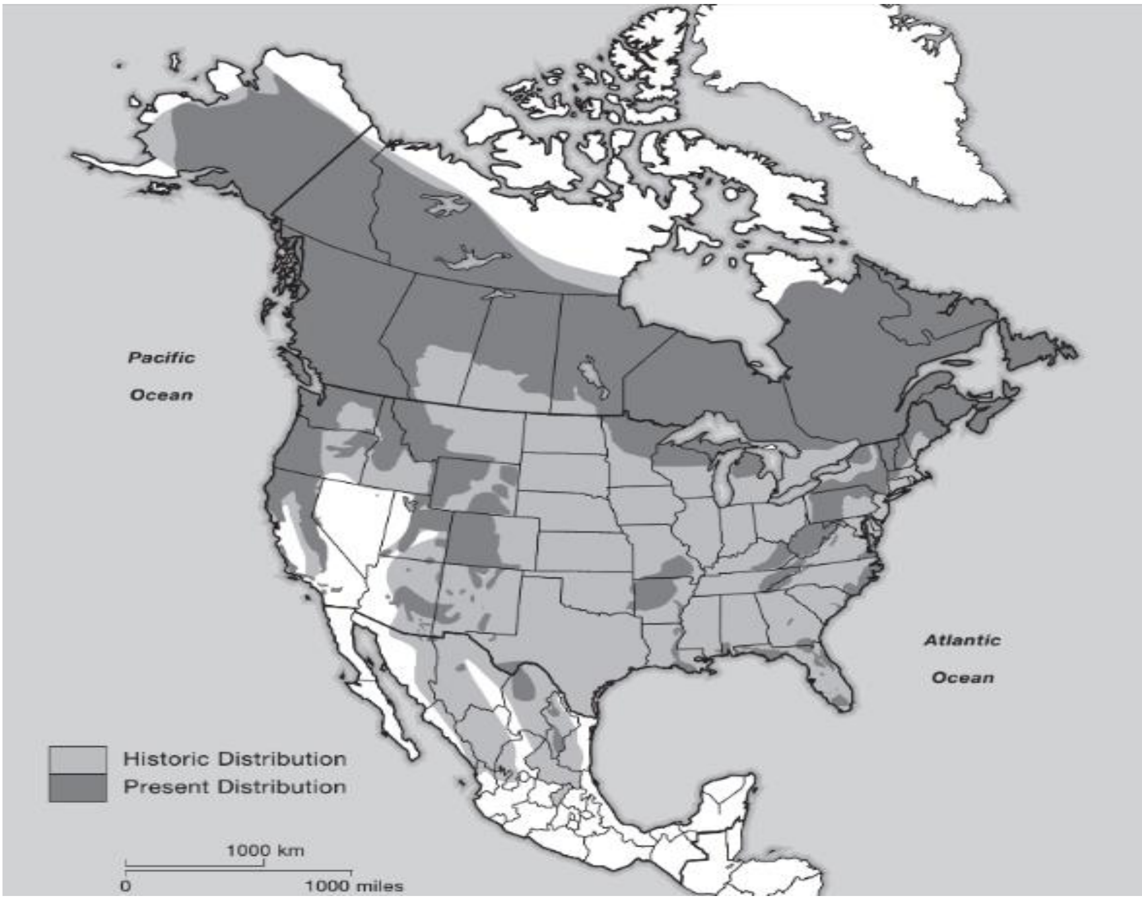


Figure 3. Historic (light grey) and current (dark grey) distribution of black bears in North America (Ulev 2007).

Beginning in 1985, hunting was restricted to two separate and shorter seasons occurring in the spring and fall. Currently, a hunter can purchase one over-the-counter black bear tag per year (Montana Fish, Wildlife, and Parks 2018). Human-bear conflicts began to increase (Mace and Chilton-Radandt 2011), and bear conflict specialists were hired to respond to livestock and bee yard depredations. Conflict specialists conducted public outreach and education on bear awareness. In 2001, the Montana legislature passed a law prohibiting the feeding of bears and other wildlife (Montana Code

Annotated 87-3-130) to reduce concerns about bear-human conflicts (Mace and Chilton-Radandt 2011).

Human expansion into natural landscapes has affected biotic integrity, species composition, and wildlife behavior (Krestser et al. 2008, Ditmer 2014), especially of opportunistic feeders such as black bears. As suburban and ex-urban areas expanded into bear habitat black bears acclimated to human presence and discovered that fruit, garbage, compost, and chickens are available near human developments (Beckman and Berger 2003). As a result, human-bear interactions have increased, especially in years of natural food shortage (Raine and Kansas 1990, Peine 2001, Merkle 2013). State wildlife agencies reduce human-bear conflicts by working with the legislature to pass more stringent laws on the prohibition of both active and passive feeding of bears and educating the public about bear awareness and safety in urban landscapes (Spencer et al. 2007).

## Grizzly Bear Habitat Selection

Space use and habitat selection by grizzly bears occurs at multiple spatial scales and is sex-specific and context dependent. Grizzly bears occur over a wide range of environmental conditions and populations exhibit varied responses to habitat and human factors (Miller 2003). Grizzly bear distribution relative to terrain and human influence varies with vegetative conditions and land cover (Apps et al. 2004). Habitat selection has been extensively studied, both in natural ecosystems and in landscapes where anthropogenic disturbances exists. Finding food, acquiring mates, developing home ranges, and selection of thermal refugia are some of the basic decisions that bears make when establishing home ranges (Schwartz et al. 2010, Hiller et al. 2017).

Habitat selection by bears, like most wildlife, is hierarchical across spatial extents. First order selection delineates the geographic distribution of a species. Within a population's distribution, bears then select a home range via second order habitat selection, and within that home range bears select areas that are used regularly (third order selection; Johnson 1980). Grizzly bears occupy extensive home ranges, and several studies show that home ranges typically vary among sex and age classes (Mattson et al. 1990, McLellan and Shackleton 1988, Wielgus and Bunnell 1994, 1995). Adult males typically occupy larger ranges than females (Blanchard and Knight 1991, Mace and Waller 1997, Ciarniello et al. 2007). Home ranges of females, especially related females, are more likely to overlap, and females and younger males tend to avoid adult male territories (Kendall et al. 2009). Females may choose different habitats than males to protect cubs from male infanticide (McLellan and Shackleton 1988) and to avoid competitive exclusion by dominant males (Mattson et al. 1990). In densely populated areas where social interactions increase, adult males have been observed to use the most productive feeding sites, leaving sup-optimal forage to juvenile males, females, and family groups (van Manen et al. 2016).

Within home ranges, habitat selection by grizzly bears vary seasonally based on food availability and other factors such as proximity to security cover and human activity (Servheen and U.S Fish and Wildlife Service 1993, Mace et al. 1997, McLellan and Hovey 2001). Grizzly bear spatial and temporal use of habitat is also related to distribution of seasonal food sources (Craighead and Craighead 1972, Stonorov and Stokes 1972, Atwell et al. 1980, Glenn and Miller 1980, Judd and Knight 1980). Improvements and application of resource selection models, GIS, and remote sensing technologies during the past two decades have rapidly improved understanding of the spatial ecology of bears (Nielsen et al. 2003). In Montana researchers have found that remotely-sensed vegetation indices such as NDVI, an index of 'greenness', is a strong predictor of grizzly bear space use (Mace et al. 1996, Mace et al. 1999). Grizzly bears follow the green up of plant species and exhibit seasonal shifts of diet in response to changes in food availability and plant phenology (Hamer and Herrero 1987). Individual bears have been observed to migrate to riparian areas in the spring, then move back to higher elevations in the late summer and fall, while other bears remained in mountainous terrain and high elevation throughout all seasons (McLellan and Hovey 2001). Grizzly bear concentrations are lowest in spring because of dispersed forb and graminoid use, and highest in the fall when foods such as army cutworm moths, domestic fruit trees, and salmon spawning areas are concentrated (Gard 1971).

Grizzly bears are omnivores and consume a variety of foods including meat, vegetation, berries, nuts, invertebrates, garbage, fruit, and crops. Bears are opportunistic in their feeding patterns and food habits vary seasonally across their distribution. Seasonal diets are determined by resource availability and plant phenology (Servheen 1983). Forbs and perennial graminoids (*Taraxacum* spp. and *Trifolium* spp.) made up the spring diet of most grizzly bears in the NCDE (Servheen 1983). Other important spring foods include mammal carrion from winter die-off and insects from excavating tree stumps and logs (Servheen 1983). Perennial graminoids and berries are important food sources throughout the summer, and army cutworm moths are an important food source in the GYE (Chapman et al. 1953, Servheen 1983, Mace 1997).

Grizzly bears sometimes travel great distances to locate seasonally available foods; however, bears often avoid areas of high human use such as roads and trails regardless of food resources (Garshelis and Pelton 1981, Northrup et al. 2012, Lamb et al. 2018). Roads, residences, campgrounds, and other human-developed sites have been found to negatively influence the selection of otherwise suitable habitat for both black and grizzly bears (Servheen 1983, Mattson et al. 1987, McLellan and Shackleton 1988, Mace et al. 1996, Mace and Waller 1997, Mace et al. 1999, Schwartz et al. 2012). The abundance of grizzly bears in and around Glacier National Park was negatively associated with road density (Graves et al. 2011), and areas with even relatively low densities of residential development can act as demographic sinks for grizzly bears (Schwartz et al. 2012). The expansion of rural residential areas in Montana, Wyoming, and Idaho has been identified as a factor impacting bear population recovery (Schwartz et al. 2010).

## Black Bear Habitat Selection

Black bears can be either nocturnal or diurnal and exploit a wide variety of habitats to acquire the resources needed to survive and reproduce (Amstrup and Beecham 1976, Davis et al. 2006). Black bears use habitat in predictable ways, and movement patterns are dictated by seasonal food availability and distribution (Beecham and

Rohlman 1994). Habitat diversity appears to be important to black bears (Jonkel and Cowan 1971, Kemp 1979, Lawrence 1979). Like grizzly bears, black bears exhibit seasonal changes of food habits as well as habitat use, exploiting seasonal abundances of variable food resources (Jonkel and Cowan 1971, Shaffer 1971, Amstrup and Beecham 1976, Lindzey and Meslow 1976). Black bears make decisions on site selection based on the phenological development of food plants and modify habitat selection based on variations in availability (Davis et al. 2006). The abundance and value of vegetation also has a substantial effect on site selection throughout the year (Rode and Robbins 2000). Davis et al. (2006) observed radio-collared female black bears and found that the probability of site use depended on increasing values of phenologically adjusted berry value, phenologically adjusted succulent forage value, and forest harvesting. Several studies have observed bears following elevational gradients of forage green-up from April to mid-July; bears are most often associated with a plant group during peaks in production or quality (Amstrup and Beecham 1976, Young and Beecham 1986, Lyons and Servheen 2003). Early in the spring forbs and grasses are first available in dry mountain meadows and along stream banks. Feeding also occurs on south-facing slopes. As spring progresses, bears will move to lower elevations to eat forbs and sedges (Tisch 1961). By mid-July, graminoids and forbs occurring at lower elevations begin to cure and bears shift to higher elevations to take advantage of ripening berry crops until denning occurs in the late fall (Hatler 1967, Jonkel and Cowan 1971, Hererro 1972, MacHutchon 1989). Plant and berry production have shown to be limiting factors to black bear populations. Hatler (1967) reported that during a year of widespread failure of the blueberry crop in Alaska there were numerous emaciated black bears and increased use of garbage dumps, consequently leading to human-bear conflict. Schorger (1946) reported an unusual influx of black bears into Duluth Minnesota during a shortage of wild fruits. Rausch (1961) found that well fed captive black bears in Alaska developed more rapidly than wild bears. Jonkel and Cowan (1971) reported that reproduction in black bears approached zero when huckleberries were scarce for three successive years in Montana.

Black bears often select for timber, open timber, and riparian habitats while avoiding open areas such as meadows and clear-cut habitats (Beecham and Rohlman 1994), and the importance of security and denning cover has been well demonstrated (Lindzey and Meslow 1977, Novick and Stewart 1982). Black bears select secure areas for day bedding and denning in winter. Denning in black bears is an energy conserving strategy in winter when feeding opportunities are limited and temperatures unfavorable (Johnson et al. 1978, Johnson and Pelton 1981). Selection of den types is variable and includes tree cavities, hollows at the base of a tree, holes dug in the ground and brush piles (Jonkel and Cowan 1971, Beecham 1980). Bears in southern habitats den for a shorter period than those in northern habitats where winter is longer and more severe. Pregnant females den longer than non-pregnant females and males; females den longer than males (Weaver and Pelton 1994).

The home ranges of female black bears are relatively stable from year to year, whereas the size and location of males' home ranges varies seasonally (Jonkel and Cowan 1971, Amstrup and Beecham 1976). Females are thought to prefer areas that provide greater security cover for cubs whereas males show greater mobility and use more diverse habitat conditions (Herrero 1972). Adult males occupy significantly larger home ranges than adult females (Jonkel and Cowan 1971, Amstrup and Beecham 1976, Reynolds and Beecham 1980), and the longest movements occur during the breeding season (Lindzey and Meslow 1976, Reynolds and Beecham 1980). Males may shift their core use areas to be with females during this time (Barnes and Bray 1976). Several studies have followed movement of females with cubs, and the literature is inconclusive on whether cubs restrict female movement and whether females without cubs are more mobile and use larger home ranges (Barnes and Bray 1967, Eveland 1973, Lindzey and Meslow 1976, Reynolds and Beecham 1980). Home ranges of intraspecifics often overlap, and several individuals can often be observed feeding in close proximity without displaying aggressive behavior (Jonkel and Cowan 1971, Reynolds and Beecham 1980).

Both grizzly bears and black bears are generalist omnivores with some niche and diet overlap (Mattson and Merrill 2004). It has been suggested that grizzly bears are better adapted to open habitats because of their aggression, large body size, and long claws for digging, whereas black bears are better adapted to forested environments because of their smaller body size and recurved claws that allow them to climb trees (Herrero 1972). Grizzly bears dominate concentrated food sources such as dumps and salmon (Oncorhynchus spp.) streams and kill black bears occasionally, while black bears dominate areas where foods are dispersed (Welch et al. 1997, Jacoby et al. 1999, Rode et al. 2001). Both species are impacted by human developments such as roads, campgrounds, and houses. Grizzly bears may be more sensitive to human development than black bears. Black bears may benefit when humans encroach on high quality grizzly bear habitat (Kasworm and Manley 1990, Apps et al. 2004). Where the two species are sympatric, black bears tend to be more day active whereas grizzly bears are crepuscular and nocturnal (Mattson and Merrill 2004, Schwartz et al. 2010). However, both bear species are nocturnal in areas with high human use (Ayres et al. 1986, Gibeau et al. 2002, Beckman and Berger 2003, Kaczensky et al. 2006), suggesting that both species perceive humans as a threat (Schwartz et al. 2010). Anthropogenic activities on both species of bear are impactful and have consequences for population viability.

## Anthropogenic Impacts on Bears

Global urban development is rapidly expanding and can negatively affect wildlife populations, leading to reduced forage quality, survival, and reproductive success (Mattson et al. 1987, Spencer et al. 2007). Impacts include altered behavior of individuals, altered population distribution and movements of individuals, and discontinued use of corridors or linkage areas (Northrup et al.2012). Landscape connectivity is an important concept of population viability (Northrup et al. 2012, Graves et al. 2013), increased risk of disease, and both direct and indirect mortality (Mattson 1990, Craighead et al. 1995, Beckman and Berger 2003). In addition, human population growth, bear population growth, and diminishing habitats result in increased risk of human-bear conflicts. In North America, grizzly bear populations are expanding onto private lands bordering national parks, increasing bear-livestock conflict (Northrup et al. 2012). Conflicts with black bears are associated with their increasing populations and their attraction to anthropogenic sources such as bee yards, garbage, and bird feeders

(Spencer et al. 2007, Merkle 2013). Reduction of human-bear conflicts is an important element of bear conservation and management, especially to recovering grizzly bear populations. Because most deaths of these animals are caused by humans (Mattson et al. 1996, McLellan 1990, Wilson et al. 2005), conflicts have high consequences for bear recovery and demography. Removing individuals from a population can result in lower reproduction, survival, and can create demographic sinks in a population (Schwartz et al. 2006).

There are many indirect implications of anthropogenic habitat alteration on bear behavior and ecology. The response of bears to human activity is determined by spatio-temporal availability of human-mediated food resources, bear tolerance of humans and human tolerance of bears (Mattson 1990). For example, the accessibility of high value summer riparian habitats can be reduced when the densities of roads and other human infrastructure are high and deter bears (Waller and Servheen 1999, Waller and Mace 1997, McLellan and Hovey 2001, Waller and Servheen 2005). Overall, the effects of roads on bear space use and habitat selection have been well studied and largely negative.

Suburban areas produce spatially concentrated and highly productive food resources, and both species of bears take advantage of those resources (Shochat et al. 2006, Gehrt et al. 2010). During late summer and fall bears enter hyperphagia, a state of intense feeding, to gain energy reserves for hibernation (Nelson et al. 1983). During this period, they can move extensively from food source to food source and may risk moving into urban areas for anthropogenic food sources such as garbage, bird feed, and chickens which offer high caloric intake. Apple orchards are also a major part of bear diets in western Montana. The use of these habitats by bears often become a human safety risk and require management removal of offending bears (Servheen 1983). Some suburban areas act as population sinks for black bear populations due to high bear mortality (Beckmann and Berger 2003). Bears are a long-lived species and have limited ability to respond to high levels of juvenile and adult female mortality and removals due to human-conflict may reduce population viability (Congdon et al. 1993).

Bears will sometimes prey on livestock such as cattle (*Bos taurus*) and sheep (*Ovis aires*). Significant use of sheep by both species of bear has been recorded in western North America (Johnson and Griffel 1982, Brown 1985). While on summer range, sheep are in closer contact with bears and are less closely attended than any other time of year (Johnson and Griffel 1982). Significant use of cattle has been recorded in western North America as well, more often by grizzly bears than black bears (Mattson 1990). Cattle predation generally is associated with dispersal of cattle on summer ranges and appears to happen more frequently in more remote areas with greater cover (Murie 1948, Knight and Judd 1983). Wells (2017) found that annual numbers of livestock and grizzly bear density on grazing allotments in the GYE had a large, positive effect on livestock depredation, but livestock depredation was mediated by habitat conditions including terrain ruggedness, road density, and primary productivity, and distance from security cover. Increased depredations result in more intensive grizzly bear removals from a recovering population.

Agricultural crops are also a major source of conflict between bears and people (Gunther et al. 2004, Wilson et al. 2005, 2006, Northrup 2010). Bear use of agricultural crops such as fruit, forage, and cereal can be substantial because agricultural crops often overlap with riparian habitats that are heavily used by grizzly bears (Wilson et al. 2005, 2006, Northrup et al. 2012). The reduction of agricultural conflicts is important for the recovery of grizzly bear populations in the NCDE (U.S Fish and Wildlife Service 1993, Madel 1996). The use of human-associated foods such as garbage, livestock, and domesticated fruits by bears is typically mediated by the availability of natural food resources and seasonal changes in energy requirements of bears. During years of poor native food production, increased use of agricultural crops and depredation on livestock by bears have been recorded in California, the eastern United States, the GYE, and Canada (Novick and Stewart 1982, Elowe 1984, Young and Ruff 1982, Mattson 1990, Wells 2017). In many study areas, males are disproportionately represented among bears involved in human-bear conflict concerning livestock and human facilities. Males have a greater probability of encountering conflicts due to relatively large home ranges and therefore are more prone to be lethally removed due to a conflict (Mace et al. 1987, Craighead et al. 1988). Nevertheless, females and subadults have a greater tendency to occupy areas near humans (McLellan and Shackleton 1988). This behavior may be attributed to the opportunity to use higher quality foods for females and cubs and sub-adults who are preempted by dominant adult males (Mattson et al. 1987, McLellan and Shackleton 1988). Because of their omnivorous food habits and ability to move long distances, bears often share a portion of their home ranges with human settlements, leading to higher potential for human-bear conflicts. Once a bear successfully finds food at a particular location, that place becomes an important part of its home range and will be visited by the bear regularly (Stokes 1970, Meagher and Phillips 1983). These anthropogenic impacts on bears have historically been deadly and have the potential to decrease local populations. Adult females are the crucial component of bear populations, and if mortality exceeds recruitment populations experience decline. However, more proactive and nonlethal measures, including electric fence, have become popular when mitigating conflict between bears and people.

## History of Electric Fence in Bear Management

Electric fences are used worldwide, and an extensive literature exists discussing how humans have used electric fencing to protect life and property (Hoare 1992). Electric fence is used to protect wildlife preserves and villages throughout Africa (Tchamba 1995). In Japan, electric fence is used to deter Asiatic black bears from depredating agricultural crops (Huygens and Hayashi 1999). Conservationists in New Zealand use electric fence to protect the kakapo (*Strigops habroptilus*), a native flightless bird that was exposed to unsustainable predation by the introduced brushtail possum (*Thricosurus vulpeculca*; Hayward and Kerley 2009).

Electric fencing has been used to deter bears in North America for several decades. Storer et al. (1938) designed an effective electric fence to reduce black bear depredation of bee yards that has since been adapted to deter bears from chicken coops and small pastures for livestock (Sillings 1989, Jonker 1998, Witmer 2001, Clark 2005, Otto 2013). The use of electric fencing to deter bears from agricultural crops in the West has increased rapidly during the past two decades as populations have expanded onto private lands (Jonker 1998, Witmer 2001, Mace and Radandt-Chilton 2011). Producers have turned to electric fence as their primary solution to reduce livestock depredation and to reduce raids of chicken houses and bee yards (Brady and Maehr 1982, Will and Kopp 1982, Jonker et al. 1998, Lewis et al. 2015). In turn, this proactive approach decreases bear mortality and create an aversive conditioning and learning environment for the bear who receives a painful shock from touching the electric fence.

Few studies have formally tested the relative efficacy of electric fence as a deterrent for bears and none have looked at learning and behavior as a result of aversive conditioning in either species. However, several studies have tested other deterrents such as projectiles and pepper spray and found that black bears negatively responded, and that depending on the deterrent, aversive conditioning was successful (Leigh and Chamberlain 2008, Spencer 2007, Mazur 2010). Electric fence was the only tool that was 100% successful in deterring grizzlies from salmon in Alaskan streams (Gard 1971). Although details on fence design are often lacking, studies describe an effective fence as 5–8 wires with a minimum joule rating of 0.5 and a minimum output of 6,000 volts (Madel 1996, Otto 2013). Similar fences were effective at deterring grizzly bears from calving and lambing pastures (Madel 1996). The Wyoming Game and Fish Department found that an 8-strand, 33-inch-high-portable electric fence was effective at deterring bears from remote sheep allotments in Cody, Wyoming (Debolt 2001), and electric fencing has been recommended to minimize grizzly-human conflicts associated with livestock, bee yards, and boneyards in Montana (Wilson et al. 2005, 2006). Others have noted that electric fence is an effective management tool for grizzlies, but to date all electric fences have been designed with a minimum of 5 wires which is cumbersome to build (Treves et al. 2003, Gunther et al. 2004). Fencing composed of five strands of 12-guage smooth wire costs approximately $1,000 per mile (2018 dollars), whereas the same fence constructed with three strands of wire costs approximately $600 per mile. In addition to reduced cost, three-strand fencing can be installed more rapidly, increasing the potential for use if similarly effective at deterring bears.

## Study Justification

Grizzly bear populations have reestablished in the Blackfoot Valley of Montana during the last two decades, expanding their distribution within the Northern Continental Divide Ecosystem (Mace et al. 2011, Costello 2014). In western Montana, landowners are increasingly observing grizzly bears feeding in ripe alfalfa, pea, oat, and barley fields at all times of the day (W. Slaught, Ovando, personal communication). While crop depredation by bears is not considered to have high economic impacts, safety of the people who work in crop fields is a concern. During 2015 – 17, MFWP has verified reports of at least 20 grizzly bears in crop fields. Bears have been observed feeding in crop fields from May to October, and there is concern that bears are becoming dependent on crops and, as a result, traditional habitat selection patterns may be changing (J. Jonkel, FWP, personal communication).

Electric fences are used extensively throughout North America primarily for the protection and management of livestock. Electric fence is effective at protecting and controlling livestock, but only electric fences with five wires or more have successfully protected bee yards and calving pastures from bears (Madel 1996, Huygens and Hyashi 1999, Lewis et al. 2015). As electric fencing materials have improved and relative costs declined, producers have turned to electric fence as a useful tool for protecting livestock, poultry, and bees (Brady and Maehr 1982, Will and Kopp 1982, Jonker et al. 1998, Lewis et al. 2015) and bear managers are looking at electric fence as a means of keeping bears out of agricultural fields. However, constructing permanent electric fencing around large tracts of land is expensive and time consuming, and research on the efficacy of electric fence to protect agricultural crops is limited (Huygens and Hayashi 1999). As a result, regional development and testing of electric fence should occur before best management practices are developed. Temporary electric fences that can be built quickly and removed or turned off after the season of need would likely reduce installation and maintenance costs, reduce human bear conflicts, and improve human and bear safety. In this study, I describe a two-year field trial to evaluate the effectiveness of two designs of temporary electric fences at deterring black bears and grizzly bears from baited enclosures.

## Objective

My management question is whether a three-wire electric fence will deter bears from entering an enclosure that contains an attractant. My primary objective was to evaluate the permeability of 3-wire electric fencing by grizzly bears and black bears to identify a three-wire electric fencing design that deters both species of bear when energized but allows passage when not energized. I tested two different fence designs in this study. One design, hereafter referred to as the tall fence and described below, was developed to meet the Montana legislature's definition of wildlife friendly fence. The other design, hereafter referred to as the short fence, was developed from a graduate study conducted in Michigan that tested the efficacy of different fence designs to deter black bears from bee yards. Given general differences in anatomy and behavior, I expected that the effectiveness of each fence type would be species-specific. I hypothesized that tall fences would allow unhindered passage for black bears but would hinder grizzly bear movement when energized. I hypothesized that the short fence design would hinder both black bear and grizzly bear movement when energized but have no effect on bear movements when unenergized.

## STUDY AREA

The study area is located in the Blackfoot Valley watershed of western Montana (Figure 4). The Blackfoot Valley (hereafter "Blackfoot) lies along the southern edge of the Crown of the Continent, a 4.05 million-hectare landscape that borders the Bob Marshall and Scapegoat Wilderness. The 607,028-ha Blackfoot watershed extends from the Continental Divide westward 212 kilometers to the Blackfoot River's confluence with the Clark Fork River and includes portions of Lewis and Clark, Missoula, and Powell counties.

Land ownership in the Blackfoot is 49% federal, 5% state, 20% private timber company, and 24% private. Cattle grazing is the dominant land use on private lands in the Blackfoot. There are 4 small towns: Seeley Lake (population = 2,000), Ovando (92), Helmville (369), and Lincoln (1,013; Current Population Demographics 2017). The climate of the Blackfoot is cool and dry, but varies along an east-west elevational gradient. The average maximum temperature is 12.2°C and the average minimum temperature is -15°C. The warmest months of the year are usually July and August with an average temperature of 27°C and a low average temperature of 4.4°C. On average, the Blackfoot receives 30–40 cm of rain and 200 cm of snow annually (U.S Fish and Wildlife Service 2014).

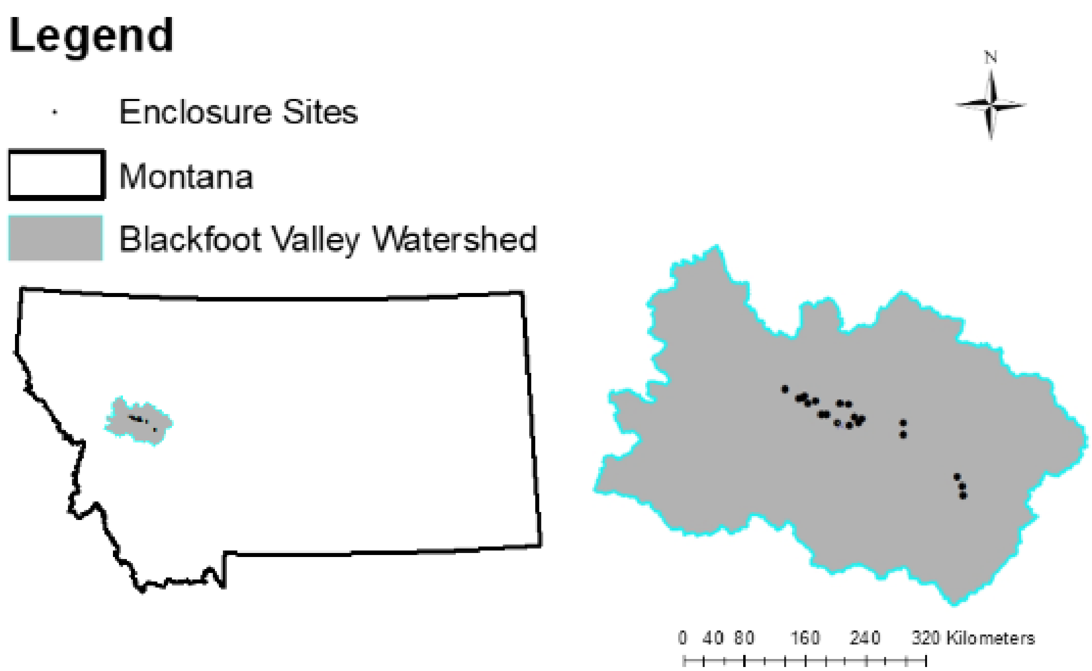


Figure 4. The Blackfoot Watershed (light grey) and enclosure sites in Montana.

The current size of the black bear population in the Blackfoot is unknown, however local biologists consider the population to be healthy (J. Jonkel, FWP, personal communication). The population size of grizzly bears in and around Glacier National Park, which lies to the north of the Blackfoot Valley, was last studied in 2004 and was estimated to be a minimum of 41 individuals using DNA methods to identify bears

(Kendall et al. 2009). The study area occurs in an area of recent grizzly bear population expansion and lies on the southern edge of Glacier National Park and the Northern Continental Divide Ecosystem. The grizzly bear population is now estimated to be at 70 resident bears with transients moving to and from the Blackfoot (J. Jonkel, FWP, personal communication). Both species end hibernation in early March to late April and are active as late as November. Black bears are observed in the higher forested regions of the Blackfoot and grizzly bears are found at high and low elevations, some occupying the mountains year-round while others migrate to the valley in the late spring and summer.

## Materials and Methods

### Field Methods

I constructed 20 electrified enclosures at 20 different sites within the Blackfoot study area. These 20 sites were selected based on 4 main criteria: 1) evidence of previous bear occupancy, 2) little to no public access for safety purposes, 3) landowner permission, and 4) attractive site characteristics such as even ground, ample sunshine to charge the fence energizers, and no underbrush that might interfere with electric fences. One of two fencing designs was randomly selected, and an enclosure constructed at each site. Both designs consisted of three wires and the same fencing materials, but had different wire spacing (Figure 5), and were selected because their deployment around large areas is quick and inexpensive relative to other 5-strand fence deigns. Fencing materials consisted of two rolls of 12-guage smooth aluminum, 60 fiberglass poles, 20

SX Stafix Solar Energizers (0.5 joules), 20 4-foot ground rods, one roll of insulwire, and two packages of butterfly nuts (SX Stafix, 528 Grant Road, Mineral Wells Texas 76067, United States). The short fence design was modified from a fence determined previously to be effective at deterring black bears from bee yards in Michigan (Otto 2013). The original 3-wire design consists of a 22-cm bottom wire, 38-cm middle wire, and 58-cm top wire (Otto 2013). I modified the design by raising each wire by 2.5 cm to compensate for the difference in grizzly and black bear size (Figure 6). The tall fence design was a 3-wire electric fence that was deemed wildlife friendly by the Montana Legislature in April of 2015 (House Bill No. 557; Karhue 2004, Paige 2008) and is used often by landowners participating in the Conservation Stewardship Program with the Natural Resources Conservation Service (NRCS). The wire spacing for the tall fence is a 55-cm bottom wire, 81-cm middle wire, and 106-cm top wire (Figure 5). Enclosures of both designs had an area of c.a. 25 $m^2$ and were built in a triangular shape so that a single camera trap could monitor the entire enclosure (Figure 6). The fence corner stays consisted of fiberglass poles roughly 5 centimeters in diameter. I placed 2 plastic 0.64-cm poles between the corner poles at equal distances to act as braces for the middle of the enclosure. Twelve-gauge smooth metal wire was energized by a 0.5-joule solar powered energizer (SX Stafix, 528 Grant Road, Mineral Wells Texas 76067, United States). I constructed the enclosures as a hot-ground system, with the top and bottom wires being electrified and the middle wire not electrified.

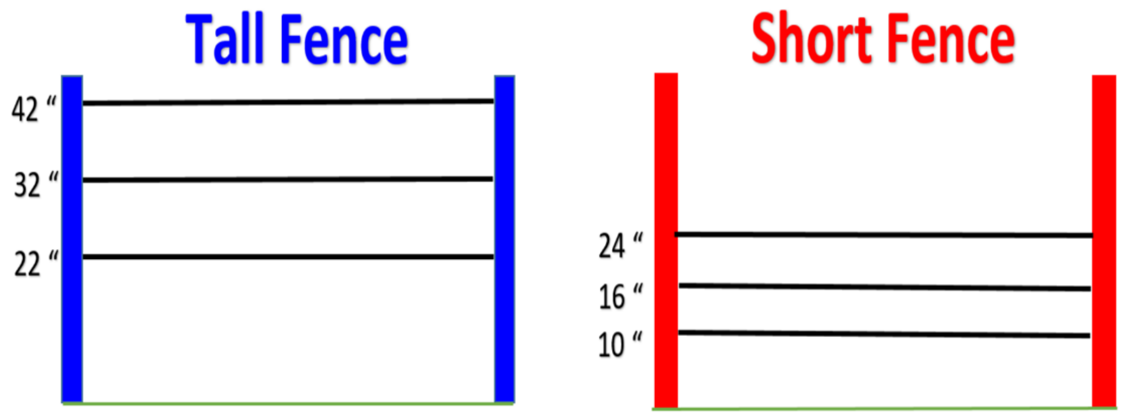


Figure 5. Two fence designs used in the study. The tall fence design was modeled after the NRCS specifications for a wildlife friendly boundary fence in Montana (House Bill No. 557, Montana Legislature). The short fence design was modeled after a 3 wire electric fence that proved effective at deterring black bears in Michigan (Otto 2013).

Figure 6. Photographs of tall (bottom) and short (top) fenced enclosures constructed at study sites within the Blackfoot Valley Watershed of Montana, 2015-2016.

I constructed the 20 enclosures at 20 different sites in late May 2015. These sites were used again in 2016, and to reduce the potential for bias I switched the type of enclosure at all sites between years of study. I placed scent attractants such as fish blood and deer appendages from road-killed deer carcasses inside each enclosure. Attractants used that day were randomly chosen. Fences were electrified in 3-day off/on cycles to prevent bears from becoming habituated to areas with bait and no deterrent. Off/on cycles within the experimental unit (the enclosure) were necessary to assess whether bears could pass the same fence when it was both electrified and not electrified.

From June 1 to August 15 of each year, all sites were video monitored by motion-activated infrared camera traps that recorded 1 minute videos (Browning HD Strike Force, One Browning Place, Morgan, Utah 84050). I visited all sites every 3 days and collected data such as voltage, electricity status, weather, any fence maintenance, and any bear behavior collected from the video (walking around the perimeter, standing over the fence, testing the fence, etc.). Videos were watched in real time and information on date, time of day, species of bear, total time of visit, behavior such as whether a bear touched the fence, attempted to pass the fence, was successful at passing the fence, or received a shock were collected. My observation units were bear visits because a significant proportion of bears were not uniquely identifiable. A visit occurred if the bear walked into view of the camera. My independent variables were enclosure type, electricity status, bear species, and year. My response variable was whether or not a bear successfully entered an enclosure. All field work was approved by Montana State University's Institutional Animal Care and Use Committee (Permit #: 2016-05).

## Analyses

Repeated observations over time at the same enclosures can produce autocorrelation in responses, a form of pseudoreplication (Hulbert 1984). However, visits to the same site by different bears could be considered independent events. Therefore, I reviewed my videos to see how many bears I could uniquely identify. I could uniquely identify bears in 22 out of 134 videos. The proportion of bears that could not be uniquely identified in the videos was 83.5%. Because most bears could not be uniquely identified, there was potential for autocorrelation in response. Thus, Generalized Estimating Equations (GEE) that account for repeated observations on the same experimental unit were initially considered to evaluate whether a bear successfully entered the enclosure or not (Liang and Zeger 1986, Harrison and Hulin 1989).

I consulted with Statistical Consulting and Research Services at Montana State University to build models. We expected that responses to the two fence designs would differ between the two bear species due to differences in anatomy and behavior (Aune 1992). Unfortunately, the GEE could not be fit to the complete dataset because of a count of 0 successes for grizzly bears at tall fences when the fence was energized. Instead, the GEE was fit only to data collected when the fences were not energized to screen for autocorrelation. The results of this preliminary screening yielded little evidence of autocorrelation in the response ($\hat{\alpha}$ = -0.008, SE = 0.04), so we applied nonparametric contingency table tests to the entire dataset. I used the Zelen test (Zelen and Dannemiller 1961) to test for a three-way association (interaction) among success, species, and fence type, and the Cochran-Mantel-Haenszel (Mantel 1963) test to test for a two-way association (main effect) between success and fence type while controlling for species. We computed exact binomial confidence intervals for the proportion of successes in each combination of the predictor variables and used Bonferroni-adjusted score intervals to perform all pairwise comparisons.

## RESULTS

I recorded 134 visits by bears to fenced enclosures during the study seasons of 2015 and 2016. Of these visits, 78 occurred in 2015 and included 57 black bears and 21 grizzly bears. Fifty-six visits occurred in 2016, including 34 black bears and 22 grizzly bears (Table 1). Black bears and grizzly bears were successful at passing the short fence 48% (95% CI: 32.0 – 63.6) and 23% (5.0 – 53.8) of the time, respectively, when it was not energized (Table 2). When the short fence was energized, black bears were 7% (0.2 – 33.9) successful in passing, whereas grizzly bears were successful in 25% (5.5 – 57.2) of attempts. When not energized, both species successfully passed the tall fence design in 58% (95% CI: 27.7 – 84.8) of attempts. Black bears and grizzly bears successfully entered energized enclosures with tall fences in 30% (95% CI: 13.2 – 52.9) and 0% (95% CI: 0.0 – 45.9) of attempts, respectively.

Table 1. Bear visit outcomes for each electricity state and fence type for black bears and grizzly bears monitored at baited enclosures in the Blackfoot Valley, Montana 2015 – 2016.

| | | | | Result | |
|---|---|---|---|---|---|
| Electricity | Fence Type | Species | Year | Success | Failure |
| Off | Short | Black Bear | 2015 | 14 | 7 |
| | | | 2016 | 6 | 15 |
| | | Grizzly Bear | 2015 | 2 | 2 |
| | | | 2016 | 1 | 8 |
| | Tall | Black Bear | 2015 | 6 | 2 |
| | | | 2016 | 1 | 3 |
| | | Grizzly Bear | 2015 | 6 | 2 |
| | | | 2016 | 1 | 3 |
| On | Short | Black Bear | 2015 | 1 | 8 |
| | | | 2016 | 0 | 5 |
| | | Grizzly Bear | 2015 | 1 | 4 |
| | | | 2016 | 2 | 5 |
| | Tall | Black Bear | 2015 | 7 | 12 |
| | | | 2016 | 0 | 4 |
| | | Grizzly Bear | 2015 | 0 | 4 |
| | | | 2016 | 0 | 2 |

Table 2. Observed proportions (± 95% CI) of successful and failed entry of enclosures with short and tall fence designs by black bears and grizzly bears when electricity was turned off and on for 20 baited sites monitored in the Blackfoot Valley, Montana 2015 – 2016.

| | | | Result | | |
|---|---|---|---|---|---|
| Electricity | Fence Type | Species | Success | Failure | Proportion (95% CI) |
| Off | Short | Black Bear | 20 | 22 | 0.476 (0.320, 0.636) |
| | | Grizzly Bear | 3 | 10 | 0.231 (0.050, 0.538) |
| | Tall | Black Bear | 7 | 5 | 0.583 (0.277, 0.848) |
| | | Grizzly Bear | 7 | 5 | 0.583 (0.277, 0.848) |
| On | Short | Black Bear | 1 | 13 | 0.071 (0.002, 0.339) |
| | | Grizzly Bear | 3 | 9 | 0.250 (0.055, 0.572) |
| | Tall | Black Bear | 7 | 16 | 0.304 (0.132, 0.529) |
| | | Grizzly Bear | 0 | 6 | 0.000 (0.000, 0.459) |

Black bear visits that resulted in an attempt to pass the short fence when it was unenergized were 100% successful, however only 48% of visits resulted in an attempt to pass (Table 3). Fifty-eight percent of black bear visits to the tall fence when it was unenergized resulted in an attempt to pass the fence and all attempts to pass were successful. Twelve visits were recorded at the tall fence when it was unenergized. Fifty-eight percent attempted to pass and were successful in doing so. When the tall fence was energized, 23 visits were recorded. Of those, 43% resulted in an attempt and 70% of attempts to enter the enclosure were successful. Thirty percent received a shock and were deterred (Table 3).

Twelve grizzly bear visits were recorded at tall fence enclosures when unenergized, and 7 of 12 visits resulted in a successful attempt to pass the fence. I recorded 13 visits by grizzly bears to short fence enclosures when they were unenergized: 3 of those visits resulted in a successful attempt to pass. Six grizzly bear visits were recorded at the tall fence when it was energized and none of those visits resulted in an attempt to pass the fence. Twelve grizzly bear visits were recorded at the short fence when it was energized and resulted in a 42% attempt rate, with 60% of those attempts resulting in success and 40% of those attempts resulting in the bear receiving a shock (Table 4).

Table 3. The proportion of black bears that visited, attempted and succeeded, attempted and failed, or did not attempt to pass a tall and short fence when it was energized and unenergized in the Blackfoot Valley, Montana 2015 – 2016.

| Black Bear Tall Fence OFF | | | Black Bear Tall Fence ON | | |
|---|---|---|---|---|---|
| | Number | Proportion | | Number | Proportion |
| Visits | 12 | - | Visits | 23 | - |
| No Attempt | 5 | 42% | No Attempt | 13 | 57% |
| Attempts | 7 | 58% | Attempts | 10 | 43% |
| Success | 7 | 100% | Success | 7 | 70% |
| Shock | 0 | 0% | Shock | 3 | 30% |
| **Black Bear Short Fence OFF** | | | **Black Bear Short Fence ON** | | |
| | Number | Proportion | | Number | Proportion |
| Visits | 42 | - | Visits | 14 | - |
| No Attempt | 22 | 52% | No Attempt | 7 | 50% |
| Attempts | 20 | 48% | Attempts | 7 | 50% |
| Success | 20 | 100% | Success | 1 | 14% |
| Shock | 0 | 0% | Shock | 6 | 86% |

Table 4. The proportion of grizzly bears that visited, attempted and succeeded, attempted and failed, or did not attempt to pass a tall and short fence when it was energized and unenergized in the Blackfoot Valley, Montana 2015 – 2016.

| Grizzly Bear Tall Fence OFF | | | Grizzly Bear Tall Fence ON | | |
|---|---|---|---|---|---|
| | Number | Proportion | | Number | Proportion |
| Visits | 12 | - | Visits | 6 | - |
| No Attempt | 5 | 42% | No Attempt | 6 | 100% |
| Attempts | 7 | 58% | Attempts | 0 | 0% |
| Success | 7 | 100% | Success | 0 | 0% |
| Shock | 0 | 0% | Shock | 0 | 0% |
| **Grizzly Bear Short Fence OFF** | | | **Grizzly Bear Short Fence ON** | | |
| | Number | Proportion | | Number | Proportion |
| Visits | 13 | - | Visits | 12 | - |
| No Attempt | 10 | 77% | No Attempt | 7 | 58% |
| Attempts | 3 | 33% | Attempts | 5 | 42% |
| Success | 3 | 100% | Success | 3 | 60% |
| Shock | 0 | 0% | Shock | 2 | 40% |

Pairwise comparisons indicated that black bears were on average less successful at entering enclosures with short fences whereas grizzly bears were less successful at entering enclosures with tall fences (Figure 7). However, I found no statistical support for differences in success among any fence type – species combination. For the unenergized periods, the data did not support an interaction between bear species and fence type ($P$ = 0.57). A Cochran-Mantel-Haenszel test indicated that successful entry of an enclosure was not affected by the type fence for both species ($P$ = 0.13). Similarly, an interaction between fence type and species influencing successful passage of bears when fences were energized was not supported ($P$ = 0.14). A Cochran-Mantel-Haenszel test indicated no support for a fence type main effect when controlling for species ($P$ = 0.51).

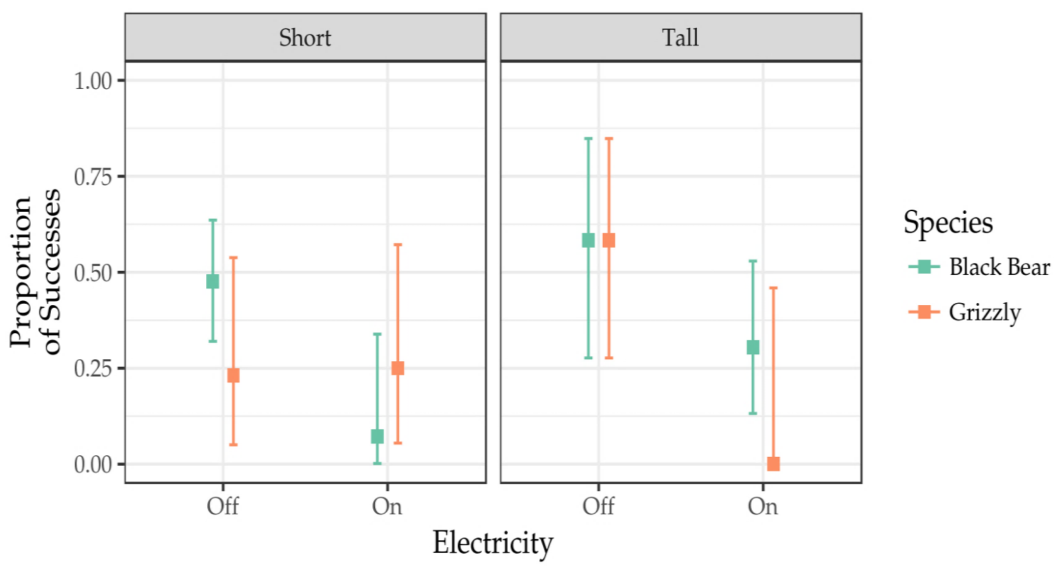


Figure 7. Observed proportions (± 95% CI) of successful entry of enclosures with short and tall fence designs when electricity was turned off and on for 20 baited enclosures monitored in the Blackfoot Valley Montana, 2015 – 2016.

# DISCUSSION

This study provides the first quantitative information regarding the effectiveness of three-strand electric fencing for deterring both black and grizzly bears from baited enclosures. Major findings were that 1) neither fence type allowed unhindered movement of bears when electricity was off, and 2) effectiveness of electric fencing was dependent on fence type and species of bear. My objective was to identify a fence that deters bears when energized but allows passage when it is not. When unenergized, tall fences were generally better at allowing bear passage, with just over half the bears of each species getting through. Short fences allowed roughly 48% and 23% of grizzly and black bears, respectively, to pass when not energized. When fences were energized, both fence types had relatively low rates of bear passage, but the tall fence was more effective at hindering grizzly bears and the short fence was more effective at deterring black bears. Generally, statistical tests of fence effectiveness were not significant, likely due to small sample sizes of enclosures and bear visits. Nevertheless, variation in success among bear species and fence type suggest biologically meaningful patterns that may be useful to managers and land owners.

When energized, short fences were more effective at deterring black bears than grizzly bears. When the short fence was unenergized, 42 black bear visits were recorded and only 3 of those resulted in attempts. When it was energized, 12 visits were recorded and 20 resulted in attempts. However, all black bears who attempted to pass the fence were successful. When the short fence was energized, 14 black bear visits were recorded. Seven attempted and were successful in doing so. Only half of black bear visits resulted in attempts and successful entry into baited short-fence enclosures was reduced by 85% from 48% to 7% when fences were energized. In contrast, electrification did not reduce the proportion of successful entry by grizzly bears into short fence enclosures. Nevertheless, grizzly bears were hindered by the short fence regardless of whether it was energized. Thirteen grizzly bear visits were recorded at the short fence when it was unenergized. All bears that were successful in passing the short fence did so by jumping over all three wires. Grizzly bears successfully passed short fences in only 23 – 25% of encounters, suggesting a general aversion to fences of short stature and potential limitation to unimpeded bear movement even when unenergized. In previous work, I have observed at least 20 individual grizzly bears being shocked and deterred with other types of electric fences in the Blackfoot (MFWP, unpublished data). Therefore, grizzly bears in the Blackfoot may have been conditioned to avoid electric fences prior to the onset of my study. Huygens and Hyashi (1999) observed that Asiatic black bears avoided electric fences after being shocked, and Otto (2013) noted that an individual black bear left the site permanently after receiving a shock. Although previous studies of bear behavior in relation to electric fences are lacking, studies of other species of wildlife, including coyotes and deer, reported similar long-term behavioral aversion to electric fencing (Cornell and Cornely 1979, Jordan and Richmond 1991, Karhue 2004, Paige 2008).

The tall fence design reduced successful entry into enclosures for both species. When unenergized, black and grizzly bears were only 58% successful in crossing tall fences to recover bait. Successful entry of black bears was reduced by 48% when energized and no grizzly bear successfully entered a tall fence enclosure when energized. Black bears were more successful than grizzly bears at negotiating energized tall fences; 30% and 0% of attempts were successful for black bears and grizzly bears, respectively. Black bears that successfully entered tall fence enclosures, regardless of whether they were energized or not, did so by crawling under the bottom wire which was 56 cm from the ground. Grizzly bears never attempted to crawl under an electric fence when energized, and my observations support previous behavioral studies describing black bears as being more flexible (Hererro 1972, Beckman and Berger 2003). In most instances, (7 of 8), black bears that were deterred from electrified enclosures received a shock on their noses. Bears investigate novel situations and potential food items with their noses (Hererro 1972, Aune 1994, personal observation). Thus if the sole objective of electric fencing is deterring bears, then applying food smells to energized electric fences may increase the odds of nose contact with the fence (Jordan and Richmond 1991). In most cases, bears who made initial contact with energized fences on the tops of their back were not deterred, likely due to the insulative properties of their dense fur.

Although not statistically significant, I observed meaningful improvement in electric fence effectiveness at deterring bears in 2016 over 2015. Overall, the percentage of successful entries into enclosures regardless of whether they were energized declined from 65% in 2015 to 21% in 2016 for black bears, and from 43% to 18% for grizzly bears. Declines in bear successes may have resulted from either 1) a learned behavioral response of bears across time, 2) differences in environmental conditions or natural food abundance between the years of study, or 3) a combination of these factors. An early spring with summer drought conditions likely resulted in a bad food year for bears in 2015 relative to 2016 and may explain higher visitation and success rates at baited enclosures in the first year of my field trial. Bear foraging selection is flexible and bears are known to adapt to seasonal and annual shifts in food resources (Servheen 1983, Mace et al. 1996, Waller and Mace 1997). Alternatively, bears receiving shocks from electric fencing in 2015 may have been less likely to engage with electric fences the following year. I did not identify individual bears in this study; however, a lower proportion of successful entry into energized fence enclosures in 2016 may have occurred because of aversive conditioning response to receiving a shock. Aversive conditioning responses have been observed in previous studies with other kinds of deterrent conditions (Cornell and Cornely 1979, Jordan and Richmond 1991 Huygens and Hyashi 1999, Rauer 2003, Otto 2013).

There are potential ecological and conservation implications of widespread use of electric fence. Many landowners and ranchers are replacing kilometers of old barbed-wire with electric fences in the Blackfoot Valley, as well as looking to build electric fence around large agricultural fields to keep bears out. I observed that many bears will not attempt to pass a three-strand electric fence even when unenergized, suggesting that electric fences may be potential barriers to the movement of bears. Habitat selection has been extensively studied in both natural ecosystems and in landscapes where anthropogenic disturbances exists. Roads and human settlements have been found to negatively influence the selection of otherwise suitable habitat for both black and grizzly bears (Servheen 1983, McLellan and Shackleton 1988, Mace et al. 1996, Mace and

Waller 1997, Mace and Waller 1999). My results suggest that, similar to roads, electric fences have the potential to negatively impact the accessibility and use of habitats by both species.

Despite implications of electric fences to deter bear movements and habitat use, there are potential negative demographic impacts to bears resulting from conflicts that might occur if electric fences are not used to secure attractants. Knight and Eberhardt (1984) reported that most grizzly bears who sought attractants in settlements around the GYE from 1973 – 1985 were removed from the population. The sex and age distribution of deaths and the magnitude of losses in relation to recruitment are key issues in evaluating demography, recruitment in isolated populations depends solely on reproduction which is relatively low for bears (Knight and Eberhardt 1984). Viability of bear populations is determined largely by adult survival (Shaffer 1983, Johnson et al. 2004). Thus, the potential of electric fencing to reduce management removals of depredating bears may offset the effective loss of agricultural habitats with electric fencing (Madel et al. 1996). However, future research should evaluate landscape-level space use and demography of bears in relation to electric fencing before population-level inferences on the effects of electric fence can be made.

## MANAGEMENT IMPLICATIONS

Constructing permanent electric fencing around large tracts of land is expensive and time consuming. Temporary electric fences that can be built quickly and removed or turned off after the season of need (e.g., when crops are ripe, calving season) would reduce installation and maintenance costs, reduce long-term impacts to bear movements, and improve human and bear safety. The objective of this study was to identify a three-wire electric fencing design that deters bears when energized but allows passage for bears when not energized. Neither of the fence designs completely satisfied my criteria for an effective electric fence. Bear passage of both designs of fence was less than 100% even when the fences were not energized, indicating some level of hindrance to black and grizzly bear movements. The tall fence design more closely met my standards, allowing more than half of bears to pass when not energized and, when energized, reducing passage by 48% and 100% for black bears and grizzly bears, respectively. However, less than perfect permeability and notable reductions in bear success at crossing both fence types in 2016 versus 2015 suggest potential learned aversion to electric fences by bears in my study and potential long-term negative impacts to bear movements and space use.

With the proposed delisting of the Northern Continental Divide Ecosystem grizzly bear population comes the responsibility for state agencies to successfully mitigate human-bear conflicts. Agricultural production is important to the economy and livelihood of the Blackfoot Valley ranching community and while grizzly bears currently are not impacting those crop fields economically, there is potential for that to occur with an increasing population. The tall fence design needs to be tested further and potentially modified to improve effectiveness, but more closely met our standards than the short fence design. It remains unknown how widespread implementation of electric fencing will affect movements and habitat use of the Blackfoot black and grizzly bear populations.  My study provides valuable information for others seeking realistic solutions for human-bear conflicts in agricultural settings.

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