Understanding and Preventing Elk Use of Agriculture Crops

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Authorization to Submit Thesis

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Table of Contents

List of Tables

List of Figures

CHAPTER 1. INTRODUCTION

1.1. GENERAL INTRODUCTION

Elk (*Cervus canadensis nelsoni*) are a highly valued, iconic ungulate species occupying much of North America, where they provide great value to the public and generate tremendous revenue through hunting and wildlife viewing (Bunnell et al. 2002). In the late 1800s, unregulated harvest nearly extirpated elk across much of North America, but with careful and intensive population and habitat management, elk populations have increased dramatically and the species now occupies nearly all suitable habitats in the Rocky Mountain west (Burcham et al. 1999). In some areas, this dramatic increase in elk populations has led to an overabundance of the species, especially in areas where natural habitats interface with agricultural lands (Walter et al. 2010). As elk populations have increased, humans and agriculture production have simultaneously encroached into natural elk habitats (Walter et al. 2010), which has inevitably led to conflicts between elk and agriculture producers (Wagner et al. 1997).

Relative to natural forages, the higher nutritional values found in agriculture crops make them ostensibly attractive to elk (Mould and Robbins 1982, Sorensen et al. 2014), and in North America, wild ungulates, such as elk, are responsible for causing more agriculture damage than any other species (Conover 2002). Mitigating these elk-caused agriculture damages has been a significant and costly challenge for the agencies responsible for managing elk and consequently controlling elk damage (Walter et al. 2010). In southern Idaho, where elk populations have grown substantially in size and geographic range since the 1990’s (IDFG 2014*a*), the Idaho Department of Fish and Game (IDFG) has increased funding for damage compensation and worked aggressively to prevent elk-agriculture conflicts. While in some instances these efforts have lessened the impacts of elk, such successes have been only partially or temporarily effective in reducing damages (IDFG 2019).

To aid wildlife managers and private landowners in mitigating elk-caused damages to agriculture, the overall goals of this study were to 1) provide a better understanding of the mechanisms that drive how elk navigate landscapes in areas of southern Idaho that are dominated by agriculture production, and 2) design, test, and evaluate lethal and non-lethal depredation management tools aimed at deterring elk from using and subsequently damaging agriculture crops.

1.2. BACKGROUND: HABITAT USE OF ELK IN AN AGRICULTURE-DOMINATED LANDSCAPE

There is little understanding of how elk use habitats in an agriculture-dominated landscape. While there are myriad studies evaluating habitat selection patterns of elk in landscapes unaltered by humans (Edge et al. 1987, Unsworth et al. 1998, Ager et al. 2003, Beck et al. 2013), few studies have focused on how elk select habitats where agriculture crops dominate the landscape (but see DeVore et al. 2016, Hinton et al. 2020). While the life history strategies of elk living in natural or agriculture-dominated landscapes are similar, forage composition and availability, and plant phenology, along with predation risk vary greatly between the two landscapes (Barker et al. 2019). Thus, it cannot be assumed that elk living in areas dominated by agriculture navigate the landscape in the same way as elk living in areas that are relatively unaltered by humans. To better understand how elk navigate landscapes dominated by agriculture, we evaluated summer home-range scale habitat selection patterns of elk in two areas of southern Idaho where elk have a history of using and damaging agriculture crops.

1.3. RESEARCH QUESTIONS

In this chapter, we address the following questions:

1. What vegetation and landscape predictor variables do elk select for, or avoid during the summer months?
2. How does changing plant phenology (natural and agricultural) influence habitat selection?
3. How do life history strategies vary among elk living in an agriculture-dominated landscape?

1.4. BACKGROUND: BEHAVIOR-MODIFYING DETERRENTS FOR REDUCING ELK DEPREDATION

Significant efforts have been put forth in identifying tools and tactics for deterring elk from damaging agriculture crops. While some deterrents have shown promise in lessening the impacts of elk (Johnson et al. 2014), many of the deterrents tested have been only partially or temporarily effective in reducing damages (Walter et al. 2010). Most commonly used non-lethal deterrents (i.e., repellents, frightening devices, and hazing) are designed to induce a predator-aversion response through auditory and visual stimuli or sensations of pain (Provenza and Lauchbaungh 1999); however, animals can rapidly habituate to the superficial risks posed by these types of deterrents and long-term relief from damages is seldom accomplished (Walter et al. 2010). Lethal methods for controlling elk-caused agriculture damages typically take the form of recreational public harvest (i.e., hunting; Hegel et al. 2009). However, hunting is not always a feasible option (due to public safety concerns), or an effective method for reducing crop damages because animals forage on crops outside of legal hunting hours (e.g., during the night). In such instances, trained professionals (i.e., sharpshooters) removing offending wildlife is a feasible option, but testing the effectiveness of sharpshooting has been limited to white-tailed deer (Denicola and Williams 2006*a*). Furthermore, this approach is often met with high levels of scrutiny from the public as an inhuman or unacceptable method for managing overabundant wildlife (Mawson et al. 2016).

Different from deterrents that induce a predator-aversion response, exclusionary ungulate-proof fences have been proven effective in preventing elk from damaging agriculture crops (Knight 2014). A downside to permanent exclusionary fences is that they are expensive to construct and maintain, and they negatively impact non-target wildlife species (Craven and Hygnstrom 1994, Jachowski et al. 2013). There has been recent interest in semi-permanent or temporary fence designs, which are inexpensive to build, and easy to construct when needed and remove when not in use to allow movement of wildlife (Knight 2014). While the effectiveness of temporary fences in reducing crop damages has been evaluated in multiple studies, most were focused on excluding white-tailed deer (Palmer et al. 1985, VerCauteren et al. 2006, Hildreth et al. 2012), and few have focused on excluding elk (but see Johnson et al. 2014).

To meet the growing need for depredation management tools that are specific to elk, we developed and tested the efficacy of management treatments aimed at modifying elk behavior to reduce agriculture crop damages. We tested two deterrent treatments: targeted lethal removal of elk actively using agriculture fields (i.e., sharpshooting), and a fence modification design which used electrified wire to temporarily increased the heights of existing pasture fence.

1.5. RESEARCH QUESTIONS

In this chapter, we address the following questions:

1. Can lethally removing elk from herds that are damaging agriculture crops induce antipredator behavior, resulting in elk avoiding the areas where lethal removal occurred?
2. Can lethal removal cause elk to not only avoid a specific agriculture field (where lethal removal occurred), but also cause elk to avoid all other agriculture crops?
3. Can pasture fences, designed for livestock containment, be modified to act as a psychological barrier and deter elk from using agriculture fields?

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CHAPTER 2. HABITAT USE OF ELK IN AN AGRICULTURE-DOMINATED LANDSCAPE

2.1. ABSTRACT

Since the early 1900s, elk (*Cervus canadensis nelsoni*) populations throughout much of the Rocky Mountain west have expanded in size and geographic range. Simultaneously, humans and agriculture production have encroached into natural elk habitat, and human-elk conflicts have arisen, most notably between elk and agriculture producers. With expanding elk populations and increasing elk-caused damages to agriculture, there remain many unresolved questions regarding the mechanisms that influence habitat selection patterns of elk in an agriculture-dominated landscape. To address this need, we analyzed habitat selection patterns of elk at the summer home-range scale (i.e., 3rd order selection), using high-frequency location data from GPS-collared elk (n = 67), which were captured throughout southern Idaho in areas with high elk use of agriculture. We used logistic regression with the interactive effects of agriculture and time to evaluate how changes in agriculture crop phenology influence habitat selection. We found that elk selected for areas that provided security from predators and thermal cover during the day, while foraging habitats, primarily in the form of agriculture, were selected for during the night. We observed a strong relationship between plant phenology and agriculture use, with an increase in agriculture selection occurring through the growing season. Variation in life-history strategies of elk emerged in our analyses, relative to the proportional use and availability of agriculture in elk home ranges. In general, agriculture lands were present in all home ranges of elk in our study; however, the levels at which elk used these agriculture lands varied. This variation in life-history strategies suggest that elk can live in agriculture landscapes without relying on agriculture as a primary food source.

2.2. INTRODUCTION

Elk (*Cervus canadensis nelsoni*) are a highly valued, iconic ungulate species occupying much of North America, where they generate tremendous revenue from hunting and wildlife viewing (Bunnell et al. 2002). Due to the high social value of elk, substantial efforts and resources have been devoted to their management, including intensive population and habitat management programs that have increased elk populations (Bunnell et al. 2002). As elk populations have expanded, humans and agriculture production have simultaneously encroached into natural elk habitat (Walter et al. 2010), and human-elk conflicts have arisen, most notably between elk and agriculture producers (Wagner et al. 1997). This growing issue has created significant challenges for the agencies responsible for managing elk and consequently controlling elk damage (Walter et al. 2010).

Many wildlife management agencies have identified reducing conflicts between elk and private landowners as a primary objective of elk population management (Walter et al. 2010). Increased funding for damage prevention and compensation, along with the implementation of aggressive hunting seasons aimed at reducing depredating elk herds, are the primary mitigation tactics used by most wildlife management agencies (Wagner et al. 1997, Walter et al. 2010). These approaches have, in some instances, lessened the impacts of elk (Kessler 1995, Wagner et al. 1997, IDFG 2014); however, throughout much of the Rocky Mountain west, elk-related depredations, landowner complaints, and compensation for crop damages have increased drastically in recent decades (Wagner et al. 1997, Messmer 2000).

In Idaho, elk populations, particularly in the southern portion of the state, have grown substantially in size and geographic range since the 1990's (IDFG 2014; Table 2.1). While some user groups (e.g., hunters) have enjoyed the increase in elk numbers, increasing conflicts between elk and producers suggests elk in these areas have exceeded their social carrying capacity. In response to the growing elk populations and waning tolerance of agriculture producers toward elk using private lands, Idaho lawmakers enacted legislation in 1990 which mandated the Idaho Department of Fish and Game (IDFG) to work cooperatively with landowners to prevent wildlife damage (Idaho Code § 36-1108). While IDFG has made prevention of elk-agriculture damage a top priority, preventative efforts employed to date have been relatively unsuccessful (IDFG, personal communication). Deterrents aimed at modifying elk behavior (e.g., hazing), and hunting seasons implemented to specifically target depredating elk herds are the primary tactics used by IDFG for damage prevention (IDFG, personal communication); however, there is little understanding of the ecological mechanisms that drive elk herds to use and subsequently damage agriculture.

The rapid expansion of human populations into historic elk habitats (Woodroffe et al. 2005), and changing agriculture practices (Haggerty and Travis 2006) have redistributed and changed the foraging habits of elk in agriculture-dominated landscapes. The conversion of non-irrigated hay meadows and pastureland to irrigated crops such as alfalfa (*Medicago sativa*) has created dense stands of highly nutritious forage for elk (Johnston 2014). While patterns of elk habitat use in landscapes that are relatively unaltered by humans have been thoroughly investigated, few studies have focused on habitat use of elk along the agriculture-wildland interface. As the human footprint continues to expand across much of the Rocky Mountain west, understanding how elk use habitats in agriculture-dominated landscapes will greatly enhance wildlife managers' ability to maintain healthy elk populations while mitigating for conflicts with private agriculture.

To address this need, we sought to quantify the spatiotemporal relationship between agriculture and elk herds in a human-modified landscape. We used resource selection functions (RSF) to evaluate the relative probability of use and influence of different habitats within the summer home ranges of elk (Johnson 1980). Elk space use is dictated in part by the spatial configuration of available habitat. While forage acquisition and security from predators act as functional drivers in how elk use landscapes, changes in environmental conditions and physiological states of elk result in seasonal variation in how such functional habitats are used (Millspaugh et al. 2001, Long et al. 2014). In a landscape where agriculture crops provide elk with a highly nutritious and predictable food source, we hypothesized that the spatial configuration of agriculture habitats would influence where forage acquisition occurred and have an overarching effect on habitat use. In the arid environments of southern Idaho, limited precipitation necessitates the use of irrigation for most agricultural production, while also inducing early senescence and reduced nutritional qualities of natural vegetation (Walther et al. 2002, Brodie et al. 2013). With elk living in landscapes that interface with agriculture, we predict that during the summer months, the changes in female physiology associated with reproduction and offspring rearing, paired with increasing disparity of nutritional quality between agriculture and natural forages will lead to seasonal increases in the selection of agriculture.

2.3. METHODS

2.3.1. Study Area

We evaluated patterns of elk habitat use in two geographical areas (

Figure 2.1) in southern Idaho. Our focus was to better understand habitat use of elk in an agriculture-dominated landscape; therefore, all study areas were comprised of similar natural habitats interfacing with agriculture. The Magic Valley study area included three elk management zones: Big Desert (Game Management Units [GMU] 52A, 68), Smoky-Bennett

(GMUs 43, 44, 45, 48, 52), and Pioneer (GMUs 49, 50, 36A). The Weiser study area included the Brownlee (GMU 31) and Weiser River (GMUs 22, 32, 32A) management zones. Throughout the last 10 years, elk populations within the management zones included in our study have increased (Table 2.1). With these steady population increases, crop depredations have become a chronic issue and current management directions for each zone include reducing elk depredations through increased antlerless harvest (IDFG 2014). In the Magic Valley and Weiser study areas, several hunting seasons for elk open on 1 August; however, these early-season hunts have a limited number of available permits. Hunting seasons where only archery equipment is allowed open on 30 August and continue until 30 September, and most ‘any weapon’ elk hunting opportunities open in early to mid-October.

The geographically-isolated Bennett Mountain range lies at the center of the Magic Valley study area, in Elmore, Camas, Gooding and Lincoln Counties. Land ownership in this study area is 67% federal (primarily Bureau of Land Management (BLM) and U.S. Forest Service) and 27% private. There are three geographically-separate study sites surrounding the mountain range: a southern, northern, and eastern site. Habitats surrounding the southern and eastern sites primarily consist of arid/semi-desert habitats with sagebrush and perennial grass plant communities. Corn (*Zea mays*) and alfalfa are the primary agriculture crops produced in these areas. The southern site, located north of Bliss, ID, is relatively low in elevation (1,050 m), where the eastern sites, located south of Bellevue, ID are substantially higher (1,500 m). Average annual precipitation varies, ranging from 25.4 cm in the southern area to 32.9 cm, and 33.8 cm in the eastern and northern areas, respectively. Average minimum and maximum temperatures in the southern, eastern, and northern areas are similar, ranging from -3.2 C to 12.6 C, respectively. Recent fires have severely impacted native plant communities in this study area. Invasive plants, such as cheatgrass (*Bromus tectorum*) and medusahead rye (*Taeniatherum caput-medusae*) have spread and are now a major component of the plant community in the area. Higher elevation (>1,800 m) areas consist of sagebrush-grass and mixed mountain shrub communities with small pockets of aspen (*Populus tremuloides*) and Douglas fir (*Pseudotsuga menziesii*) on northern exposures.

The Camas Prairie, consisting of approximately 40,000 ha of land used for agriculture production, is in the northernmost portion of the mountain range. This high-elevation prairie (1,500 m) has relatively flat topography with vast tracts of privately owned land. IDFG owns and manages the Camas Prairie Centennial Marsh Wildlife Management Area, consisting of 3,100 ha of predominantly migratory bird habitat that lies in the geographic center of the prairie. Agriculture crops commonly grown in the Camas Prairie include small-grains, such as barley (*Hordeum* sp.) and wheat (*Triticum* sp.), and alfalfa.

Common ungulate species, other than elk, present in the Bennett Mountain area include mule deer (*O. hemionus*) and pronghorn (*Antilocarpa Americana*). White-tailed deer (*O. virginianus*) are extremely rare in the area. In the Smoky Mountains, located north of the Bennett Mountain range, wolves (*Canis lupis*) were first documented in the late 1990's and have since become established in the area (IDFG 2019). Radio-telemetry data have shown that elk, which traditionally wintered in the South Fork Boise River drainage, have begun moving to lower-elevation winter habitats in the Bennett Mountain area in recent years. Wolves may be a factor in prompting these new seasonal movement patterns (IDFG 2019). Wolves are occasionally documented in the Bennett Mountains, but no packs have become established. Other predators in the area include black bears (*Ursus americanus*), coyote (*Canis latrans*) and mountain lions (*Puma concolor*).

The Magic Valley study area also included a small area of the western-most portion of the Big Desert elk management zone, located in Blaine County, near Carey, ID. This area is adjacent to Craters of the Moon National Monument and Preserve and consists of sagebrush-grass plant communities interfacing with expansive basalt lava flows. The average elevation in this area is 1,400 m and annual precipitation (30.5 cm) is similar to other Magic Valley study areas. Common ungulate species include elk, mule deer and pronghorn. Mountain lions are the dominant predator in this area and wolves are occasionally observed, but no packs have become established. Most private land in the Carey area is used for alfalfa and small-grain agriculture production.

The Weiser study area, located in Washington County, ID, includes two elk management zones: Weiser River and Brownlee. This area is largely dominated by private landownership (>85%) with only small, non-contiguous parcels of federal land owned and managed by the BLM. Much of the private land is managed for agriculture production and commonly grown crops include alfalfa, corn, sugar beets (*Beta* sp.) and small-grains, all of which are grown under irrigation. Most of the agriculture in the Weiser study area is located on broad, flat valleys bordering river drainages. Elevations range from 600 m to 850 m. The terrain transitions to rolling hills in the northern parts of the area, where livestock grazing is common, and elevations range from 730 m to >1,000 m. The Weiser River flows through the geographic center of the area and drains into the Snake River. In the lower elevations, where land has not been converted to agriculture, habitats are dominated by sagebrush shrub-steppe communities, which transition to forested habitats in higher elevations. Annual average precipitation in the study area is 29.4 cm with average minimum and maximum temperatures of 4.4 C and 18.4 C, respectively. Mule deer are common in the area. White-tailed deer and pronghorn are present at low densities. Wolves have recently colonized the area but there is no data suggesting that this recent colonization has changed the seasonal movement patterns of elk. Black bears and mountain lions occur in moderate to high numbers in the Weiser area; however, there is no indication that predation has had a significant impact on elk survival or calf recruitment (IDFG 2019). In the Weiser River and Brownlee zones, limited hunting on privately owned land, paired with conservative general public hunting seasons has led to a dramatic increase in elk populations (Table 2.1).

2.3.2. Animal Capture

Using location data from elk previously collared by IDFG in the Magic Valley and Weiser area, we identified 10 distinct elk herds that cause depredations during the growing season. Several of these herds are non-migratory, never moving far from agriculture fields (IDFG 2019). We primarily captured and collared female elk in early July 2018 and 2019, and 1-3 adult female elk were collared within each of the 10 herds included in our study. During summer months, elk were chemically immobilized via helicopter darting (15 mg Etorphine HCl, Wildlife Pharmaceuticals, Fort Collins, Colorado USA). Elk were captured at or near fields that were actively being utilized and damaged. Capturing elk during this time period ensured collars were placed on actively depredating elk.

In the Magic Valley study area, 24 female elk were collared in summer 2018 and 16 were collared in summer 2019. In the Weiser area, nine elk were collared in early July 2019. An additional four elk were collared south of the Bennett Mountain range (Magic Valley area), with aerial net-gunning methods, in January 2018. We did not capture elk in the Weiser area in summer 2018; however, seven females were collared in January 2018.

All captured elk were fitted with global positioning system (GPS) collars with two-way Iridium communication capabilities (*n* = 47) or store-on-board technology (*n* = 16). We used a combination of Advanced Telemetry Systems (G2110E2 Iridium, Advanced Telemetry Systems, Isanti, Minnesota USA), and Lotek (Litetrack 420 Iridium and 4400m, Lotek Wireless, Newmarket, Ontario Canada) GPS collars. Collars were programmed to collect locations every 20 minutes from 1 July – 15 October, 2018 and 2019. All capture and animal handling procedures were conducted under the approval of the University of Idaho Animal Care and Use Committee (IACUC-2017-70).

2.3.3. Statistical Analysis

We used logistic regression to estimate elk resource selection with a use-versus-availability design at the third-order scale (Johnson 1980). We estimated selection using resource selection functions (RSF) of the form $w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 \ldots + \beta_n x_n)$, where $w(x)$ is the relative probability of selection for predictor variables x_n. We limited the timeframe of our analysis to 15 July – 15 October, 2018 and 2019. We chose this timeframe because it represents the period when agriculture crops are growing and when elk cause the most substantial damage to such crops. Because elk typically forage in agriculture crops during the night, we partitioned our data based on elk selection or avoidance of agriculture habitat and only included locations during midday and night hours (

Figure 2.2). The day period, representing the timeframe when elk generally avoided agriculture, included location data from 2 hours before to 4 hours after solar noon (when the sun was at the highest position). The night period, when elk use of agriculture was highest, included location data from 2 hours after sunset to 3 ½ hours before sunrise (

Figure 2.2). We excluded location data during morning, afternoon and crepuscular hours from our analyses.

Preliminary data exploration showed distinct differences in life history strategies among collared elk, in relation to the selection of agriculture. A subset, or 'ecotype', of our collared elk spent the entire season in agriculture-dominated habitats. Agriculture habitat selection ratios for this ecotype of elk, which we labeled 'high-use' (*n* = 14), ranged between 0.5 and 1.0. Other elk in our study primarily used agriculture habitats only at night. This ecotype of elk, which we labeled 'mid-use' (*n* = 26), had agriculture habitat selection ratios that ranged from 0.1 and 0.49. Finally, a subset of elk in our study were seldom present in agriculture. This ecotype of elk, which we labeled 'low-use' (*n* = 27), had agriculture habitat selection ratios that were <0.1. To account for these differences, we pooled individuals into ecotypes of elk based on proportional agriculture use relative to other habitats and modeled habitat selection independently for each group (Table 2.3).

Home ranges were delineated for each elk based on a Minimum Convex Polygon (MCP) encompassing 98% of all individual locations during the timeframe of our analysis. Availability was defined for each elk by generating five random locations for each used location within an individual elk's respective 98% MCP home range.

Based on biological relevance to elk ecology established from past studies in the Rocky Mountain west (e.g., Sawyer et al. 2007, Beck et al. 2013, Lehman et al. 2016), we considered the following non-vegetative predictor variables in our analysis: elevation, terrain roughness, slope, and distance from roads and water. We used USDA Landfire Existing Vegetation Type (LANDFIRE 2008) spatial data to obtain vegetation predictor variables which included forest, shrubland, grassland, and agriculture (Table 2.4). We also included a cover variable, which was a combination of forest and shrubland habitat (Table 2.4). For vegetation predictor variables, we evaluated habitat selection as a function of distance from each variable. We scaled all predictor variables so their values ranged from 0 to 1.

We modeled selection for each predictor variable independently, and subsequently included only variables for which elk exhibited meaningful patterns of selection or avoidance (± 95% confidence intervals not overlapping zero), in our global models. Prior to global model building, we tested for correlations between individual variables, and when there was significant correlation between variables (> |0.60|), we used Akaike information criteria (AIC) scores from models that included a single predictor variable to identify the top ranking variable (of the two correlated variables) to carry forward with additive modeling (Burnham and Anderson 2002). Distance from agriculture was correlated with distance from roads and because we were particularly interested in selection of agriculture, we chose not to consider a global model that included distance from roads. We were interested in how elk selection of agriculture was influenced by plant phenology; therefore, we considered an interaction between distance from agriculture and season time (i.e., day of year, scaled between 0 and 1). Because elk-caused depredations typically increase with season time and only subside when elk leave their summer home-range, we did not consider an interaction with agriculture and time of season in the quadratic form. We then used those non-correlated predictor variables that elk exhibited meaningful patterns of selection or avoidance towards to develop study area-specific global model sets that were the same for each diel period and ecotype.

We used generalized linear models (GLMs) to evaluate the relative probability of use and influence of different predictor variables on elk habitat selection. We chose not to use a mixed-effects (generalized linear-mixed models [GLMMs]) modeling approach, because analysis results were not significantly influenced by including a random intercept term to account for individual elk variability (Figure 2.6). All modeling and predictor variable extraction was conducted using R version 3.5.1 (R Core Team 2018).

2.4. RESULTS

Magic Valley

All ecotypes of elk in the Magic Valley avoided agriculture during the day, but exhibited a linear increase in agriculture selection from mid-July to mid-October during both diel periods. However, only high-use elk, which were those elk with agriculture habitat selection ratios ranging between 0.5 and 1.0, selected positively for areas close in distance to agriculture during night hours (Table 2.5*a*). Intra-seasonal variation in agriculture selection was most apparent for mid-use elk (those elk with agriculture habitat selection ratios ranging between 0.1 and 0.49), with agriculture selection probabilities increasing substantially as the summer progressed (Figure 2.4*b*).

With the exception of agriculture, high-use and mid-use elk exhibited similar patterns of selection for vegetative habitat types, selecting for grasslands and forest habitat during both diel periods. These two ecotypes also selected for shrublands during the day, but avoided shrubland habitat at night (Figure 2.5*a*, *b*, Table 2.5*a*). High-use elk avoided rugged terrain during the day, but their selection was unaffected by terrain ruggedness during the night (Table 2.5*a*). Mid-use elk selected for areas with rugged terrain during the day and showed indifference for rugged terrain during the night (Figure 2.3*a*, *b*, Table 2.5*a*). Counter to the mid-use and high-use ecotypes, low-use elk avoided grasslands during both diel periods (Figure 2.3*a*, *b*, Table 2.5*a*). This group also avoided shrublands (Figure 2.5*a*), and instead selected for forest habitats with more rugged terrain during both periods (Figure 2.3*a*, *b*, Table 2.5*a*).

Weiser

Mid-use elk in Weiser selected for agriculture during both diel periods and increased their selection with season time, most notably during night hours (Table 2.5*b*). Low-use elk avoided agriculture during both diel periods, but relaxed that avoidance with season time (Table 2.5*b*). Agriculture selection probabilities increased more with season time for mid-use elk, relative to low-use elk (Figure 2.4*a, b*).

With the exception of agriculture, there was little difference in selection patterns between mid-use and low-use elk in Weiser (Figure 2.3*c*, *d*, Table 2.5*b*). Both ecotypes avoided shrubland and selected for grassland and forest habitat during both diel periods; however, grassland confidence intervals overlapped zero for mid-use elk during night hours (Table 2.5*b*). Both ecotypes selected for steeper terrain during the day and mid-use elk avoided steep terrains during the night (Figure 2.3*c*, *d*, Table 2.5*b*). Low-use elk showed indifference toward terrain steepness during the night, with confidence intervals overlapping zero (Table 2.5*b*).

2.5. DISCUSSION

The intra-seasonal and diel variation in habitat selection of elk in our study suggest elk make time-dependent trade-offs between security from predators, primarily in the form of humans and nutritional demands. Additionally, we found that there are distinctly different ecotypes of elk within the same region that differ not only in their use of agricultural landscapes but also in their selection of other important environmental variables. However, common ecological drivers across ecotypes also emerged from our work. In general, areas that provided security from predators and thermal cover were selected for during the day, while foraging habitats, primarily in the form of agriculture, were selected for during the night. Our results show a relationship between plant phenology and agriculture use with an increase in agriculture selection occurring through the study period during day and night hours.

Climatic changes and plant phenology have been shown to alter resource availability for a variety of organisms (Walther et al. 2002). In our study area, summer weather patterns are characterized by decreasing rainfall and increasing temperatures as the summer progressed. With limited rainfall, the nutritional quality of natural forage decreases with time (Beck and Peek 2005). Simultaneously, due primarily to irrigation, the relative nutritional qualities of agriculture increase (Sheaffer et al. 1986). As predicted, we found that the selection of agriculture varied substantially in our diel-scale modeling, but increased with time through the growing season for elk in the high-use and mid-use ecotypes. Our results show that elk, primarily the high-use ecotype, take advantage of agriculture food sources by making diel and seasonal shifts in habitat selection, selecting for agricultural foraging habitat nocturnally but not diurnally, and increasing their selection of agriculture through the growing season as crop phenology progresses and natural forage plants senesce.

The observed intra-seasonal shifts in agriculture selection are also likely due to functional changes in security habitat. In early summer months when most female elk birth and raise calves in our study system, female elk select for areas that provide hiding cover for calves and allow females to forage adequately (Irwin and Peek 1983, Unsworth et al. 1998). A lack of security cover in proximity to agriculture may cause elk to perceive agriculture habitats as high-risk food sources, especially in early summer when calves are less mobile and more vulnerable to predators. However, avoiding agriculture during this time period likely has little impact on fitness because the nutritional qualities of natural forages are high. As calves become more mobile, maternal selection of security habitats is relaxed (Paquet and Brook 2004). Therefore, the patterns we observed in selection of habitats that provide high quality nutrition (e.g., agriculture) intensified in late summer, could also be partially explained by female elk relaxing their aversion to anthropogenic disturbances in late summer as offspring become more robust. In general, elk in the Magic Valley selected more strongly for agriculture compared to elk in Weiser. In the Magic Valley, agriculture fields where more expansive and continuous across the landscape, while in Weiser, there were more residential areas intermixed with agriculture fields that were relatively small in size. A possible hypothesis for why the selection of agriculture differed between the study areas could be associated with the spatial configuration of agriculture lands in the Magic Valley providing elk with more secure areas, with abundant agriculture and lower levels of human disturbance, compared to Weiser.

The partitioning of elk-groups (i.e., ecotypes) relative to their preference for agricultural habitat types was supported based on variability in life-history strategies. While all elk in our study selected for agriculture to some extent, changing plant phenology affected elk ecotypes differently. All ecotypes of elk increased their use of agriculture through the growing season, but marked increases were observed in some ecotypes. High-use elk increased their selection of agriculture as the season progressed, but the increase was less dramatic relative to mid-use elk. This minimal increase in agriculture habitat selection throughout the season can potentially be attributed to high-use elk already using agriculture at such a high level that there was little opportunity for increasing the strength of this selection. Home ranges of high-use elk were comprised of 23% agricultural lands, while agriculture only comprised 7% of home ranges for mid-use elk. With agriculture encompassing such a relatively large proportion of available habitat for high-use elk, it is likely that agriculture was used as a primary food source throughout the entire summer, regardless of changes in seasonal plant phenology. Additionally, high-use elk selected positively for security cover, i.e., forested habitats, throughout both diel periods; however available security habitat for elk in this ecotype was relatively limited. In our study areas, deciduous forests are commonly adjacent to agriculture habitats which suggests that high-use elk use these areas to quickly evade predation or human disturbance, while staying in proximity to foraging areas (i.e., agriculture habitat).

Mid-use elk exhibited the highest levels of seasonal shifts in selection of agriculture. Agriculture made up a small proportion (7%) of habitats in mid-use elk home ranges; however, this ecotype of elk increased their selection of agriculture substantially as the season progressed. We observed mid-use elk frequently traveling large distances from daytime security habitats to forage in agriculture during the night, particularly as the season progressed. We suspect these movements were related to the growing disparity between natural and agriculture forage quality. It is likely that in the early summer months, when natural vegetation was more nutritious, the benefits gained from travelling such distances were small as natural forages were equally as nutritious and readily available. The average levels of summer rainfall in 2018 and 2019 in our study areas likely resulted in relatively normal rangeland and natural forage conditions; however, in drier years, with limited precipitation, it could be assumed that natural forage conditions would be below average, and elk use of agriculture lands would increase proportionally throughout the summer months.

We expected all elk in this study to exhibit high levels of agriculture use because we limited our capture efforts to areas < 1km from agriculture fields. Despite this, low-use elk avoided agriculture in both diel periods, but relaxed this avoidance as the season progressed. Additionally, mid-use elk selected more strongly for agriculture as the season progressed, but continued to select for security habitats that were spatially distant from agriculture. These differences in life-history strategies may be associated with variation in how elk respond to risk and human disturbance. Elk that select home ranges within agriculture landscapes, e.g., high-use elk, presumably encounter humans at a relatively high rate, and it has been shown that repeated human encounters or disturbances can result in elk becoming desensitized to humans (Found and St. Clair 2016, 2017). Conversely, mid-use and low-use elk may have a stronger aversion to risk and disturbance associated with agriculture habitat, but this aversion is eventually offset by the seasonal shifts in natural and agricultural forage quality. Low-use elk also avoided shrubland habitat and displayed no diel shifts in such avoidance. While mid-use and high-use elk avoided shrublands during the night, they selected positively for shrublands during the day. Forested habitat was more common in the mountainous home ranges of low-use elk. We suspect this intra-ecotype variation in daytime selection of shrubland is linked to the availability of forest habitats, with low-use elk choosing security areas containing forested habitats over shrubland, but all ecotypes selecting for some type of forested or shrubland security cover, dependent on what was available to them.

With some hunting seasons opening as early as 1 August in many areas throughout our study area, most agriculture producers who allow unlimited hunting access experience minimal elk-caused agricultural damages (Burcham et al. 1999); however, this study focused on areas with limited hunting access, chronic depredation issues, and high numbers of elk.

These areas are ostensibly attractive for elk because they provide security habitat from hunting risk with ample and predictable food sources. It has been shown that elk generally avoid areas with hunting pressure (Marcum 1975, Thurfjell et al. 2017). If elk security was consistently threatened by hunting, it can be assumed that elk would potentially exhibit some level agriculture habitat avoidance in our study area. Considering this, we did not feel a need to account for the effects of hunting on habitat selection.

While habitat use of elk has been widely studied in mountainous terrains (Edge et al. 1987, Unsworth et al. 1998, Ager et al. 2003, Beck et al. 2013), there is limited research on how elk use habitats in agriculture-dominated landscapes (but see DeVore et al. 2016, Hinton et al. 2020). The overarching similarity in our findings, relative to those few studies that investigated habitat use of elk in agriculture landscapes, is that high quality and abundant agriculture is preferred by elk, and this preferential selection increases throughout the summer months.

The different ecotypes of elk in our study suggests that elk can live in proximity to agriculture without relying on it as a primary food source. The intrinsic or extrinsic factors influencing such a gradient of agriculture use (from low to high frequency) by elk remains unknown. Competition for forage among elk and livestock may be displacing elk into agriculture lands, but this inter-specific competition is not considered to be a primary cause of elk depredation in the areas included in our study (IDFG 2019). Elk make adjustments to their behavior through learning, especially when human disturbances or hunting pressure is high (Thurfjell et al. 2017). The majority of high-use elk in our study spent the summer months on private land, which was inaccessible to the public for hunting in the autumn months. Conversely, low-use elk had home ranges that were located primarily on public lands, accessible to hunters. While we do not believe that hunting played a significant role in the patterns of elk habitat selection, learned behaviors associated with previous experiences with risks posed by hunters, or natural predators may have influenced space use of elk during the summer months. We suggest that variability in how elk perceive those risks (i.e., human or natural predator), and how elk learn to avoid such risks to be a potential explanation for differences in agriculture use between ecotypes of elk. Based on this hypothesis, it can be assumed that low-use elk have experience in avoiding humans because they are often pursued by hunters during hunting seasons. The low-use ecotype may also be selecting more for security habitats, such as forested areas, as means of avoiding other natural predators such as wolves or mountain lions. High-use elk have also learned to avoid human disturbances by inhabiting refuges of private land where hunting is generally not allowed. In so doing, this ecotype of elk has simultaneously become habituated to the presence of humans, resulting in a loss of perceived risk towards humans. Additionally, the propensity of high-use elk to avoid more natural landscapes may be a reflection of this ecotype of elk being more aversive to natural predators, relative to human predators. With public hunting being the primary tool used for preventing elk-agriculture damages (Walter et al. 2010), finding ways to promote hunter access into areas where damage is occurring would likely make such areas less attractive to elk. Our study shows that security from predators and high quality forage are the driving mechanisms behind how elk navigate agriculture-dominated lands. This exemplifies the importance of a multipronged approach for mitigating depredations by 1) maintaining quality natural habitat that attracts elk away from agriculture food sources, and 2) reducing the attractiveness of security cover near agriculture lands to discourage elk, such as the ecotype of high-use elk in our study, from using such areas, which may be accomplished by increasing hunter access into agriculture lands that also act as refuge habitat for elk. While elk will always be attracted to nutritionally rich agriculture, we suggest it is possible to maintain sustainable populations of elk in human-modified landscapes without causing substantial damages to agriculture.

2.6. TABLES

Table 2.1: Smoky-Bennett, Pioneer, Big Desert, Weiser River and Brownlee elk population survey estimates.

Zone	Survey Year	Cows	Bulls	Calves	Total
Smoky-Bennett	1999/2009 [a]	1860	677	728	3265
Smoky-Bennett	2015	2712	986	1173	4871
Pioneer	2013	5544	2045	2149	9738
Pioneer	2017	6727	2440	2559	12206
Big Desert [b]	--	--	--	--	--
Weiser River	2007	5372	909	1571	7852
Weiser River	2013	7461	1116	1894	10471
Brownlee	2007	412	206	159	777
Brownlee	2013	841	333	249	1423

[a] GMU's 45, 52 surveyed in 1999, GMU's 43, 44, 48 surveyed in 2009

[b] Aerial surveys are not conducted in the Big Desert Zone

Table 2.2: Smoky-Bennett, Pioneer, Big Desert, Weiser River and Brownlee elk zone population objectives.

Zone	Cows	Bulls	Adult Bulls
Smoky-Bennett	2000-3000	620-930	400-595
Pioneer	3150-5600	1025-1820	630-1120
Big Desert [a]	--	--	--
Weiser River	3300-5000	670-1000	325-500
Brownlee	550-850	150-200	75-125

[a] Aerial surveys are not conducted and population objectives are not established.

Table 2.3: Number of GPS-collared elk in each life-history group. Individual elk were pooled into groups based on agriculture habitat selection ratios during day and night hours. Elk groups and associated selection ratios include: high-use = 0.5 – 1.0, mid-use = 0.1 – 0.49, low-use = <0.1.

	Population	High-use	Mid-use	Low-use
# Individuals	*Magic Valley*	14	15	17
	Weiser	--	11	10

Table 2.4: Description of predictor variables considered in elk resource selection analysis for the Weiser and Magic Valley study areas.

Magic Valley Predictor Variable (Data Source)	Resolution Spatial (Temporal)	Description	Mean	SD	Min.	Max.
Topography and Landscape						
Elevation (USGS)	30 meters (2017)	Elevation, in meters, above sea level	1610.6	296.0	756.6	2813.9
Slope (USGS)	30 meters (2017)	Degree of slope	9.1	8.8	0.0	53.8
Terrain roughness (USGS)	30 meters (2017)	Elevational difference, in meters	13.4	13.2	0.0	105.7
Distance from Roads (ITD)	meters (2020)	Center lines of all Idaho roads	1916.8	1836.1	0.0	11765.7
Vegetation						
Distance from Agriculture (LANDFIRE, USGS)	30 meters (2014)	All agriculture vegetation types	1187.0	1478.1	0.0	14221.0
Distance from Forest (LANDFIRE, USGS)	30 meters (2014)	Conifer, hardwood and conifer-hardwood vegetation types	755.0	1064.6	0.0	13458.0
Distance from Shrubland (LANDFIRE, USGS)	30 meters (2014)	Shrubland vegetation types	141.4	361.1	0.0	4426.0
Distance from Grasslands (LANDFIRE, USGS)	30 meters (2014)	Grassland, sparsely vegetated and exotic herbaceous vegetation types	424.1	516.1	0.0	4254.7
Distance from Cover (LANDFIRE, USGS)	30 meters (2014)	Shrubland, conifer, hardwood and conifer-hardwood vegetation types	90.0	185.0	0.0	4426.0

Weiser Predictor Variable (Data Source)	Resolution Spatial (Temporal)	Description	Mean	SD	Min.	Max.
Topography and Landscape						
Elevation (USGS)	30 meters (2017)	Elevation, in meters, above sea level	930.1	161.7	633.7	1812.6
Slope (USGS)	30 meters (2017)	Degree of slope	10.7	6.4	0.0	47.7
Terrain roughness (USGS)	30 meters (2017)	Elevational difference, in meters	15.4	9.3	0.0	93.3
Distance from Roads (ITD)	meters (2020)	Center lines of all Idaho roads	2250.8	1484.4	0.0	12240.0
Vegetation						
Distance from Agriculture (LANDFIRE, USGS)	30 meters (2014)	All agriculture vegetation types	1218.9	1620.7	0.0	10118.0
Distance from Forest (LANDFIRE, USGS)	30 meters (2014)	Conifer, hardwood and conifer-hardwood vegetation types	647.5	542.0	0.0	4082.9
Distance from Shrubland (LANDFIRE, USGS)	30 meters (2014)	Shrubland vegetation types	39.1	127.3	0.0	1624.7
Distance from Grasslands (LANDFIRE, USGS)	30 meters (2014)	Grassland, sparsely vegetated and exotic herbaceous vegetation types	115.4	163.1	0.0	1662.2

Table 2.5: Model coefficients, with standard error (SE) and 95% confidence intervals, from models describing diel resource selection of three ecotypes of elk (high-use, mid-use, low-use) inhabiting the Magic Valley (a) and Weiser (b) study areas of Idaho, 2018-2019.

(a) Magic Valley

	Night hours				**Day hours**			
High use								
Variable	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Intercept	-0.57	0.03	-0.63	-0.51	-0.22	0.02	-0.27	-0.17
Terrain roughness	0.11	0.12	-0.13	0.35	-2.50	0.10	-2.71	-2.30
Agriculture	-33.08	1.98	-37.05	-29.29	1.46	0.42	0.63	2.28
Agriculture*time	-45.99	5.50	-56.88	-35.29	-9.37	0.97	-11.27	-7.47
Shrubland	2.54	0.26	2.02	3.06	-4.32	0.21	-4.74	-3.90
Grasslands	-6.73	0.17	-7.07	-6.39	-7.04	0.14	-7.32	-6.76
Forest	-3.88	0.35	-4.56	-3.20	-10.56	0.25	-11.06	-10.06
Mid use								
Variable	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Intercept	-1.44	0.04	-1.51	-1.37	-1.15	0.03	-1.20	-1.09
Terrain roughness	0.04	0.10	-0.16	0.25	0.16	0.08	0.01	0.30
Agriculture	0.77	0.19	0.40	1.14	2.40	0.14	2.13	2.68
Agriculture*time	-14.03	0.49	-15.00	-13.06	-7.32	0.31	-7.93	-6.71
Shrubland	0.21	0.27	-0.32	0.73	-4.54	0.26	-5.05	-4.03
Grasslands	-0.89	0.14	-1.18	-0.61	-8.08	0.18	-8.44	-7.72
Forest	-2.53	0.20	-2.93	-2.13	-4.72	0.16	-5.04	-4.40
Low use								
Variable	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Intercept	-1.63	0.04	-1.70	-1.56	-1.76	0.03	-1.82	-1.70
Terrain roughness	0.33	0.10	0.13	0.53	0.27	0.08	0.12	0.42
Agriculture	0.63	0.24	0.15	1.11	2.47	0.19	2.09	2.84
Agriculture*time	-2.14	0.47	-3.07	-1.22	-1.61	0.37	-2.34	-0.88
Shrubland	5.02	0.20	4.64	5.41	7.58	0.17	7.25	7.91
Grasslands	1.06	0.12	0.82	1.30	0.99	0.09	0.81	1.18
Forest	-11.89	0.39	-12.65	-11.14	-19.66	0.37	-20.40	-18.93

(b) Weiser

	Night hours				Day hours			
	Mid use							
Variable	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Intercept	-0.52	0.04	-0.60	-0.44	-1.77	0.03	-1.83	-1.71
Slope	-1.93	0.11	-2.14	-1.72	1.36	0.07	1.23	1.49
Agriculture	-4.78	0.50	-5.78	-3.81	-1.14	0.18	-1.49	-0.79
Agriculture*time	-57.95	1.57	-61.04	-54.87	-3.94	0.35	-4.63	-3.24
Shrubland	5.27	0.13	5.02	5.52	3.38	0.08	3.23	3.53
Grasslands	-0.14	0.13	-0.39	0.11	-0.72	0.09	-0.89	-0.55
Forest	-3.19	0.11	-3.41	-2.98	-1.02	0.07	-1.17	-0.88
	Low use							
Variable	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**	**β**	**SE**	**Lower 95% CI**	**Upper 95% CI**
Intercept	-1.97	0.04	-2.05	-1.88	-2.26	0.04	-2.33	-2.19
Slope	-0.01	0.08	-0.17	0.16	0.72	0.06	0.60	0.85
Agriculture	2.78	0.11	2.57	2.99	3.23	0.08	3.07	3.39
Agriculture*time	-7.04	0.23	-7.51	-6.59	-5.60	0.17	-5.93	-5.27
Shrubland	3.79	0.17	3.46	4.12	0.97	0.19	0.60	1.34
Grasslands	-2.39	0.21	-2.81	-1.97	-2.97	0.18	-3.33	-2.62
Forest	-2.27	0.12	-2.51	-2.04	-2.87	0.10	-3.07	-2.68

2.7. FIGURES

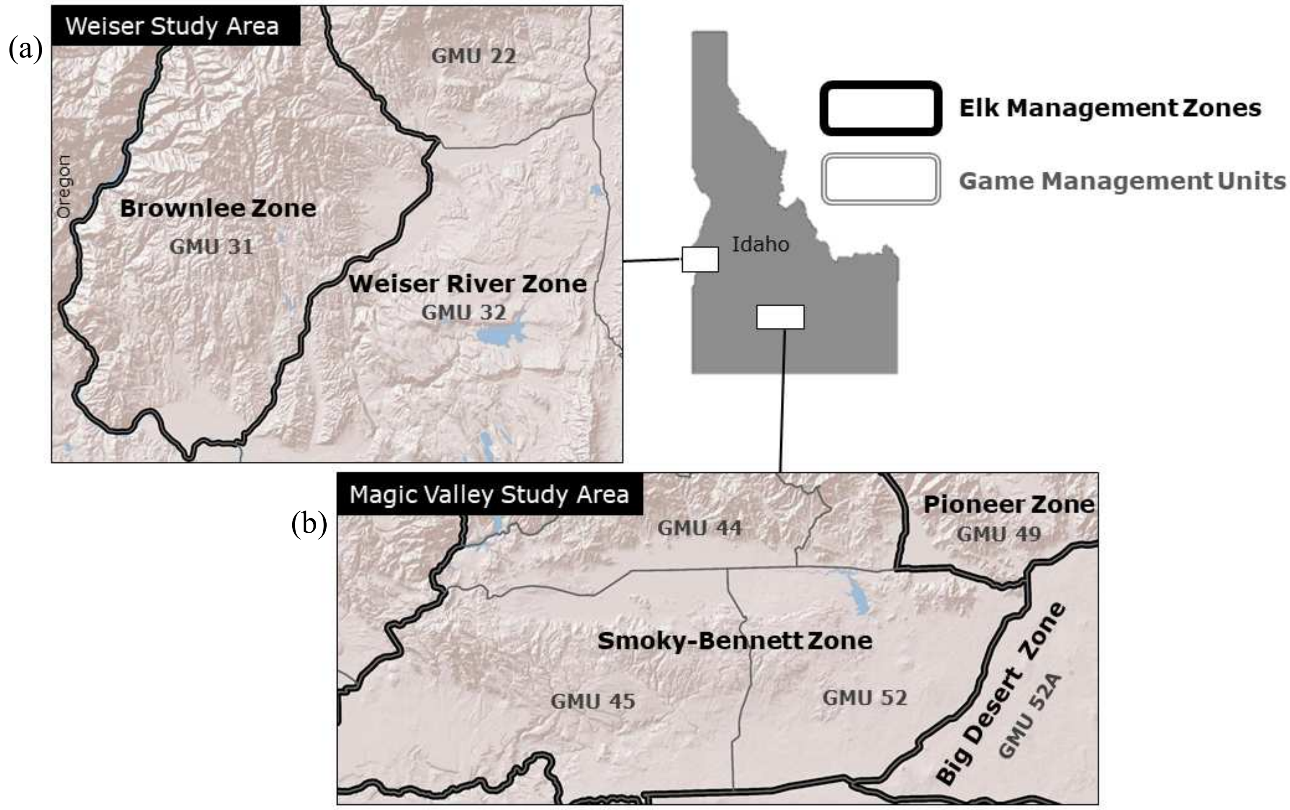

Figure 2.1: The study areas were located near Weiser (a) and the Magic Valley (b).

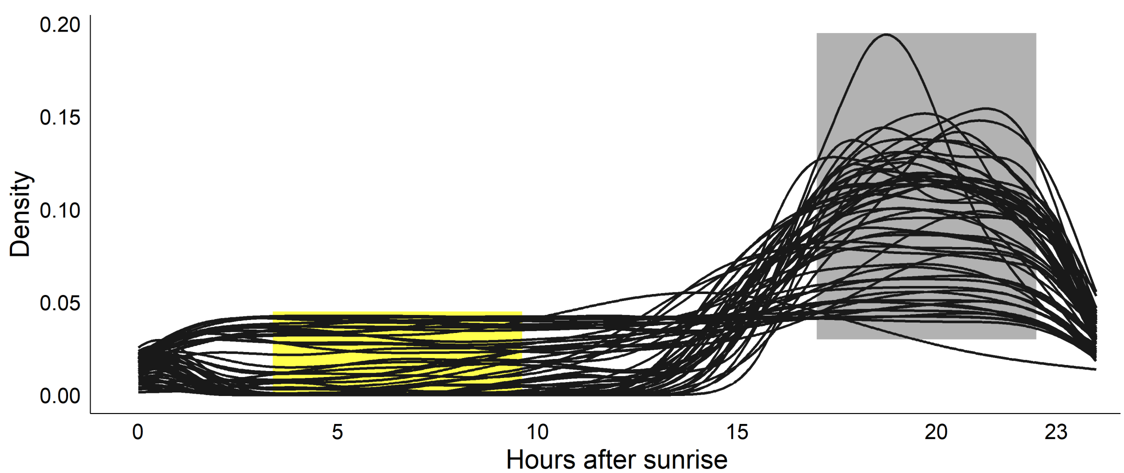

Figure 2.2: Kernel density estimates of all study elk presence in agriculture habitat, on which we based diel data partitioning break-points. Areas shaded in yellow represent the day period and the area shaded in grey represents the night period.

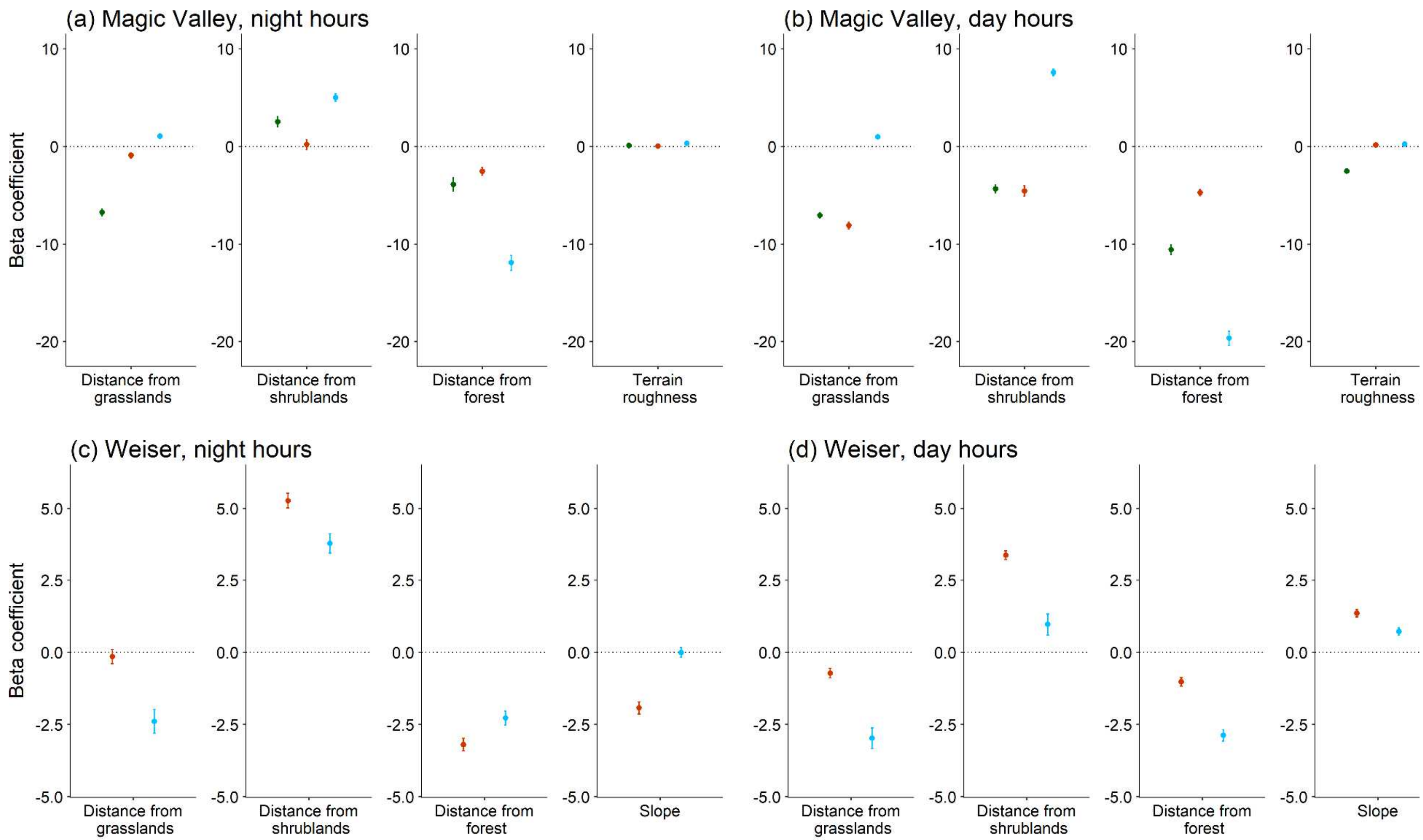

Figure 2.3: Magic Valley and Weiser study area global model results (non-agriculture) showing beta coefficients from GLMs (± 95% CI) during night (a) and day (b) hours for high-use (green), mid-use (red) and low-use (blue) elk ecotype groups. Negative beta coefficients indicate a positive selection for areas in proximity to the particular habitat.

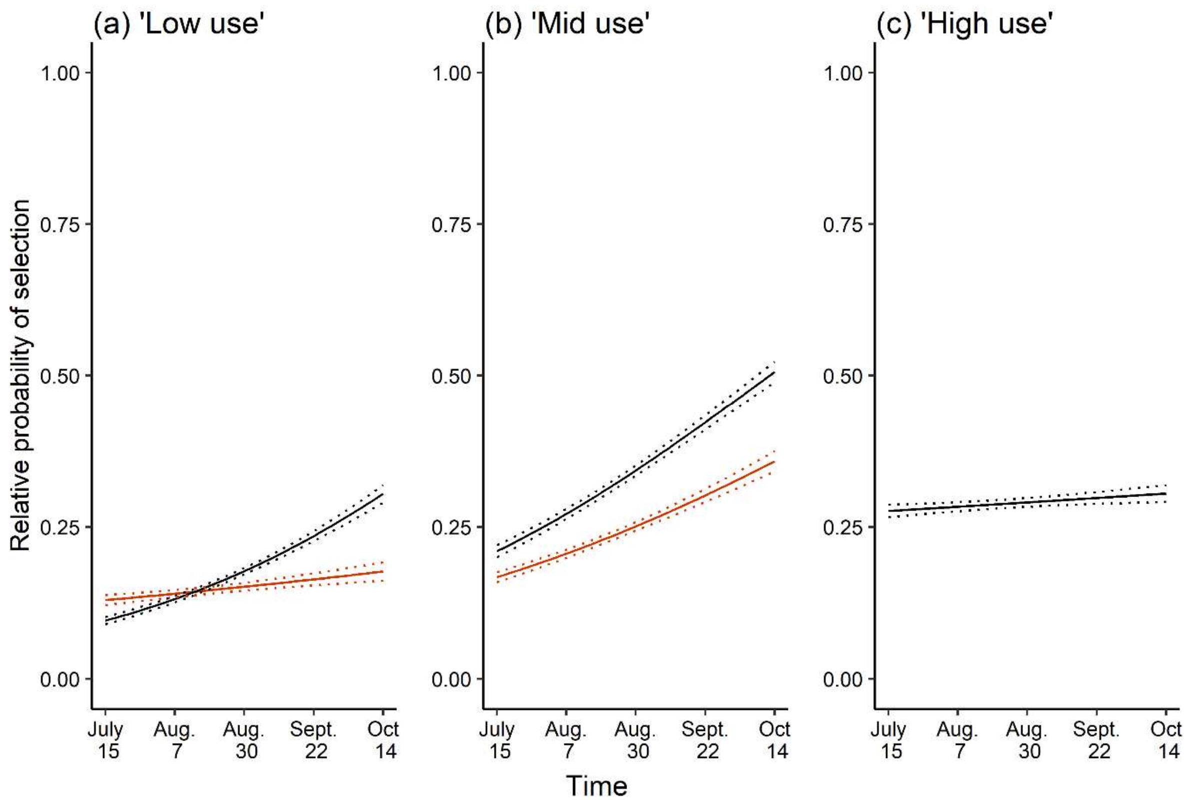

Figure 2.4: Predicted probabilities (± 95% CI) of agriculture selection during night hours for low-use (a), mid-use (b), and high-use (c) elk. Magic valley study elk are shown in black and Weiser study elk are shown in red.

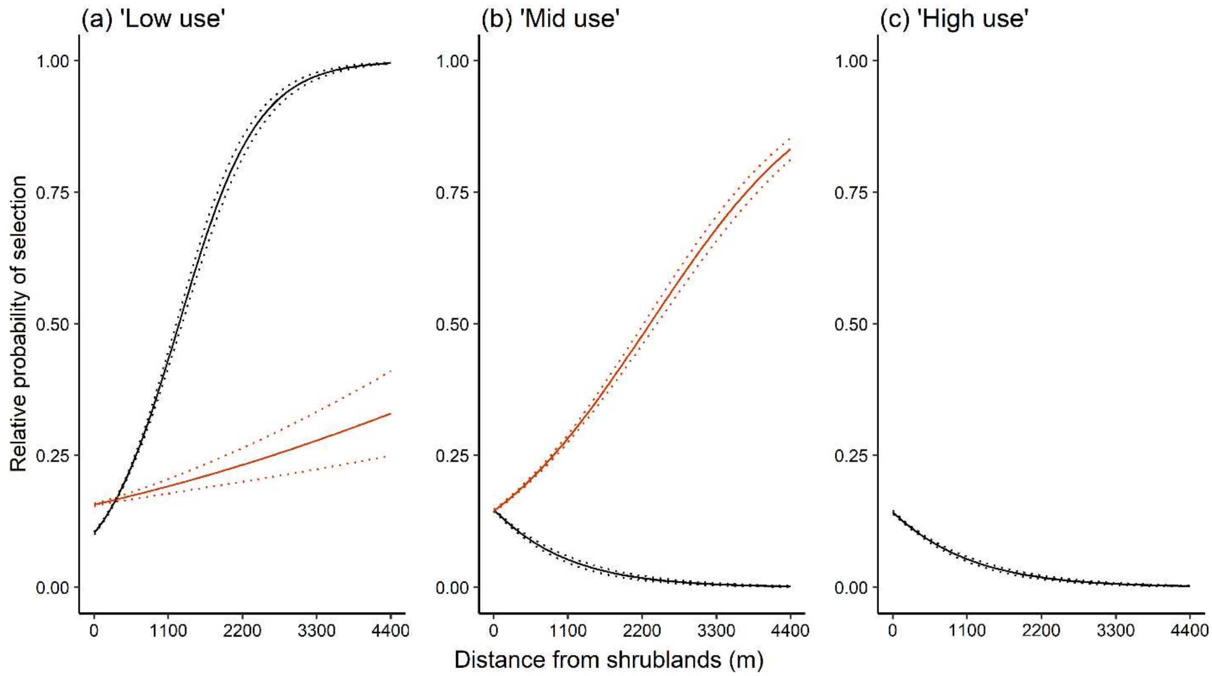

Figure 2.5: Predicted probabilities (± 95% CI) of shrubland selection during day hours for low-use (a), mid-use (b), and high-use (c) elk. Magic valley study elk are shown in black and Weiser study elk are shown in red.

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APPENDIX 1

S1. FIGURES

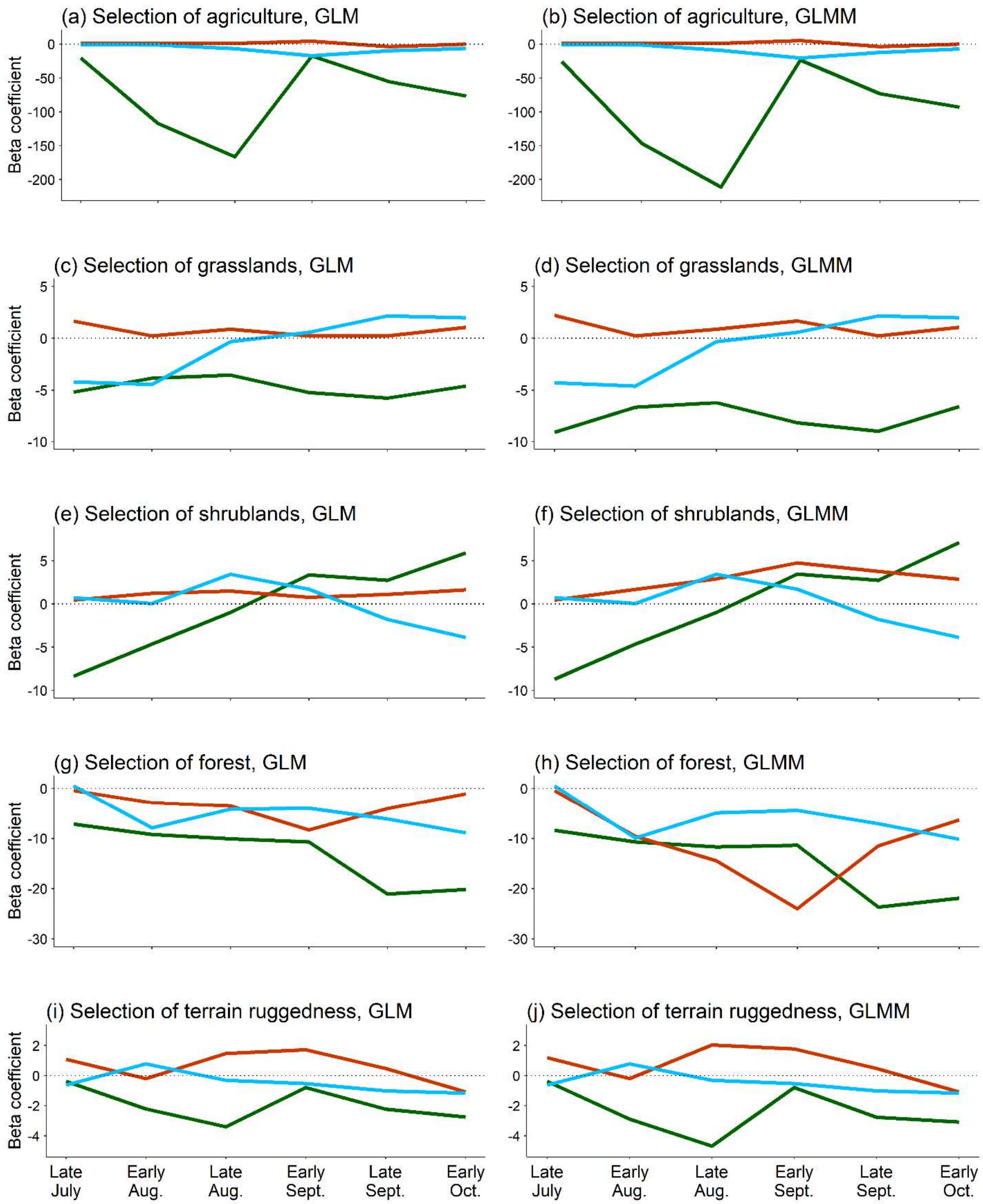

Figure 2.6: Comparison of univariate model results through time (days) for generalized linear models (GLM; left panels) and generalized linear-mixed models (GLMM; right panels) at the summer home-range scale for elk with differing levels of agricultural use, represented by green (high-use), red (mid-use), and blue (low-use) lines.

CHAPTER 3. BEHAVIOR-MODIFYING DETERRENTS FOR REDUCING ELK DEPREDATION

3.1. ABSTRACT

Burgeoning elk (*Cervus canadensis nelsoni*) populations in southern Idaho have resulted in significant increases in agriculture crop damages and damage complaints from landowners. While efforts have been made to minimize or prevent these damages, deterrents employed to date have proven costly and are only partially or temporarily effective. We developed and tested the efficacy of deterrent treatments designed to reduce elk use of agriculture crops and evaluated how these treatments affected elk behavior and subsequent crop damage during the growing season. Deterrents tested included: 1) targeted lethal removal of elk (non-collared) actively utilizing agriculture fields; and 2) pasture fence modification with electrified wire to exclude elk from crops. We used GPS-collar data from 60 adult female elk that were captured in areas with high levels of elk use in agriculture throughout southern Idaho. Approximately 53% of the collared elk (n = 32) received deterrent treatments, while the remaining 46% were not deterred from fields (n = 28), and used as a control. We compared habitat selection patterns of GPS-collared treatment (e.g., elk treated with sharpshooting) and control elk at the summer home-range (i.e., 3rd order selection) and movement-step (i.e., 4th order selection) scale to quantify the effect of sharpshooting. We used observation survey and camera trap data to evaluate the effectiveness of our pasture fence modification treatment. We found that a portion of elk herds that treated with sharpshooting reduced their selection of treatment fields where sharpshooting occurred, and movement-step scale results showed that elk treated with sharpshooting avoided all agriculture in general more than control elk. Our pasture fence modification treatment moderately reduced elk use of treatment fields, but results across treatment sites (n = 5) varied. We found that as time since constructing the modified pasture

fence increased, more elk crossed into the treatment fields. For both deterrents tested, we found they were most effective in areas where elk densities were low and alternative agriculture food sources were abundant, suggesting our deterrents where more effective in displacing elk from specific locations rather than deterring elk from using agriculture lands more generally.

3.2. INTRODUCTION

Conflicts between wildlife and agriculture have been a long-standing issue around the world (Conover 2002). In North America, wild ungulates, such as elk (*Cervus canadensis nelsoni*) and deer (*Odocoileus* sp.), are responsible for causing more agriculture damage than any other species (Conover 2002). Despite significant efforts by wildlife management agencies and private landowners to mitigate ungulate-caused agriculture damages, expanding ungulate populations and agriculture lands encroaching into natural wildlife habitats have resulted in conflicts between ungulates and agriculture persisting and even increasing (Conover 2002, Walter et al. 2010). Ungulate-agriculture conflicts are often mitigated through programs that compensate landowners for crop losses (Wagner et al. 1997), liberal hunting seasons designed to target agriculture-damaging populations (Walter et al. 2010), and the use of deterrents aimed at preventing ungulates from using agriculture lands (Conover 2002). While some deterrents have had localized success in reducing damages, particularly those caused by white-tailed deer (*Odocoileus virginianus*; Swihart and Conover 1990, Hildreth et al. 2013, Monteith et al. 2019), there has been limited success in preventing agriculture damages caused by the abundant elk populations throughout much of the Rocky Mountain west (Walter et al. 2010, IDFG 2014*a*, 2019).

Over the last four decades, North American elk populations have expanded in size and geographic range (Burcham et al. 1999). In Idaho, the Idaho Department of Fish and Game (IDFG) has identified reducing conflicts between elk and private landowners as a primary management objective for many of the state's elk populations (IDFG 2014*a*). In an attempt to accomplish these objectives, IDFG has implemented liberal hunting seasons in areas with high levels of elk depredation and increased funding for damage prevention and compensation (IDFG 2014*a*). While in some instances such efforts have lessened the impacts of elk, such successes have been only partially or temporarily effective in reducing damages, primarily due to a lack of effective deterrents for dissuading elk from using agriculture (IDFG, personal communication). Nevertheless, elk-related depredations, landowner complaints and compensation for crop damage have increased drastically throughout much of the state (IDFG 2019). This increase in elk-agriculture conflict is most apparent in southern Idaho and preventing such conflicts in this region is a top priority for IDFG and landowners alike (IDFG, personal communication).

3.2.1. Southern Idaho Elk Populations

Elk have not always been as abundant in Idaho as they are today. In the early 1900s, the overgrazing of domestic livestock paired with unregulated harvest likely caused significant reductions in southern Idaho's elk populations (IDFG 2019). In response to these reduced populations, the recently formed IDFG began supplementing the nearly extirpated elk herds in southern Idaho with translocated elk from Yellowstone National Park (IDFG 2019). In the mid-1900s, grazing practices improved, promoting more natural grass production, while continued logging produced early seral habitats, which enabled elk populations to grow to record highs in the latter half of the 1900s (Irwin and Peek 1983, IDFG 2014*a*).

In southern Idaho, much of the higher-quality elk habitat has been purchased by private landowners, as such habitat also provides environments for optimal agriculture production, and as a result, many already-robust elk populations have continued to increase, especially on private lands. While some user groups, such as hunters, have enjoyed the increase in elk numbers, increasing conflicts between elk and agriculture producers suggests elk in these areas have exceeded their social carrying capacity. IDFG is legally responsible for assisting private landowners in preventing crop depredations caused by big game, including elk (Idaho

Code § 36-1108). When damages cannot be sufficiently reduced or prevented, landowners may file a claim for damage compensation (Idaho Code § 36-1108). While many elk populations in Idaho are largely reliant on habitat located on private land, this reliance comes with a cost to the landowners. Consequently, landowners' tolerance toward elk on their private land has decreased and participation in the damage compensation program and elk-related damage claim payments have continued to grow throughout the state (Figure 3.1; IDFG unpublished data).

Elk-agriculture conflicts have been further compounded by a redistribution of elk populations due to changing agriculture practices and values (Haggerty and Travis 2006), and variation in modes of recreational hunting (Cromsigt et al. 2013, Visscher et al. 2017). In recent decades, the conversion of non-irrigated hay meadows and pastureland to irrigated crops such as corn (*Zea mays*) and alfalfa (*Medicago sativa*) has created dense stands of highly nutritious, unnatural forage for elk (Johnston 2014). Concurrently, there has been an increase in agricultural lands being purchased by new owners more interested in recreational amenities, such as hunting, than agriculture production for profit (Gosnell et al. 2006). Such changes in land use have reduced the effectiveness of management via hunting, the primary tool traditionally used to manage abundant wildlife (Haggerty and Travis 2006), because recreational properties typically allow limited or no public hunting access (thus creating a private land refuge for elk). Elk avoid increased hunting pressure outside, or on the fringes of private land by spending more time on such refuges (Burcham et al. 1999). Although the perception and response of landowners towards increasingly abundant elk on their land varies, this redistribution inevitably leads to increased crop depredation, and fence damage, with the associated financial costs of such damages leading to a decrease in tolerance for elk (Conover

1994, Burcham et al. 1999). With the sustainability of elk populations being equally dependent on public and private land habitats, finding opportunities to increase landowner tolerance, while minimizing the financial costs due to elk, is crucial for wildlife management agencies (Johnson et al. 2014). Consequently, the need for reliable tools that reduce the impact of elk on private agriculture land while providing for healthy elk populations that offer quality hunting opportunities is paramount.

3.2.2. Review of Control Methods to Reduce Depredations

Management tools for abundant elk and other ungulate populations typically rely on ungulates' instincts to avoid predation risk while seeking to optimize nutritional intake. Many wildlife species process predation risks through auditory and visual stimuli and sensations of pain (Provenza and Lauchbaungh 1999); therefore, most lethal and non-lethal deterrents are designed to induce a predator-aversion response through such stimuli and sensations.

Lethal methods primarily take the form of recreational public harvest, which is regulated by wildlife management agencies, to control or reduce the size of elk populations (Bunnell et al. 2002, Hegel et al. 2009) or through the lethal removal of animals outside the framework of traditional hunting seasons and restrictions, commonly known as sharpshooting (Walter et al. 2010). Recreational public harvest (hunting) is often the more socially acceptable lethal method for regulating populations. Furthermore, hunting is often considered a more ethical management tool by the general public, as there is much support for the increased funding for habitat improvements and wildlife management that is generated through hunting license sales and other hunting related expenditures (Jordan and Workman 1986, Cooper et al. 2002, Loveridge et al. 2006).

In some areas, hunting may not be practical or socially accepted by the public due to offending wildlife being near residential areas where public safety associated with hunting is a concern. In such instances, trained professionals removing offending wildlife is a feasible option (Denicola and Williams 2006*b*). However, this method can also be viewed as less acceptable by the general public as it may be considered an unethical mode of wildlife management (Walter et al. 2010). While the effectiveness of lethal control, or sharpshooting, has proven effective in reducing offending deer populations (e.g., Kilpatrick et al. 1997, Denicola and Williams 2006), there is limited research on the effectiveness of sharpshooting as a depredation management tool for elk. Furthermore, the different mechanisms by which lethal control methods could reduce depredations varies. For instance, lethal control can be utilized to reduce the overall population or herd size of crop-damaging animals. Alternatively, wildlife managers can use lethal control in attempts of inducing a behavioral response in animals by removing a small number of targeted individuals in hopes of deterring crop-damaging herds from using a specific area. When using lethal control in attempts of modifying animals behavior, the mechanism underpinning a behavioral effect assumes that animals learn and subsequently avoid areas where conspecifics are being lethally removed (Thurfjell et al. 2017).

In contrast to lethal techniques where animals are killed to reduce damages, a variety of non-lethal techniques have also been employed for reducing elk damages. Conventional non-lethal techniques are designed to either physically exclude problem wildlife (e.g., exclusion fences) or reduce the motivation of animals to utilize agriculture crops by reducing the nutritional reward or creating an unpleasant taste (Nolte 1999). Many repellents have been tested for their effectiveness in deterring wildlife from crops (see review Ward and Williams

2010, and references therein) and there are a wide array of commercially manufactured products designed to deter depredating wildlife available for agriculture producers and homeowners alike. However, most repellants have proven to be only moderately effective at consistently discouraging foraging wildlife (Walter et al. 2010) and to date, studies focused on limiting elk foraging have only been conducted on captive animals (Andelt et al. 1992, Baker et al. 1999). Additionally, most studies found repellents must be applied at a high frequency and concentration to be effective, reducing their applicability for most agriculture producers. Such limitations make currently available commercial products unrealistic as a damage management tool for managers or landowners (Baker et al. 1999, Brown et al. 2000, Kimball and Nolte 2006).

Creating physical barriers (i.e., fencing) that prevent access to crops is a non-lethal approach with proven effectiveness (Knight 2014). While fences have long been used to provide effective long-term relief from damages caused by ungulates, they can be expensive to construct and maintain (Palmer et al. 1985, Craven and Hygnstrom 1994, de Calesta 1994). Effective permanent fencing designed to exclude deer and elk is typically constructed using 2 m – 2.5 m tall woven wire. These relatively tall fences are permanent barriers, which consequently impact movements of non-target species and negatively affect the connectivity and diversity of wildlife habitats (Jachowski et al. 2013), along with being visually unpleasant. Recently, there has been an increased interest in semi-permanent or temporary fence designs, which are more cost-effective than permanent fencing (Knight 2014) and can be deployed to deter wildlife when needed, then removed when not in use to allow movement of target and non-target wildlife.

Another non-lethal technique that may alleviate crop damages is modification of habitat use by presenting a more-appealing alternative to depredated crops. Such habitat modifications have been tested in several different forms. Lure crops may be planted to encourage ungulates to forage away from agriculture crops (Nolte 1999), however this additional forage has the potential of increasing reproductive and survival rates along with unnaturally congregating animals (Hines et al. 2007). Planting preferred forages and herbicide application followed by fertilizer on areas adjacent to agriculture lands has potential to alleviate wildlife damages (Walter et al. 2010), but due to the scale at which these improvements would be required, these methods can be expensive, and success is not guaranteed.

In contrast to non-lethal approaches that rely on barriers or attractive alternatives, there are also a variety of approaches that aim to limit crop depredations through fear-increasing techniques. Frightening or aversive conditioning methods aim to deliver a stimulus to targeted animals that induces a response such as dispersal or flight. Frightening techniques are typically designed to induce fear through audio-visual modes (Walter et al. 2010). Fear-inducing methods require a continued disturbance, where tools such as pyrotechnics designed to scare animals are deployed by humans, or dogs are used to chase animals away from agriculture fields (Nolte 1999, Kloppers et al. 2005). The primary issue with the currently available fear-inducing methods is animals habituating to the fearful stimulus. This habituation is presumably related to a lack of negative consequences associated with the deterrent, and the deterrent being deployed on a predictable schedule, resulting in the deterrent becoming rapidly ineffective (Nolte 1999, Henigman et al. 2005).

While there are a number of promising techniques available, both lethal and non-lethal, to limit ungulate damage, most techniques have been tested for white-tailed deer (e.g., Belant et al. 1996, 1998, Beringer et al. 2003) and their efficacy remains unknown for elk. Considering the differences in behavior, along with the differing preferred habitats, a deterrent that is effective for deer may not have the same results on elk. Elk adapt to changing environments through adjustments in their distribution across the landscape and changes in their foraging behaviors (Nolte 1999). When faced with increased predation risk, elk will often trade habitats with high-quality forages for more secure areas, where the risk of predation is decreased, but forage quality is also low (Creel et al. 2005). Considering the plasticity of elk foraging behavior and resource use, tactics aimed at limiting the use of agriculture crops through behavioral modifications could provide a plausible method for mitigating elk-agriculture conflicts (Nolte 1999, Thurfjell et al. 2017).

To meet the growing need for management tools that prevent crop damage caused by elk, our study developed and tested the efficacy of management treatments aimed at modifying elk behavior to reduce agriculture crop depredations. Our management treatments included targeted lethal removal of elk actively using agriculture fields (hereafter ‘sharpshooting’) and a fence modification design that temporarily increased the heights of existing pasture fence (hereafter ‘fence modification’). We also conducted pilot testing of several other deterrents; however, data collected for these treatments were insufficient and not analyzed. (See Appendix 2 for a description of additional deterrents tested.)

3.3. METHODS

3.3.1. Study Areas

We evaluated the efficacy of our deterrent treatments in three general locations, which were comprised of similar natural habitats interfacing with agriculture: the Magic Valley, Weiser, and Diamond Creek areas (Figure 3.2**)**. Testing of the sharpshooting deterrent occurred in the Magic Valley and Weiser, and testing of the fence modification treatment occurred in the Magic Valley and Diamond Creek.

Sharpshooting treatments occurred at eight locations around south Idaho. We identified locations with a history of chronic elk-caused depredation issues during the summer growing season with private landowners who were willing to allow sharpshooting to occur on their land. In the Magic Valley area, sharpshooting occurred at six different locations. The Carey site was located in the northwest corner of the Big Desert elk management zone (Game Management Unit [GMU] 52A), where relatively flat, arid grass and shrubland vegetation is intermixed with lava flows. Alfalfa and small grains are the primary agriculture crops grown in this area. In contrast, on the Camas Prairie, the Little Camas, Hill City, Chimney Creek and Deer Creek sharpshooting sites (GMUs 44 and 45) all had natural habitat consisting of gentle topography with sagebrush-conifer vegetation, and crops consisting primarily of alfalfa and small grains (although potatoes (*Solanum* sp.) are grown in some fields at Little Camas). Finally, the Bliss site (GMU 45) was the farthest south, with natural habitats dominated by xeric grasslands, and cottonwoods (*Populus* sp.) and other common riparian species are present along the perennial stream that flows through the center of the site. There are no other agriculture lands adjacent to the Little Camas treatment site; however, agriculture lands were adjacent and abundant at all other Magic Valley treatment sites. See Chapter one for a detailed description of landownership distribution, and other wildlife species present in the Magic Valley study area.

In the Weiser area, sharpshooting was conducted at two sites: Weiser-west, located in the southernmost portion of GMU 31, and Midvale, located in the northwest corner of GMU 32. Both sharpshooting sites are partially surrounded by agriculture lands, and natural habitats consist of rolling hills with shrub and grasslands intermixed with sparse conifers. Cottonwoods and other riparian species are abundant along the Weiser River, which flows through the Midvale site. Alfalfa, small-grains, such as barley (*Hordeum* sp.) and wheat (*Triticum* sp.) and corn were grown at both Weiser sites. See Chapter one for a detailed description of landownership distribution, and other wildlife species present in the Weiser study area.

Fence modification treatments were implemented at five sites in south Idaho. Two sites were located in the Magic Valley area and three sites were located in the Diamond Creek area. We chose sites to test this treatment that had 1) a history of chronic elk depredation issues during the summer growing season, 2) agriculture fields that were surrounded by an existing (low in height) livestock fence, and 3) landowner willingness to allow us to test the fence modification treatment.

Within the Magic Valley area, we tested the fence modification at two sites (Figure 3.2**,** Table 3.1): Big Wood, which was located in GMU 52 along the Big Wood River, and Bellevue, which was located in southwest portion of GMU 49. Habitats surrounding the Bellevue site were xeric shrublands dominated by sagebrush, whereas the Big Wood site consisted of riparian areas dominated by willows (*Salix* sp.) and cottonwood.

The Diamond Creek area (Figure 3.2), located in Bear Lake County, ID and focused primarily around Geneva, ID (GMU 76), is 65% federal (primarily U.S. Forest Service) and 35% private. Diamond Creek habitat consist of sagebrush-grasslands intermixed with aspen and conifer forests, with crops made up primarily of alfalfa and small-grains. Elevations range from 1,800 m to 2,800 m, and annual average precipitation in the area is 36.7 cm. The average minimum and maximum temperatures are -2.8 C and 13.6 C, respectively. Mule deer (*Odocoileus hemionus*) are common in the area. Black bears (*Ursus americanus*) are present in the area at low densities and mountain lions (*Puma concolor*) occur in moderate to high numbers. Wolf (*Canis lupus*) sightings are not uncommon; however, there are currently no known wolf packs established in the area and there is no indication that predation is having an impact on elk survival or calf recruitment (IDFG 2019). In the Diamond Creek area, we tested the fence modification treatment at three sites (Table 3.1): South Geneva, Geneva, and North Geneva. Natural habitats surrounding the three Diamond Creek treatment areas are similar and consist of xeric shrublands with willow and cottonwood dominated riparian areas. We tested the fence modification treatment at all sites in 2019; however, only at the Geneva and North Geneva sites did testing of the fence modification occur during both years of our study.

3.3.2. Animal Capture

The behavioral and movement responses of GPS-collared elk were used to quantify the effectiveness of the sharpshooting deterrent. The capture and collaring process is known to affect normal animal behavior (Mech and Barber 2002). Because elk were GPS-collared in proximity to agriculture, they could associate the negative effects of the capture process with agriculture fields. To avoid confounding capture-related with treatment-related agriculture aversions, elk were not treated for a minimum of seven days post-collaring. The use of treatment fields specifically, in addition to all other agriculture lands and other landscape variables, was compared between GPS-collared elk treated with sharpshooting and control elk (i.e., GPS-collared elk not treated with sharpshooting). The locations that sharpshooting occurred varied between the two years of our study, but we repeated sharpshooting testing at all locations in 2019 where sharpshooting occurred in 2018. If elk used fields in 2018 (when no sharpshooting occurred at the specific field), but that field was included as a sharpshooting treatment field in 2019, they were considered as a control elk. Additionally, if elk used a sharpshooting treatment field in a specific year, but use of this field occurred before sharpshooting treatments began, they were also considered as a control elk. Treatment elk were those individuals that were subjected to sharpshooting in a specific year (i.e., 2018 or 2019), and once elk were subjected to a sharpshooting treatment, they were considered as treatment elk for the remainder of the season. See Chapter one for a detailed description of animal capture.

3.3.3. Sharpshooting Methods

Inducing antipredator behavior is dependent on prey animals having both a clear perception of the risk and accurately linking it to a predictable spatial location (Lima and Bednekoff 1999, Stankowich 2008). To meet these two criteria for successful inducement of fear-based avoidance of an agricultural field, we aimed to induce high levels of antipredator behavior in elk by lethally removing individuals (that were not GPS-collared) from herds that contained GPS-collared animals used in this study. We predicted that with repeated sharpshooting in predictable spatial locations (i.e., the same field for multiple nights), herds containing GPS-collared elk would associate the death of individuals from their herds with the spatial location where sharpshooting occurred, and consequently avoid the area due to this high, spatially-predictable risk. All of the areas where sharpshooting occurred were agriculture fields (e.g., alfalfa, small grain, corn crop types), and our objective was to induce an aversion toward the specific treatment site (localized response associating risk with treatment site), and ideally, to agriculture in general throughout the home ranges of treated elk (generalized response associating risk with agriculture). Accordingly, we predicted that sharpshooting would have a stronger effect inducing treatment site avoidance, but less of an effect on the avoidance of agriculture in general.

We only treated elk when they were actively using agriculture, which occurred almost exclusively at night. In both field seasons, sharpshooting would occur only when GPS-collared animals were present, or when the most recent location data showed that animals were travelling to treatment fields. We used recent location data from satellite-linked GPS-collars, and thermal imaging bi-oculars (FLIR Command 336 5-20x75, FLIR Systems, Wilsonville, Oregon USA) to monitor the location of animals in relation to treatment fields.

After identifying the location of elk that would be treated, precautions were taken to ensure no humans, livestock or infrastructure were near the sharpshooting area. Once the area was deemed safe for rifle discharge, we would devise a site and situation-specific strategy for approaching elk to distances <200 m. Because elk in our study were increasingly averse to human presence as their exposure to sharpshooting events increased, we used varying methods for approaching elk during sharpshooting. In early and mid-summer, when elk had been subjected to few sharpshooting events, we were able to approach elk conspicuously, often in a motorized vehicle. After elk were subjected to multiple treatments, the presence of a motorized vehicle would result in elk immediately fleeing the area, which required subsequent approaches to be conducted on foot. Once shooters were within 200 m from target elk, highpowered rifles, equipped with spotlights (750 HD Kill Light, Elusive Wildlife Technologies, Conroe, Texas USA) were used to lethally remove targeted individuals, which were those animals (i.e., female elk) that provided us with opportunities to make clean and ethical shots (i.e., standing broadside). We predicted implementing the treatment from close range would create a stronger perception of risk when GPS-collared "treatment" elk associated the death of nearby individuals from their herds with the presence of a predator (i.e., human); this close distance also facilitated ethical and lethal shots.

Risks that are temporally unpredictable (i.e., variable), but spatially predictable, have been shown to induce the greatest antipredator behavior in wildlife (Lima and Bednekoff 1999). In 2018, we attempted to implement sharpshooting in a temporally unpredictable, yet spatially predictable manner. Therefore, while sharpshooting events were restricted to the same treatment fields (i.e., sites), following each sharpshooting event we would allow elk to use the treatment fields undeterred for a period of 24 hours. We predicted that agriculture avoidance would not be dependent on the number of animals removed during each sharpshooting treatment. Therefore, in 2018, we limited the number of animals removed during each sharpshooting event to a maximum of two, to minimize numeric impacts to elk herds.

Preliminary results from the 2018 season suggested sharpshooting was effective in reducing elk use of agriculture. To evaluate whether this aversion could be enhanced by increasing the intensity and frequency of sharpshooting, we did not limit the number of elk removed per sharpshooting event in 2019. We also implemented the deterrent whenever elk were present in treatment fields rather than waiting 24 hours between sharpshooting events.

In both field seasons, after animals had been lethally removed, we field dressed and retained all legally required and edible meat (Idaho Code § 36-1202). Retained meat was removed from the field and immediately frozen. Meat was delivered to a professional meat-processing facility. Processed meat was donated to local food pantries for distribution to families in need within the local community.

Sharpshooting response-to-treatment data included high-frequency location data from GPS-collared elk during and following sharpshooting treatment periods. Treatment data were compared to location data from individual elk within herds that regularly used treatment sites (within and across years), but were not subjected to sharpshooting (control data). In 2018, GPS-collared elk started using treatment sites in early July; however, we did not begin sharpshooting until 1 August, so that locations from elk that were using treatment sites in July could act as "before treatment" control data. In 2019, waning landowner tolerance towards elk using their agriculture crops paired with IDFG's legal responsibility for reducing big game-caused agriculture damages (Idaho Code § 36-1108) necessitated earlier implementation of sharpshooting at several treatment sites. Elk using treatment sites where landowners were more tolerant of depredations were left undeterred throughout the month of July and elk locations from this period were used as "before treatment" control data. In areas where landowners were less tolerant of depredations, we began sharpshooting in late July; therefore, several treatment sites had a limited amount of "before treatment" control data.

In 2018, we implemented sharpshooting at four sites. Three sites where in Weiser and one site was in the Magic Valley. Three elk herds that included GPS-collared individuals were treated with sharpshooting. The movement patterns of these treated herds were compared to location data from the same individuals prior to the implementation of sharpshooting, and location data from herds that were not subjected to sharpshooting. In 2019, we implemented sharpshooting at seven sites. In Weiser, GPS-collared elk did not use any of the treatment sites where sharpshooting was tested in 2018; therefore, we did not have site-specific repeated treatments across years in this study area. In the Magic Valley, we repeated sharpshooting at the Hill City site, where treatments occurred in 2018, and included an additional five new treatment sites. Within herds that were treated with sharpshooting in 2019, a total of 22 GPS-collared elk were treated and compared with 19 control elk. In both field seasons, after elk were initially exposed to sharpshooting, they were classified as treated elk throughout the remainder of the season.

3.3.4. Fence Modification Methods

Fences >2 m-tall are effective in creating an impassible barrier for most ungulates found in North America (Craven and Hygnstrom 1994). While fences offer the most reliable long-term solution compared to other deterrent methods, they are considered visually unattractive (VerCauteren et al. 2006), very expensive to construct, and often create barriers to movement for non-target wildlife (Craven and Hygnstrom 1994, de Calesta 1994). Furthermore, permanent fences are often more expensive to construct than the value of the agriculture crop the fence is intended to protect (Knight 2014).

Agriculture crops in southern Idaho are often surrounded by an existing low perimeter fence designed for livestock containment, as most producer's use their agriculture fields for livestock grazing post-growing season. These existing perimeter fences are typically <1.5 m-tall and do not usually form a barrier to wild ungulates, particularly elk. Given the proven effectiveness of high fences in excluding ungulates from agriculture fields, identifying cost-effective fence designs that can simply increase the functional height of existing livestock fences would, in theory, reduce crop damages caused by elk with reduced additional costs (Knight 2014).

Much research has been conducted on the effectiveness of various fence modification designs on excluding ungulates from crops; however, most of these studies have either focused on white-tailed and mule deer, or excluding ungulates from relatively small-sized areas, such as haystacks during winter (e.g., VerCauteren et al. 2006). Additionally, there is limited research testing the effectiveness of using electrified fence to create a barrier around large-scale (>60 ha) crops during the growing season.

To fill this knowledge gap, our objective was to design and test the effectiveness of a temporary fence modification for protecting entire fields. Typical pasture fences are <1.5 m-tall, and our fence modification electrified and increased the height of existing pasture fence by approximately 1 m to reduce elk-caused agriculture damage. Rather than creating a permanent barrier, the fence design was intended to create a psychological barrier around agriculture fields. To increase the height of existing pasture fence, we constructed fence extensions using 3.81 cm diameter polyvinyl chloride (PVC) pipe, which were 117 cm in total height (Figure 3.3). A 46 cm section of PVC pipe, attached to the top of the extension, extended horizontally away from the fence at a 90-degree angle. We attached wire to the extension by drilling holes through the PVC pipe and used small (20 cm) pieces of wire to secure the wire to the extension. One strand of wire was attached 2 cm from the end of the horizontal portion of the extension. To accommodate for uneven terrain, which would change the vertical height of our wire relative to the ground, we drilled three holes at 46 cm, 56 cm, and 76 cm from the bottom of the vertical extension, which could be used for attaching wire. One strand of wire was attached to the vertical portion of the extension approximately 173 cm above the ground. The fence extensions were placed on top of the metal fence posts and small screws were used to secure them.

In 2018, we attached 2 cm-wide polyethylene tape (polytape) containing conductive metal threads that transmit voltage, to our fence extensions. We chose to use polytape as it was proven effective in reducing deer damages in smaller fields (<6 ha) by Hygnstrom and Craven (1988). Two strands of polytape were secured to the fence extensions at 173 cm and 228 cm above the ground. During 2018 testing, polytape was frequently broken by elk attempting to cross the fence. When polytape was broken, it was no longer electrified, which resulted in the fence becoming relatively ineffective in deterring elk from the treatment field. To mitigate this, we used high-tensile strength wire in the 2019 field season, which was more resistant to stretching and breaking. At all sites in 2019, we attached two strands of high-tensile strength wire (14 gauge, 1.6 mm thickness) to the PVC fence extensions. Because high-tensile strength wire was less visible than polytape, we attached 60 cm-lengths of plastic flagging to the high-tensile wire at 3-4 m-intervals (i.e., turbo-fladry; Musiani et al. 2003). The PVC fence extensions used in 2019 were identical to those used in 2018 and high-tensile strength wire was attached to the extensions at 173 cm, and 228 cm above ground.

The polytape or wire attached to fence modification was electrified using Gallagher S100 Solar Fence Chargers (Gallagher USA Electric Fencing, Riverside, MO USA), capable of maintaining one Joule of stored energy. Because the extensions were made from PVC, electrical current was not transferred to the metal fence posts that extensions were secured to. Due to tall vegetation contacting our electrified wire and other losses of electrical current, we used one solar charger for every 1.5 km of fence.

The proportion of available forages, both natural and agricultural, has been shown to influence the motivation of animals to use agriculture crops as food sources (Nixon et al. 1991, Walter et al. 2010, Visscher et al. 2017). Thus, we predicted our temporary fence modification would be more effective in reducing elk use of treatment fields in areas with higher proportions of available agriculture (i.e., agriculture lands where we didn't deploy the fence modification but were adjacent to fence modification treatment sites). We also predicted that differences in nutritional qualities of natural and agricultural forages would influence the effectiveness of the fence, with elk being more motivated to cross into the treatment fields in late summer when crop phenology progresses and natural forages senesce. Finally, we predicted that as time since erecting the fence modification increased, elk would become more habituated to the psychological barrier created by the fence, resulting in an increased number of fence crossings.

2018: Measuring Fence Modification Effectiveness

In 2018, we conducted observation surveys, recording the number of elk crossing into the treatment fields to quantify the effectiveness of our fence modification deterrent. Observation surveys were conducted from 5 m-tall towers, located approximately 0.5 km from the modified fence. Towers were located in areas that allowed observers to be undetected by elk using the treatment areas. Because elk exclusively used our treatment fields during night hours, surveys were conducted using thermal imaging bi-oculars (FLIR Command 336 5-20x75) with 4x digital zoom and high-resolution video recording capabilities. Bi-oculars were capable of differentiating between ungulate species (mule deer and elk) at distances > 0.5 km.

We conducted observation surveys at each site on an every-other-night basis. Observation surveys began at sunset and continued until 1 hour before sunrise. To standardize our observation surveys, we identified latitudinal scanning grids, corresponding with unique landmarks at each location, and observers would scan across the fields, at minimum, every 5 minutes. When animals were observed, we recorded: species, number of animals, approximate age and sex, time of initial detection, location (e.g., inside or outside of the treatment area), and if they encountered or attempted to cross the modified fence. To ensure observations were accurately documented we recorded video (through the thermal bi-oculars) of animals detected near or within the treatment field.

Prior to constructing the modified fence, observation surveys were conducted at treatment sites for two weeks. We regularly monitored treatment sites for elk presence, and pre-treatment surveys began when elk were consistently observed using the sites. After pre-treatment observation surveys were complete, we immediately constructed the fence modification and continued observation surveys at each site for approximately two weeks (Table 3.2).

2019: Measuring Fence Modification Effectiveness

In 2019, we repeated testing the fence modification at the Geneva and North Geneva sites, while including three additional sites: South Geneva, Big Wood, and Bellevue (Table 3.3). With the increased number of treatment sites and intensive time commitments associated with observation surveys, we used remote camera traps (rather than observation surveys) to measure our fence modifications effectiveness in 2019. At each site, we placed a minimum of one camera per 175 m-section of fence at the most heavily-used game trail within that section (Table 3.4). If no game trails were located, we selected a random location to place cameras; however, it was rare that game trails were not identified. To maximize crossing detections, cameras were secured to fence posts approximately 1.3 m above ground, and aimed parallel to the fence (Ford et al. 2009, Visscher et al. 2017). A combination of Reconyx HF2X HYPERFIRE 2, Reconyx PC900 HYPERFIRE (Reconyx, Holmen, WI USA), and Bushnell Trophy Cam HD (Bushnell Corporation, Overland Park, KS USA) cameras were deployed and equally distributed by brand across study sites. All cameras had a detection distance of approximately 18 m. Cameras were programmed to take three consecutive images for each trigger, with no time delay between images. Cameras were inspected at least once every 10 days to ensure they were functioning properly.

Our 2019 treatment schedule followed similar methods to those used in 2018. We began testing fence modifications after regular elk use was observed at each treatment site. However, for purposes of increasing the sample size of periods when the fence modification was present or absent, rather than each treatment site having one pre- and during-modification period, there were multiple, alternating periods at each site, when the fence modification was 'on' and 'off'. At least one week prior to testing, we constructed fence extensions at each site, but did not place the extensions onto existing fence posts to allow for animal habituation to fence materials. Following this habituation period, the fence modification was raised and electrified, and remained in the 'on' position for two weeks. After two weeks in the 'on' position, electrical power was turned off and the fence was lowered for two weeks, in an 'off' position. Following the 'off' period, we would reposition the fence to 'on' for the next two week period. At each site, we followed this 'on' and 'off' schedule throughout the entire testing period (Table 3.3).

Cameras were removed from the treatment sites at the end of our 2019 testing period. All images captured by cameras ($n > 800{,}000$) were downloaded and classified using Timelapse image classification software (Greenberg et al. 2019). To allow for the pooling of 2018 observation survey data and 2019 camera trap data, we classified images in the same way as we recorded observation survey data in 2018. For each camera, we collected all images containing elk and recorded, for each image: number of animals visible, sex, approximate age class (adult, young, unknown), and location (e.g., inside or outside of the treatment area). We also recorded the number of animals observed physically crossing the fence and direction of the fence crossing (i.e., into or out of the treatment field). At all sites, fence posts were spaced approximately 3 m apart, and we used the number of fence posts between the animal and camera to determine the animal's distance from the camera. To minimize inaccurate classifications, we only recorded animals that were within approximately 30 m of the camera. We pooled crossing data from 2018 and 2019 for the Geneva and North Geneva sites, where fence modification testing occurred in both years of our study.

3.3.5. Statistical Analysis

Sharpshooting Statistical Analysis

We compared habitat selection patterns of treatment and control elk at two spatial scales to quantify the effect of sharpshooting. Elk herds associated with our study areas were very cohesive in their movement patterns and behaviors (IDFG, personal communication); therefore, we used the response of GPS-collared individuals within elk herds as a surrogate for quantifying the herd-level response. We used resource selection functions (RSF) to make summer home-range scale comparisons between treatment and control elk (i.e., 3rd order selection; Johnson 1980), and fine-scale comparisons were made using step selection functions (SSF; Fortin et al. 2005). An SSF is similar to an RSF, with both approaches comparing habitat characteristics at locations used by animals, relative to locations that were available to the animal but were not recorded as used (Manly et al. 2002). An RSF typically confines the extent of available habitat to the animals seasonal home range or study area of interest (e.g., Manly et al. 2002, Boyce et al. 2003), while SSFs incorporate turning angles and distances traveled between used locations to account for individual animal movements, resulting in more localized definition of availability (Fortin et al. 2005). The extent of availability in an SSF is constrained to random locations associated with empirical distributions of used 'steps,' with steps being defined as two consecutive locations used by an animal (Fortin et al. 2005, Thurfjell et al. 2014). Logistic regression was used to estimate elk resource selection with a use-versus-availability design at the summer home-range scale. Movement-step scale analyses were conducted using conditional logistic regression (case-control design; Andersen and Gill 1982) with an individual's used locations (i.e., steps) being compared to corresponding available steps (Avgar et al. 2017).

At the summer home-range scale, we delineated home ranges for each elk based on a Minimum Convex Polygon (MCP) encompassing 98% of all individual locations during the timeframe of our analysis. Availability was defined for each elk by generating five random locations for each used location within an individual elk's respective 98% MCP home range. At the movement-step scale, five random steps where generated for each associated used step (Thurfjell et al. 2014).

The seasonal timeframe for both scales of analysis was from 30 June – 15 October 2018 and 2019, and we pooled location data for individual elk across years; however, the timing at which elk were treated varied based on their use of areas where sharpshooting was implemented. In 2018, we began treating elk on 1 August and no treatments occurred after 17 August. In 2019, the earliest treatment occurred on 14 July and treatments ceased on 17 September. Because our primary interest focused on elk use of agriculture, we partitioned our data relative to elk presence in agriculture habitats, only including locations during midday and night hours (see Chapter 1 for analysis). The day period, representing the timeframe when elk generally avoided agriculture, included location data 2 hours before to 4 hours after solar noon (when the sun was at the highest position). The night period, when the proportional use of agriculture was highest, included location data collected from 2 hours after sunset to 3.5 hours before sunrise (Figure 3.4).

Based on biological relevance, as determined in Chapter 1, we considered the following non-vegetative predictor variables in both scales of analysis: elevation, terrain ruggedness, slope, distance from roads and water, and distance from treatment site (Table 3.5). Vegetative classes included forest, shrubland, grassland, cover (forest and shrubland habitat), and agriculture (Table 3.5). Selection of vegetative predictor variables were measured as a function of distance from a particular covariate. All continuous predictor variables were scaled so their values ranged from zero to one. To control for plant phenology influencing how elk selected for agriculture, we included a season time variable (hereafter ‘phenology time’). In analyses of treated elk response, we also included a time-since-previous treatment variable (hereafter ‘treatment time’) to account for potential attenuation in elk’s response to sharpshooting. The treatment time variable was reset at zero after each treatment event. Both time variables included in our analyses were scaled so their values ranged from zero to one.

We conducted population and scale-specific (i.e., seasonal home range and movement-step scale) modeling for each biologically relevant predictor variable independently and for control elk only. This was done so that we could compare the patterns of selection displayed by control elk to elk treated with sharpshooting. Variables that were selected for or avoided by control elk in models that included individual predictor variables, based on 95% confidence intervals not overlapping zero, were included in global models. Prior to global model building, we tested for correlations between individual variables, and when there was significant correlation between variables ($> |0.60|$), we used Akaike information criteria (AIC) scores from models that included a single predictor variable to identify the top ranking variable (of the two correlated variables) to carry forward with additive modeling (Burnham and Anderson 2002). We then used those non-correlated predictor variables that elk exhibited meaningful patterns of selection or avoidance towards to develop study area-specific global models for control elk at both spatial scales included in our analysis. Because we were most interested in how elk used agriculture, agriculture and the two-way interaction of agriculture and season time were included our global models. These global models for control elk where then fit to each population of treated elk, and selection coefficients of treatment and control elk were compared to quantify the effect of sharpshooting.

For treatment analyses, we then used AIC scores to compare our global model (which included agriculture and the interaction of agriculture and season time, among other variables) with models that included all the same predictor variables, but agriculture was replaced with treatment site, and season time was replaced with treatment time. We also compared our global model with three-way interaction models, which included all the same predictor variables as global models, but had agriculture or treatment site interacting with season time and treatment time (Table 3.7; Table 3.8).

To account for pseudo-replication among marked individuals in the same herd, we attempted to include a random effect term for each elk herd; however, the inclusion of this random effect resulted in models not converging. Therefore, we did not account for pseudo-replication among marked individuals in the same herd, and our model results may underestimate the true variance. All modeling and predictor variable extraction was conducted using R version 3.5.1 (R Core Team 2018).

Fence Modification Statistical Analysis

Independently and across sites, differences between conditional means and variances, along with goodness-of-fit chi-squared tests resulted in us using negative binomial regression models to analyze our over-dispersed fence crossing data. To evaluate the overall effectiveness of the fence modification, we pooled data across sites and included a random intercept for study site. Our response variable was the number of animals that were observed physically crossing into the treatment field. We kept the status of the fence modification (e.g., on or off) and the random intercept of treatment site constant in our models during model forming processes and evaluated models, based on AIC score, that also included the number of days after the fence status had changed (scaled so that values ranged between 0 and 1) and the crop type at different treatment sites (Table 3.9). We also conducted site-specific modeling, to evaluate the fence modifications effectiveness at each of our treatment sites using the same predictor variables that were used in our model that included pooled data across all treatment sites.

3.4. RESULTS

3.4.1. Sharpshooting Results

Sharpshooting was tested at three sites in summer 2018; two sites were in Weiser, and the other in the Magic Valley. In total, we conducted 13 sharpshooting treatments in 2018 (Table 3.6*a*). In 2019, we tested sharpshooting at five sites where testing did not occur in 2018, and repeated testing at the Hill City site. A total of 70 sharpshooting treatments occurred in 2019 (Table 3.6*b*). All sharpshooting in 2019 occurred in the Magic Valley area. IDFG lethally removed additional elk at several of the 2019 treatment sites, but this removal occurred as part of depredation management activities, and after the timeframe of our analysis, and was therefore outside the scope of this project.

At both scales of analyses, we kept agriculture and the two-way interaction of agriculture and season time constant in our global models. At the movement-step scale, predictor variables, other than agriculture and season time, included in our global model for the Magic Valley were distance from roads, forest, grasslands, shrublands, elevation and slope. In Weiser, the movement-step global model included distance from cover (i.e., shrubland and forest habitat), forest, elevation and slope. At the summer home-range scale, the global model was the same for Weiser and the Magic Valley and included terrain roughness, shrublands, grasslands and forest. At both spatial scales, when comparisons were made between global models and models with different combinations of treatment site and our time variables, the top-ranking model, based on AIC included a three-way interaction term (Table 3.7; Table 3.8).

At the movement-step scale, treated and control elk in the Magic Valley increased their selection of agriculture during night hours as time throughout the summer progressed (Figure 3.6). At both spatial scales, sharpshooting resulted in Magic Valley elk avoiding agriculture most in early summer months, regardless of how much time had passed since a sharpshooting treatment (Figure 3.11). In Weiser, elk treated with sharpshooting reduced their selection of agriculture as the season progressed (Figure 3.5*b*, *d*); however, control elk in the Weiser increased their selection of agriculture with increasing time (Figure 3.5*b*). Across populations and at both spatial scales, modeling selection independently for each treatment site (i.e., herd-level response) produced site-specific variability in elk’s response to sharpshooting (Figure 3.7; Figure 3.9).

Magic Valley: Response to Sharpshooting at Multiple Spatial Scales

At the movement-step scale during night hours, treatment elk avoided sharpshooting treatment sites more than control elk in early summer, but increased their selection dramatically, relative to control elk as the summer progressed (Figure 3.6). At the summer home-range scale, treatment and control elk decreased their selection of sharpshooting fields as the summer progressed, but treatment elk selected more strongly for those sites relative to control elk (Figure 3.8*b*). At both spatial scales, results from three-way interaction models suggested that sharpshooting was most effective in deterring elk from agriculture in general, and sharpshooting treatment sites in early summer, regardless of the amount of time that passed since a previous sharpshooting treatment. (Figure 3.11). At the summer home-range scale, there was little difference in how treatment and control elk selected for agriculture and both groups reduced their selection of agriculture as the summer progressed (Figure 3.8*a*).

Weiser: Response to Sharpshooting at Multiple Spatial Scales

The sample size and period of analysis was relatively small for treated elk in Weiser. Sharpshooting treatments only occurred in 2018, and only two herds where treated with sharpshooting. At the movement-step scale, treated elk in Weiser increased their selection of agriculture as the summer progressed, while control elk responded oppositely, avoiding agriculture more throughout the summer (Figure 3.6*b*). At the summer home-range scale, control elk increased their selection of agriculture and treatment site throughout the summer. Treatment elk responded oppositely, selecting more strongly for treatment site and agriculture in early summer months, but reducing this positive selection as the summer progressed (Figure 3.8*c*, *d*). During night hours, three-way interaction models at the movement-step scale indicated that sharpshooting had a more pronounced and lasting effect on treatment site and agriculture avoidance in late summer.

3.4.2. Fence Modification Results

Our top-ranking model, based on AIC score included the status of the fence, the time since fence status changed, the crop type at treatments sites, and the random intercept for treatment site as predictor variables (Table 3.9). Across all sites, the highest number of elk observed crossing the modified fence occurred immediately after the fence was changed to the 'off' position (Figure 3.12). However, after approximately 13 days since changing the fence position, more fence crossings occurred when the fence was 'on', relative to the fence being 'off'.

Our results from combined-site modeling showed the probability of elk crossing into treatment fields was slightly lower when the fence was 'on' (β = -0.39, p = 0.03), relative to being 'off' (In other words, the estimated mean for the number of fence crossings when the fence was off was 2.53, and the estimated mean for the number of fence crossings when the fence was on was reduced by -0.39; β = 2.53, p = <0.001; Figure 3.13*a*). However, results from site-specific modeling varied greatly across treatment sites (Figure 3.13). In Diamond Creek, we tested the fence modification longest at the South Geneva site (n = 85 days), and crossing probabilities where higher when the fence was 'on', relative to when the fence was 'off', which is likely due to the high numbers of elk that consistently used this treatment site regardless of the fence modification being present (Figure 3.13*d*). Only at the Geneva site did crossing probabilities increase as time since the position of the fence changed, regardless of the fence being 'on' or 'off' (Figure 3.13*e*). At the Bellevue site, crossing probabilities were substantially higher when the fence was 'on', relative to all other sites (Figure 3.13*c*). The amount of time since the fence was switched 'on' or 'off' most strongly affected crossings at the North Geneva site (β = -0.12, p = 0.006), and least at the Big Wood site (β = 0.005, p = 0.88). While our results suggested that less elk crossed into the Big Wood treatment site when the fence was 'on', the effect size was small (β = -0.096, p = 0.72).

3.5. DISCUSSION

3.5.1. Sharpshooting Discussion

As predicted by foraging theory, elk in our study appeared to make some level of trade-off decisions between the acquisition of high-quality forages and security from predators, in this case humans (Lima 1998, Lima and Bednekoff 1999). However, it is possible that rather than sharpshooting, changing plant phenology, both natural and agricultural, played more of a roll in how elk selected for agriculture habitats. In early summer, when sharpshooting treatments began, treated elk in the Magic Valley avoided agriculture more than control elk at both spatial scales, but as the summer season progressed, our results show that the effectiveness of sharpshooting substantially decreased. In late summer, movement-scale analyses showed that elk treated with sharpshooting increased their selection of agriculture, while summer home-range analyses showed minimal differences in how agriculture was selected by treated and control elk. At both spatial scales, control elk in Weiser generally avoided agriculture more than elk treated with sharpshooting. However, elk in Weiser were exposed to substantially less sharpshooting treatments, relative to elk in the Magic Valley (Figure 3.15).

Although sharpshooting did not generally induce strong avoidance behavior in elk towards treatment sites, there was variability in the response across individual treatment sites. We observed a relatively muted response to sharpshooting at Little Camas, where the cost of elk-caused agriculture damages have historically been highest (IDFG unpublished data), and where we regularly observed more animals (> 200) using the treatment fields (far higher than all other sites). As a result, 81% of the total Magic Valley elk removed in this study were from Little Camas, representing 42% (*n* = 32) of sharpshooting events (Figure 3.14**)**. Despite this intensity of sharpshooting treatments, elk response and their selection of treatment site was much more muted than we had expected. However, while we did not measure actual elk-caused damages to agriculture during our study, the total amount of compensation provided by IDFG to the areas producer for such damages declined from $1,028,519 in 2018 to $80,000 in 2019 (IDFG unpublished data), implying that sharpshooting may have been more effective in preventing damages than our results suggest. In contrast, our results suggest that at both spatial scales, sharpshooting was most effective in deterring elk at Chimney Creek with elk increasingly avoiding the treatment site and agriculture in general throughout the season. Elk at Chimney Creek were treated within minutes of their initial use of the treatment field. Additionally, during this first treatment, we were within very close range (<45 m) when individuals were lethally removed. Following this treatment, elk did not use the Chimney Creek site again for 23 days, and use continued to be minimal throughout the remainder of the season (Figure 3.7*c*; Figure 3.9*c*). This result supports the "hunting for fear" concept introduced by Cromsigt et al. (2013) and suggests that clear cues of predation risk from our initial treatment prompted a strong and lasting aversion to the treatment site, and agriculture more generally.

One important question regarding the efficacy of "hunting for fear" (Cromsigt et al. 2013) is whether fear effects from sharpshooting persist through multiple years for long-lived animals such as elk. Several recent longitudinal studies have demonstrated that adult female elk learn to better avoid hunters throughout the course of their lifetimes (Ciuti et al. 2012, Thurfjell et al. 2017). In our study, we were only able to repeat treatments in both 2018 and 2019 at single site, Hill City. In 2018, movement-step scale results showed that elk in Hill City generally avoided agriculture and increasingly avoided the treatment site throughout the season (Figure 3.16*a*). No collared elk from Hill City survived the 2018 winter, resulting in no longitudinal data from GPS-collared elk. Regardless, it is likely the elk herd using the Hill City site in 2019 included unmarked individuals that were treated in 2018. As demonstrated by Thurfjell et al. (2017), elk possess the ability to learn to avoid human disturbance and risk with age. Considering this, we expected elk to display stronger levels of agriculture avoidance in 2019. However, at the movement-step scale, elk selected for agriculture, but showed great variability in their selection of the treatment site (Figure 3.16*b*), suggesting that the temporary aversion to agriculture induced by sharpshooting in 2018 did not persist. A possible explanation for this could be that the intensity and frequency of the risks posed by sharpshooting in 2018 were not substantial enough to induce avoidance behavior of the treatment site.

At the Weiser home-range scale, treated elk increasingly avoided the sharpshooting sites and agriculture throughout the summer, while control elk increased their selection of agriculture. Control elk in Weiser primarily used natural habitats and avoided agriculture in early summer; however, in late summer, these elk moved to lower elevations, taking advantage of refuge habitats where agriculture forage was abundant. We did not remove any elk from Weiser treatment sites in 2019 because elk use of such areas was minimal or non-existent. In 2018, a large fire burned much of the area surrounding the Weiser treatment sites after the conclusion of sharpshooting testing. This fire likely resulted in an increase of available and preferred natural forages (Canon et al. 1987). The low levels of animals removed in Weiser during 2018 (Figure 3.15) was a result of elk not returning to treatment sites following a successful sharpshooting event. While it is probable that fire-related habitat changes reduced elk use of agriculture in the following year, there may have been lasting residual effects of 2018 sharpshooting that additionally influenced elk avoidance of agriculture and treatment sites.

The logistics of implementing a “hunting for fear” sharpshooting program to deter agricultural damages are considerable. Critically, treatment frequency was dictated by elk use patterns at treatment sites, whereas landscape characteristics at treatment sites influenced the number of animals removed per treatment. In general, more animals were removed per treatment at sites with more roads open for motorized travel, and fewer areas of security cover in proximity to the treatment site. For example, at the Deer Creek and Little Camas sites, our ability to easily observe elk as they travelled to the treatment sites likely resulted in a high number of animals being removed (Figure 3.14*a*, *d*). Conversely, at the Bliss site there was ample security cover adjacent to the sites agriculture crops and elk could quickly evade sharpshooting teams by moving relatively short distances to more secure areas. This resulted in fewer animals being removed from this site and the overall effectiveness of sharpshooting being minimal (Figure 3.9*f*). This finding implies that sharpshooting can be effective in some areas, where more open landscapes facilitate managers’ ability to lethally remove more animals.

3.5.2. Fence Modification Discussion

While permanent exclusionary fences have been proven to prevent ungulates, such as elk, from damaging agriculture crops (Knight 2014), the monetary cost of fence construction and maintenance, paired with the negative impacts such fences cause to non-target wildlife species limit their applicability (Craven and Hygnstrom 1994, Jachowski et al. 2013). Although the fence modification we designed and tested did not effectively exclude all elk from agriculture fields, our results suggest some evidence that it could be effective in moderately limiting elk use and subsequent crop damages. While several other studies have found different variations of electric fencing to be successful in reducing deer-caused crop damages (Hygnstrom and Craven 1988, Johnson et al. 2014), to the best of our knowledge only Johnson et al. (2014) tested the efficacy of semi-temporary electric fencing as an elk deterrent. While the electric fence design tested by Johnson et al. (2014) was somewhat different than our modified fence, both designs attempted to utilize electrical shock to create a psychological barrier to elk.

Rather than creating a physical and impenetrable barrier, our fence was designed to create a psychological barrier to elk. Considering this, we predicted that elk would habituate to the psychological barrier created by the fence, and the number of fence crossings would increase proportionally with time after the fence was erected. However, this prediction was only supported at the Geneva site where uneven terrain resulted in an increased span between the bottom wire attached to the modified fence and the top wire on the existing pasture fence. We suspect that as time increased after the fence was moved to the ‘on’ position, elk increasingly used these areas at the Geneva site to cross through our modified fence.

Regardless of elk being inside, or out of the treatment fields, camera trap and observation survey data showed elk frequently crowding at, and moving back and forth along the fence for extended periods of time before attempting to cross. While we attempted to quantify elk abundance in treatment fields relative to the fence being ‘on’ or ‘off’, such behavior displayed by elk led to difficulties avoiding double-counting of individuals. However, we observed more elk during surveys in 2018 and camera trap detections of elk in 2019 were highest at the

North Geneva and South Geneva sites. Consequently, at these sites the modified fence was frequently damaged. At the Bellevue site, where camera trap detections of elk were relatively low, we rarely needed to repair the fence as it was seldom damaged. When fences were damaged in our study, we did not change the general layout or structure of our fence modification in order to maintain experimental consistency. If wildlife managers or agriculture producers were to use this temporary fence design for routine damage prevention, additional materials and structural improvements could be made at high-use crossing areas to increase the effectiveness of the fence.

Typical permanent fencing used to exclude ungulates is extremely time intensive to construct (Craven and Hygnstrom 1994, de Calesta 1994) and materials alone can cost over US$25/m; however, the fence modification we designed cost approximately US$0.77 - $1.00/m and three people were able to construct 1.5 km of fence in <10 hours. The low cost of fencing materials and ease of construction, paired with the relative success of the fence in deterring elk suggest this modified fence design could be a cost-effective tool for managing ungulate damage, especially in areas with low densities of offending animals and where existing pasture fences are present.

3.6. MANAGEMENT IMPLICATIONS

Differences in landscape characteristics and elk herd dynamics across treatment sites resulted in variability in the effectiveness of the two deterrent treatments tested in our study. The availability of food sources, both agricultural and natural, played a major role in the effectiveness of the deterrent. Additionally, historic elk use (or lack thereof) of treatment sites dictated elk's motivation to use those sites. Although we didn't consider elk abundance in our analyses, sharpshooting and fence modification treatments were more successful in deterring elk in areas with abundant agriculture in proximity to treatment fields, and relatively low densities of elk. Conversely, our deterrent treatments were least effective in areas characterized by high numbers of elk with a long history of using treatment fields that were spatially isolated from other agriculture lands. Our sharpshooting treatment was moderately effective in deterring elk from treatment fields at some locations, such as those in the Weiser study area, but less effective in deterring elk from foraging in agriculture lands more generally. This result suggests that while elk may have been displaced from the fields where sharpshooting was being tested, they were still using and subsequently damaging adjacent landowner's agriculture crops. Similarly, our fence modification was also more effective in deterring elk at treatment sites that were adjacent to other agriculture lands that provided elk with an alternative food source.

The risk allocation hypothesis suggests that animals minimize threats from predation by avoiding risky areas during risky times (Lima and Bednekoff 1999). Commonly-used deterrents that do not signal a "true" risk (i.e., repellents, frightening devices and hazing) have been proven effective in temporarily reducing crop damages (Johnson et al. 2014). However, animals rapidly habituate to the superficial risks posed by these types of deterrents and long-term relief from damages is seldom accomplished (Walter et al. 2010). While public hunting has been the standard tool used to manage and reduce overabundant ungulate populations (Bunnell et al. 2002), this approach is rarely successful in reducing ungulate densities to desirable levels (Simard et al. 2013). While nearly extirpated across much of North America in the early 1900s, elk populations are now thriving due to intensive conservation efforts put forth by wildlife management agencies and their public constituents (Bunnell et al. 2002). While such conservation efforts are often met with high levels of public support, management actions associated with controlling overabundant wildlife are typically met with controversy (Garrott et al. 1993). We acknowledge the controversial nature associated with the sharpshooting deterrent tested in this study. Despite the fact that using public hunters to control overabundant and agriculture-damaging elk populations is highly preferred by the public and wildlife management agencies, seasonal and daily constraints (i.e., hunting regulations) associated with public hunting limit the effectiveness of this approach (Simard et al. 2013). While our results suggest repeated lethal removal of elk from agriculture fields can provide relief from crop damages, our sharpshooting deterrent was highly criticized by members of the hunting community. We suggest wildlife management agencies consider informing and educating their constituents regarding desired outcomes before implementing a deterrent such as sharpshooting.

In comparison to sharpshooting, our modified fencing treatment was met with high levels of support from the general public and landowners alike. While this deterrent did not entirely exclude elk from the agriculture crop it was intended to protect, elk use and subsequent damage of agriculture was moderately limited. If this type of fence modification is used in areas with relatively low numbers of animals, it can be effective in reducing damages and necessary maintenance should be minimal. However, if used in areas with an abundance of animals that exhibit frequent use of agriculture crops, higher levels of maintenance and lower levels of success should be expected.

In summary, while neither of the deterrents tested in this study were entirely effective in preventing all elk-related agriculture damages, both deterrents provide wildlife managers and agriculture producers with scientifically-tested methods for limiting elk use of agriculture crops. With the limited number of effective deterrents currently available, especially for reducing elk-specific agriculture damage, we hope our findings will not only assist wildlife managers in reducing elk-agriculture conflicts, but also foster an increase in landowner support for elk utilizing private lands.

3.7. TABLES

Table 3.1: Size and crop types of fence modification treatment sites in 2018 and 2019.

Study area	**Treatment site**	**Treatment site size (ha)**	**Fence length**	**Crop type**	**Year tested**
Diamond creek	North Geneva	31.5	2 km	Alfalfa/grass hay	2018/2019
Diamond creek	Geneva	33	1.49 km	Alfalfa/oat hay	2018/2019
Diamond creek	South Geneva	14.25	2.69 km	Alfalfa	2019
Magic Valley	Bellevue	33.9	2.44 km	Alfalfa	2019
Magic Valley	Big Wood	2.1	0.78 km	Alfalfa	2019

Table 3.2: Timing and duration of pre- ('off' period) and during ('on' period) fence modification treatment periods in 2018.

	North Geneva	*Geneva.*
Off period	3 Aug. - 18 Aug.	19 Aug. - 31 Aug.
On period	20 Aug. - 5 Sept.	31 Aug. - 15 Sept.

Table 3.3: Timing and duration of fence modification treatment periods in 2019.

	North Geneva	*Geneva*	*South Geneva*	*Bellevue*	*Big Wood*
Habituation Period	30 July-6 Aug.	25 July-2 Aug.	26 June-3 July	27 June-14 July	3 June-21 July
On period 1	6 Aug.-19 Aug.	2 Aug.-19 Aug.	3 July-19 July	14 July-31 July	21 June-5 July
Off period 1	19 Aug.-2 Sept.	19 Aug.-2 Sept.	19 July-2 Aug.	31 July-15 Aug.	5 July-20 July
On period 2	2 Sept. 16 Sept.	2 Sept.-17 Sept.	2 Aug.-19 Aug.	15 Aug.-29 Aug.	20 July-6 Aug.
Off period 2	*NA*	*NA*	19 Aug.-2 Sept.	29 Aug.-14 Sept.	6 Aug.-21 Aug.
On period 3	*NA*	*NA*	2 Sept.-16 Sept.	*NA*	21 Aug.-3 Sept.

Table 3.4: Fence length and number of cameras used at fence modification treatment sites in 2019.

Treatment site	**Fence length**	**# cameras**	**# cameras/km**
North Geneva	2 km	9	1 camera/0.22 km
Geneva	1.49 km	9	1 camera/0.16 km
South Geneva	2.69 km	15	1 camera/0.17 km
Bellevue	2.44 km	13	1 camera/0.18 km
Big Wood	0.78 km	10	1 camera/0.08 km

Table 3.5: Description of predictor variables considered for treated and control elk in Magic Valley and Weiser study areas for resource selection analysis. Check marks indicate the particular variable was used in final analyses. Positive or negative symbols indicate *a priori* hypotheses about how selection would be affected by the particular variable.

Predictor Variable	**Resolution Spatial**		**Magic Valley**		**Weiser**	
(Data Source)	**(Temporal)**	**Description**	**Treatment**	**Control**	**Treatment**	**Control**
Topography and Landscape						
Elevation (USGS)	30 meters (2017)	Elevation, in meters, above sea level	✓ (-)	✓ (-)	✓ (-)	✓ (-)
Slope (USGS)	30 meters (2017)	Degree of slope	✓ (+)	✓ (+)	✓ (+)	✓ (-)
Terrain roughness (USGS)	30 meters (2017)	Elevational difference, in meters	✓ (+)	✓ (-)	✓ (+)	✓ (-)
Distance from Roads (ITD)	meters (2020)	Center lines of all Idaho roads	✓ (+)	✓ (-)	(+)	(-)
Distance from Treatment site	meters (2018-19)	Area where sharpshooting occurred	✓ (-)	✓ (-)	✓ (-)	✓ (-)
Vegetation						
Distance from Agriculture (LANDFIRE, USGS)	30 meters (2014)	All agriculture vegetation types	✓ (-)	✓ (-)	✓ (-)	✓ (-)
Distance from Forest (LANDFIRE, USGS)	30 meters (2014)	Conifer, hardwood and conifer-hardwood vegetation types	✓ (-)	✓ (+)	✓ (-)	✓ (+)
Distance from Shrubland (LANDFIRE, USGS)	30 meters (2014)	Shrubland vegetation types	✓ (-)	✓ (+)	✓ (-)	✓ (+)
Distance from Grasslands (LANDFIRE, USGS)	30 meters (2014)	Grassland, sparsely vegetated and exotic herbaceous vegetation types	✓ (-)	✓ (+)	✓ (-)	✓ (+)
Distance from Cover (LANDFIRE, USGS)	30 meters (2014)	Shrubland, conifer, hardwood and conifer-hardwood vegetation types	(-)	(+)	✓ (-)	✓ (+)

Table 3.6: Number of sharpshooting treatments per site in 2018 (a) and 2019 (b). For each treatment site, the total number of animals removed per month are shown in parentheses.

(a) 2018

Location	**July**	**August**	**September**	**Total treatments**
Hill City	0	6 (12)	0	6
Midvale	0	4 (6)	0	4
Weiser-west	0	3 (4)	0	3

(b) 2019

Location	**July**	**August**	**September**	**Total treatments**
Hill City	0	2 (8)	0	2
Little Camas	6 (8)	14 (35)	12 (34)	32
Chimney Cr.	1 (3)	5 (17)	1 (3)	7
Deer Cr.	3 (9)	6 (14)	5 (11)	14
Carey	3 (9)	5 (11)	0	8
Bliss	2 (4)	5 (6)	0	7

Table 3.7: Comparison of AIC scores and AIC weights and the number of parameters (K) from global, two- and three-way interaction models (night hours) at the movement-step scale for elk treated with sharpshooting in the Magic Valley (a), and Weiser (b). Models included either distance from agriculture or treatment site interacting with phenology and/or treatment time (two- and three-way interactions), along with the other variables described in Table 3.5.

(a) Magic Valley area (treatment elk)

Model	K	Δ *AIC*	*AIC weight*	
Ag. + Ag.*Phen. time*Trt. Time + Roads + Forest + Grass + Shrub + Elevation + Slope + Strata(StepID)	13	0	0.53	
Ag. + Ag.*Phen. time + Roads + Forest + Grass + Shrub + Elevation + Slope + Strata(StepID)	9	0.39	0.44	*Global model
Ag. + Ag.*Trt. Time + Roads + Forest + Grass + Shrub + Elevation + Slope + Strata(StepID)	9	5.87	0.03	
Trt. site + Trt. site*Phen. time*Trt. time + Roads + Forest + Grass + Shrub + Elevation + Slope + Strata(StepID)	13	31.2	<0.01	
Trt. site + Trt. site*Phen. time + Roads + Forest + Grass + Shrub + Elevation + Slope + Strata(StepID)	9	41.8	<0.01	
Trt. site + Trt. site*Trt. time + Roads + Forest + Grass + Shrub + Elevation + Slope + Strata(StepID)	9	43.5	<0.01	

(b) Weiser area (treatment elk)

Model	K	Δ *AIC*	*AIC weight*	
Ag. + Ag.*Phen. time*Trt. Time + Cover + Forest + Elevation + Slope + Strata(StepID)	11	0	0.97	
Trt. site + Trt. site*Phen. time*Trt. time + Cover + Forest + Elevation + Slope + Strata(StepID)	11	6.95	0.03	
Ag. + Ag.*Phen. time + Cover + Forest + Elevation + Slope + Strata(StepID)	7	14	<0.01	*Global model
Ag. + Ag.*Trt. time + Cover + Forest + Elevation + Slope + Strata(StepID)	7	14.2	<0.01	
Trt. site + Trt. site*Phen. time + Cover + Forest + Elevation + Slope + Strata(StepID)	7	17.8	<0.01	
Trt. site + Trt. site*Trt. time + Cover + Forest + Elevation + Slope + Strata(StepID)	7	17.9	<0.01	

Table 3.8: Comparison of AIC scores and AIC weights and the number of parameters (K) from global, two- and three-way interaction models (night hours; summer home-range scale) for elk treated with sharpshooting in the Magic Valley (a), and Weiser (b). Models included either distance from agriculture or treatment site interacting with phenology and/or treatment time (two- and three-way interactions).

(a) Magic Valley (treatment elk)

Model	K	Δ *AIC*	*AIC weight*	
Trt. Site + Trt. Site*Phen. Time*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	12	0	1	
Trt. Site + Trt. Site*Phen. Time + Terrain Roughness + Shrub + Grass + Forest	8	336.84	<0.01	
Trt. Site + Trt. Site*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	8	546.21	<0.01	
Ag. + Ag.*Phen. Time*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	12	1,432.07	<0.01	
Ag. + Ag.*Phen. Time + Terrain Roughness + Shrub + Grass + Forest	8	1,459.51	<0.01	*Global model
Ag. + Ag.*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	8	1,566.79	<0.01	

(b) Weiser (treatment elk)

Model	K	Δ *AIC*	*AIC weight*	
Ag. + Ag.*Phen. Time*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	12	0	1	
Trt. Site + Trt. Site*Phen. Time*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	12	407.72	<0.01	
Ag. + Ag.*Phen. Time + Terrain Roughness + Shrub + Grass + Forest	8	441.8	<0.01	*Global model
Ag. + Ag.*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	8	451.11	<0.01	
Trt. Site + Trt. Site*Phen. Time + Terrain Roughness + Shrub + Grass + Forest	8	537.96	<0.01	
Trt. Site + Trt. Site*Trt. Time + Terrain Roughness + Shrub + Grass + Forest	8	546.82	<0.01	

Table 3.9: Comparison of AIC scores and AIC weights and the number of parameters (K) for models considered in fence modification analyses.

Model	K	Δ *AIC*	*AIC weight*
Fence status + Time since fence status changed + crop type + (1|treatment site)	7	0.00	0.52
Fence status + Time since fence status changed + (1|treatment site)	5	0.76	0.35
Fence status + crop type + (1|treatment site)	6	3.83	0.08
Fence status + (1|treatment site)	4	4.57	0.05

3.8. FIGURES

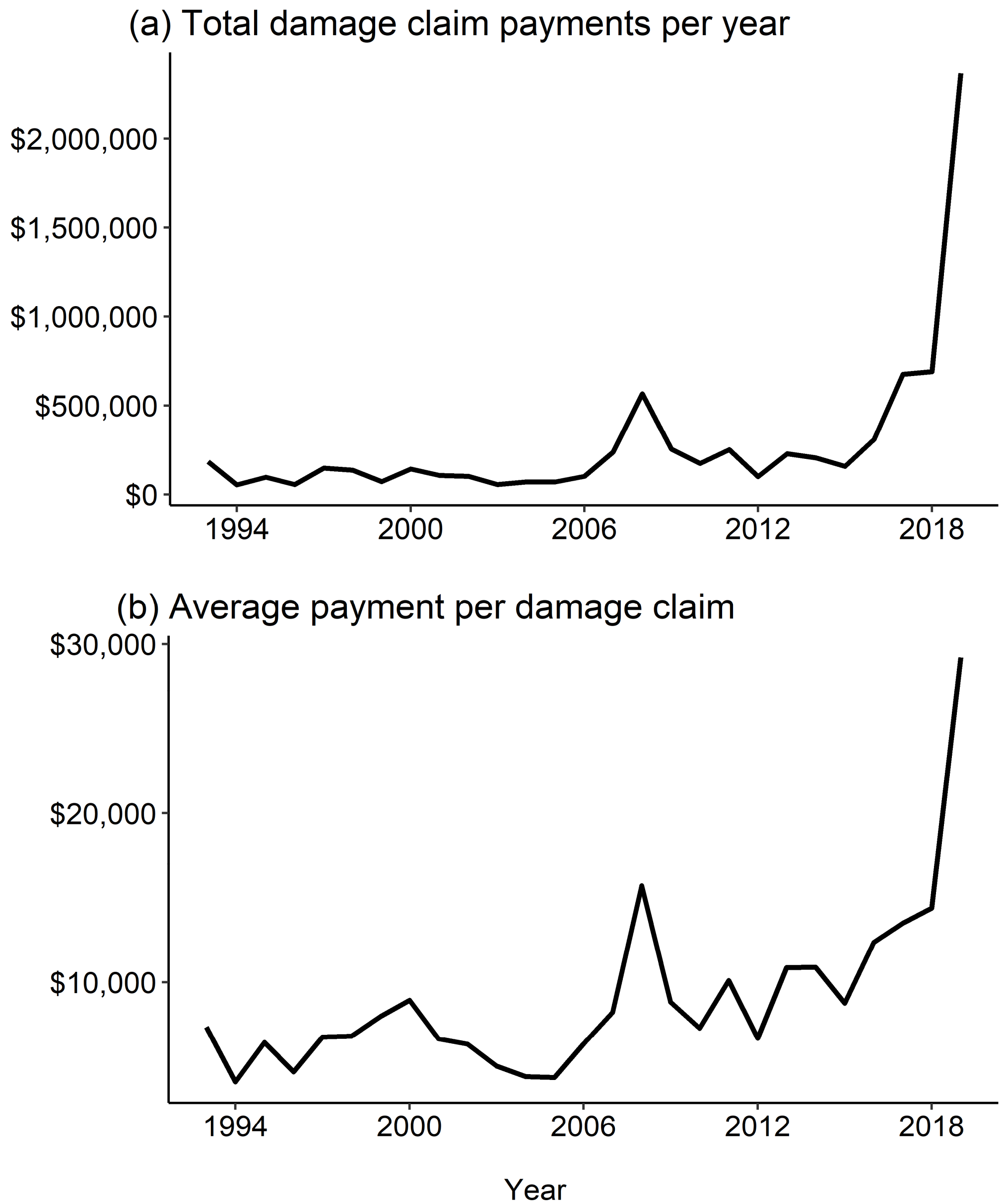

Figure 3.1: Elk-related depredation claim payments in Idaho, 1993-2019, adjusted to $ USD 2020.

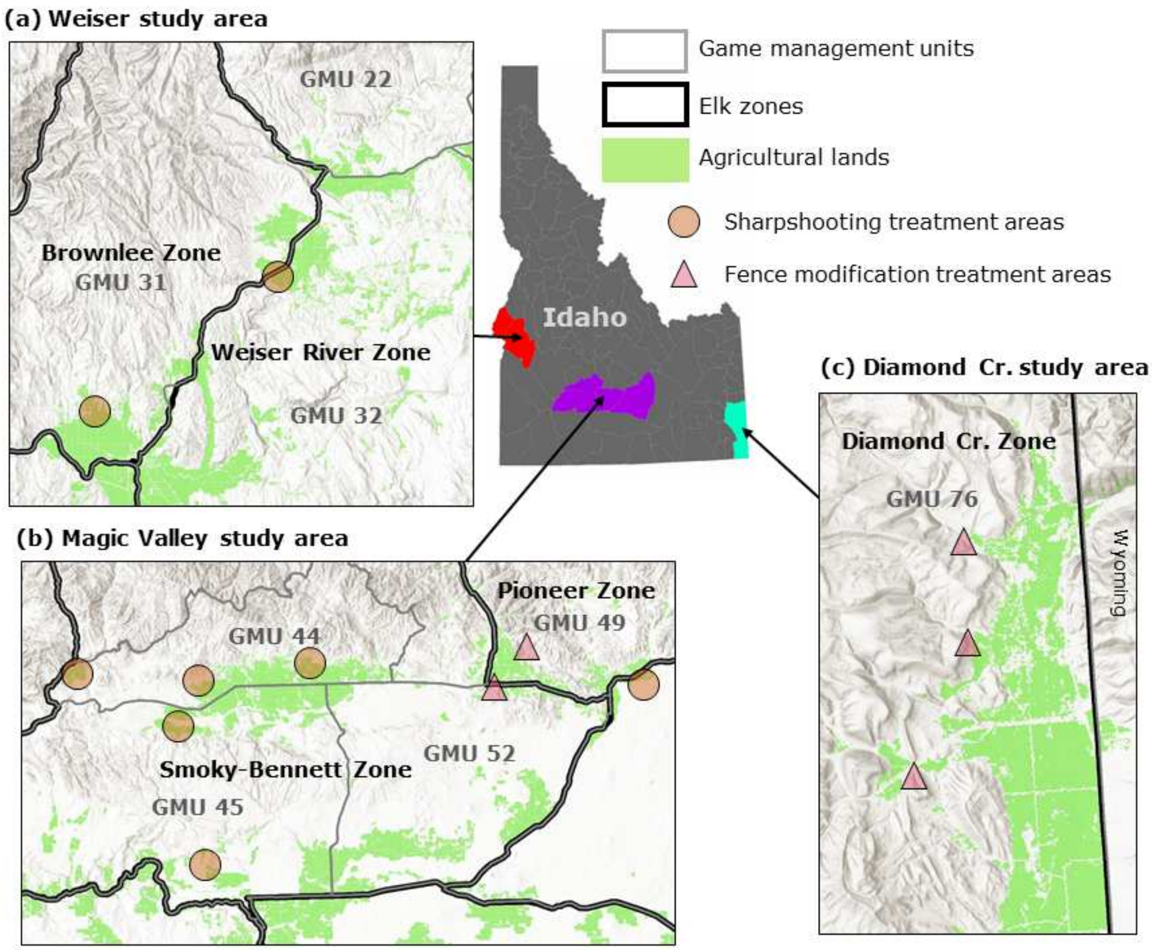

Figure 3.2: Weiser (a), Magic Valley (b), and Diamond Creek (c) study areas. Orange circles represent sharpshooting treatment areas. Red triangles represent fence modification treatment areas. Areas colored in green represent agricultural lands.

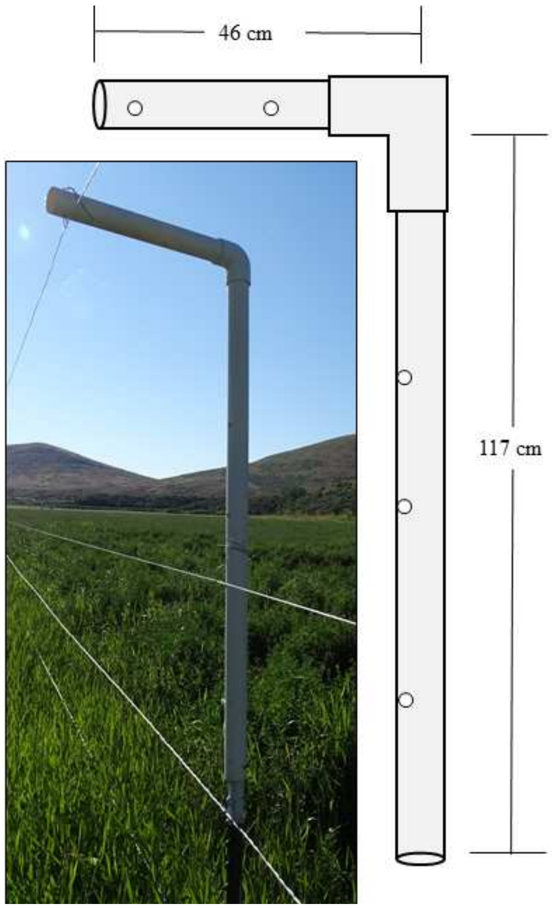

Figure 3.3: PVC fence extensions used in fence modification treatment.

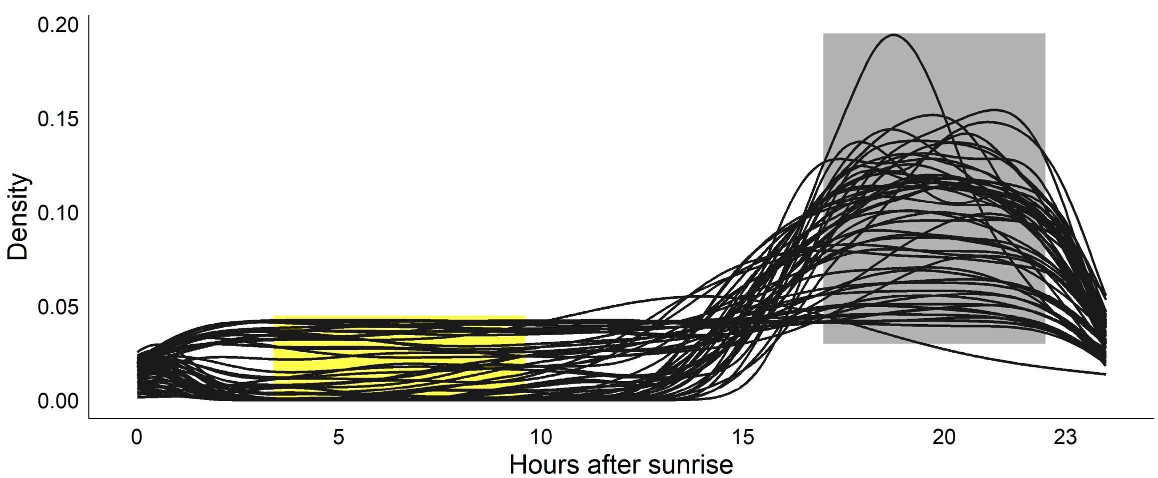

Figure 3.4: Kernel density estimates of all study elk locations in agriculture habitat, on which we based diel data partitioning break-points. The area shaded in yellow represents the day period and the area shaded in grey represents the night period.

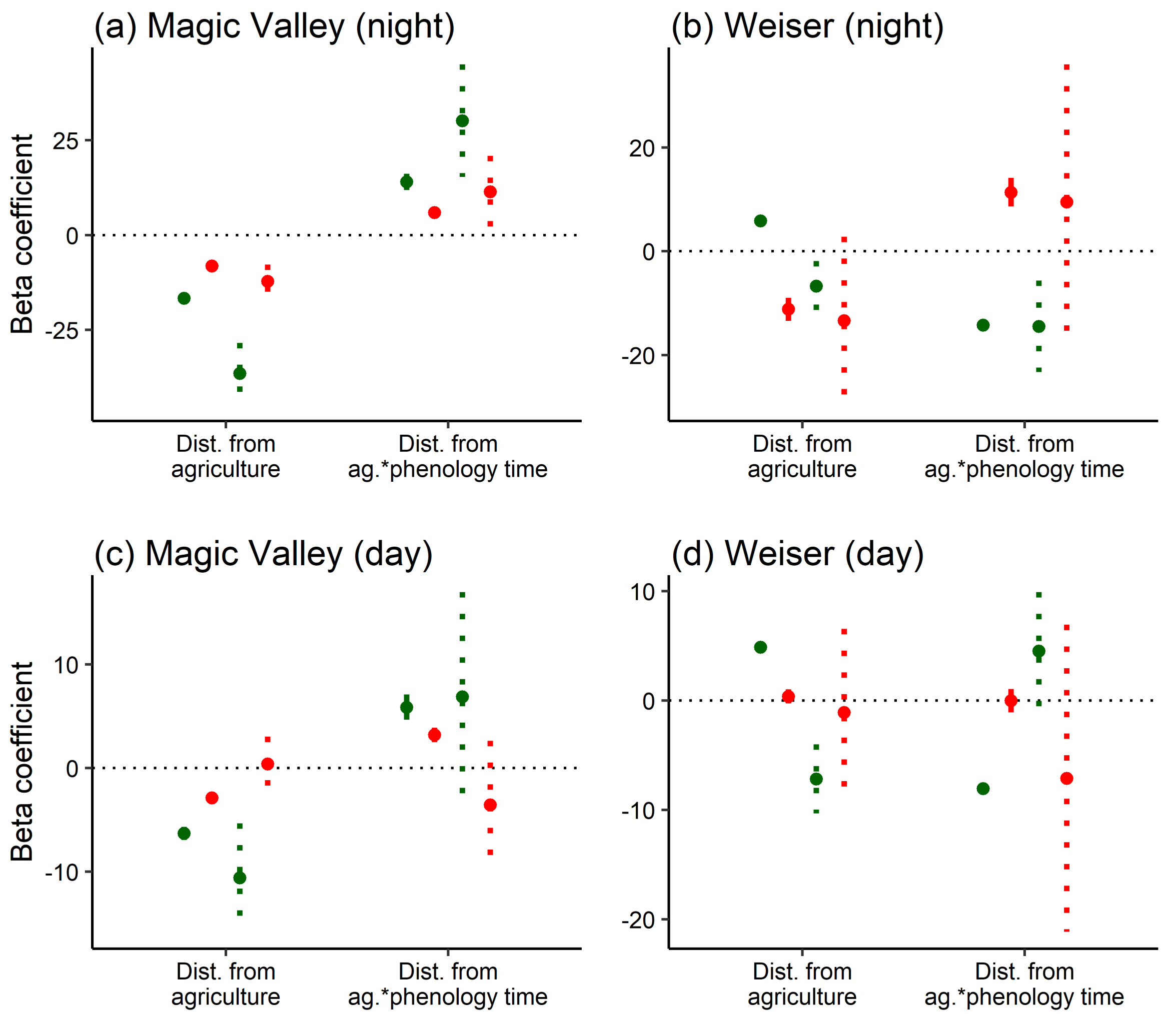

Figure 3.5: Day and nighttime global model results for the selection of distance from agriculture and the interaction between distance from agriculture and phenology time (±95% confidence intervals) for elk in the Magic Valley (a, c) and Weiser (b, d) study areas. Solid lines indicate selection at the summer home-range (RSF) scale and dotted lines indicate selection at the movement-step (SSF) scale. Elk treated with sharpshooting are shown in red and elk left untreated (control elk) are shown in green. Selection was measured as a distance from a particular variable; therefore, negative beta coefficients indicate a positive selection for areas in proximity to agriculture or treatment area.

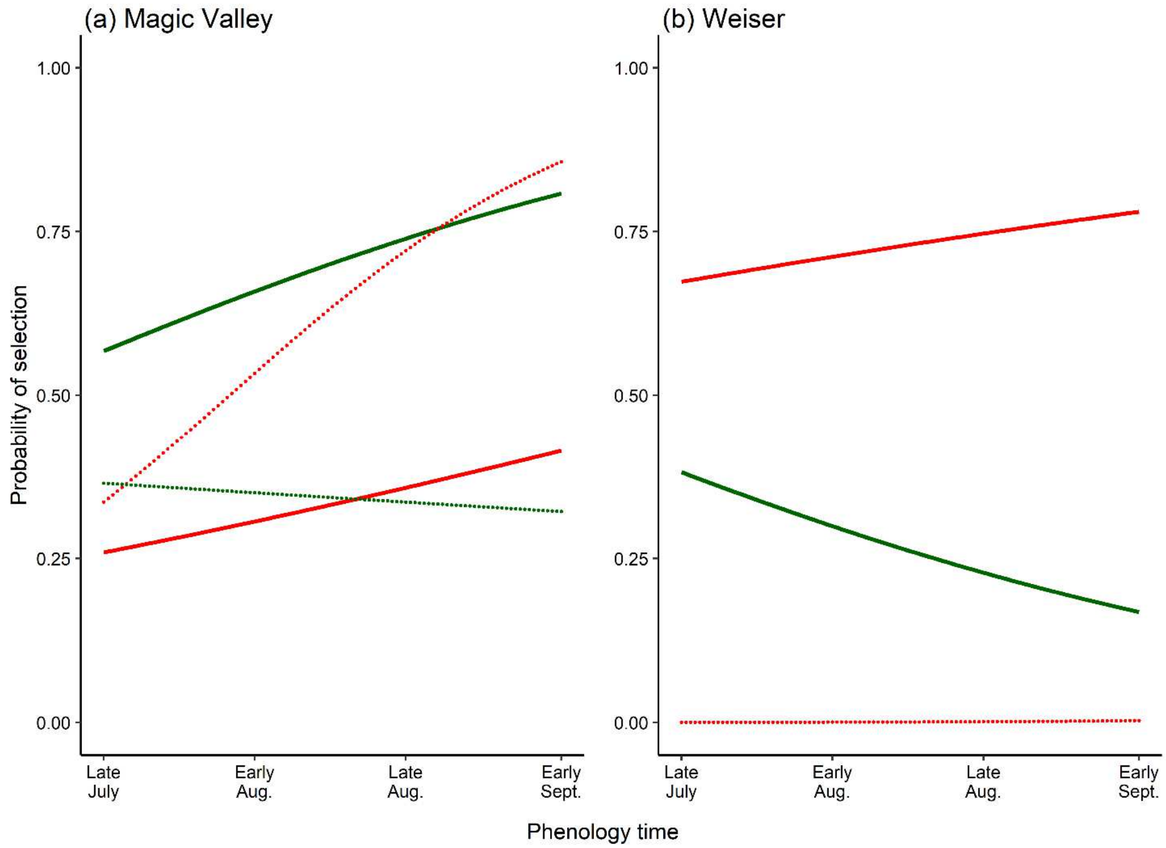

Figure 3.6: Relative probability of agriculture (solid lines) and treatment site (dotted lines) selection at the movement-step scale with phenology time for treatment and control elk in the Magic Valley (a) and Weiser (b) study areas. Elk treated with sharpshooting are shown in red and control elk are shown in green.

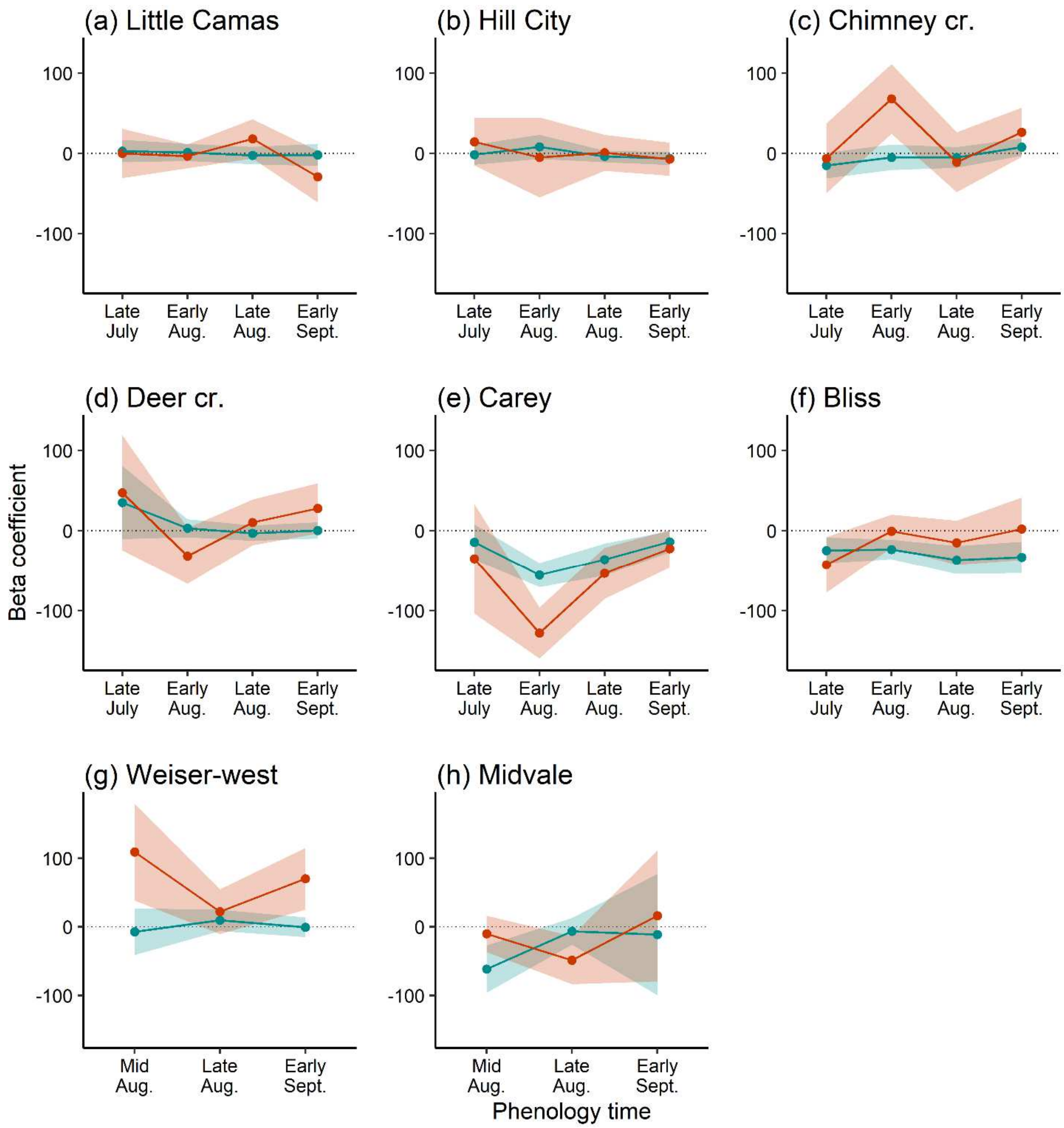

Figure 3.7: Herd-level response of elk at the movement-step scale, with ± 95% confidence intervals, at different sharpshooting treatment areas in the Magic Valley and Weiser study areas. Selection was modeled through the depredation season. General agriculture selection is shown in red and selection of specific sharpshooting treatment areas is shown in blue. Selection was measured as a distance from a particular variable; therefore, negative beta coefficients indicate a positive selection for areas in proximity to agriculture or treatment area.

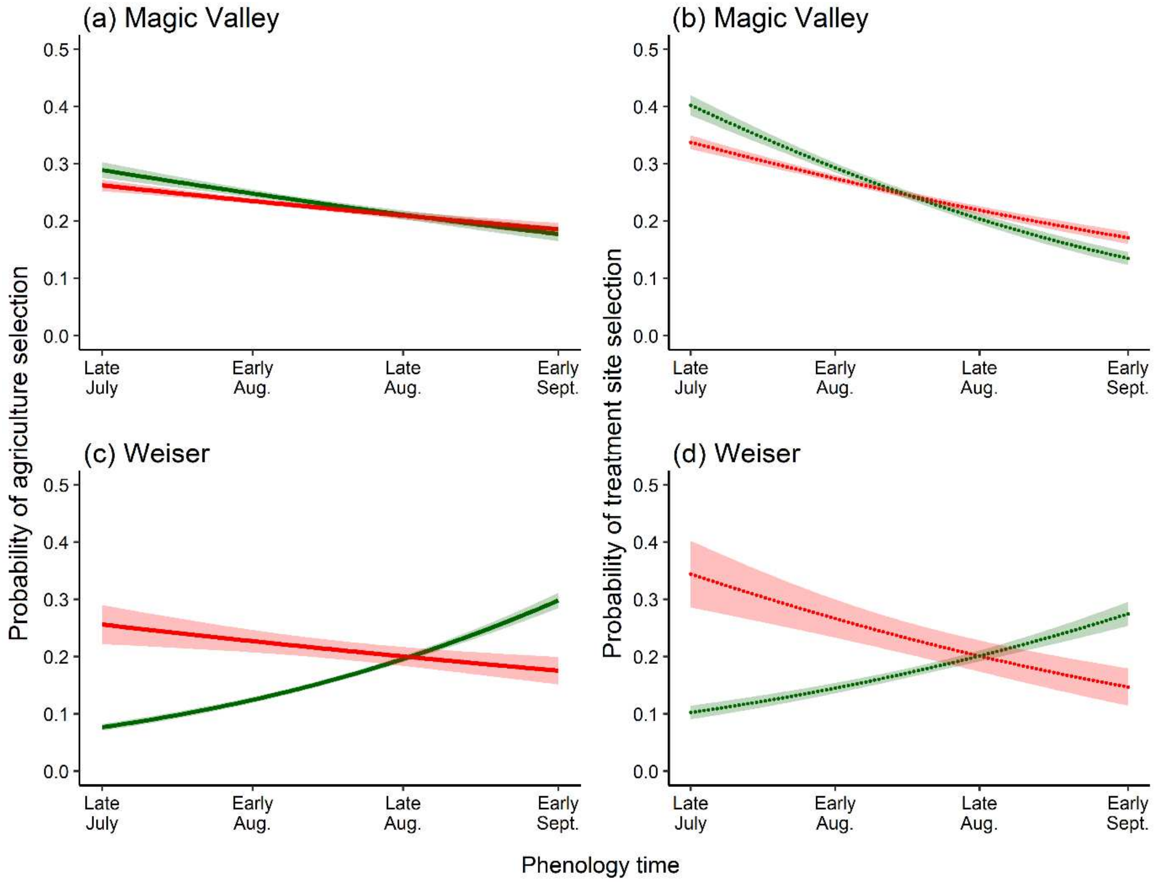

Figure 3.8: Relative probability of agriculture (solid lines; a, c) and treatment site (dotted lines; b, d) selection at (±95% confidence intervals) at the home-range scale with phenology time for treatment and control elk in the Magic Valley (*a*, *b*) and Weiser (*c*, *d*) study areas. Elk treated with sharpshooting are shown in red and control elk are shown in green.

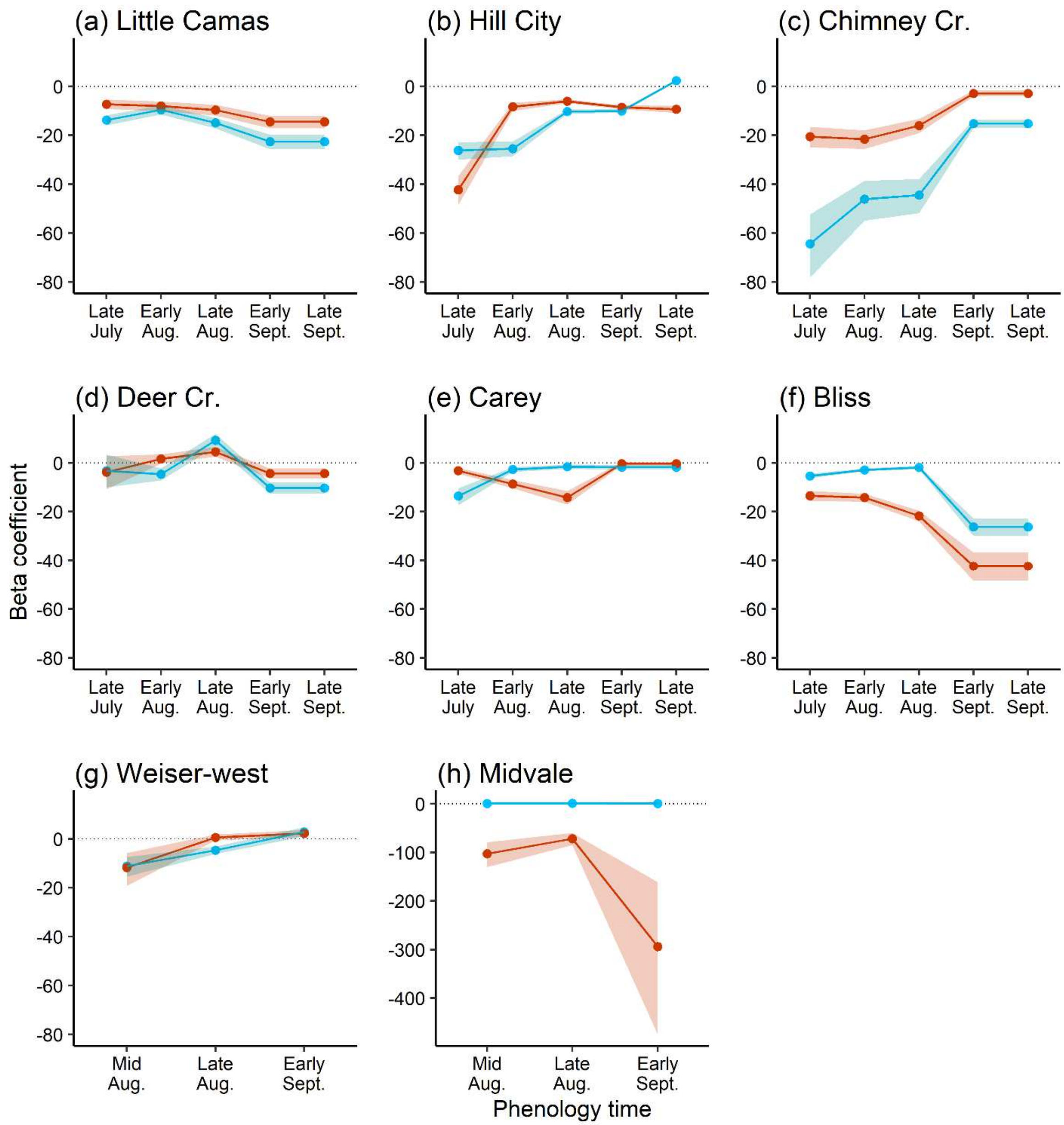

Figure 3.9: Herd-level response of elk at the summer home-range scale, with ±95% confidence intervals, at different sharpshooting treatment areas in the Magic Valley and Weiser study areas. Slection was modeled through the depredation season. General agriculture selection is shown in red and selection of specific sharpshooting treatment areas is shown in blue. Selection was measured as a distance from a particular variable; therefore, negative beta coefficients indicate a positive selection for areas in proximity to agriculture or treatment area.

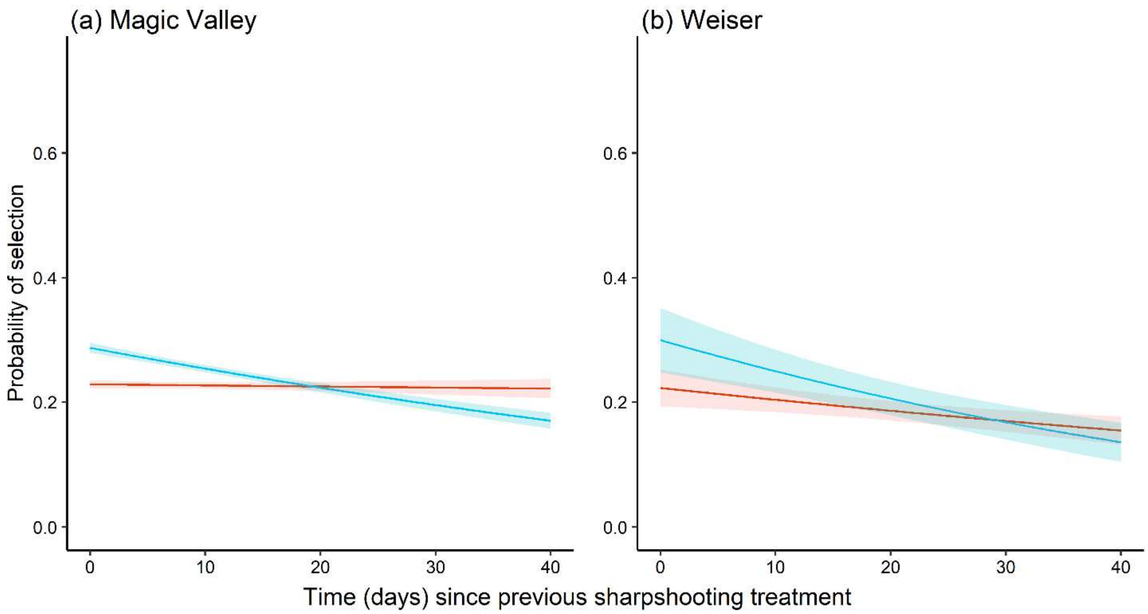

Figure 3.10: Summer home-range scale relative selection probabilities with ±95% confidence intervals for elk in the Magic Valley (a) and Weiser (b), for all agricultural habitats (red) versus treatment site (blue) with increasing time since a previous sharpshooting treatment.

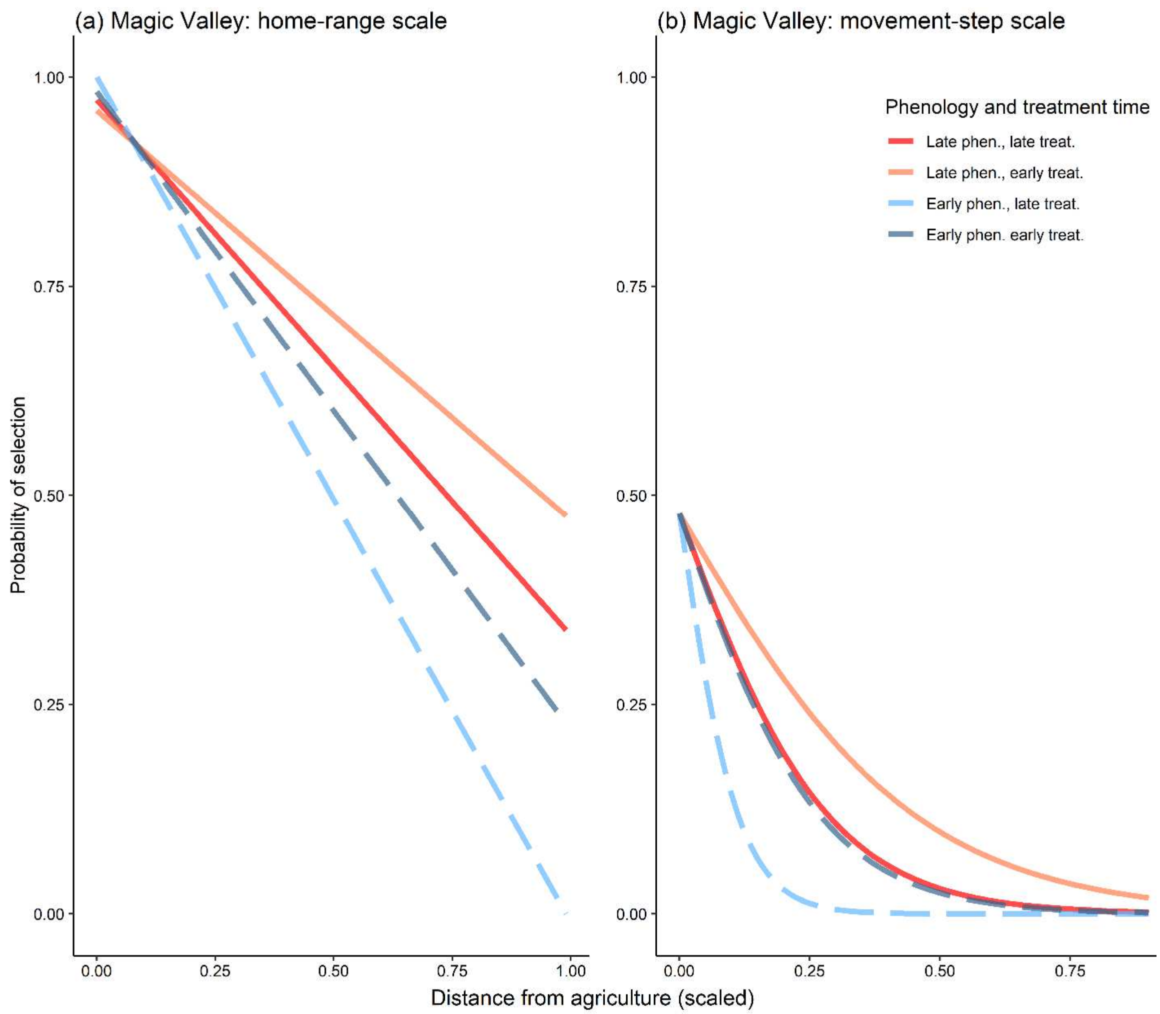

Figure 3.11: Summer home-range (a) and movement-step (b) scale agriculture selection probabilities for elk treated with sharpshooting in the Magic Valley area. Selection probabilities were obtained from the model which included a three-way interaction between distance from agriculture, phenology time and treatment time. Solid lines indicate late (max.) phenology times. Dashed lines indicate early (min.) phenology times.

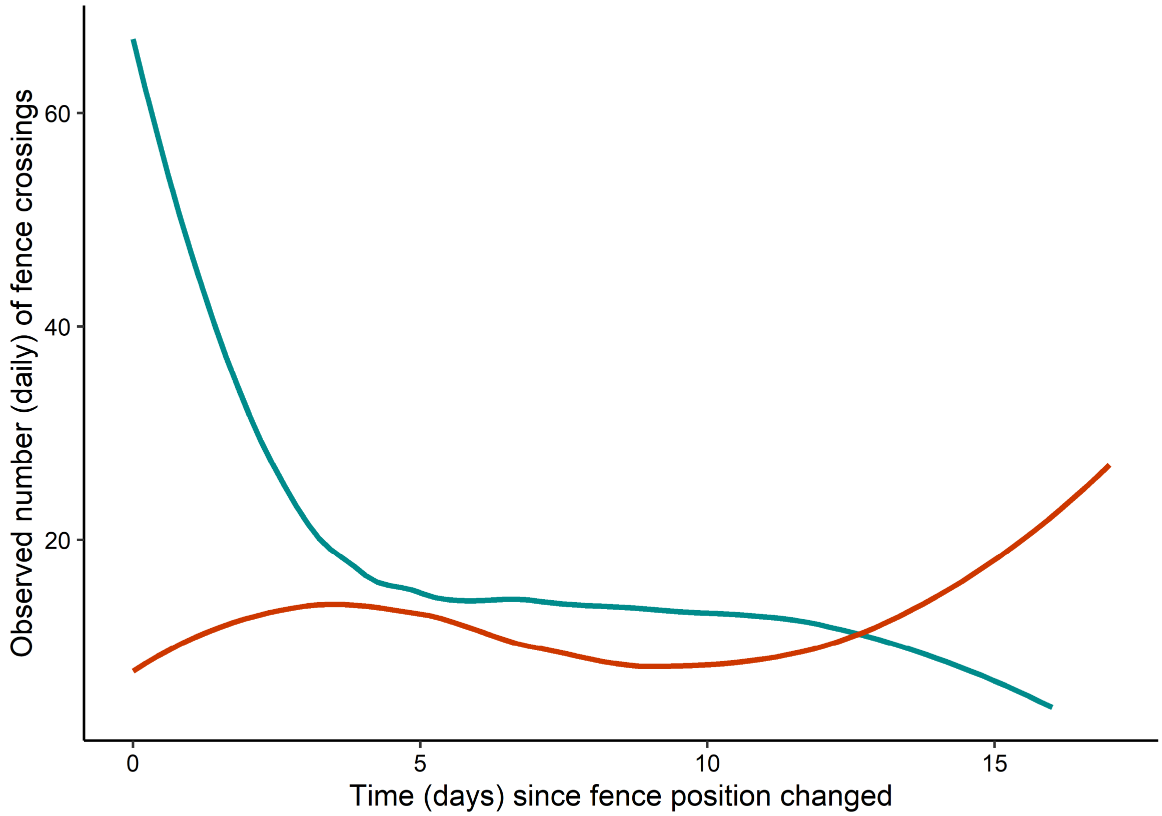

Figure 3.12: Observed number of elk crossing the modified fence in the 'off' (blue) and 'on' (red) position, at all treatment sites in 2018 and 2019, based on camera trap imagery. Lines were smoothed with a loess function for interpretation purposes.

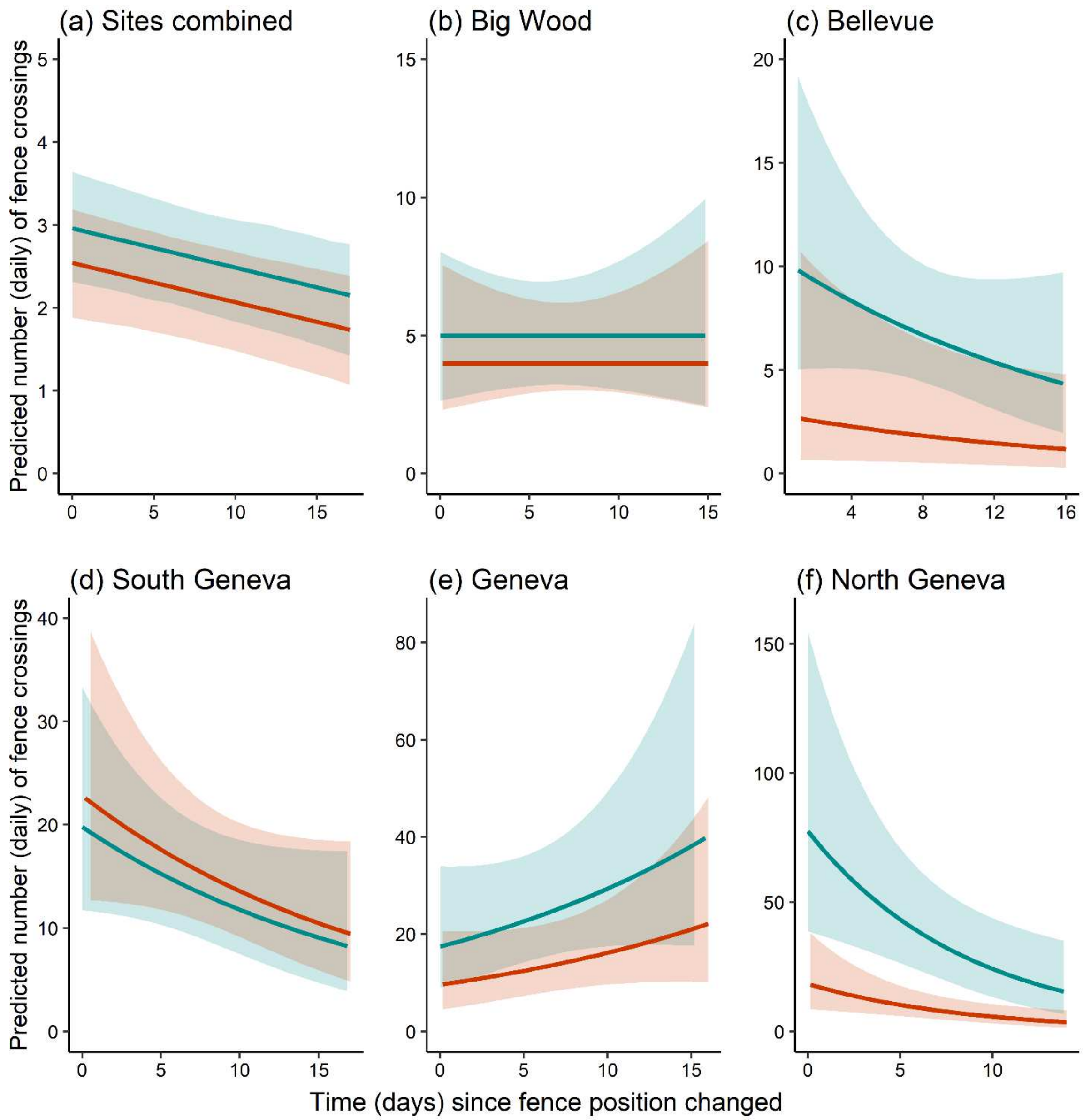

Figure 3.13: Predicted number of elk crossing the modified fence, with ± 95% confidence intervals, in the 'off' (blue) and 'on' (red) position as time since the position of the fence changed.

3.9. REFERENCES

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APPENDIX 2

S2. FIGURES

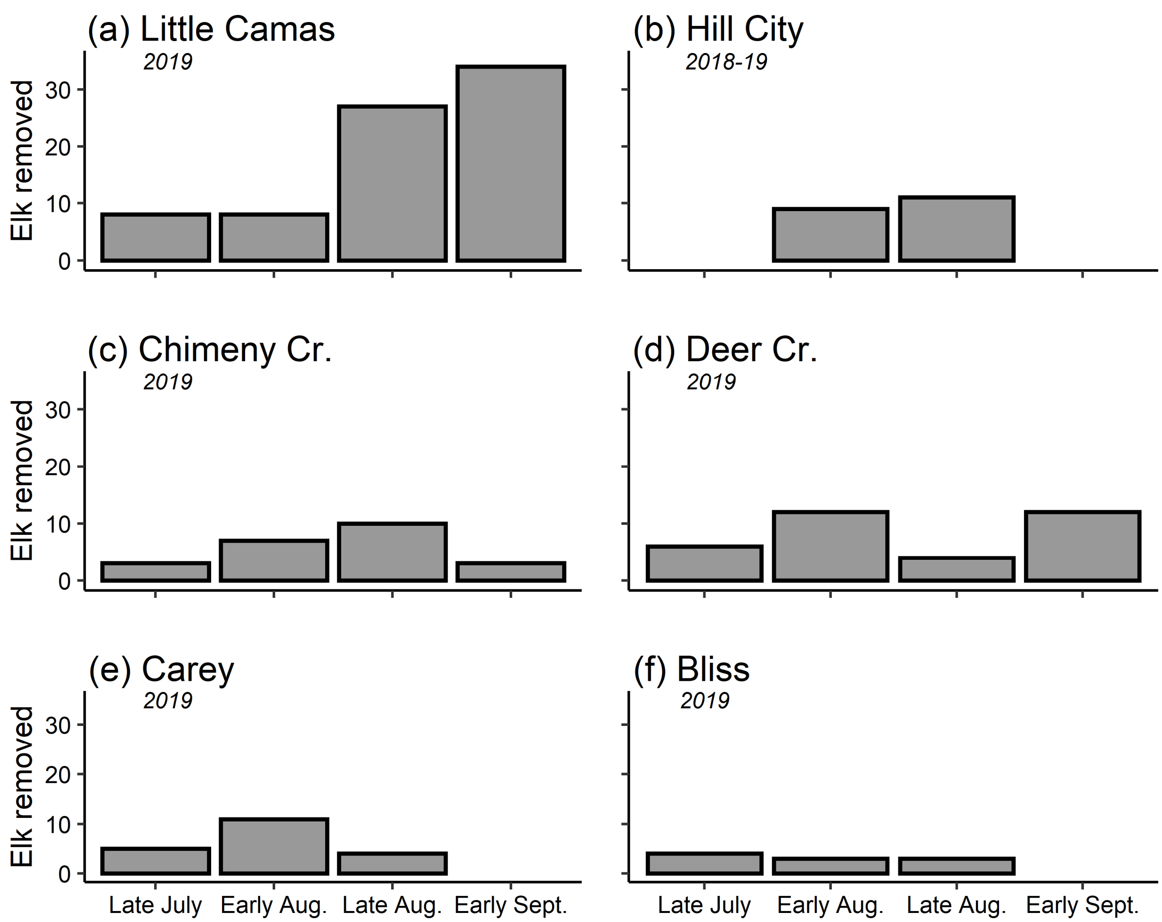

Figure 3.14: Number of animals removed at Magic Valley sharpshooting sites in 2018 and 2019.

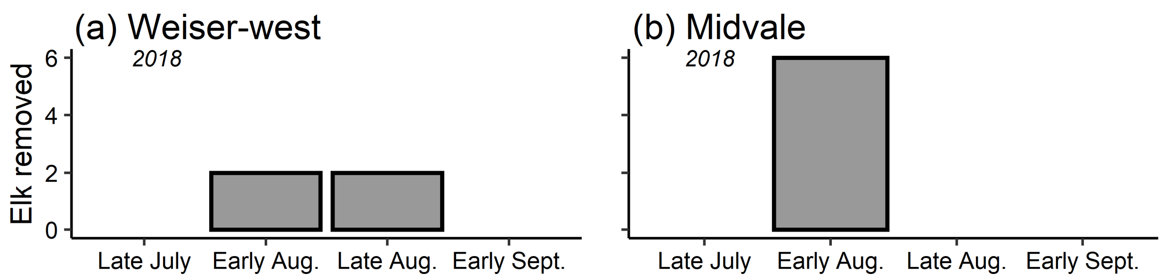

Figure 3.15: Number of animals removed at Weiser sharpshooting sites in 2018.

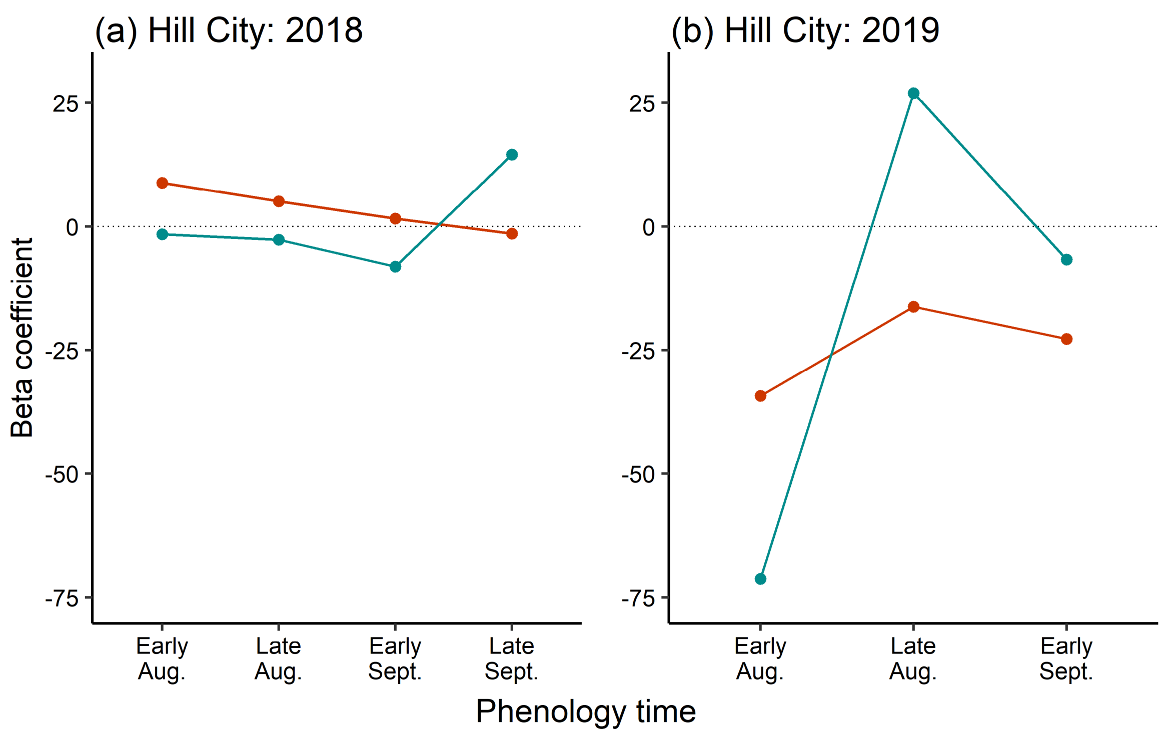

Figure 3.16: Selection of agriculture (red) and sharpshooting treatment site (blue) for elk treated with sharpshooting at the Hill City sharpshooting treatment site in 2018 (a) and 2019 (b). Selection is modeled at the movement-step scale through the depredation season. Selection was measured as a distance from a particular variable; therefore, negative beta coefficients indicate a positive selection for areas in proximity to agriculture or treatment area.

S3. USING DOGS TO DETER ELK FROM CORN FIELDS

S3.1 Introduction

Domestic dogs (*Canis familiaris*) have long been used as a tool to reduce and alleviate human-wildlife conflicts (VerCauteren et al. 2014). Regardless of breed, the presence of dogs alone can dissuade wildlife from agricultural crops (VerCauteren et al. 2005). Kloppers et al. (2005) demonstrated that using dogs to simulate predators chasing elk was an effective aversive conditioning treatment for deterring semi-habituated elk from urban areas. With the growing attractiveness of using dogs to mitigate human-wildlife conflicts, research in this field has been primarily focused on using livestock protection dogs to deter predators from depredating on livestock or preventing ungulates from depredating on small-acreage or stored crops (e.g., haystacks).

Corn (*Zea mays*) is the most widely grown grain crop in the United States (National Agriculture Statistics Service 2019), and elk are responsible for causing significant damage to corn in southern Idaho (IDFG unpublished data). However, due to crops being planted in dense plant populations to maximize harvest yields, commonly used damage prevention tools (e.g., hunting, hazing, and sharpshooting) are relatively ineffective in deterring elk from corn. Elk typically begin using corn fields in late June (IDFG unpublished data), feeding on the palatable corn seedlings, and consequently stunting the growth of the plant (Tzilkowski et al. 2002). However, elk bedding, and travelling through corn fields cause the most substantial damages, as these activities often break corn stalks, which kills the plant (IDFG unpublished data).

Considering the difficulties, and lack of effective methods for preventing and deterring elk from corn fields, we tested the efficacy of aversively conditioning elk with highly-trained dogs that possessed innate chasing behavior. Different from livestock protection dogs, which are less effective at protecting expansive agriculture crops (VerCauteren et al. 2014), we used dog breeds (e.g., livestock herding dogs [LHDs], and hounds used for hunting) that would chase and pursue animals, and theoretically simulate a predator chasing sequence.

S3.2. Methods and Results

We tested the efficacy of LHDs in reducing elk depredations in the Magic Valley study area, as this area contains the highest amount of corn production in the state (National Agriculture Statistics Service 2019). LHD testing occurred in Gooding and Lincoln Counties (Figure 3.17), where corn represents 55% and 22% of the total agriculture crops grown, respectively (National Agriculture Statistics Service 2019). (See Chapter one for a detailed description of the Magic Valley study area.)

In 2018, we used the services of Canine Solutions, (Canine Solutions, Medicine Hat, Alberta Canada) an organization specializing in using Border Collies for mitigating human-wildlife conflicts. Elk cause the most severe damage to corn fields in late August and early September, immediately prior to corn being harvested (IDFG unpublished data). Thus, from 1 – 6 September 2018, Canine Solutions used six, highly trained LHDs to attempt to deter elk from corn fields at four locations in the Magic Valley (Figure 3.17).

We used location data from GPS-collared elk to identify corn fields where LHD testing occurred. After determining the approximate location in the field that was being used by elk, the handler and LHDs would enter the field at a location which theoretically allowed the LHDs to chase elk from the targeted field. The handler would deploy the LHDs in the direction of elk, with the intent that the LHDs would locate and subsequently chase the elk from the field.

While the handler attempted to use vocalized commands and whistles to control and direct LHDs towards the targeted elk, LHDs had significant difficulties in physically locating elk inside the fields. The breed of LHDs (Border Collies) used in 2018 relied primarily on visual and auditory commands from the handler to locate animals, not olfactory senses. With the dense plant populations within corn fields, providing such commands to dogs at distances >5 m was nearly impossible. However, we hypothesized that increasing the LHDs familiarity to environments inside corn fields, in addition to increased exposure to elk would enhance LHDs ability to locate and subsequently chase elk. However, after five days of testing, the LHDs never successfully displaced elk from corn fields. Additionally, to the best of our knowledge, the LHDs never encountered an elk inside corn fields. Our goal of this deterrent treatment was to use LHDs independently, without needing constant commands from the handler, to deter elk from corn fields. However, the dependence of LHDs on instructions from their handler significantly limited their applicability and effectiveness for preventing elk damages in corn fields.

With LHDs being ineffective at deterring elk from corn fields, we did not continue using this breed of dogs in 2019. Rather than using LHDs, we contracted the services of a dog handler that used highly trained Walker Running Hounds (hereafter 'hounds') to aid in hunting white-tailed deer (in areas of the U.S. where such practices are legal). Hounds and LHDs are similar, with both breeds having the innate disposition to chase other animals; however, compared to LHDs, hounds are more independently motivated and rely heavily on their profound olfactory senses (Goldblatt et al. 2009). Additionally, and different from the LHDs used in 2018, the independent nature of hounds, paired with their drive to chase animals (Miller et al. 2014) did not necessitate the handler to accompany the hounds into the field. We tested the effectiveness of hounds as an elk deterrent from 1 – 7 September, 2019, and used similar methodology and tested the hounds in the same general areas as in 2018.

When the hounds were inside corn fields, they would become extremely vocal (i.e., barking) when they encountered the scent of, or presumably observed an elk. At all locations where we tested hounds in 2019 (n = 3), elk had been using the corn fields for >14 days prior to testing, and location data from GPS-collars showed that elk remained inside the corn fields throughout the majority of this time. With elk using corn fields at a proportionally high level, it can be expected that there was an abundance of elk scent throughout the fields. Consequently, we suspect it was difficult for the hounds to decipher subtle differences between relatively recent (i.e., day-old) and older (i.e., week-old) elk scents. While location data from GPS-collared elk in corn fields suggested that the hounds were displacing elk, the hounds were unable to consistently locate and subsequently chase elk out of the targeted fields. However, on two occasions the hounds displaced an individual GPS-collared elk from a corn field. On both occasions, we observed the elk running out of the corn field and continue running for >1.5 km, but location data showed this individual returned to the corn field <8 hours after being displaced, on both occasions (Figure 3.18). We continued our attempts of using the hounds to deter elk from corn fields, but with the exception of the two instances when an individual elk was displaced, we were unsuccessful in deterring any other elk from the targeted corn fields.

S3.3. Discussion

Preventing elk-caused corn damages has been a longstanding issue in the Magic Valley region for several decades (IDFG 2019). IDFG has put forth significant efforts and tried a variety of novel techniques to mitigate such damages, but success has been relatively non-existent. Breed and training strongly influenced the dog's ability to locate elk in corn fields. While LHDs are specifically bred and trained to chase animals, such as livestock, their dependency on receiving direction from a handler highly limited their applicability for deterring elk from corn fields. Conversely, the hounds tested in this study were successful in locating and displacing an elk from a corn field, although repeated and predictable success was limited. Hounds possess many behavioral attributes that would allow them to be used as an effective tool for preventing elk damages to corn. Their strong sense of smell, paired with an innate drive to chase animals are necessary characteristics that we identified as being crucial for using dogs under this application. We believe that with increased training and exposure to elk, especially inside corn fields, hounds could provide wildlife managers with an effective tool for preventing corn damages caused by elk.

S3.4. Figures

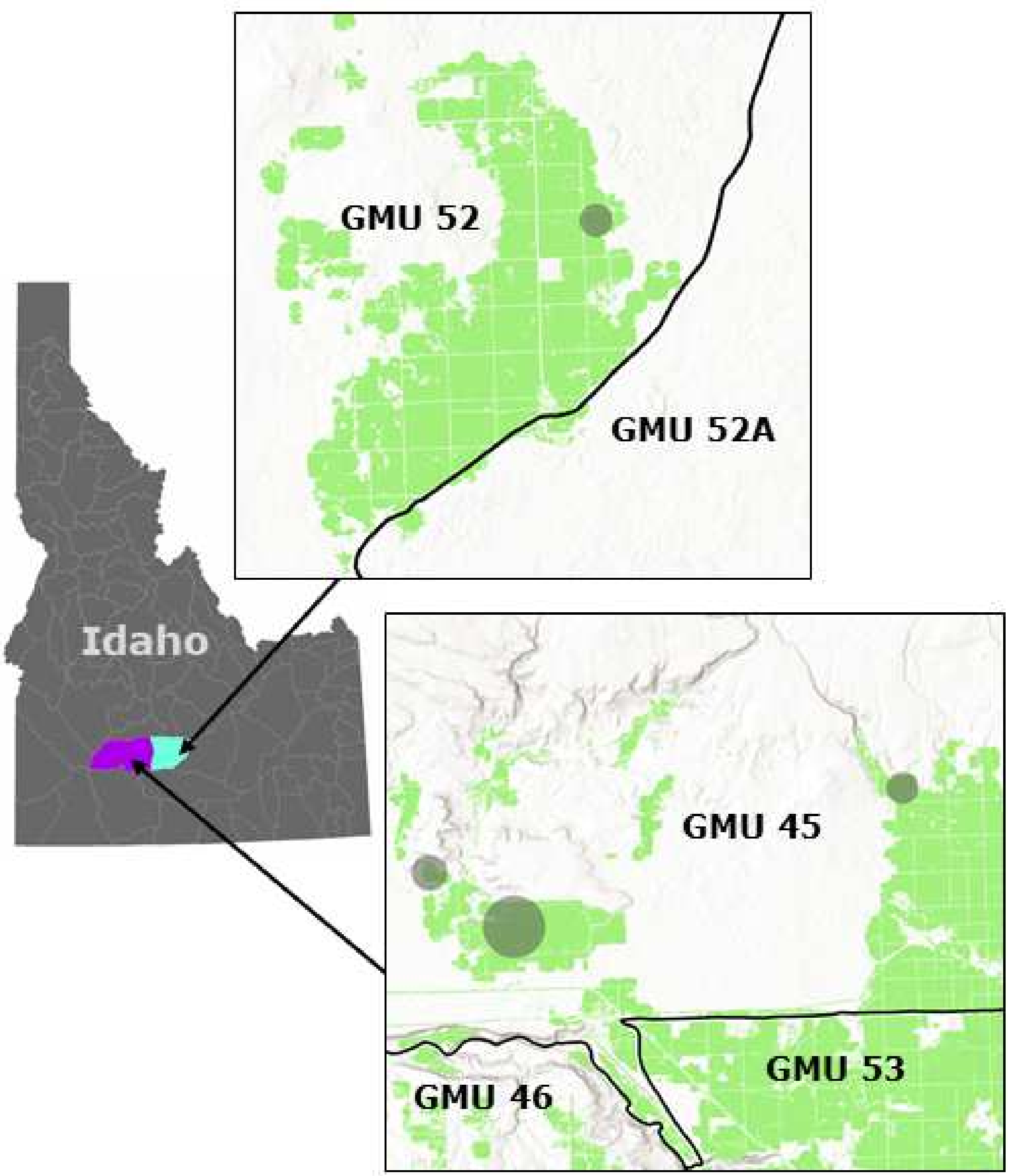

Figure 3.17: Livestock herding dogs (LHDs) and hound treatment areas in the Magic Valley. Areas colored in green represent agriculture lands. Gray circles represent treatment sites where dogs were tested.

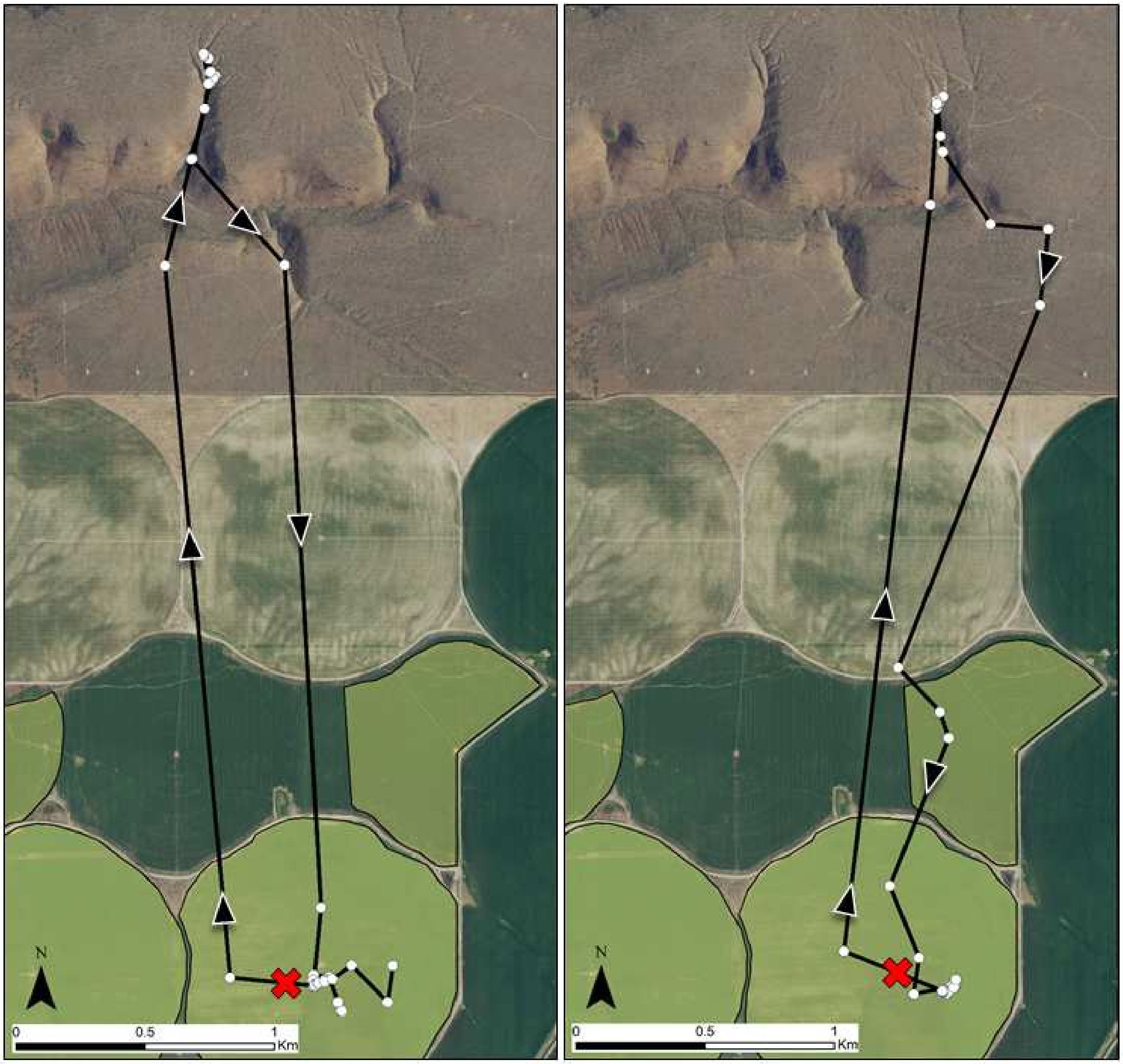

Figure 3.18: Location data (white dots; 20 min. duration between relocations) and direction of travel (black triangles) from a GPS-collared elk that hounds displaced from a corn field in the Magic Valley study area. Red X's indicate the approximate location where hounds first encountered the GPS-collared elk.

S3.5. References

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S4. HYDROLYZED CASEIN: A TASTE-BASED REPELLANT FOR REDUCING ELK DEPREDATION

S4.1. Introduction

Nutrition-altering repellents have been used and researched extensively for purposes of reducing crop damages; however, the vast majority of this work has been conducted on white-tailed deer (for a recent see Ward and Williams 2010). In contrast, there is limited research on using repellents to limit crop damages caused by elk, and such work is focused on testing repellent effectiveness on captive elk. Casein, which is a protein found in mammalian milk, along with a hydrolyzed form of casein has a notable and offensive bitter taste. Several studies have taken advantage of the bitter-tasting nature of the protein and found it to be effective in reducing herbivore foraging when it is applied to plants or feed (Field et al. 2009) and more specifically, Kimball and Nolte (2006) found that both casein and hydrolyzed casein (hereafter ‘HC’) were effective in reducing white-tailed deer browsing. However, both studies were again focused on captive animals.

Although HC shows promise for reducing elk damages to agricultural crops, we found no studies that have focused on using this type of repellent with non-captive elk in an agriculture-dominated landscape. Previous studies have shown that HC was more effective in reducing foraging than the non-hydrolyzed casein (Kimball et al. 2005, Field et al. 2009); therefore, we tested the effectiveness of HC in reducing elk-caused damages to alfalfa (*Medicago sativa*) and corn (*Zea mays*) agriculture crops in areas of southern Idaho with chronic elk depredation issues.

S4.2. Methods

HC was tested at one location in the Weiser study area and one location in the Magic Valley. (See Chapter one for a detailed description of the Magic Valley study area.) In the Magic Valley, a 3.9 ha timothy (*Phleum pretense*) hay field was treated with HC, and a 2.8 ha corn field was treated with HC in Weiser. We were interested in testing the effectiveness of HC as a deterrent when it was applied only around the outer edges of a field; therefore, we also treated a 1.4 ha buffer strip around the outer edges of an alfalfa field in Weiser. In the Magic Valley, we began applying HC to the treatment field on 9 July 2018, and continued treating the field every two weeks until 20 August 2018. In Weiser, we began applying HC to the treatment areas on 20 July 2018, and continued treating the areas every two weeks until 31 August 2018. In both study areas, we used a 10% solution (weight/volume) of HC (HCA-411 Hydrolyzed Casein, AMCO Proteins, Burlington, NJ USA) mixed with water. To reduce the potential for HC to be washed off the treated plants by irrigation, we included an adjuvant to our solution (0.22% volume/volume; Antero-EA, Wilbur-Ellis, Aurora, CO USA). HC was applied to treatment fields using an electric sprayer, similar to those commonly used for applying herbicides, which was attached to an all-terrain vehicle (ATV). We calibrated our electric sprayer to apply 97 liters/hectare when the ATV was traveling 11.2 km/hour.

S4.3. Results

In both study areas, we detected minimal changes in how GPS-collared elk used the fields treated with HC (Figure 3.19). At the HC treatment site in the Magic Valley study area, 13.6% of elk locations were inside the treatment area during the timeframe when HC was being applied, and 6.5% of elk locations were inside the treatment area outside the HC treatment timeframe. At the HC treatment site in Weiser, 5% of elk locations were inside the treatment area during the timeframe when HC was applied. During the timeframe outside the HC treatment in Weiser, 3.5% of elk locations were inside the area treated with HC.

S4.4. Discussion

While many taste-based repellants have been designed and made commercially available for reducing ungulate damages, their effectiveness remains variable and testing has occurred primarily in captive settings (El Hani and Conover 1995, Walter et al. 2010, Monteith et al. 2019). A taste-based repellant may show promise in captive settings, where animal densities and the retention of the repellant to plants is heavily monitored (Monteith et al. 2019); however, in non-captive settings, these variables are difficult to control. Regardless, if an effective repellant was identified, it could provide user-friendly and socially-preferred relief from ungulate-caused agriculture damages. Unfortunately, at both locations where the HC treatment was tested in our study, it was very apparent that crops were used and subsequently damaged by elk. Anecdotally, the amount of observed damages suggest that additional non-collared elk were using the treated areas more extensively than the individual radio-collared elk. With the high levels of observed elk-caused damages to the crops treated with HC, the private landowners who owned the fields where testing occurred were reluctant to continue allowing this deterrent to be tested on their fields. Additionally, because HC did not appear to be a promising deterrent for reducing elk-caused damages to agriculture crops, we did not continue testing HC in 2019.

While our results suggest that HC was not effective in reducing elk-caused agriculture damages, we had a limited number of GPS-collared animals ($n = 3$) using the HC treated areas, and we only tested HC for a limited length of time. Using different methodology to test HCs effectiveness, such as camera traps, exclosure plots intended to measure consumption by ungulates, or increasing the number of GPS-collared individuals using treatment areas could have provided us with different results. We believe that taste-based repellents are a promising tool for mitigating agriculture damages caused by wildlife and encourage the testing of novel repellants in the future.

S4.5. Figures

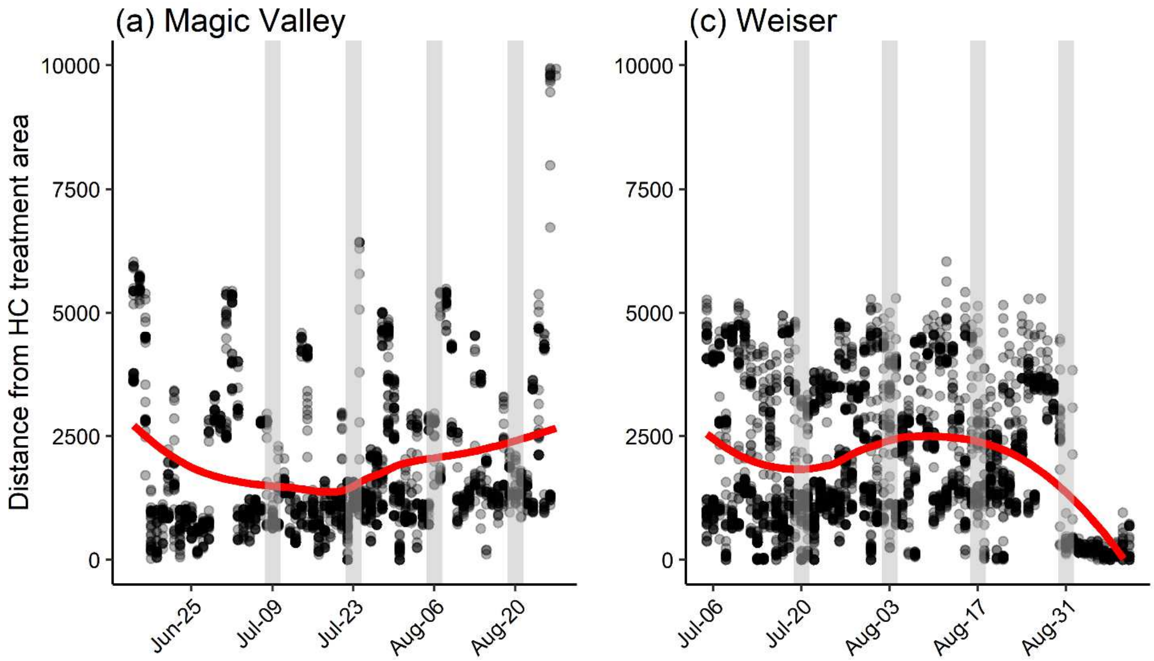

Figure 3.19: Nighttime GPS-location data from elk using HC treatment areas in the Magic Valley (a) and Weiser (b). Grey vertical bars indicate dates when HC was applied to treatment fields. Trend lines where smoothed with a loess function.

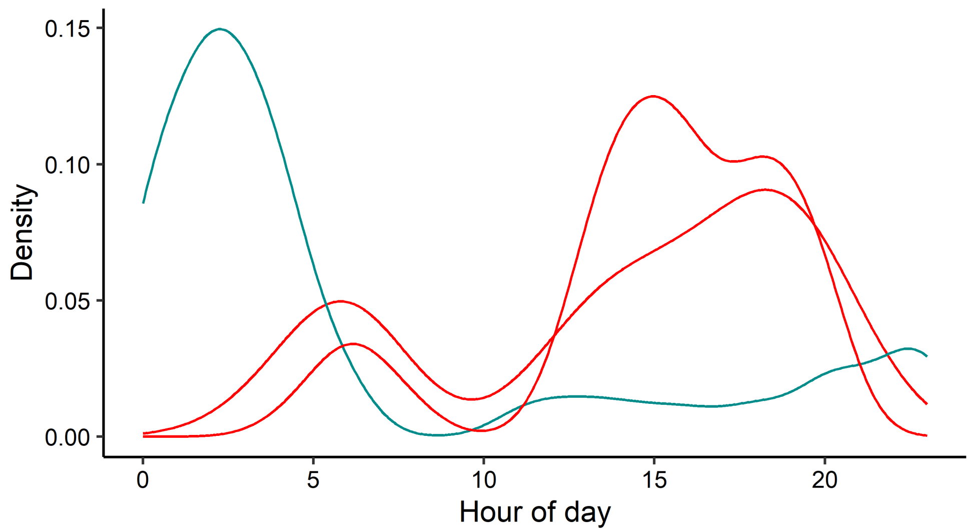

Figure 3.20: Kernel density estimates of GPS-location data from elk using HC treatment areas relative to the time of day. Red lines indicate elk in the Magic Valley and the blue line indicates elk in Weiser.

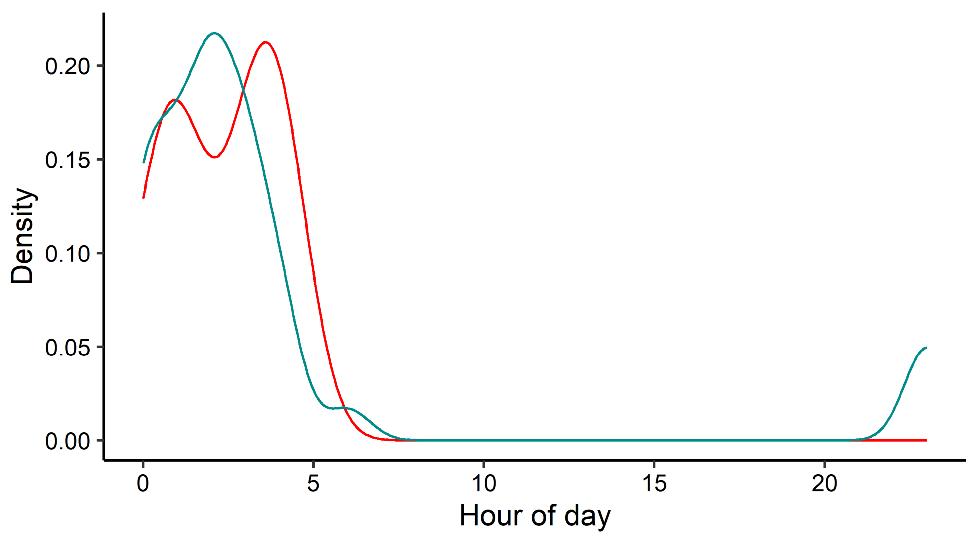

Figure 3.21: Kernel density estimates of GPS-location data from elk at the HC treatment area in Weiser. The red line indicates GPS-locations in the alfalfa field (inside the buffer strip treated with HC). The blue line indicates GPS-locations in the buffer strip treated with HC.

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CHAPTER 4. CONCLUSIONS

Wildlife managers are tasked with managing wildlife as a public trust resource for all citizens. The paradox of wildlife management is providing abundant and healthy wildlife populations while mitigating the negative impacts caused by overabundant wildlife (Conover et al. 2018). While the former has been achieved in many instances, overabundant wildlife such as elk, have caused remarkable damages to agriculture crops (Conover 2002, Conover et al. 2018). Not only does our work provide a better understanding of general elk ecology, we also provide insight to how elk use habitats in an agriculture-dominated landscape. We show that changing phenology of natural forages and agriculture crops influence how elk select habitats. The higher nutritional values of agriculture crops, relative to natural forages, make agriculture inevitably attractive to elk (Mould and Robbins 1982, DeVore et al. 2016, Smith et al. 2018); therefore, identifying methods for mitigating the damages elk cause to agriculture is paramount. There are limited options available for the difficult task of controlling the damages that overabundant elk cause to agriculture crops (Walter et al. 2010). While the deterrent treatments we tested did not eliminate elk-caused agriculture damages, we identified two depredation management techniques that proved to moderately lessen the negative impacts that elk cause to agriculture crops.

4.1. VARIABILITY IN HOW ELK USE AGRICULTURE

The different ecotypes of elk that emerged in our study suggest that elk can live in agriculture landscapes without relying on agriculture as a primary food source. Variability in how elk respond to the risks posed by humans, and how elk learn to avoid such risks (Thurfjell et al. 2017) may explain why we observed such a gradient in how elk use agriculture. Based on this hypothesis, it can be assumed that some elk herds have a stronger aversion to human disturbance, while other herds have learned to avoid human disturbances by inhabiting refuges of private land. Trade-offs between high-quality forage and secure areas can be driven by predation risk alone (Hernández and Laundré 2005), which exemplifies the importance of increasing hunter access into areas where elk cause damages to agriculture, while maintaining quality natural habitat that attracts elk away from agriculture food sources.

4.2. EFFECTIVENESS OF BEHAVIOR-MODIFYING DETERRENTS

The sustainability of elk populations is equally dependent on public and private land habitats (Johnson et al. 2014), but with the exception of deer (Odocoileus sp.), elk cause more damages to agriculture crops than any other wildlife species (Conover et al. 2018). Considering this, and to increase landowner tolerance of elk living amongst agriculture lands, there is much need for reliable tools that reduce the impact of elk on agriculture. In response to this need, we developed two behavior-modifying deterrents that were moderately effective for reducing elk use of agriculture crops.

Our sharpshooting deterrent took advantage of the strong propensity elk have to avoid predation risks posed by human hunting (Morgantini and Hudson 1985, Skovlin et al. 2002), while our fence modification deterrent utilized electrical shock to induce aversion behavior via sensations of pain (Provenza and Lauchbaungh 1999). The sharpshooting deterrent caused elk to avoid agriculture fields where sharpshooting occurred. While we were not necessarily effective in causing elk to avoid all agriculture lands, sharpshooting did elicit some level of avoidance behavior of agriculture lands and sharpshooting treatment sites.

Ungulate-proof exclusionary fences nearly guarantee the elimination of depredations, but they can have severe and deleterious impacts on non-target wildlife (Hayward and Kerley 2009). Considering the effectiveness of exclusionary fences, we developed a temporary fence design that effectively limited elk depredations and did not create a long-lasting barrier for target and non-target wildlife. While it is unrealistic to assume our fence modification design could be utilized across a large area of agriculture crops, it does provide an effective tool for preventing localized depredations.

4.3. FUTURE DIRECTION AND NEEDS

This thesis provides wildlife professionals with valuable information regarding the management of elk in landscapes dominated by agriculture. However, with the complex nature of controlling wildlife damages, many unknowns remain. We recommend future work to consider: a) how does the nutritional quality of natural vegetation influence elk-caused crop damages; b) how successful are the deterrents tested in this study when measuring actual crop losses is used to evaluate the deterrents' effectiveness; c) does the effectiveness of sharpshooting increase when it is conducted across multiple depredation seasons; and d) what is the optimal, or minimum level at which deterrents should be deployed while still maintaining effectiveness?

As we observed when implementing our sharpshooting deterrent, management actions associated with controlling overabundant or crop-damaging wildlife are often met with controversy (Garrott et al. 1993). Nevertheless, it is paramount that public stakeholders are involved and educated in the processes of controlling wildlife damage. Thus, we strongly suggest that considerations be taken to educate the public regarding the impacts wildlife cause to agriculture, the limitations associated with lethal and non-lethal deterrents, and the contributions and quality habitat that private landowners provide to the publics wildlife.

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