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Bryson L. Webber   Date

ANALYZING THE BEHAVIOR OF DOMESTIC SHEEP IN RELATION TO THE PRESENCE OF LIVESTOCK GUARDIAN DOGS USING GPS AND GIS

By

Bryson L. Webber

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COMMITTEE APPROVAL

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ABSTRACT

The use of livestock guardian dogs (LGDs) reduces predation and mitigates the need to remove predators from ecosystems. The purpose of this study is to determine if the presence of LGDs also changes the grazing behavior of domestic sheep in an environment where predators are common. To address this question, GPS and GIS technology were used. Collars with attached GPS receivers collected point locations of sheep at one second intervals. These data were then processed with GIS. Data were analyzed using a linear mixed modeling procedure where daily distance traveled by sheep was the dependent variable, and LGD presence, day of trial were considered fixed effects. A difference in distance traveled by sheep was found relative to LGD presence ($P<0.05$). Sheep in the presence of LGDs traveled farther ($\overline{X}$ = 7 864 m, SE=434) than those without LGDs present ($\overline{X}$ = 7 157 m, SE=451). Comparing speed of sheep found no significant differences between groups with and groups without LGDs present. This study represents an incremental step toward better understanding livestock behavior, and their interactions with LGDs as well as an insight on how to analyze high frequency GPS data.

CHAPTER 1: INTRODUCTION

1.1 Problem Statement

The use of livestock guardian dogs (LGDs) reduces predation on domestic livestock. Can quantitative measurements be derived from collar mounted GPS receivers using GIS and statistics that will prove or disprove that the presences of LGDs has a behavioral modification effect on domestic sheep? Does the presence of LGDs have other positive influences on the health and wellbeing of the domestic sheep they protector or does their presence modify domestic sheep behavior that through additional studies may show a positive relationship to animal health?

1.2 Literature Review

Bradley and Pletscher (2005) assessed factors relating to wolf depredation on cattle within fenced pastures in Montana and Idaho. This study was done by using data where confirmed wolf kills on cattle occurred. Reports by ranchers of confirmed kills determined if there was any relevance to distance from residences, bordering pasture habitat, wildlife presence, or specific husbandry practice were related to the kill sites. Bradley and Pletscher (2005) found that pastures where the most depredation occurred were larger in size, contained more cattle, and were farther from residences then those with lower depredation rates. Pastures with elk present were also more likely to have livestock depredation reports than those without as well as those close to wolf dens during denning season. What had no relevance was distance to a forest edge, percent vegetation cover, cattle breed, cattle type, and carcass disposal practices (USDA Animal and Plant Health Inspection Service 1994, Green and Woodruff 1999). This study is applicable to all livestock species, because the spatial attribute and wildlife dispersion results can be effective to assist in localized management practices. As wolf populations in Idaho, Wyoming, and Montana increase, so does the relevance of this study.

Sibbald et al (2008) studied the spatial distribution of sheep grazing in a complex vegetation mosaic. Sheep were split into six groups of six in six pastures, where there was preferred habitat and vegetation (grasses) dispersed unevenly throughout heather (shrubs). The sheep were observed from an adjacent hillside, so as to not disturb grazing. The observers noted the location of each sheep, distance from its nearest neighbor, and the vegetation type being foraged. It was then analyzed statistically and spatially using GIS to determine what motivated the grazing behavior, and distribution. Being social animals domestic sheep have a grouping instincts. The Sibbald study was set up in a vegetative mosaic to see what would influence the sheep more, grouping behavior, or preferred grazing habitat. The frequency of sheep visits and grazing on the same patches of preferred vegetation showed that the animals made a positive choice to graze together. The mean distance to nearest neighbor was affected by patch size. In the smaller patches the sheep forged closer together, in the larger patches they foraged farther apart (preferring 5 meters). This study is important because it shows how important grouping is in domestic sheep behavior.

Between January 1994 and November 2001 Marker et al (2005) studied 117 LGDs placed on Namibian Farms in Africa. The main predator of concern in these regions was the cheetah (*Acinonyx jubatus*), which is protected and ranchers cannot use lethal removal because of local and international laws protecting these animals. Approximately half of the ranches in Namibia given LGDs were commercial livestock ranches. The other half of LDGs were given to small communities who pool livestock together and pay a shepherd to watch the flock. In 2002 the farmers were surveyed to determine satisfaction with the LGDs based on Coppingers' (1983) three traits for a successful LGD (attentiveness, trustworthiness, and protectiveness) as well as farmer satisfaction. The farmers surveyed, 78.7% reported that the dogs preformed as they had expected and 69.8% said they saw an economic benefit to having a LGD. Most of the ranchers that received dogs previously had high levels of livestock predation; after having a dog placed with the herds 70% reported no further losses to predation. A majority of respondents (73%) reported a large decrease in livestock lost to predation.

While the reduction of livestock predation loss is of primary importance for producers, the effect of stress on livestock due to predator activity is also a concern. Grandin (1997, 1989) suggested that stress can reduce the weight of livestock, decrease health, reduce weaning weights, and increase proportions of unusable meat. Grandin also reported that livestock that are stressed during certain situations will more readily become stressed when the same situation occurs again; this is called a fear memory. Reducing fear memories can improve general health in livestock (Grandin 1998). Rashford et al. (2010) suggested stress on livestock exposed to predators can lead to reduced weight gains in calves and negatively affect the health of these animals. In this same study, models were created to determine the economic impact of predation on the livestock industry at the ranch level by both direct predation losses and reduced weaning weights of calves through predator-related stress. Rashfords' (2010) model used 4%, 6%, 8%, and

10% calf mortality rates resulting in average annual profits from $27 822 to $9 634. A subsequent simulation model for reduced weaning weights had a reduced average annual profit from $27 822 to -$727 for reduced weaning weights ranging from 1% to 10%. Clark et al (2009) and Rasford et al (2010) suggest that stress to livestock exposed to high predation levels can reduce weight gain in calves, and negatively affects the health of these animals.

Throughout the world livestock are experiencing increased pressure by predators. In the Swiss Alps, wolves are returning to historic ranges (Landry 1999). Regions of Romania have wolf and bear populations; predation on livestock by these predators is rising (Mertens and Promberger, 2001). In Africa, even with sheep and goats being corralled every night, predation is still occurring from growing populations of Cheetah (*Acinonyx jubatus*), leopards *(Panthera pardus*), lions (*Panthera leo*), hyenas (*Hyaenidae spp.*), and jackals (*Canis spp.*) (Ogada et al 2003). Norway is experiencing predation on its livestock by brown bears (Zimmerman et al 2003) and in the western United States wolves and grizzly bear populations are growing as a result of the reintroduction of wolves and management practices for grizzly bears. With all these threats to livestock, new, growing, or old, ranchers are looking for effective methods to reduce predation on their livestock that will be economically viable to their ranching business (Berger 2005). The use of predator proof electric fencing has been found to be moderately effective but expensive to install and maintain (Hulet et al 1987). Fladry barriers, the use of high visibility flags, can be temporarily effective only when food is abundant (Musiani 2003). The use of selective predator removal of coyotes has shown to be effective temporarily until another breeding pair fill the vacancy left, this occurs in about two to four months

(Blejwas et al 2002). The use of LGDs has been shown to be effective with the proper breeding and training (Coppinger et al 1983; Marker et al 2005; Andelt 1999; Andelt 1992; Black 1981; Hansen et al 2002; Rigg 2001), and can also be economically feasible for large and small production ranches (Andelt and Hopper 2000; Green et al 1984; Lorenz et al 1986; Berger 2005).

LGDs have proven to be effective at reducing predation on livestock (Andelt 1992, 1999; Black 1981; Coppinger et al 1983; Hansen et al 2002; Marker et al 2005; Rigg 2001; USDA Animal and Plant Health Inspection Service 1994). What is not clear however is if the use of LGDs modifies the behavior of livestock and thereby reduces or eliminates the negative effects of predator-related stress. The focus of this study was not to determine how effective LGDs are at reducing predation, but if the presence of LGDs changed the grazing activity (specifically daily distance traveled and speed) of domestic sheep with the treatment of LGD presence.

In this study, both sheep and LGD’s were fitted with Global Positioning System (GPS) collars, which continuously recorded their location at a one-second interval. These data were then analyzed to address the research question using GIS. The use of GPS technology to map and analyze animal (Morehouse 2010, Woodside 2010) activities has become common practice. Johnson and Ganskopp (2008) showed how the frequency of data collected with GPS affected resulting measures of routes and habitat resources used. They concluded the more frequent the locational data the more accurate their measurement of animal activity became. Ungar et al. (2005) was able to differentiate behaviors of resting, foraging, and traveling using GPS data coupled with observational data. Using technology such as motion sensors or post-process differential correction can improve the horizontal positional precision achieved with GPS (Ganskopp 2007). Using GPS technology, evaluating animal movement and activity can be measured more effectively and efficiently, including the position and speed of the animal at high temporal periodicity. The present study appears to be the first study to analysis livestock activity in the presence of LGDs, to do this GPS had to be utilized.

1.3 A Brief History of Livestock Guardian Dog Use

The domestication of sheep (*Ovis aries*) and goats (*Capra aegagrus*) is estimated to have taken place 7 000 or 8 000 years BCE in the area of present day Iran and Iraq (Rigg 2001). Since the introduction of domesticated livestock mankind has relied on them for food and clothing (Rigg 2001). The Spanish brought sheep and goats to the Americas and taught several American Indian tribes how to raise and breed livestock (Black 1981). Today a lot of the traditional methods of livestock husbandry have been lost and only a few cultures in Europe, Asia, and Africa continue to practice livestock husbandry as their ancestors have. In the Americas only the Navajo people continue to raise sheep in the manner taught by the Spanish in the 1700s (Black 1981).

Historically LGDs have been used as predation deterrents along with increased presence of herders (Gehring et al 2010, Rigg 2001). Some European and Asian ranchers have continued to use LGDs throughout history and into the modern day. Within the United States it has been a lost technique among most ranchers until recently (Andelt 1999). Researchers and non-governmental organizations (NGO's) through education have helped create this growing use of LGDs (Coppinger et al 1983, Andelt and Hopper 2000, Marker et al 2005). This has resulted in a recent increase in the use of LGDs to protect livestock (Andelt and Hopper 2000). Various methods have been used to reduce predation on livestock including the use of llamas (*Lama glama*), donkeys (*Equus asinus*), and livestock guardian dogs (LGDs) (*Canis lupus familiaris*) as guard animals, electric predator fencing to exclude predators, predator removal, sound, scent, and light devices to deter predators, selective chemical agents (collars with poison packets targeting predator of that animal), non-selective chemical agents (poisoned bait), "fladry" barriers (high visibility flagging), and increased herder activity (Allen and Sparkes 2001; Andelt 1992; Blejwas et al. 2002; Bradley and Pletscher 2005; Gazzola et al. 2008; Green et al. 1984; Hansen et al. 2002; Hulet et al. 1987; Knowlton et al. 1999; Marker et al. 2005; Ogada et al. 2003). Of these methods, LGDs have been widely considered most effective at reducing predation while also being cost effective for the producer (Andelt 1992, 1999; Black 1981; Coppinger et al. 1983; Hansen et al. 2002; Marker et al. 2005; Rigg 2001; USDA Animal and Plant Health Inspection Service 1994).

It is important to distinguish the difference between a guardian dog and a herd dog. Herding dogs display predatory behavior while herding and pushing livestock. Conversely guardian dogs bond with livestock, protect them from predators, and exhibit no herding tendencies (Rigg 2001, Landry 1999). It is not uncommon for LGDs to attack herd dogs because of the predatory behavior displayed while they move herds. Studies show that some breeds of dogs do better as guarding dogs than others, though training may arguable be more important (Andelt 1999, Andelt and Hopper 2000, Black 1981, Marker et al 2005). Effective training and the acclimation processes of LGDs must begin before they create a social attachment to other dogs or humans, or they may leave the herds to be with people or dogs. The most effective way to do this is to put the pup between the age of three and 12 weeks in with livestock full time. In doing this the pup will bond with the livestock, be accepted, and show protective traits towards the livestock. Training continues for the first two years of the dogs live. After the first year or two the dog becomes an asset to the rancher for about eight to ten years (Green and Woodruff 1999, Green et al 1984, Green et al 1984, Andelt 1992, Andelt 1999, Black 1981, Coppinger et al 1983).

LGDs use has become more common with the rise in predator populations. Throughout Europe and Asia wolves and bears have returned to their historical home ranges. In Canada there is also a growth in predators, mostly the grey wolf (*Canis lupus*). The United States has recently (1995) reintroduced wolves (*Canis lupus*) and grizzly bear (*Ursus arctos*) populations have grown, in Idaho, Montana, and Wyoming. In Europe, Asia, North America, and Africa many of these predators are protected and lethal management is not allowed or strictly governed. The listing of animals under protected status, growing numbers of predators, and the reintroduction of specific predators has raised questions as to what economic impact this will have on the ranching industry. In 2005, Wyoming reported 4,000 cattle, and 24,000 sheep lost to predation, a market value totaling 4 million dollars. In the same year, Wyoming state and federal agencies in Wyoming spent approximately 4 million dollars on predator control (Rashford et al. 2010). With approximately 8 million dollars lost due to depredation in Wyoming alone, LGDs can be a tool to help ranchers protect their livestock, and governmental agencies reduce money spent on predator control and removal. The use of LGDs may be the alternative to lethal predator removal, in areas where removal of protected predators is forbidden or restricted.

1.3. Study Area: United States Sheep Experiment Station

The United States Sheep Experiment Station (USSES) is located in Eastern Idaho and Southwestern Montana (Figure 1.1). The USSES consists of five separate ranches totaling approximately 19,558 ha of land. These lands are used for grazing spring, summer, or fall with feed lots being used year round. The elevation ranges from 1,463 meters to around 3,048 meters above sea level. Within the Snake River Plains of Idaho, the USSES receives approximately 25.4 cm of precipitation annually. The USSES maintains 3,000 adult sheep with additional attending young (Laufman 2009). The sheep managed by the USSES are exposed to predation by grizzly bears (*Ursus arctos horribilis*), black bears (*Ursus americanus*), mountain lions (*Puma concolor*), grey wolves (*Canis lupus*), and coyotes (*Canis latrans*) (Kozlowski 2009, Shivik 1996, Zimmermann 2003).

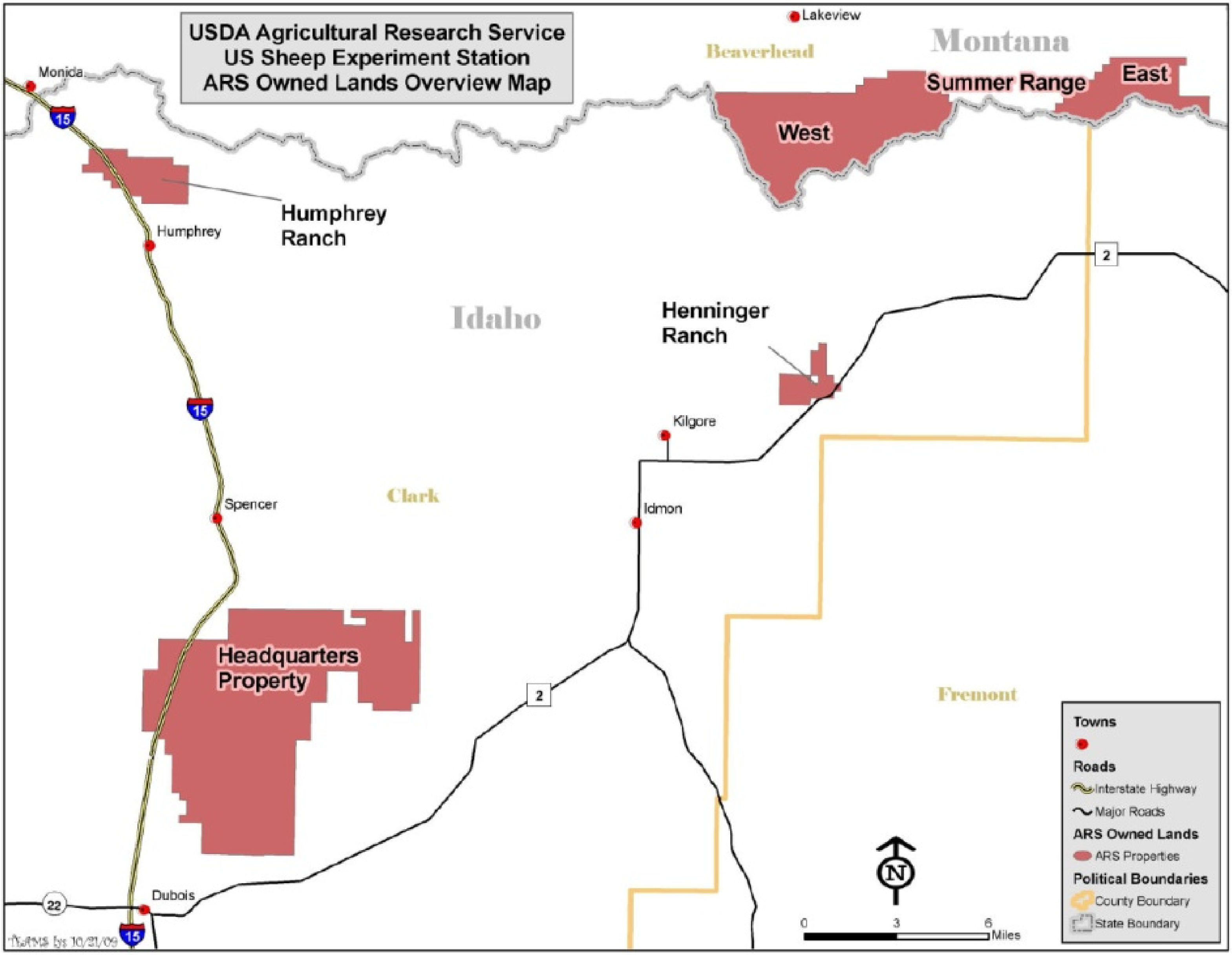

Figure 1.1 USSES properties in Eastern Idaho and Southwestern Montana. Source www.ars.usda.gov

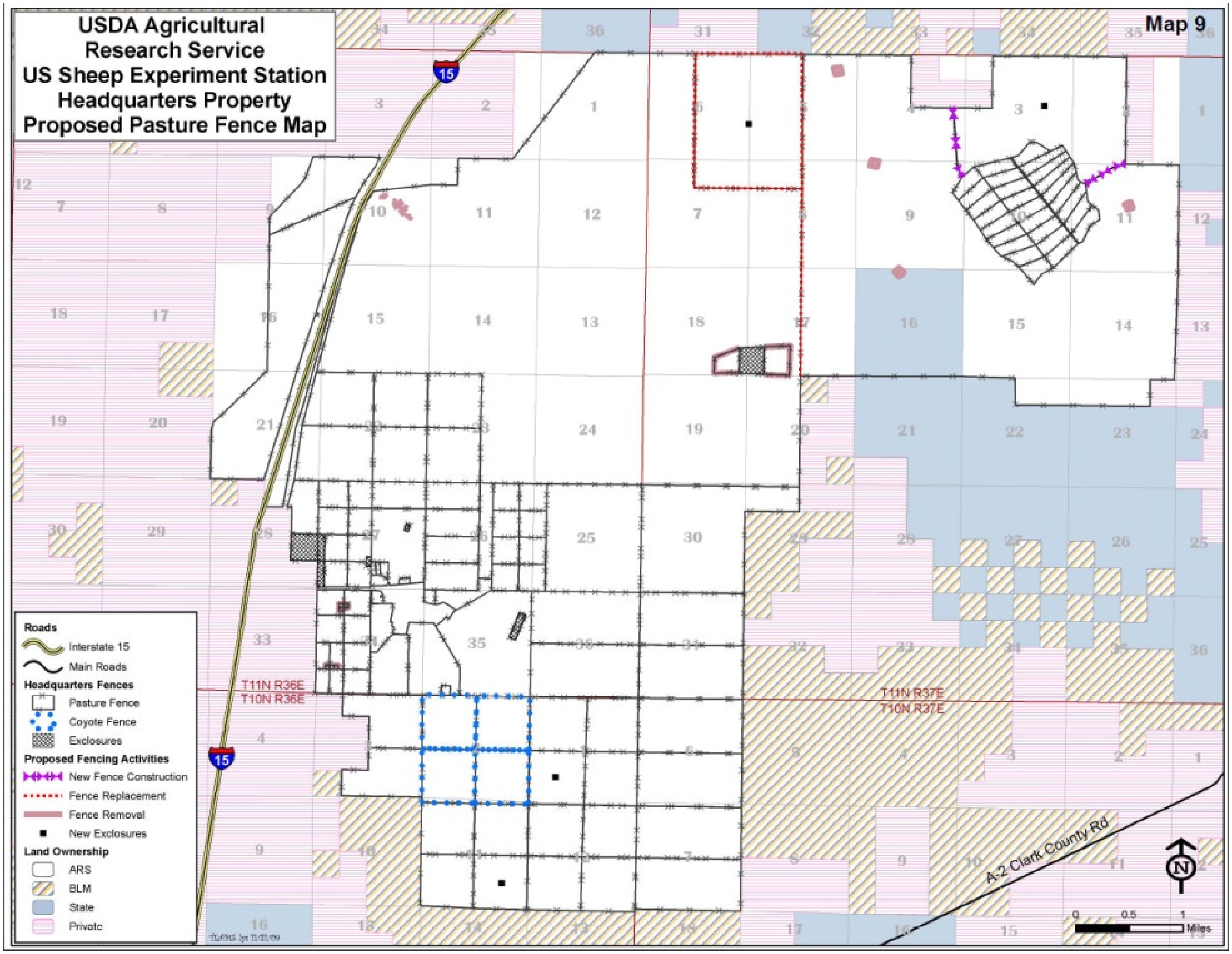

Figure 1.2 USSES Headquarters property. Pastures marked in blue dotted outline were the study area and is predator-proof fencing. Source www.ars.usda.gov

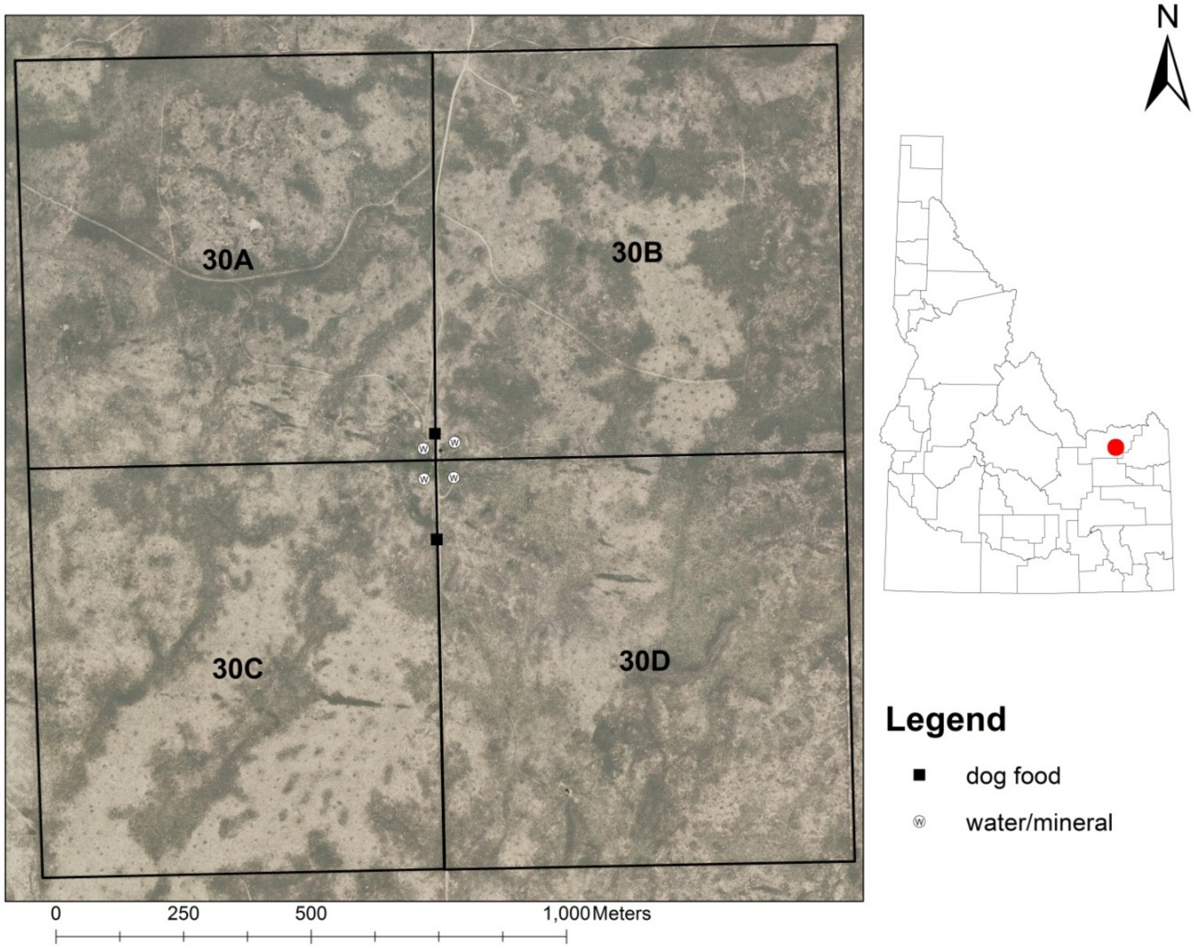

Figure 1.3 Map of four pastures (65 ha each), located at the U.S. Sheep Experiment Station near Dubois, Idaho. Pastures were enclosed with predator-proof fencing and used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence on the daily distance traveled by sheep grazing sagebrush steppe rangelands. Water/mineral supplement and dog food locations are marked.

Data for this study was collected on the USSES Headquarters Property (Figure 1.2) within four pastures (approximately 65 ha each in size), fenced with predator proof fencing. Each pasture's annual plant production is approximately 144 AUM. The pastures are designed in a 2x2 grid (Figure 1.3). The plant community found within the USSES Headquarters property is primarily Three-tip sagebrush (*Artemisia tripartite*) and Mountain Big sagebrush (*Artemisia tridentate*) among lava ridges. Blue bunch wheatgrass (*Psuedoroegenaria spicata*) is predominant among the grasses with the exception of crested wheatgrass (*Agropyron cristatum*) where it has been planted. Other vegetation species are as fallows; Indian rice grass (*Achnatherum hymenoides*), arrow-leaf balsamroot (*Balsamorhiza sagittata*), Indian paintbrush (*Castilleja linariaefoia*), rabbit brush (*Chrysothamnus nauseosus*), taper-tip hawksbeard (*Crepis acuminate*), buckwheat species (*Eriogonum*), needle and thread grass (*Hesperostipa comate*), broom snakeweed (*Gutierrezia sarothae*), prairie June grass (*Koeleria macrantha*), lupine (*Lupinus spp.*), western wheat grass (*Pascopyron smithii*), Nevada blue grass (*Poa nevadensis*), Sandberg bluegrass (*Poa secunda*), and antelope bitterbrush (*Purshia tridentata*).

This experiment was conducted using 560 mature ewes (Targhee, Columbia, Polypay, or crossbreeds) with their suckling lambs, provided by the USSES. All ewes were between 32 and 45 days postpartum at the start of the study (28 April 2010). The ewes and lambs were provided *ad libitum* access to water and mineral supplements throughout the course of the study. LGDs (two were used in the study, an Akbash and Akbash/Great Pyrenees cross) were also provided *ad libitum* access to water (shared with the sheep) and dog food. These ewes were experienced with LGDs and, prior to the study had been continuously managed with them throughout all parts of the year. While being managed with LGDs the sheep were commonly exposed to coyotes as well as other predators.

1.4. Research Objectives and Hypotheses

This research is motivated by the hypothesis that there is a significant difference in the behavior of domestic sheep that have LGDs present relative to those that do not have LGDs present. Two specific research objectives intended to help test this hypothesis include 1) evaluating overall movement of sheep (distance traveled); and 2) evaluating the time spent by sheep in predefined speed (m/s) classes. Additionally, this thesis presents techniques for appropriately managing data in light of GPS precision and other errors associated with experimental design including pseudo replication and auto-correlation.

1.5 Thesis Outline

The remainder of this thesis is organized as follows. Chapter 2 contains the results of a research effort focused on determining the movement and distance factors related to sheep in the presence of LGDs. Chapter 3 presents the results of a speed analysis of the LGD and sheep data. Chapter 4 presents considerations for using high frequency GPS data in animal behavior analyses. Chapter 5 presents conclusions and discussion of results from the complete thesis research project. Note that Chapter 2, 3 and 4 were written as standalone papers and are not necessarily meant to be read in sequential order.

CHAPTER 2: MOVEMENTS OF DOMESTIC SHEEP IN THE PRESENCE OF LIVESTOCK GUARDIAN DOGS

[This chapter contains material that was submitted for publication in the Journal of Rangeland Management and Ecology and hence is formatted as a standalone paper.]

Abstract: As a result of successful predator reintroductions, livestock are experiencing increased predation in many parts of the US relative to that witnessed just a few decades ago. Of the methods used to reduce predation on livestock, livestock guardian dogs (LGDs) have been the most effective. The use of LGDs reduces predation and mitigates the need to remove predators from the ecosystem. The purpose of this study was to determine if the presence of LGDs changes the grazing behavior (i.e., distance traveled per day) of domestic sheep in an environment where predators are common. To address this question, daily distance traveled was measured for individual sheep grazing on sagebrush steppe rangelands with and without the presence of LGDs. This was done using a repeated measures study of sheep and LGDs managed inside pastures enclosed by predator-proof fencing. Four 4-day trials were conducted and GPS collars were used to collect continuous (1 second) positional data of sheep during the trials. Data were analyzed using a linear mixed model procedure where daily distance traveled by sheep was the dependent variable, and LGD presence, day of trial, and collar type (two GPS collar types were used) were considered fixed effects. A difference in distance traveled by sheep in the presence of LGDs relative to those without LGDs present was found ($P<0.05$). Sheep in the presence of LGDs traveled farther ($\overline{X}$ = 7 864 m, SE=434) than those without LGDs present ($\overline{X}$ = 7 157 m, SE=451). This study represents an

incremental step toward better understanding livestock behavior, and their interactions with LGDs.

2.1 Introduction

Increasing predator populations on rangelands have resulted in a concomitant increase in livestock predation especially when compared to that seen just a few decades ago (Landry 1999; Merten and Promberger 2001; Blejwas et al 2002; Ogada et al 2003; Zimmermann et al 2003). The negative impact of predation on profitability in the livestock industry has forced ranching communities throughout the United States to make substantial economic investments in livestock protection (Berger 2006; Rashford et al 2010). Given these threats to livestock, producers must seek economically feasible and effective methods to reduce predation (Berger 2005).

Various methods have been used to reduce predation on livestock including the use of llamas (*Lama glama*), donkeys (*Equus asinus*), and livestock guardian dogs (LGDs) (*Canis lupus familiaris*) as guard animals, electric predator fencing to exclude predators, predator removal, sound, scent, and light devices to deter predators, selective chemical agents (collars with poison packets targeting predator of that animal), non-selective chemical agents (poisoned bait), “fladry” barriers (high visibility flagging), and increased herder activity (Green et al. 1984; Hulet et al. 1987; Andelt 1992; Knowlton et al. 1999; Allen and Sparkes 2001; Blejwas et al. 2002; Hansen et al. 2002; Ogada et al. 2003; Bradley and Pletscher 2005; Marker et al. 2005; Gazzola et al. 2008). Of these methods, LGDs have been widely considered most effective at reducing predation while also being cost effective for the producer (Black 1981; Coppinger et al. 1983; Andelt

1992, 1999; USDA Animal and Plant Health Inspection Service 1994; Rigg 2001; Hansen et al. 2002; Marker et al. 2005). Missing from these studies is an analysis of the actual movements of sheep in the presence of LGDs. Such an analysis can be informative from both animal behavior and livestock production perspective.

While the reduction of livestock predation losses is of primary importance for producers, the effect of stress on livestock due to predator activity is also a concern. Grandin (1997, 1989) suggested that stress can reduce the weight of livestock, decrease overall health, reduce weaning weights, and increase proportions of unusable meat. Rashford et al. (2010) suggested stress on livestock exposed to predators can lead to reduced weight gains in calves and negatively affect the health of those animals.

While it is not possible to know why animals respond as they do to various stimuli, one can quantify responses and make meaningful inferences when responses are consistently observed. To accomplish this and yet minimize false inferences it is reasonable to test a hypothesis that is small in scope. As a result, incremental gains in our understanding of animal behavior become substantial over time. Thus, the objective of this study was to evaluate whether the presence of LGDs affected daily distance traveled by domestic sheep (*Ovis aries*) on sagebrush steppe rangelands.

2.2. Methods

2.2.1 Study Area

This study was conducted at the U.S. Sheep Experiment Station (USSES) (19 558 ha) located in East Idaho and southwestern Montana. The USSES maintains 3 000 adult sheep (Rambouillet, Targhee, Columbia, Polypay, Suffolk, and crossbreeds) with additional attending young (Laufman 2009). These sheep are grazed on the sagebrush steppe and forested rangelands of the USSES and may have been previously exposed to predation threat by grizzly bears, black bears (*Ursus americanus*), mountain lions (*Puma concolor*), grey wolves, and coyotes (Kozlowski 2009, Shivik 1996, Zimmerman 2003).

The study area (259 ha) was located at approximately 1 670 m elevation on the USSES headquarters property near Dubois, Idaho (lat. 44°13'24", long. 112°11'03"). This area was surrounded and cross-fenced with 2 m high predator-proof fencing thus forming four 65 ha pastures in a 2x2 grid (Fig. 2.1). Sheep watering and mineral supplement locations for each pasture were near the center of the 2x2 grid. Topography is gently rolling with slopes ranging from zero to 20 percent averaging approximately four percent. The dominant plant community type in each pasture is three-tip sagebrush (*Artemisia tripartita*) overstory with blue bunch wheatgrass (*Psuedoroegenaria spicata*) understory. Annual forage production is relatively uniform among the pastures and estimated at 144 animal unit months (AUM) for each pasture.

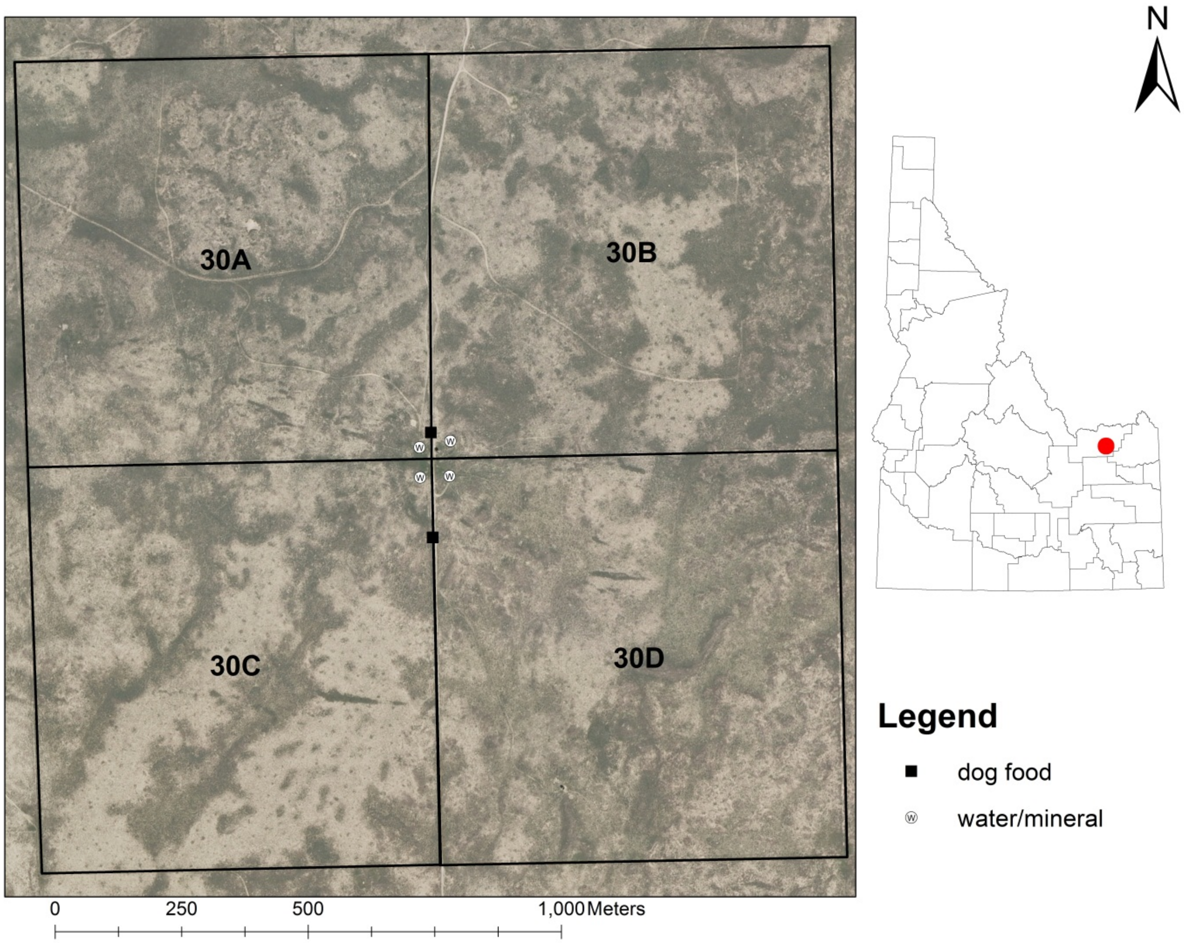

Figure 2.1 Map of four pastures (65 ha each), located at the U.S. Sheep Experiment Station near Dubois, Idaho. Pastures were enclosed with predator-proof fencing and used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence on the daily distance traveled by sheep grazing sagebrush steppe rangelands. Water/mineral supplement and dog food locations are marked.

2.2.2 Data Collection

Sheep were fitted with Global Positioning System (GPS) collars, which recorded their location at one-second intervals. The use of GPS technology and radio telemetry (Shivik et al. 1996) to map and analyze animal activities is common practice (Morehouse 2010, Woodside 2010). Results from Johnson and Ganskopp (2008) demonstrate a positive relationship between the frequency of positional data collection and the accuracy of animal activity measurements. Using GPS, evaluating animal movement can be effectively measured at high temporal periodicity.

This experiment was conducted using a study flock of 560 mature ewes and their suckling lambs (Targhee, Columbia, Polypay, or crossbreeds) or about 19% of the USSES adult population. All these ewes were between 32 and 45 days postpartum when placed in pastures for this study. These ewes were experienced with LGDs and, prior to the study had been continuously managed with them throughout all parts of the year. These ewes with their attending lambs were randomly assigned to four groups (Groups 1, 2, 3, and 4) of 140 ewes each. These groups were studied in specific trial periods called Trials 1, 2, 3, and 4 and described in more detail below. Groups 1 and 2 were used during Trials 1 and 2 and Groups 3 and 4 were used during Trials 3 and 4. During each trial, groups were placed in diagonally adjacent pastures, one group with two LGDs (an Akbash and an Akbash/Great Pyrenees cross) and one group without LGDs. At the end of each trial the sheep were moved to opposing pastures and the LGDs were placed with the previously unaccompanied group of sheep. Following trial two, the sheep were removed from the pastures and the experiment was replicated with the remaining two groups of sheep and the same LGDs. Throughout the course of the study the sheep were provided *ad libitum* access to water and mineral supplements. LGDs were also provided *ad libitum* access to water (shared with the sheep) and dog food.

A sampling of ewes from Groups 1, 2, 3, and 4 were randomly selected and fitted with GPS collars, (n = 12, 18, 12, and 18, respectively). The somewhat disproportional sampling was due to logistical difficulties experienced as sheep were collared and placed in pastures. The average age of collared ewes was 2.6 years (SE=0.10). Two GPS collar types were used and later determined to be distinguishable by their level of positional precision. Horizontal positional precision for collar type one was ± 4.45 m at 95% confidence interval (CI). Horizontal positional precision for collar type two was ± 3.56 m at 95% CI. All GPS collars were programmed to collect and record the collared sheep's location and speed at one-second intervals during the trials. The date and time of each location record along with additional quality parameters such as the number of GPS satellites used to calculate the location were also recorded.

Each trial was 2 days (48 hrs.) in duration (Table 2.1). Each trial was immediately preceded by a 12-hr pre-trial period during which the sheep were moved into the trial pastures and allowed to explore and acclimatize to the pasture environment. Sheep were in each pasture for approximately four days including the acclimation period and a post-trial period. Trial 1, involving Groups 1 and 2 took place on 29-30 April 2010 (beginning of test period one). Group 1 was accompanied by two LGDs and placed in the southeast pasture (30D; Fig. 2.1), Group 2 was not accompanied by LGDs and was placed in a diagonally opposed pasture (30A) to minimize or eliminate interaction between groups. For Trial 2, Group 1 was moved to the southwest pasture (30C) and

Group 2 was moved to the diagonally opposed pasture (30B). The LGDs were moved from pasture 30D and placed with sheep in pasture 30B. At the end of Trial 2, the GPS collars from sheep Groups 1 and 2 were removed, GPS data were downloaded to a computer, batteries were replaced, and the collars were then placed on Groups 3 and 4. The individual sheep in these groups were not members of the same groups from Trials 1 and 2, but rather represent entirely new flocks of sheep and the second test period or repeated measure. Trial 3 began on 6 May 2010, with Group 3 in the southeast pasture (30D) (without LGDs present), and Group 4 placed in the diagonally adjacent pasture (30A) (with LGDs present). Trial 4 began on 9 May 2010 with Group 3 in the southwest pasture (30C) and Group 4 in the diagonally adjacent pasture (30B). The LGDs were placed with Group 3 in pasture 30C; Group 4 did not have LGDs present for this final trial.

Table 2.1 Livestock guardian dog (LGD) treatment and pasture assignments for sheep behavioral trials conducted at the U.S. Sheep Experiment Station near Dubois in eastern Idaho during spring 2010.

Test Period	Trial	Start Date	End Date	Sheep Group	Pasture	LGDs
1	1	4/29/2010	4/30/2010	1	30D	Present
1	1	4/29/2010	4/30/2010	2	30A	Absent
1	2	5/2/2010	5/3/2010	1	30C	Absent
1	2	5/2/2010	5/3/2010	2	30B	Present
2	3	5/6/2010	5/7/2010	3	30A	Present
2	3	5/6/2010	5/7/2010	4	30D	Absent
2	4	5/9/2010	5/10/2010	3	30B	Absent
2	4	5/9/2010	5/10/2010	4	30C	Present

2.2.3 Data Processing and Analysis

After the conclusion of the trials, data were retrieved from the GPS collars and imported into a spreadsheet for error checking. Errors caused by GPS low-battery conditions, power interrupts, signal loss, and multi-path effects were detected and removed using three steps. The first, by sorting the spreadsheet and removing any corrupted data which were readily recognized as strings of random characters instead of positional numeric data. After this initial screening, the resulting files were imported into a GIS as feature classes and projected into Idaho Transverse Mercator (IDTM) NAD83 coordinate system. These point feature classes were then overlain on a GIS layer representing the boundaries of the study site pastures. Points falling outside the relevant study pasture perimeter at a distance greater than the GPS horizontal precision for that particular collar type were tagged as erroneous and removed from the data set. On average only 0.27% of the points from each 2-day (48-hour) trial were removed due to error. The final error-removal step was to use the GIS to convert the location points for each collar into a single line, representing the movement path of the sheep. Because the GPS data were not differentially correctable, GPS positions tended to wander when the animal was stationary. To remove these errors each line was simplified by removing line vertices that were within one meter of the preceding vertex. This distance was selected for the simplification threshold of the lines as it is well within the known precision of the GPS chipsets and will remove erroneous positions while preserving actual movement observations. The length of each simplified line was recorded as the daily travel distance, in meters, for each collared sheep.

2.2.4 Statistical Analysis

The treatment effect of LGD presence on daily distance traveled by domestic sheep was analyzed using a mixed linear procedure (Baayen et al. 2006, Littell et al. 1998, Singer 1998) within SAS PROC MIXED (SAS 2011). Individual sheep were considered as the sample units, Day of Trial was the repeated measure term, and the experiment was replicated during two test periods where, Period 1 included Trials 1 and 2 and Period 2 included Trials 3 and 4. LGD presence, Day of Trial, and Collar Type were considered fixed effects in the model and Period was considered a random effect. Battery failures and other equipment malfunctions caused some GPS collars to fail before the conclusion of a trial. The data was non-normal due to high residuals. The samples with high residuals were subsequently excluded (n = 3) from further analysis. PROC MIXED was run with and without these outliers with little to no change in parameter estimates or effects. While this comparison demonstrated PROC MIXED was robust, the assumption of normality still needed to be met, thus the model is presented here without these outliers. A Tukey-Kramer adjustment was used to account for unequal sample sizes (SAS 2011) and a Shapiro-Wilk's test of normality was used to determine if residual of distance traveled met the statistical assumptions of these tests (SAS 2011).

2.3 Results and Discussion

All data used in the analysis met the Shapiro-Wilk's test of normality ($P > 0.05$). The results of PROC MIXED tests indicate no difference in distance traveled by sheep in the presence versus absence of LGDs on the first day of each trial ($P > 0.05$). However, using these same parameters for the second day of each trial revealed a difference in distance traveled by sheep relative to the presence of LGDs ($P < 0.05$). Looking at other interactions, PROC MIXED revealed a difference in distance traveled by sheep accompanied by LGDs, when tested as a single fixed effect, relative to those without LGDs present ($P < 0.05$), thus addressing the original question posed in this study; there is a difference in distance traveled by domestic sheep in the presence of LGDs relative to the distance traveled by sheep without LGDs present.

Collar type and day of trial were identified as potential factors explaining the recorded interaction of sheep and LGDs. Collar type was found to be significant ($P <0.05$), while collar type coupled with day of trial or LGD presence, and day of trial and LGD presence was not significant (P= 0.8409, 0.8911, and 0.9915 respectively). This indicates that collar type by itself is significant but has no effect on the interactions of LGD presence or day of trial. Collar type does not interact with day of trial or LGD presence, but was included in the model to limit uncertainty. Day of trial as a fixed effect alone (without LGD presence) was not a significant factor ($P = 0.97$).

Day of trial, along with LGD presence (as fixed effects) proved to be a significant factor ($P < 0.05$). This indicates that simply being in the pasture from day one to day two did not determine distance traveled. When day of trial was added as a fixed effect to LGD presence, no difference in distance traveled was found on day one, but on day two, a change in distance traveled was observed. Sheep accompanied by LGDs traveled farther on the second day than on the first day. The average distance traveled by sheep with LGDs present on day one of all trials was 7 517 m (SE=465), while on day two the distance increased to 8 210 m (SE=517). Sheep in groups without LGDs traveled less on day two of each trial. The average distance traveled by sheep without LGDs present on day one of each trial was 7 515 m (SE = 495), while on day two the distance decreased to 6 797 m (SE = 538).

The results of this study indicate there is a change in distance traveled by domestic sheep when LGDs are present. Sheep with LGDs traveled farther than those without LGDs. There are many factors that could help explain the observed activity. For example, sheep without LGDs may remain near areas previously proven safe from predators or may be trying to remain in closer proximity to other sheep (Sibbald et al 2008). Alternatively, sheep with LGDs may be more mobile as they spend less time being attentive of danger and more time grazing and moving.

Interestingly, results from a companion study exploring the speed profile of sheep show no significant difference in the proportion of time spent by sheep within different speed classes (stationary, mid-speed, and high speed) relative to the presence of LGDs. This is important to note because while sheep with LGDs traveled farther, they did not spend significantly more time travelling in faster speed classes. This supports the hypothesis that sheep with LGDs spend less time being vigilant for predators and more time slowly moving about and grazing. In speculation, the presence of LGDs may offer more than just protection for domestic livestock. Their presence may result in less restricted movement and decreased stress (Grandin 1998). While this study cannot show any direct positive impact on the general health of domestic sheep it does show that a sheep behavior (distance traveled) has been altered by the presence of LGDs.

2.4 Implications

Animals grazing in areas with high predator populations may continually be placed in situations of stress by either direct predation or fear memories of predation. This may have a negative impact on the overall health of livestock resulting in lower weight gains. The end result is an economic loss for the rancher and ultimately the nation. This study demonstrated the effect of the presence of LGDs on sheep movement and suggests that using LGDs may also reduce indirect effects associated with local predator populations. In addition, the observed changes in movement behavior may result in more effective use of pasture resources. This study offers insight into domestic animal interactions that may also help direct future studies.

Research by Grandin (1989, 1997, and 1998) and Coppinger (1983) has changed the way livestock are managed. This study offers another step toward improving the health of domestic livestock, as well as increase awareness of the benefits of LGDs. If the presence of LGDs is shown to increase weight gains, improve animal health, and increase lamb weaning weights, then the use of LGDs will carry increased economic importance to the livestock industry. While currently only speculation, these questions should be investigated in future studies.

CHAPTER 3: SPEED OF DOMESTIC SHEEP IN THE PRESENCE OF LIVESTOCK GUARDIAN DOGS

[The material presented in this chapter has been published as a white paper and hence is formatted here as a standalone paper.]

Abstract: The purpose of this study was to determine if the presence of livestock guardian dogs (LGDs) changes the behavior of domestic sheep in an environment where predators are common – specifically with respect to movement speed. To address this question, the percent time spent in three speed classes (stationary [< 0.09 m/sec], low-speed [0.09-2.2 m/sec], and high-speed [> 2.2 m/sec]) was measured and comparative statistics were used to determine if percent time spent in each speed class differs for sheep where LGDs are present/absent. This experiment was conducted using a repeated measures study of sheep and LGDs managed inside pastures enclosed by predator-proof fencing. Four 4-day trials were conducted and GPS collars were used to collect continuous (1 second) positional data of sheep and LGDs during the trials. Data were analyzed using a MIXED Procedure in SAS (PROC MIXED), which included percent time spent in each speed class; stationary, low, and high-speed class. LGD presence, day of trial, and collar type (two GPS collar types were used) were fixed effects, and period of the trial (repeated measure) was a random effect. The speed classes were reclassified to stationary (< 0.09 m/sec) and non-stationary because the high speed classes violated the assumptions of this test. There was no difference in time spent by speed classes relative to LGD presence (P = 0.35). As a result, we conclude the presence of LGDs does not cause a change in movement speed of domestic sheep.

3.1 Introduction

Livestock spending time at activities requiring greater speed will expend more energy than spending time at activities not requiring high speed. Additional time spent at high speed results in more energy expenditures which ultimately can result in lower health. Identifying factors that may limit time spent in high speed would be an important step to increasing the health of livestock.

The livestock industry is large and economically important. Large amounts of time, money, and energy are expended to help make breeding, raising, and selling livestock profitable. Predation is a key factor related to profitability in the livestock industry and ranching communities throughout the United States have made substantial economic investments in livestock protection (Berger 2005; Rashford et al 2010). Various methods have been used to reduce predation on livestock. Of these methods, LGDs have been widely considered most effective at reducing predation while also being the most cost effective for the producer (Andelt 1992, 1999; Black 1981; Coppinger et al 1983; Hansen et al 2002; Marker et al 2005; Rigg 2001; USDA Animal and Plant Health Inspection Service 1994). Even with reduced predation on livestock there may be undue stress placed upon these animals due to the presence of predators and fear memories of predator activities (Grandin 1998).

The efficacy of LGDs was the focus of a study by Marker *et al.* (2005) who studied 117 LGDs placed on Namibian Farms in Africa. Many of the farms in Namibia experienced high predation from protected animals such as the cheetah (*Acinonyx jubatus*). The protection status of these animals did not allow for predator removal by the ranchers. Of the ranchers surveyed, 79% reported LGDs performed as expected and 70%

indicated they saw an economic benefit to having an LGD. Ranchers receiving dogs had previously experienced high levels of livestock predation. After LGDs were placed with their herds, 70% of ranchers reported no losses to predation. Overall, 73% of ranchers in the Marker *et al.* study reported a substantial decrease in livestock lost to predation. Marker et al. (2005) showed the perceived effectiveness of LGDs at reducing predation on livestock but does not address if there are other benefits to using LGDs.

Successful predator reintroductions and management practices have resulted in livestock experiencing increased predation relative to that witnessed just a few decades ago. For example, in the Swiss Alps, wolves (*Canis lupus*) are recolonizing (Landry 1999) resulting in increased predation; while in Romania, rising wolf and brown bear (*Ursus arctos*) populations have resulted in increased predation on livestock equivalent to 10% of ranchers total expenses (Mertens and Promberger, 2001). In Kenya, sheep (*Ovis aries*) and goats (*Capra aegagrus*) are herded into bomas (stone, wooden, brush, or open bedding area) nightly yet predation, by large African predators, still occurred in 34 of 52 bomas studied by Ogada *et al.* (2003). Producers in Norway experience livestock predation (approximately 4,000 sheep annually from 40% of farmers in the study region) from brown bears (Zimmermann et al 2003) and in the western United States, wolves have been reintroduced, grizzly bear populations are growing, while coyotes (*Canis latrans*) remain the leading predator of livestock (approximately 61% of livestock lost to predation in 2000) (Blejwas et al 2002). Given all these threats to livestock, producers seek effective methods to reduce predation in a way that is economically feasible to their ranching business (Berger 2005).

While the reduction of livestock predation losses is of primary importance for producers, the effect of stress on livestock due to predator activity is also a concern. Grandin (1997, 1989) suggested stress can reduce the weight of livestock, decrease health, reduce weaning weights, and increase proportions of unusable meat. Grandin also reported that livestock that are stressed during certain situations will more readily become stressed under similar circumstances; this is called a fear memory. She concluded that reducing fear memories can improve general livestock health (Grandin 1998). Rashford *et al.* (2010) similarly suggested stress on livestock exposed to predators can lead to reduced weight gains in calves and negatively affect the health of these animals.

LGDs have proven to be effective at reducing predation on livestock (Andelt 1992, 1999; Black 1981; Coppinger et al 1983; Hansen et al 2002; Marker et al 2005; Rigg 2001; USDA Animal and Plant Health Inspection Service 1994). What is not clear however is if the use of LGDs modifies the behavior of livestock and thereby may also modify the effects of predator-related stress? The focus of this study was not to determine how effective LGDs are at reducing predation, but if the presence of LGDs changes movement activity of domestic sheep (speed).

3.2 Methods

3.2.1 Study Area

This study was conducted at the U.S. Sheep Experiment Station (USSES) located in East Idaho and Southwestern Montana. The USSES consists of five separate ranches totaling approximately 19 558 ha. These lands are used for spring, summer, and fall grazing with feed lots used year-round as necessary. The USSES maintains 3 000 adult sheep (Rambouillet, Targhee, Columbia, Polypay, Suffolk, and crossbreeds) with additional attending young (Laufman 2009).These sheep may be exposed to predation by grizzly bears, black bears (*Ursus americanus*), mountain lions (*Puma concolor*), grey wolves, and coyotes (Kozlowski 2009, Shivik 1996, Zimmermann 2003). Elevation at the USSES ranges from 1 463 meters to over 3 000 meters above sea level. USSES lands within the Snake River Plain of Idaho receive approximately 25 cm of precipitation annually.

The specific site selected for this study were four pastures (approximately 65 ha each in size) at the USSES Headquarters Property near Dubois, Idaho (Fig. 3.1). These pastures were fenced with predator-proof fencing. Annual plant production was relatively uniform and estimated to be 144 animal unit months (AUM) within each pasture. The primary plant community is three-tip sagebrush (*Artemisia tripartita*). Blue bunch wheatgrass (*Psuedoroegenaria spicata*) is the dominant grass species.

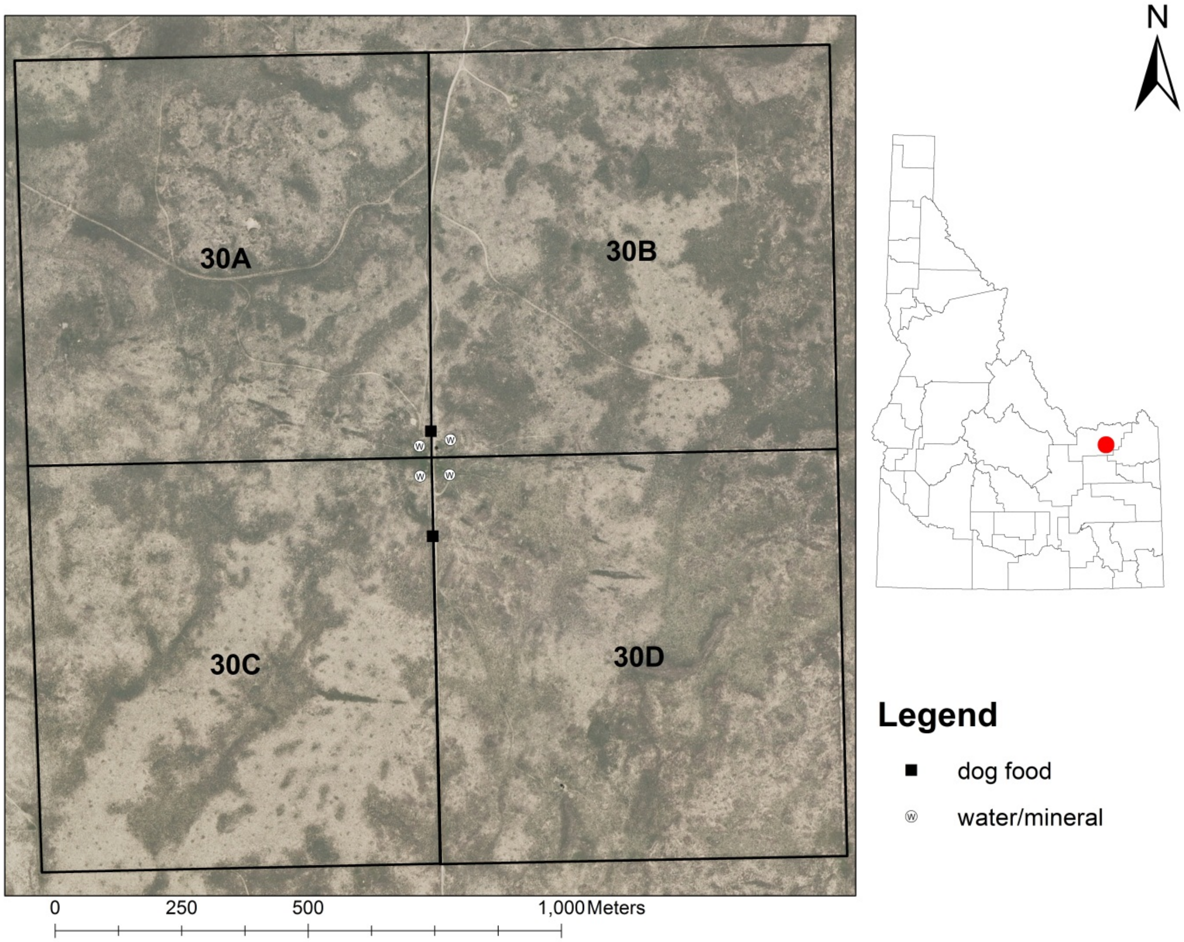

Figure 3.3 Map of four pastures (65 ha each), located at the U.S. Sheep Experiment Station near Dubois, Idaho. Pastures were enclosed with predator-proof fencing and used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence on the daily distance traveled by sheep grazing sagebrush steppe rangelands. Water/mineral supplement and dog food locations are marked.

3.2.2 Data Collection

Data was collected per the experimental designed described in detail in Chapter 2 of this document. The GPS (Global Navigation Satellite System) receivers collected positional and speed data at one second intervals in a repeated measures experimental design.

Table 3.2 Livestock guardian dog (LGD) treatment and pasture assignments for sheep behavioral trials conducted at the U.S. Sheep Experiment Station near Dubois in eastern Idaho during spring 2010.

Test Period	Trial	Start Date	End Date	Sheep Group	Pasture	LGDs
1	1	4/29/2010	4/30/2010	1	30D	Present
1	1	4/29/2010	4/30/2010	2	30A	Absent
1	2	5/2/2010	5/3/2010	1	30C	Absent
1	2	5/2/2010	5/3/2010	2	30B	Present
2	3	5/6/2010	5/7/2010	3	30A	Present
2	3	5/6/2010	5/7/2010	4	30D	Absent
2	4	5/9/2010	5/10/2010	3	30B	Absent
2	4	5/9/2010	5/10/2010	4	30C	Present

3.2.3 Data Processing and Analysis

Preliminary data processing was completed as described in Chapter 2. Additional processing and analysis are outlined below.

Using 24-hour periods (24 hr. period beginning at 0700:00 hours and ending at 2359:59 hours) for data collection, point feature classes were created for each individual sheep. This resulted in two full 24-hour periods (Day 1 and Day 2) for each sheep during each trial (n= 86 400 points per 24-hour period). On average only 0.27% of the points were removed from each 24-hour period because of GPS error. Speed were then sorted to exclude unrealistic speed (> 9 meters per second). The maximum number of points removed at this step was < 200 (0.23%) per daily collection period (n=86 400). Data were then classified into one of three speed classes; stationary (< 0.09 m/s), mid-speed (0.09 to 2.20 m/s), and high speed (2.20 to 9.0 m/s). This was accomplished using the Animal Classification Tool (ECT created by Michael Johnson of the University of California Santa Barbara).

A Mixed Procedure (PROC MIXED) statement to evaluate repeated measures (Baayen et al. 2006, Littell et al. 1998, Singer 1998, SAS 2011) was built in SAS statistical software taking into account LGD presence/absence, day of trial, and collar type in comparing time spent in a speed class. Individual sheep were used as the sample units and repeated measures corresponded with the two testing periods (testing period one included trials 1 and 2 and trials 3 and 4 were the repeated [second] testing period). LGD presence, Day of Trial, and Collar Type were considered fixed effects in the model and Period was considered a random effect. Battery failures and other equipment malfunctions caused some GPS collars to fail before the conclusion of a trial. Individual samples exhibiting extremely high residuals led to non-normality in the data set. These samples were subsequently excluded (n = 3) from further analysis. PROC MIXED was run with and without these outliers with little to no change in parameter estimates or effects. While this comparison demonstrated PROC MIXED was robust, the assumption of normality still needed to be met, thus the model is presented here without these outliers. A Tukey-Kramer adjustment was used to account for unequal sample sizes (SAS 2011) and a Shapiro-Wilk's test of normality was used to determine if residual of distance traveled met the statistical assumptions of these tests (SAS 2011).

3.3 Results and Discussion

Initial speed classes were reclassified into two classes; stationary and moving because the high-speed class did not meet the assumptions of normality through the Shapiro-Wilk's test ($P < 0.05$). The two resulting speed classes met the Shapiro-Wilk's test of normality ($P > 0.05$). PROC MIXED revealed there was no significant difference in percent time spent in speed classes by sheep accompanied by LGDs ($P > 0.35$).

Collar type and day of trial were also identified as factors that may contribute to observed interactions of sheep and LGDs. Collar type was not found to be significant but was included to reduce uncertainty of the model (P = 0.06), collar type coupled with day of trial or LGD presence, and day of trial and LGD presence were also not significant ($P > 0.05$ in all cases for both moving and stationary speed classes). This indicates that collar type by itself is significant but has no bearing on the interactions of LGD presence or day of trial. Collar type does not interact with day of trial or LGD presence, but was included in the model to characterize uncertainty. Day of trial as a fixed effect alone was not a significant factor (*P* = 0.27). Day of trial, along with LGD presence (as fixed effects) was also not significant (*P* = 0.35).

The results of this study indicate LGD presence has no effect on sheep movement speed. There are many factors that could help explain the observed activity Results from a Chapter 2 exploring distance traveled by sheep found significant difference in daily distance traveled by sheep relative to the presence of LGDs (Webber et al. 2012). This is important to note because while sheep with LGDs traveled farther, they did not spend significantly more time travelling in faster speed classes. Sheep spend more time moving but do so at speed consistent with normal grazing behavior. Between these studies inferences can be drawn that sheep may be spending more time grazing but this cannot be quantified using the data collected for this study

Based on these results, it is speculated that the presence of LGDs may offer more than just protection for domestic livestock. Their presence may result in less restricted movement and decreased stress (Grandin 1998). While these studies cannot show any direct positive impact on the general health of domestic sheep it does illustrate that sheep behavior (distance traveled) has been altered by the presence of LGDs.

3.4 Implications

Animals grazing in areas with high predator populations are chronically placed in situations of stress by either direct predation or fear memories of predation. This can have negative impacts on the overall health of livestock resulting in lower weight gains (Grandin 1998). The result is an economic loss for the rancher and ultimately the nation. This study demonstrated that while the presence of LGDs results in further distance traveled by sheep, their movement speed were indistinguishable when compared to groups of sheep without LGD’s. These results suggest that using LGDs may reduce the negative impacts associated with local predator populations and offers insight into domestic animal interactions that may help direct future studies.

Research by Grandin (1989, 1997, and 1998) and Coppinger (1983) has changed the way livestock are managed today. This study may ultimately offer an incremental step toward better understanding the interactions of domestic sheep and LGDs. If the presence of LGDs lowers livestock stress and as a result leads to increased weight gains, improved animal health, and increased lamb weaning weights, then the use of LGDs will carry increased economic importance to the livestock industry.

CHAPTER 4: CONSIDERATIONS FOR USE OF COLLAR MOUNTED GNSS RECEIVERS TO ANALYZE ANIMAL BEHAVIOR

[The material presented in this chapter has been published as a white paper and hence is formatted here as a standalone paper.]

Abstract: The use of GNSS (Global Navigation Satellite System) technology to analyze animal movements and behavior has become common practice. As with any technology proper experimental design is important to limit uncertainty. However the use of new technologies brings an additional consideration as a well-accepted experimental design may not exist. This paper addresses common problems associated with GNSS technology to analyze animal behavior using a case study by Webber et al. (2012). Issues addressed in this paper are 1) how GNSS receiver precision can be calculated, 2) receiver failures, 3) pseudo replication, and 4) spatial auto-correlation and sampling frequency. Using GIS, a precision assessment was calculated for two types of GNSS receivers. Horizontal precision was ± 4.45 m at 95% confidence interval (CI) and ± 3.56 m at 95% CI for receiver types one and two respectively. An overall failure rate of 79% was observed. By using a true repeated measures experiment, simple and sacrificial pseudo replication was eliminated. Lastly, the use of an appropriate statistical test (e.g., PROC MIXED) excludes implicit pseudo replication concerns. In this way, the experimental design and analysis techniques precluded the problematic issues of both pseudo replication and spatial auto-correlation.

4.1 Introduction

Methods to monitor animal location vary from observational position plotting, to radio telemetry, to collar mounted GNSS (Global Navigation Satellite System) receivers. The use of GNSS technology (Morehouse 2010, Woodside 2010) and radio telemetry (Shivik et al. 1996) to map and analyze animal activities has become common practice. Three types of GNSS receivers may be used; recreational-, mapping-, or survey-grade. Collar mounted GNSS receivers are typically considered either recreational- or mapping-grade receivers. Recreational-grade GNSS receivers cannot be differentially corrected and cannot achieve greater than ± 3 m precision, while mapping-grade receivers are differentiated by the ability to be differentially corrected (Ganskopp and Johnson 2007) and thereby achieve sub-meter precision. The precision of each receiver also depends on the chip set it contains as well as environmental factors encountered during the recording period.

The use of any methodology to plot animal locations requires an evaluation of positional uncertainty. Inferring action from a series of locations additionally requires an evaluation of sample frequency. Results from Johnson and Ganskopp (2008) demonstrated a positive relationship between the frequency of positional data collection and the precision of perceived animal activity measurements. In the Johnson and Ganskopp study sampling frequencies from five minutes to 160 minute intervals were used to measure distance traveled by each animal. Results illustrate a direct relationship between sampling frequency and the measurement of distance traveled. When sample frequency was raised from five minutes to ten minutes there was an approximate 12% decrease in overall distance traveled. As the frequency was raised to 160 minutes the estimated distance traveled was reduced by approximately 50% of the original five minute interval estimate. Measurement of distance traveled decreased as data frequency decreased but it is important to note as data collection frequency increases so does spatial autocorrelation, and the independence of a sample point. This study did not measure data collection at closer intervals than five minutes; in this way it could not determine when the points became so autocorrelated that there was no new data by the more frequent collection of points (e.g. - one second intervals or sub-second intervals).

In addition to positional uncertainty and sample frequency there is also concern of pseudo replication and spatial auto-correlation. Hurlbert (1984 and 2004) described pseudo replication by first identifying four types of pseudo replication; simple, sacrificial, Chi-square, and implicit pseudo replication. Simple pseudo replication is a non-replicated experiment. Sacrificial pseudo replication is where the experiment involves true replication but the data for the replicates is joined before statistical analysis or where more than one sample is taken from an experimental unit and treated as individual replicates, not subsamples. Chi-square pseudo replication is the misuse of the Chi-square test resulting in simple or sacrificial pseudo replication. Lastly, implicit pseudo replication involves using standard errors or confidence interval along with the mean to discuss effects of a variable in a non-replicated experiment without applying any direct tests of significance. Avoiding pseudo replication is important and needs to be considered at the experimental design stage of any study. It is important to note that some debate these guidelines and argue it is acceptable to use inferential statistics without replication (Oksanen 2001, Oksanen 2004, Cottenle and Meester 2003).

Spatial auto-correlation is also another relevant and important issue (Legendre 1993). Integrally tied to spatial auto-correlation is the independence of animal movements (Swihart and Slade 1997, Weber et al. 2001). Swihart and Slade (1997) described a method to determine independence of animal movements; they also state that independent observations contain more spatial information than auto-correlated observations. For instance, the measure of distance traveled may be directly affected because *where* an animal moves is effected by factors such as habitat (Dausrud et al 2006), the location of other animals (Animut et al 2005, Dausrud et al 2006, and Sibbald 2008), aspect, and slope. Once again experimental design is important to avoid issues of spatial auto-correlation as is the understanding that some types of auto-correlation may be unavoidable but are nonetheless important to be recognized.

To better understand these issues, a case study is introduced (Webber et al. 2003) where domestic sheep were fitted with collars carrying GNSS receivers to determine if the presence of livestock guardian dogs (LGD's) affect their behavior. This study was a manipulative study (Hurlbert 1984) consisting of four trials where each trial had a group of sheep with LGDs and another group where LGD's were absent. The experimental design used two replicated trials varying spatially or temporally. Within each of the four trials subsamples were taken of individual sheep and the movement and behavior of these sheep used to determine if a change in behavior was observed relative to LGD presence.

4.2 Methods

4.2.1 Study Area

The case study was conducted at the U.S. Sheep Experiment Station (USSES) located in East Idaho and Southwestern Montana. The USSES consists of five separate ranches totaling approximately 19558 ha. These lands were used for spring, summer, and fall grazing with feed lots used year-round as necessary. The USSES maintains 3000 adult sheep (Rambouillet, Targhee, Columbia, Polypay, Suffolk, and crossbreeds) with additional attending young (Laufman 2009).The sheep may be exposed to predation by grizzly bears (species), black bears (*Ursus americanus*), mountain lions (*Puma concolor*), grey wolves (species), and coyotes (species) (Kozlowski 2009, Shivik 1996, Zimmermann 2003). Elevation at the USSES ranges from 1463 meters to over 3000 meters above sea level. USSES lands within the Snake River Plain of Idaho receive approximately 25 cm of precipitation annually.

The specific site selected for this study were four pastures (approximately 65 ha each in size) at the USSES Headquarters Property near Dubois, Idaho (Fig. 4.1). These pastures were fenced with predator-proof fencing. Annual plant production was relatively uniform and estimated to be 144 animal unit months (AUM) within each pasture. The primary plant community is three-tip sagebrush (*Artemisia tripartita*). Blue bunch wheatgrass (*Psuedoroegenaria spicata*) is the dominant grass species.

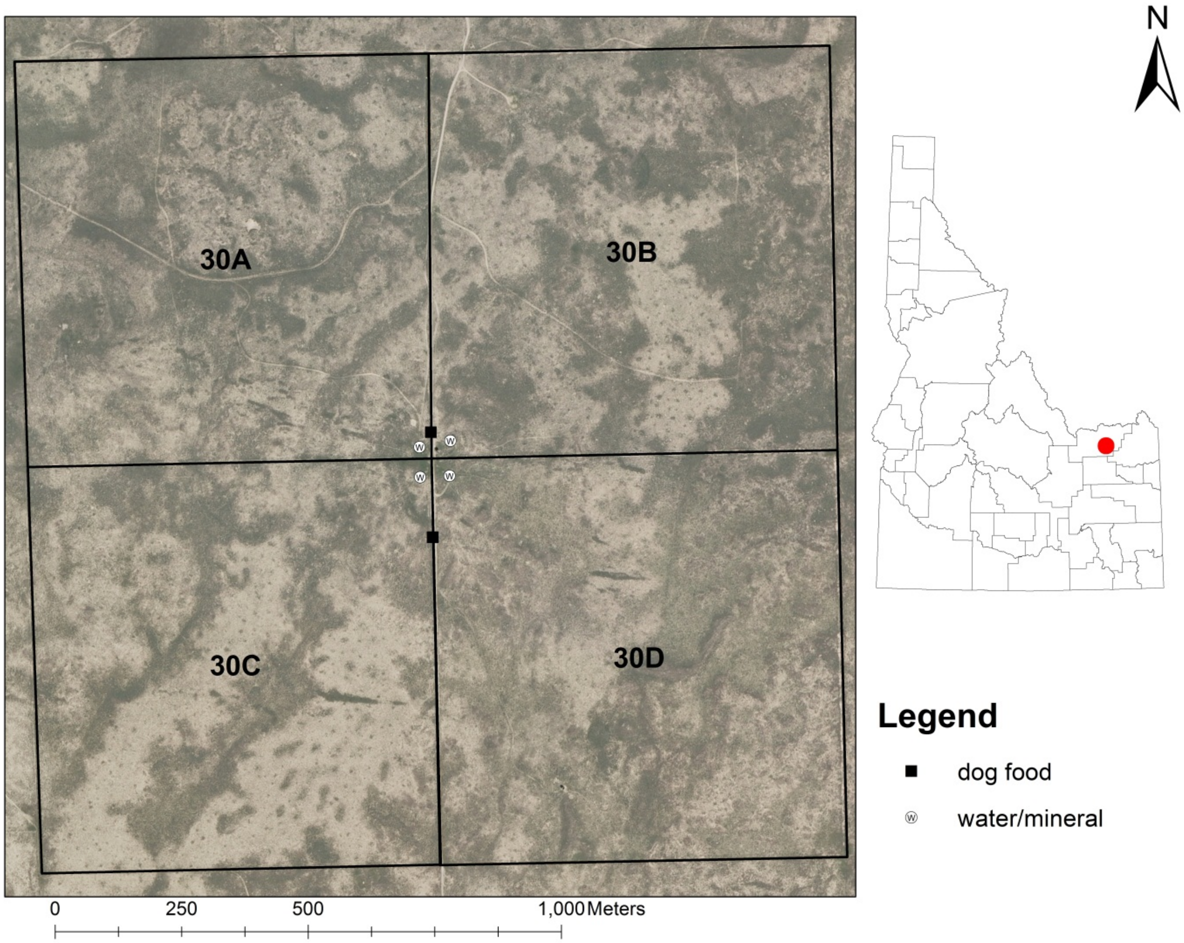

Figure 4.1 Map of four pastures (65 ha each), located at the U.S. Sheep Experiment Station near Dubois, Idaho. Pastures were enclosed with predator-proof fencing and used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence on the daily distance traveled by sheep grazing sagebrush steppe rangelands. Water/mineral supplement and dog food locations are marked

4.2.2 Experimental Design

With proper experimental design and true replication the problem of pseudo replication can be eliminated. In this case study 560 mature ewes and their suckling lambs (Targhee, Columbia, Polypay, or crossbreeds) --or about 19% of the USSES adult sheep population-- were used. These ewes were experienced with LGDs and, prior to the study had been continuously managed with them throughout all parts of the year. Ewes, with their attending lambs, were randomly assigned to four groups (Groups 1, 2, 3, and 4) of 140 ewes each. These groups were studied in specific trial periods called Trials 1, 2, 3, and 4 (described in more detail below). Groups 1 and 2 were used during Trials 1 and 2 (test period one) and Groups 3 and 4 were used during Trials 3 and 4 (test period two). During each trial, groups were placed in diagonally adjacent pastures, one group with two LGDs (an Akbash and an Akbash/Great Pyrenees cross) and one group without LGDs. At the end of each trial the sheep were moved to opposing pastures and the LGDs were placed with the previously unaccompanied group of sheep. Following trial two, the sheep were removed from the pastures and the experiment was replicated with the two independent groups of sheep and the same LGDs (table 4.1). This represented a true replication, where animals were not resampled but additional samples came from new groups of sheep.

Table 4.1 Livestock guardian dog (LGD) treatment and pasture assignments for sheep behavioral trials conducted at the U.S. Sheep Experiment Station near Dubois in eastern Idaho during spring 2010.

Test Period	Trial	Start Date	End Date	Sheep Group	Pasture	LGDs
1	1	4/29/2010	4/30/2010	1	30D	Present
1	1	4/29/2010	4/30/2010	2	30A	Absent
1	2	5/2/2010	5/3/2010	1	30C	Absent
1	2	5/2/2010	5/3/2010	2	30B	Present
2	3	5/6/2010	5/7/2010	3	30A	Present
2	3	5/6/2010	5/7/2010	4	30D	Absent
2	4	5/9/2010	5/10/2010	3	30B	Absent
2	4	5/9/2010	5/10/2010	4	30C	Present

4.2.3 Data Collection

Two GNSS receiver types were used and later determined to be distinguishable by their level of precision. All GNSS receivers were programmed to collect and record the collared sheep's location and speed at one-second intervals. The date and time of each location record along with additional quality parameters such as the number of GNSS satellites used to calculate the location were also recorded.

4.2.4 Positional Uncertainty and Receiver Failure Rates

Neither of the two GNSS receiver types used was differentially correctable. To determine their positional uncertainty, two GNSS receivers (one of each type) were attached to fence posts within the study area, and remained stationary throughout the entire study. These receivers were used to determine the precision of each type of GNSS receiver and were assumed to be representative of each receiver type. However, since only one sample of each collar type was used, measures of central tendency are not available for this case study. Using the ArcGIS spatial statistics tool (Directional Distribution using Standard Deviational Ellipse) positional uncertainty was calculated using two standard deviations about the mean resulting in an ellipse with 95% of observations falling within the ellipse.

Many factors effect receiver functionality such as physical impact and battery failure. Overall failure rate was calculated as was failure rate by sheep group. Batteries were replaced at the end of each test period and not when animals were moved between pastures.

4.3 Results and Discussion

The design strengths of this study are that its experimental design limited the treatment within the experiment to one, LGD presence, while still having replication within the experiment. A weakness of the study is that variation existed spatially (Hurlbert 1984). Since the experiment took place from 29 March 2010 to 10 April 2010 there is a period of temporal variability to be addressed. As a result, several related factors could play a role in altering animal behavior across this time period. One factor is varying weather conditions, another is the fact that the young lambs are aging and growing and may exhibit different nutritional demands between the beginning and end of the experiment period, thereby effecting the movement and behavior of the sheep, and yet another temporal factor is related to the phenology of forage in the pastures which can rapidly change in the active growth periods of the spring. The temporal issues of this study were minimized by completing the entire experiment in approximately one week.

Another weakness of this study's experimental design was that there is only one true replication within the study (test period two was a replicate of test period one).This was done to eliminate other errors such as having limited forage availability that would likely confound LGD effects.

By applying tests of significance (PROC MIXED) and having a true replicated study, both implicit and simple pseudo replication were eliminated (Hurlbert 1984, 2004). Chi-squared pseudo replication does not apply to this study or sacrificial pseudo replication because each trial was not treated as a repeated measure.

Calculated positional uncertainty was ± 4.45 m for receiver type one and ± 3.56 m for receiver type two (at 95% CI) (figure 4.2). The precision of GNSS receivers varied between types by almost one meter. Although this did not affect the outcome of the case study it had to be accounted for in the statistical model. This is important because an experiment tested with less rigor could make false inferences. It is recommended that only one receiver type be used in future studies to eliminate the receiver type effect.

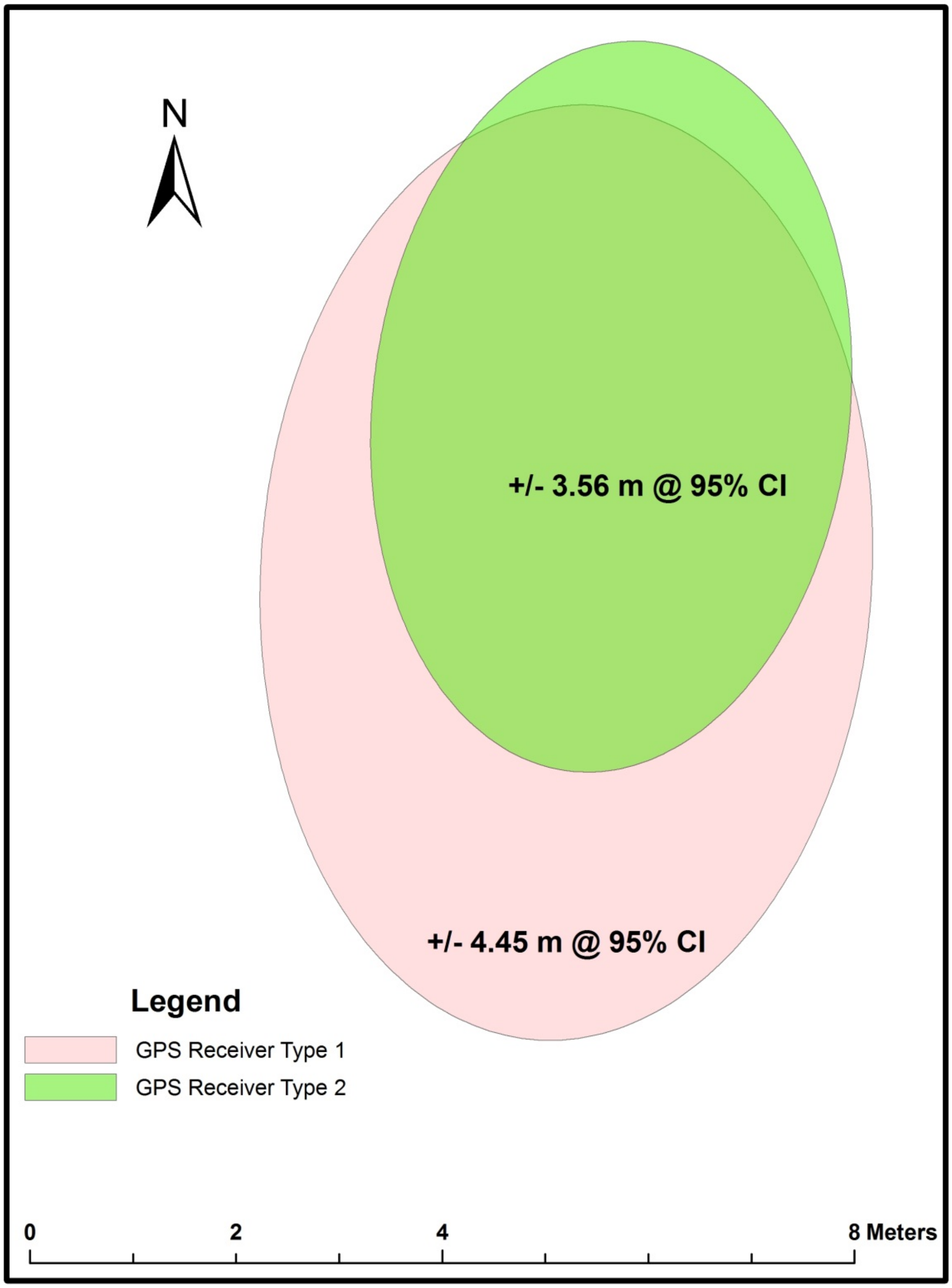

Figure 4.2 Standard deviational ellipses (two standard deviations) of type one and type two GNSS receivers representing 95% CI.

The high rate of GNSS receiver failures (79%) resulted in unequal sample sizes among trials (Table 4.2). For instance group one began with 11 functioning GNSS receivers on day one of trial one and ended with only four functioning receivers on day two of trial two. Failure rates by group were 60%, 67%, 100%, 88% (groups one through four, respectively).

Table 4.2 Number of functioning GNSS receivers at the end of each test period by receiver type.

	Test Period 1		Test Period 2	
	Start	End	Start	End
Type 1	16	8	15	1
Type 2	9	0	2	0

When conducting an experiment, planning and developing a robust experimental design is important. While not all problems can be foreseen (e.g., GNSS receiver failures) the experimental design needs to account for all known factors within the experiment. In addition, appropriate statistical analyses need to be selected which are complimentary of the study’s goals and structure of collected data. A well-developed statistical test should account for any weaknesses and these weaknesses and assumption plainly disclosed to the scientific community

4.4 Conclusion

When planning a manipulative experiment, the design of that experiment needs to be planned so that pseudo replication is reduced or eliminated. Other factors also need to be taken into account such as what type of positional precision or precision is required (i.e., is non-differentially corrected data sufficient). In addition it became very clear in the case study discussed here that only one type of GNSS receiver should be used and in addition, a large number of receivers should be available to accommodate equipment failure without jeopardizing the entire study. Sampling frequency and battery life should be balanced with battery changes planned accordingly.

CHAPTER 5: CONCLUSIONS

The results of this study indicate there is a change in distance traveled by domestic sheep when LGDs are present. Sheep with LGDs traveled farther than those without LGDs. There are many factors that could help explain the observed activity. For example, sheep without LGDs may remain near areas previously proven safe from predators or may be trying to remain in closer proximity to other sheep (Sibbald et al 2008). Alternatively, sheep with LGDs may be more mobile as they spend less time being attentive of danger and more time grazing and moving.

Interestingly, results from the study measuring the speed profile (Doppler based) of sheep show no significant difference in the proportion of time spent by sheep as stationary or non-stationary relative to the presence of LGDs. This is important to note because while sheep with LGDs traveled farther, they did not spend significantly more time travelling at a recognizable non-stationary speed. This supports the hypothesis that sheep with LGDs spend less time being vigilant for predators and more time slowly moving about and grazing. In speculation, the presence of LGDs may offer more than just protection for domestic livestock.

In speculation, the presence of LGDs may offer more than just protection for domestic livestock. Their presence may result in less restricted movement and decreased stress (Grandin 1998). While these studies cannot show any direct positive impact on the general health of domestic sheep it does illustrate that sheep behavior (distance traveled) has been altered by the presence of LGDs.

Animals grazing in areas with high predator populations are chronically placed in situations of stress by either direct predation or fear memories of predation. This can have negative impacts on the overall health of livestock resulting in lower weight gains (Grandin 1998). The result is an economic loss for the rancher and ultimately the nation. This study demonstrated that while the presence of LGDs results in further distance traveled by sheep, their movement speed were indistinguishable when compared to groups of sheep without LGD's. These results suggest that using LGDs may reduce the negative impacts associated with local predator populations and offers insight into domestic animal interactions that may help direct future studies.

Research by Grandin (1989, 1997, and 1998) and Coppinger (1983) has changed the way livestock are managed today. This study may ultimately offer an incremental step toward better understanding the interactions of domestic sheep and LGDs. If the presence of LGDs lowers livestock stress and as a result leads to increased weight gains, improved animal health, and increased lamb weaning weights, then the use of LGDs will carry increased economic importance to the livestock industry.

Although it is difficult to understand animal behavior using GNSS receivers these studies gives insight into how to design a successful experiment and also what problems may arise during the data analysis part of the study. The design of a manipulative experiment needs to be planned so that pseudo replication is reduced or eliminated. Other factors also need to be taken into account such as what type of positional accuracy or precision is required (i.e., is non-differentially corrected data sufficient). In addition it became very clear in this thesis research that only one type of GNSS receiver should be used and in addition, a large number of receivers should be available to accommodate equipment failure without jeopardizing the entire study. Sampling frequency and battery life should be balanced with battery changes planned accordingly.

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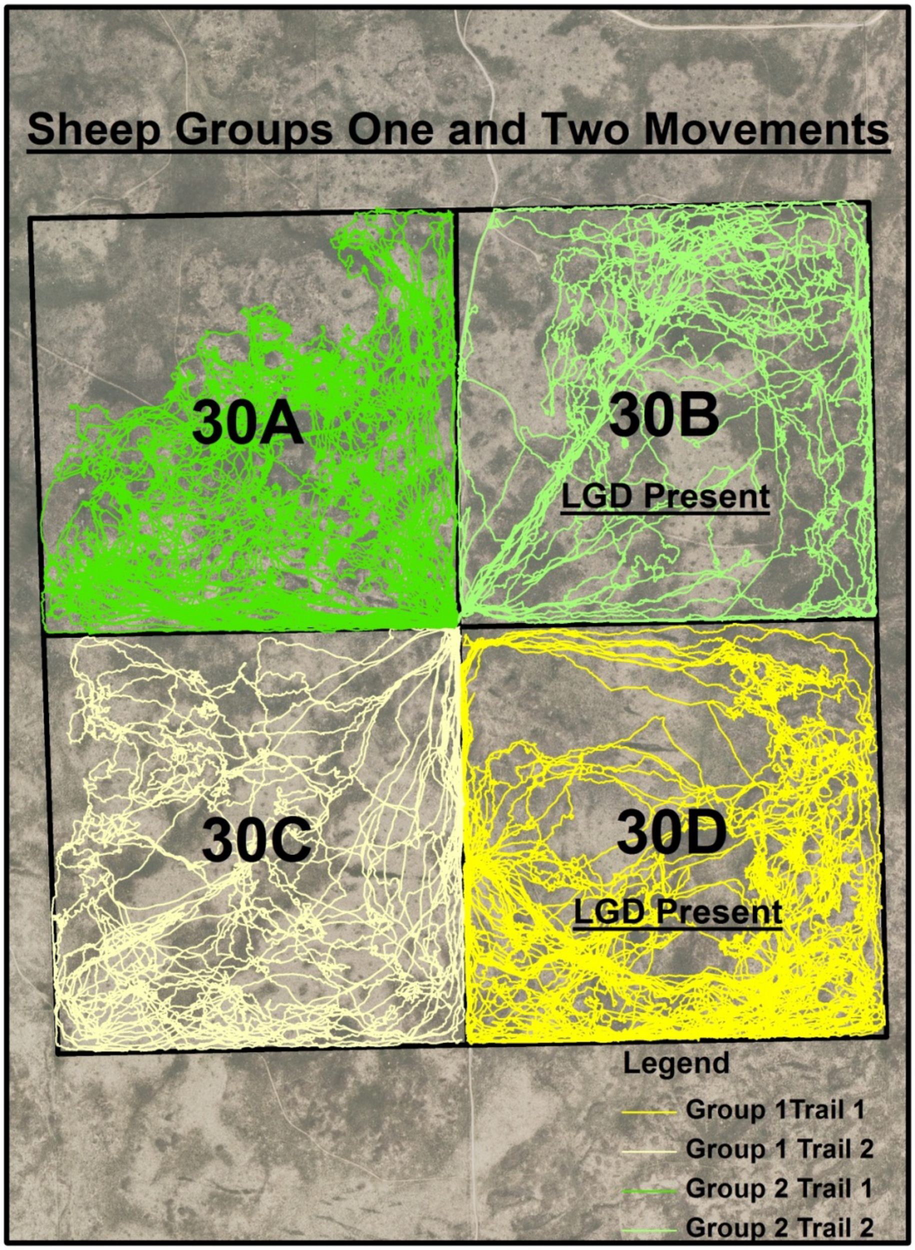
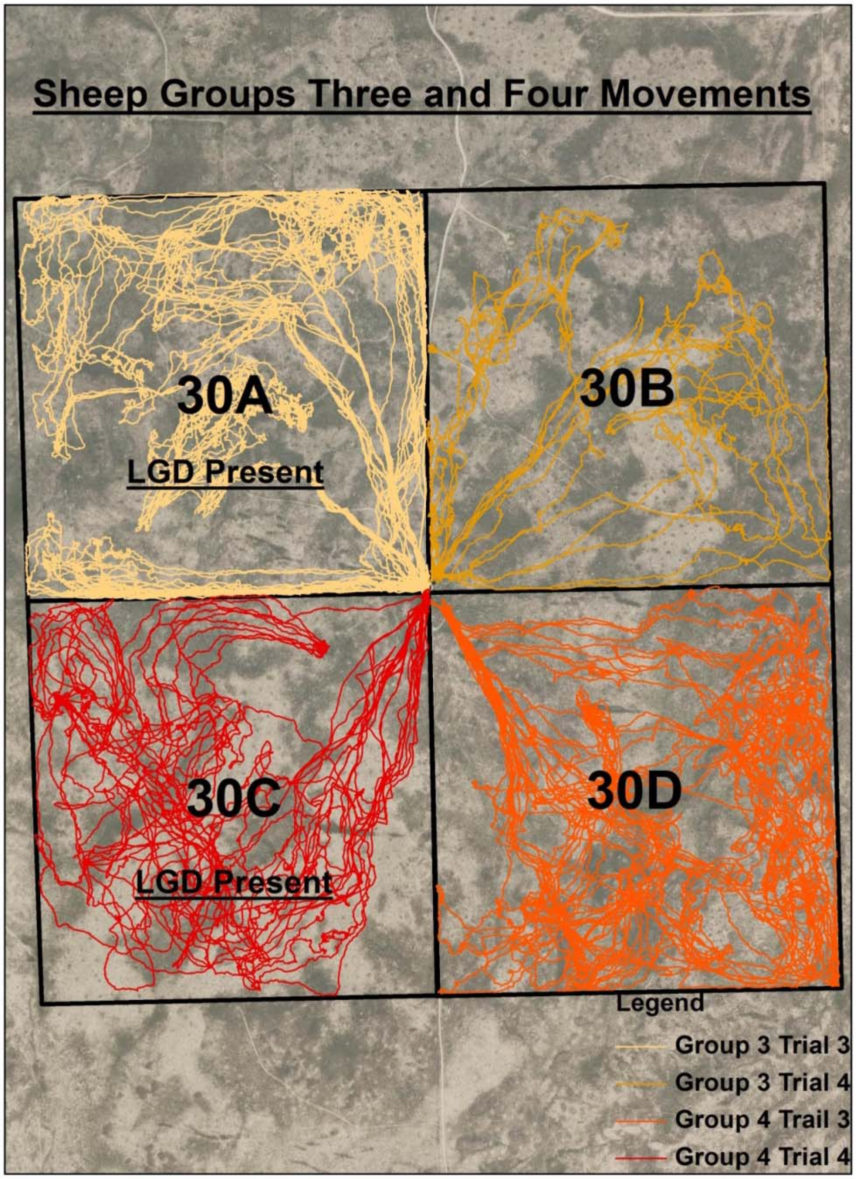
APPENDIX 1: SHEEP MOVEMENT IN ASSIGNED PASTURES

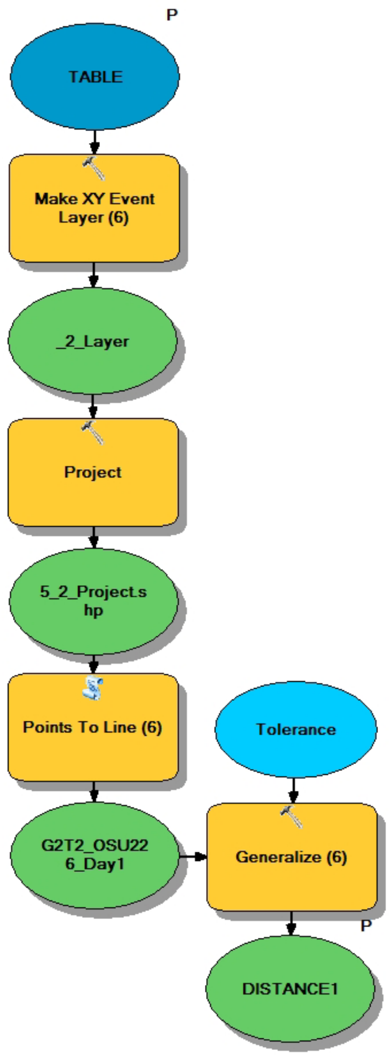


Map of four pastures within the US Sheep Experiment Station used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence by sheep grazing sagebrush steppe rangelands. Polylines are representative of movements of sheep groups one and two during trials one and two.



Map of four pastures within the US Sheep Experiment Station used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence by sheep grazing sagebrush steppe rangelands. Polylines are representative of movements of sheep groups three and four during trials three and four.

APPENDIX 2: DISTANCE CALCULATION WORK FLOW



Work flow used to derive distance of sheep movements using Esri's ArcGIS software.

APPENDIX 3: DAILY DISTANCE TRAVELED BY SHEEP

Spreadsheet showing sheep distance sheep traveled in meters by GPS receiver (collar number) collar type, sheep number (each individual sheep was assigned a number for evaluation), sheep group (group), trail number (trail), LGD presence, day of trail, and pasture used.

Collar Number	Collar Type	Sheep Number	Group	Trial	LGD Presence	Day of Trail	Pasture	Distance in Meters
131e	1	1	1	1	1	1	30D	5069
131e	1	1	1	1	1	2	30D	6422
131e	1	1	1	2	0	1	30C	6500
131e	1	1	1	2	0	2	30C	5698
131s	1	2	1	1	1	1	30D	4913
131s	1	2	1	1	1	2	30D	5239
131s	1	2	1	2	0	1	30C	7369
131s	1	2	1	2	0	2	30C	5274
132e	1	3	1	1	1	1	30D	6581
132e	1	3	1	1	1	2	30D	7135
132e	1	3	1	2	0	1	30C	8451
132e	1	3	1	2	0	2	30C	6038
132s	1	4	1	1	1	1	30D	7108
132s	1	4	1	1	1	2	30D	8947
132s	1	4	1	2	0	1	30C	10163
133s	1	5	1	1	1	1	30D	6110
133s	1	5	1	1	1	2	30D	8522
133s	1	5	1	2	0	1	30C	5914
134e	1	6	1	1	1	1	30D	4509
134e	1	6	1	1	1	2	30D	5432
134e	1	6	1	2	0	1	30C	4670
134s	1	7	2	1	0	1	30A	5408
134s	1	7	2	1	0	2	30A	5534
134s	1	7	2	2	1	1	30B	4852
135s	1	8	2	1	0	1	30A	4316
135s	1	8	2	1	0	2	30A	5182
136e	1	9	2	1	0	1	30A	3897
136e	1	9	2	1	0	2	30A	3839
136e	1	9	2	2	1	1	30B	4324

136e	1	9	2	2	1	2	30B	5036
136s	1	10	2	1	0	1	30B	4696
136s	1	10	2	1	0	2	30A	3285
136s	1	10	2	2	1	1	30B	6153
137e	1	11	2	1	0	1	30A	4925
137e	1	11	2	1	0	2	30A	4722
137e	1	11	2	2	1	1	30B	5481
137e	1	11	2	2	1	2	30B	3124
137s	1	12	2	1	0	1	30A	5525
137s	1	12	2	1	0	2	30A	5145
137s	1	12	2	2	1	1	30B	5507
137s	1	12	2	2	1	2	30B	6173
138e	1	13	2	1	0	1	30A	5363
138e	1	13	2	2	1	2	30B	5725
138s	1	14	2	1	0	1	30A	6422
138s	1	14	2	1	0	2	30A	6953
138s	1	14	2	2	1	1	30B	6590
140e	1	15	2	1	0	1	30A	6259
140e	1	15	2	1	0	2	30A	6341
140s	1	16	2	1	0	1	30A	4937
140s	1	16	2	1	0	2	30A	3759
140s	1	16	2	2	1	1	30B	6817
140s	1	16	2	2	1	2	30B	6106
osu202	2	17	1	1	1	1	30D	8520
osu202	2	17	1	1	1	2	30D	9282
osu203	2	18	1	1	1	1	30D	9449
osu203	2	18	1	1	1	2	30D	9873
osu203	2	18	1	2	0	1	30C	11751
osu204	2	19	1	1	1	1	30D	7987
osu204	2	19	1	1	1	2	30D	10082
osu205	2	20	1	1	1	1	30D	7787
osu205	2	20	1	1	1	2	30D	10726
osu222	2	21	2	1	0	1	30A	9690
osu222	2	21	2	1	0	2	30A	8417
osu222	2	21	2	2	1	1	30B	7663
osu223	2	22	2	1	0	1	30A	6715
osu223	2	22	2	1	0	2	30A	5986
osu223	2	22	2	2	1	1	30B	7942
osu224	2	23	2	1	0	1	30A	6278
osu224	2	23	2	1	0	2	30A	7555
osu224	2	23	2	2	1	1	30B	5956

osu225	2	24	2	1	0	1	30A	6443
osu225	2	24	2	1	0	2	30A	4322
131s	1	25	3	3	1	1	30A	5841
131s	1	25	3	3	1	2	30A	6565
131s	1	25	3	4	0	1	30B	6702
132e	1	26	3	3	1	1	30A	6428
132e	1	26	3	3	1	2	30A	8812
132s	1	27	3	3	1	1	30A	8346
133e	1	28	3	3	1	1	30A	8569
133e	1	28	3	3	1	2	30A	9649
133s	1	29	3	3	1	1	30A	5776
133s	1	29	3	3	1	2	30A	6880
133s	1	29	3	4	0	1	30B	4325
134s	1	30	3	3	1	1	30A	7310
134s	1	30	3	3	1	2	30A	8749
134s	1	30	3	4	0	1	30B	8058
135e	1	31	3	3	1	1	30A	7258
135e	1	31	3	3	1	2	30A	9497
135e	1	31	3	4	0	1	30B	5736
136s	1	32	4	3	0	1	30D	6919
136s	1	32	4	3	0	2	30D	4486
136s	1	32	4	4	1	1	30C	6163
137e	1	33	4	3	0	2	30D	7387
137e	1	33	4	4	1	1	30C	8634
137e	1	33	4	4	1	2	30C	7582
138e	1	34	4	3	0	1	30D	7697
138e	1	34	4	3	0	2	30D	6328
138e	1	34	4	4	1	1	30C	7326
138s	1	35	4	3	0	1	30D	5874
138s	1	35	4	3	0	2	30D	5015
138s	1	35	4	4	1	1	30C	7803
139e	1	36	4	3	0	1	30D	8343
139e	1	36	4	3	0	2	30D	6704
139e	1	36	4	4	1	1	30C	8579
139s	1	37	4	3	0	1	30D	7253
139s	1	37	4	3	0	2	30D	6202
139s	1	37	4	4	1	1	30C	6223
140e	1	38	4	3	0	1	30D	5882
140e	1	38	4	3	0	2	30D	6174
140e	1	38	4	4	1	1	30C	7426
140s	1	39	4	3	0	1	30D	7807

140s	1	39	4	3	0	2	30D	5309
140s	1	39	4	4	1	1	30C	5909
osu202	2	40	3	3	1	2	30A	6150
osu204	2	41	3	3	1	1	30A	9081
osu205	2	42	3	3	1	1	30A	7281
osu205	2	42	3	3	1	2	30A	8894
osu205	2	42	3	4	0	1	30B	6683
osu226	2	43	2	1	0	1	30A	10691
osu226	2	43	2	1	0	2	30A	11617
osu226	2	43	2	2	1	1	30B	11524
136e	1	44	4	4	1	1	30C	8256
133e	1	45	1	1	1	2	30D	8361
133e	1	45	1	2	0	1	30C	9617
133e	1	45	1	2	0	2	30C	8129

APPENDIX 4: SAS STATISTICAL MODEL

A Mixed Procedure statement to evaluate repeated measures was built in SAS statistical software taking into account LGD presence/absence, day of trial, and collar type in comparing time spent in a speed class. Individual sheep were used as the sample units and repeated measures corresponded with the two testing periods (testing period one included trials 1 and 2 and trials 3 and 4 were the repeated [second] testing period). LGD presence, Day of Trial, and Collar Type were considered fixed effects in the model and Period was considered a random effect. Individual samples exhibiting extremely high residuals led to non-normality in the data set. A Tukey-Kramer adjustment was used to account for unequal sample sizes

```
data one;
set work.sheepdist;
if group=1 then rep=1;
if group=2 then rep=1;
if group=3 then rep=2;
if group=4 then rep=2;
*if distance > 11000 then delete;

run;
proc mixed;
class sheep rep trial dog day collartype;
model distance=dog|day collartype /residual
/*outp=distres*/;
repeated trial*day/subject=sheep;
random rep;
lsmeans dog;
lsmeans collartype;
lsmeans dog*day/adjust=Tukey;
run;
proc univariate data=distres Normal;
var PearsonResid;
run; */
```

APPENDIX 5: SAS STATISTICAL RESULTS/OUTPUT DISTANCE

Appendix 5.1 Test for Significance

SAS output testing for significance of LGD presence for distance traveled of domestic sheep.

Model Information			
Data Set		Work.One	
Dependent Variable		Distance	
Covariance Structure		Variance Components	
Subject Effect		Sheep	
Estimation Method		REML	
Risidual Variance Method		Parameter	
Fixed Effects SE Method		Model-Based	
Degrees of Freedom Method		Containment	
Class Level Information			
Class	Levels	Values	
Sheep	43	1-45	
rep	2	1,2	
Trial	4	1,2,3,4	
dog	2	0,1	
day	2	1,2	
collartype	2	1,2	

Dimensions			
Covariance Parameters			2
Columns in X			27
Columns in Z			2
Subjects			1
Max obs Per Subject			125
Number of Observations			
Number of Observation Read			125
Number of Observations Used			125
Number of Observations Not Used			0
Covergence Criteria met.			
Covariance Parameter Estimates			
Cov Parm	Subject	Estimate	
rep		268672	
Trial*day	sheep	2396467	
Fit Statistics			
-2 Res Log Likelihood		2073.0	
AIC (smaller is better)		2077.0	
AICC (smaller is better)		2077.1	
BIC (smaller is better)		2074.4	

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
dog	1	116	4.23	0.0100
day	1	116	0.00	0.8565
dog*day	1	116	4.26	0.0119
collartype	1	116	37.02	<0.0001
dog*collartype	1	116	0.02	0.8911
day*collartype	1	116	0.04	0.8409
dog*day*collartype	1	116	0.00	0.9915

Least Squars Means							
Effect	dog	day	Estimate	Standard Error	DF	t Value	Pr > ItI
dog	0		7156.53	451.39	116	15.85	<.0001
dog	1		7863.72	434.45	116	18.10	<.0001
dog*day	0	1	7515.39	495.40	116	15.17	<.0001
dog*day	0	2	6797.68	538.50	116	12.62	<.0001
dog*day	1	1	7517.28	464.84	116	16.17	<.0001
dog*day	1	2	8210.17	517.12	116	15.88	<.0001

Differences of Least Squares Means											
Effect	dog	day	dog	day	Estimate	Standard Error	DF	t Value	Pr > ItI	Adjustment	Adj P
dog*day	0	1	0	2	717.71	505.76	116	1.42	0.1586	Tukey-Kramer	0.4901
dog*day	0	1	1	1	-1.8937	434.10	116	0.00	0.9965	Tukey-Kramer	1.0000
dog*day	0	2	1	2	-1412.49	530.75	116	-2.66	0.0089	Tukey-Kramer	0.0435
dog*day	1	1	1	2	-692.88	460.44	116	-1.50	0.1351	Tukey-Kramer	0.4379

Appendix 5.2 Test for Normality

SAS output for the test of Shapiro-Wilk test of normality of the data obtained from distance traveled of domestic sheep

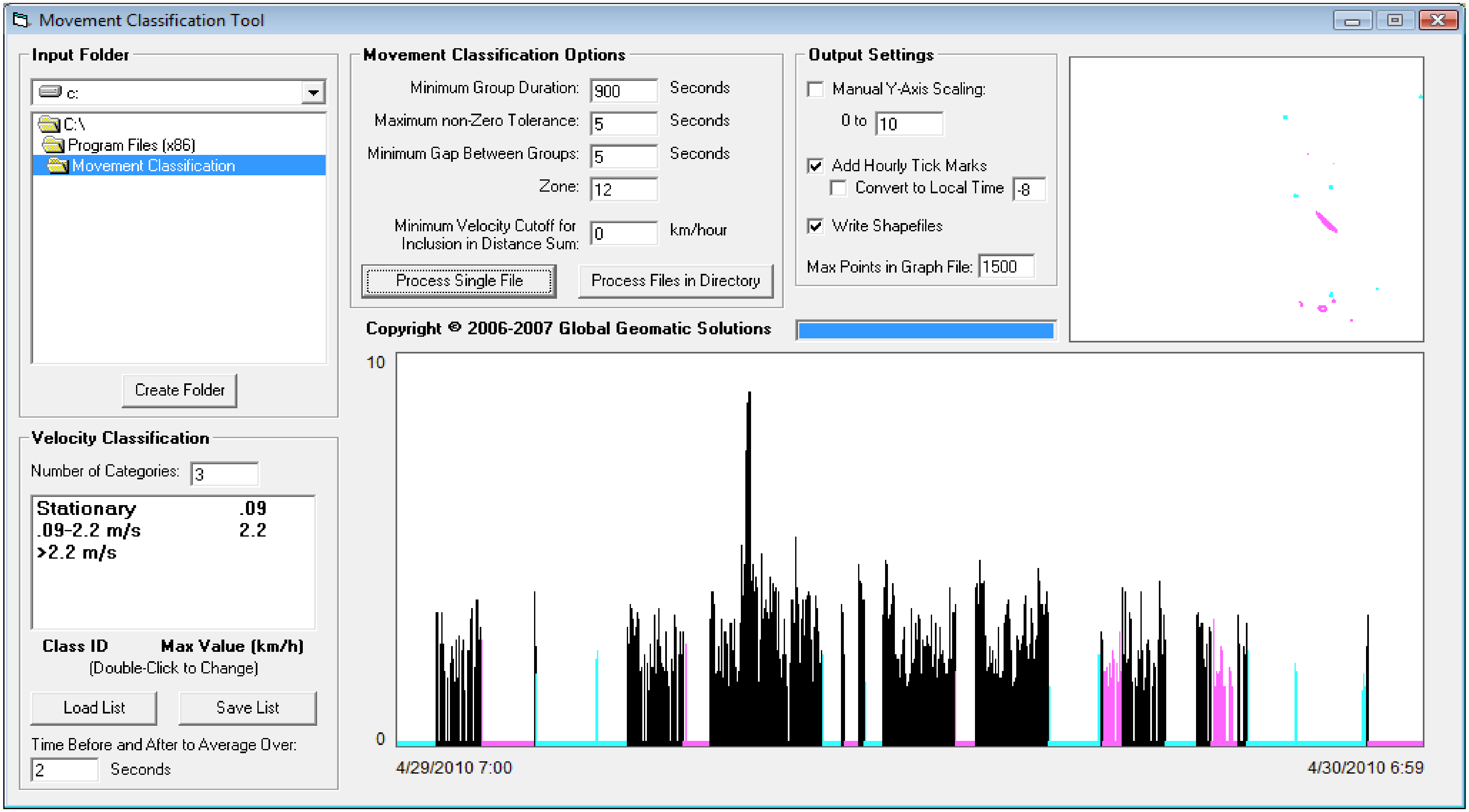
Test for Normality					
Test		Statistic		p Value	
Shapiro-Wilk		W	0.987734	Pr < W	0.3264
Kolmogorov-Smirnov		D	0.068715	Pr > D	>0.1500
Cramer-von Mises		W-Sq	0.057254	Pr > W-S	>0.2500
Anderson-Darling		A-Sq	0.404902	Pr > A-S(	>0.2500
Quantiles					
Quantile	Estimate				
100% Max	2.7141774				
99%	2.6418345				
95%	1.6103415				
90%	1.1802009				
75% Q3	0.6371209				
50% Median	-0.0236498				
25% Q1	-0.6889157				
10%	-1.1589066				
5%	-1.4565105				
1%	-2.2539007				
0% Min	-2.4091497				
Extreme Observations					
Lowest		Highest			
Value	Obs	Value	Obs		
-2.40915	37	2.14071	121		
-2.25390	114	2.28440	20		
-2.05691	72	2.30370	57		
-1.62348	83	2.64183	15		
-1.50146	70	2.71418	120		

Appendix 5.3 Group Significance Test

SAS output testing for significance of sheep group for distance traveled of domestic sheep.

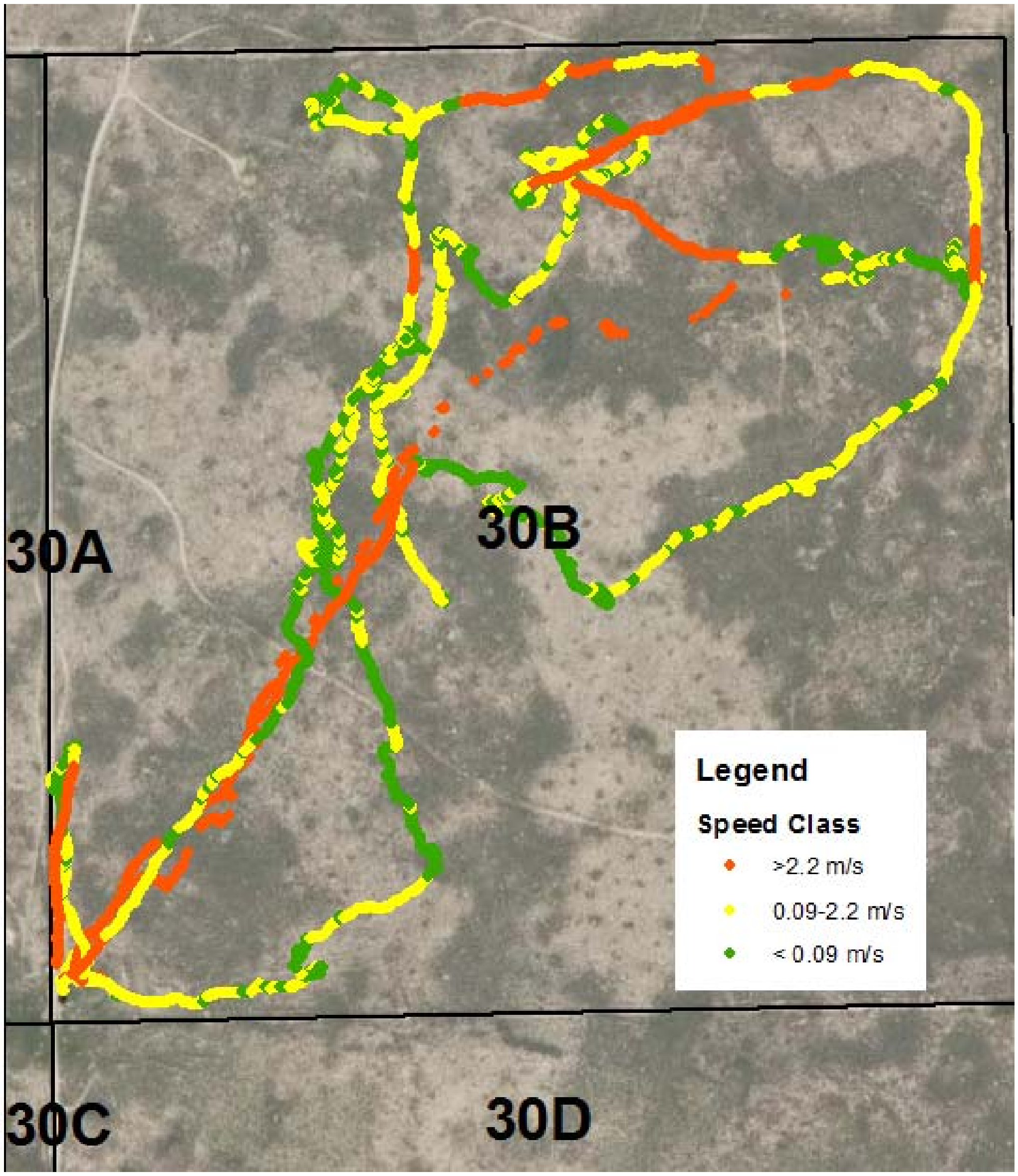
SAS				
The Mixed Procedure				
Null Model Likelihood Ratio Test				
	DF	Chi-Squared	Pr > ChiSq	
	0	0	1	
Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
dog	1	25	12.04	0.0019
day	1	35	0.07	0.7942
dog*day	1	7	6.4	0.0393
group	1	41	3.31	0.076
group*dog	1	25	0.94	0.3427
group*day	1	35	0.06	0.808
group*dog*day	1	7	0.01	0.9326

APPENDIX 6: ANIMAL MOVEMENT CLASSIFIER OUTPUT EXAMPLE



An example of the Animal Movement Classifier tool. Using this tool movement classes were determined. The tool also created resting polygons, and a graph showing movement and resting classes depicted by black bars for movement and pink and teal for resting areas.

APPENDIX 7: SHEEP SPEED EXAMPLE



Map of pasture 30B of four pastures within the US Sheep Experiment Station used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence by sheep grazing sagebrush steppe rangelands. Points are symbolizing speed classes used for speed evaluation.