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Evaluating the Effectiveness of Livestock Guardian Dogs: Loss-Prevention, Behavior, Space-Use, and Human Dimensions

Daniel Kinka

Utah State University

EVALUATING THE EFFECTIVENESS OF LIVESTOCK GUARDIAN DOGS:

LOSS-PREVENTION, BEHAVIOR, SPACE-USE,

AND HUMAN DIMENSIONS

by

Daniel Kinka

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Approved:

Julie K. Young, Ph.D. Major Professor	Daniel R. MacNulty, Ph.D. Committee Member
Lise M. Aubry, Ph.D. Committee Member	Zhao Ma, Ph.D. Committee Member
Douglas Jackson-Smith, Ph.D. Committee Member	Richard S. Inouye, Ph.D. Vice Provost for Graduate Studies

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ABSTRACT

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by

Daniel Kinka, Doctor of Philosophy

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Major Professor: Dr. Julie K. Young
Department: Wildland Resources

Livestock guardian dogs (LGDs; *Canis familiaris*) have been widely adopted by domestic sheep (*Ovis aries*) producers and reduce the need for lethal management of livestock predators. LGDs were originally used in the United States to reduce coyote (*Canis latrans*) depredations, but their efficacy against larger carnivores, including wolves (*Canis lupus*) and brown bears (*Ursus arctos*), is unclear. It is critical to identify which behavioral characteristics and LGD breeds are most effective at deterring different carnivores in order to maximize the utility of LGDs. Further, little attention has been given to how carnivores respond to sheep grazed with LGDs on open range, nor whether successfully using LGDs to reduce livestock depredations can increase tolerance for predators. This dissertation investigates the effectiveness of multiple LGD breeds in the Western U.S. to determine best management practices for LGDs. Assuming a broad definition of LGD effectiveness, I investigated (1) predator-specific loss prevention, (2)

breed-specific behavioral characteristics, (3) impact on the space use of endemic carnivore species, and (4) a potential mediating effect on tolerance for livestock predators. LGD breeds common in the U.S. were compared with three imported breeds currently underutilized in the U.S – Turkish kangals, Bulgarian karakachans, and Portuguese cão de gado transmontanos.. From 2013 – 2016 data were collected on cause-specific sheep mortality, LGD behavior, occupancy of carnivores near grazing sheep bands, and pastoralists' attitudes towards LGDs and large carnivores throughout Idaho, Montana, Oregon, Washington, and Wyoming. Results indicate that all three novel breeds of LGD offer greater protection from certain predators than mixed-breed LGDs commonly used in the U.S. Although largely similar behaviorally, some breed-specific differences in LGD behavior were also identified and may help ranchers and wildlife managers make tailored decisions about how best to select LGD breeds. Also discussed is the finding that sheep grazing with LGDs appear to displace wolves, while simultaneously attracting a host of smaller carnivores. A survey of pastoralists revealed that, although attitudes about LGDs are generally very positive, they do not temper attitudes towards wolves and grizzly bears. These and other findings are discussed in terms of broader ecological theory and management implications.

(219 pages)

PUBLIC ABSTRACT

Evaluating the Effectiveness of Livestock Guardian Dogs: Loss-prevention, Behavior, Space-use, and Human Dimensions

Daniel Kinka

Livestock guardian dogs – or “LGDs” – are commonly used by domestic sheep ranchers and reduce the need for killing wild carnivores to protect livestock. LGDs are mostly used in the United States to reduce the number of livestock killed by coyotes, but whether they can prevent killing by larger carnivores like wolves and grizzly bears is unclear. It is important to identify which behavioral traits and LGD breeds work best for guarding livestock so that ranchers can protect their stock and environmentalists can enjoy a greater number of wild animals on the landscape. This study investigated the effectiveness of different LGD breeds in the Western U.S. to help determine how best to use LGDs. I investigated (1) which LGD breed works best for each predator, (2) if LGD breeds behave differently, (3) how carnivores respond when LGDs and sheep move through their home ranges, and (4) whether having good LGDs makes ranchers more accepting of predators. I compared common U.S. breeds of LGD with three exotic breeds used primarily in other countries with wolves and grizzly bears. From 2013 – 2016 data was collected on sheep that were killed and what killed them, how different LGD breeds behaved, what carnivore species were present near sheep grazing with LGDs, and ranchers’ attitudes towards LGDs and large carnivores throughout Idaho, Montana, Oregon, Washington, and Wyoming. Results of the study show that all three of the exotic breeds of LGD are better at protecting sheep from certain predators than LGD breeds

commonly used in the U.S. There are also some breed differences in LGD behavior that may help ranchers make better decisions about which LGD breed is best for them. Sheep grazing with LGDs seemed to drive-off wolves, but they also attracted smaller carnivores. Also, ranchers' attitudes about LGDs are generally very positive, but they don't affect attitudes about wolves and grizzly bears. Below, I discuss these and other findings in terms of both ecology and wildlife management.

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Danny Kinka

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CHAPTER 1

INTRODUCTION

Livestock guardian dogs (LGDs) are domestic dogs (*Canis familiaris*) of a few dozen breeds that have been bred and trained to protect livestock from depredation, injury, and theft. LGDs (also sometimes referred to as livestock protection dogs or LPDs) enjoy a rich tradition in European history that dates back at least 5000 years (R. Coppinger and L. Coppinger, 2002; Gehring et al., 2010a; Rigg, 2001; Smith et al., 2000). A document written in 150 B.C. on Roman farm management describes the use of LGDs (Smith et al., 2000) and archaeological evidence show domestic sheep and dogs co-occurring long before that (Rigg, 2001). In fact, LGDs may represent one of the first instances of mutualism between humans and dogs, and along with hunting dogs, were probably some of the first domesticated dog breeds (see R. Coppinger and L. Coppinger, 2002). However, despite generations of use in Europe and Asia, the use of LGDs in other parts of the world is relatively new, and there is a paucity of scientific research on how they work (Gehring et al., 2010a). Coppinger and Coppinger (2002) suggest that this may have something to do with a bias among behavioral scientists against studying domestic species. However, it may also simply be an artifact of their longevity – their use and effectiveness may simply be taken for granted.

Just as pet dogs are able to establish a bond across a species boundary with humans, so too can an LGD be bonded with livestock and other non-human animals. A bond must be established within the first 12-16 weeks of a dog's life for LGDs to be effective guardians (Sims and Dawydiak, 2004). Puppies are separated from their

mothers shortly after they are weened and placed with young of the species to be protected (e.g., lambs). Contact with humans must also be carefully managed, as too much contact with people may result in a LGD that will not stay with livestock, while too little contact can result in a dog that cannot be handled. After an LGD is successfully bonded, guarding becomes an instinctual response. In fact, a good LGD will work completely independent of its handler, spending nearly all of its time with the species to which it has been bonded. Training of LGDs is usually limited to suppressing play behavior in juvenile LGDs that can result in injury to young livestock (Sims and Dawydiak, 2004), although some LGDs are also trained on basic commands or with leashes (Rigg, 2001; VerCauteren et al., 2012). Spaying and neutering animals is also recommended to prevent roaming (VerCauteren et al., 2012; 2008). A properly raised LGD can be trusted with livestock after 6-12 months, although most LGDs do not become competent guardians until about 2 years of age (van Bommel and Johnson, 2012). Having other, more experienced LGDs around to learn from is generally believed to increase the success of a new LGD as well (R. Coppinger et al., 1988; Sims and Dawydiak, 2004).

LGDs began to receive rigorous scientific attention in the United States (US) in the late-1970s when they were imported as a non-lethal alternative to poison for predator control (Feldman, 2007; C. Urbigkit and J. Urbigkit, 2010). Much of the early research on LGDs came from two sources: the US Sheep Experimental Station and Hampshire College. For the most part, this research was applied and largely intended to facilitate sheep producers' adoption of what was then a new technology in US ranching. Findings from the US Sheep Experimental Station are especially intended for agricultural

extension (see Green and Woodruff, 1990), while research out of Hampshire College is slightly more theoretical with regard to LGD behavior and ontogeny (see R. Coppinger et al., 1988). More recent research on LGDs has come from Australia, Europe, Africa, and South America, where investigations have been conducted on traditional and novel applications of LGDs (González et al., 2012; Hansen et al., 2002; Marker et al., 2005a; Rigg, 2002; van Bommel and Johnson, 2012).

LGDs can be used effectively to reduce livestock depredations (Andelt, 1992; Andelt and Hopper, 2000; Black and Green, 1984; Green et al., 1984). Andelt and Hopper (2000) showed that LGDs reduced domestic sheep (*Oves aries*) depredation, and that Colorado ranchers without LGDs lost between 2.1 and 5.9 times as many lambs as those who used LGDs. More recently, van Bommel and Johnson (2012) found that 98% of surveyed livestock producers in Australia reported a decrease in livestock depredations after acquiring LGDs. While primarily and historically used to guard sheep, LGDs have also shown some success guarding cattle *(Bos taurus*), although empirical findings are limited (Gehring et al., 2006; 2010b; VerCauteren et al., 2012). Despite much of the data on LGDs coming from rancher surveys and self-reports, it is generally concluded that LGDs are an effective tool for mitigating livestock depredations (Miller et al., 2016b; Scasta et al., 2017). Reported declines in depredation range between 11-100% (see Smith et al., 2000). Subsequently, LGDs save livestock producers money. In one study, the majority of livestock producers (89%) that had used LGDs felt they were cost effective and that savings from LGDs outweighed their costs in most cases (Green et al., 1984). Some producers reported saving up to $14,000 per year (in 1980s USD) through the use of LGDs (Green et al., 1984). In fact, van Bommel and Johnson (2012) found that the

cost of a LGD was usually fully offset by the value of livestock saved within 1–3 years of having a mature LGD (>2 years old).

Recent research on LGDs has expanded in inference to include investigations of LGD movements and space-use (van Bommel and Johnson, 2014a; 2014b; Webber, 2012; Zingaro et al., 2017), as well as their effect on wildlife communities (van Bommel and Johnson, 2016). For instance, van Bommel and Johnson (2014b) showed that LGDs outfitted with GPS collars spent most their time in close proximity to the sheep they were guarding, but occasionally made high-speed excursions away from the flock. LGDs were most active at dawn and dusk with lower levels of activity throughout the night, roughly corresponding to the activity patterns of predators in the area. LGDs also modified their responses to predators based on their proximity to sheep, travelling farther from the flock when predator incursions were closer (van Bommel and Johnson, 2014a). In a somewhat related study, Webber (2012) examined the space-use patterns of sheep in relation to LGD presence. By outfitting domestic sheep with GPS collars, this study found a small but significant difference in the average distance sheep traveled in a day with and without LGDs. Another study by van Bommel et. al. (2016), identified spatial and temporal avoidance of LGDs by large herbivores and red foxes (*Vulpes vulpes*), marking a first step in investigating LGDs as ecological actors. These recent investigations provide novel insight into the broader science of LGDs, but are limited in scale and inference. The van Bommel et. al. studies (2016; 2014b; 2014a) examined only the Maremma breed of LGD under one type of livestock operation, and it is unclear whether these findings can be generalized to all LGDs and operations.

While still primarily used as a tool to protect livestock, LGDs are increasingly

being used for a range of conservation efforts. Perhaps most notably, the Kangal breed of LGD has been used in Namibia to reduce lethal removal of cheetahs (*Acinonyx jubatus*). Farmers with Kangals there report reductions in number of livestock lost to all predators, high satisfaction with their LGDs, and a significant reduction in the number of cheetahs killed in retaliation (Marker et al., 2005a; 2005b; Potgieter et al., 2015). Use of LGDs was also found to reduce self-reported incidence of predator killings among shepherds in the Patagonia region of Argentina, with 88% of those interviewed reporting a cessation in killing carnivores after using LGDs (González et al., 2012). Further, while LGD use can indirectly protect sensitive carnivore populations by reducing retaliatory killing, LGDs can also protect sensitive wild species directly from depredation. After Maremma LGDs were placed on an island with a population of little penguins (*Eudyptula minor*) subjected to intense predation by introduced red foxes, depredations ceased completely and the population of breeding penguins subsequently increased (King et al., 2015). This case study illustrates the potential for using LGDs as a tool to reduce depredation of sensitive wild species.

Lacking in LGD research is a more thorough assessment of how they protect livestock from larger carnivores. LGD breeds initially selected for use in the US were selected at a time when wolves (*Canis lupus*) were almost entirely absent from the landscape (Bangs et al., 2005) and sheep depredations by brown bears (*Ursus arctos*) and cougars (*Puma concolor*) were rare and poorly documented (Gehring et al., 2010a; Smith et al., 2000; C. Urbigkit and J. Urbigkit, 2010). Most of the literature on LGD use in the US pre-dates the reintroduction of wolves and the expansion of brown bear and cougar populations in the Northern Rocky Mountains. Although LGDs have been used to guard

against large carnivores for centuries in other parts of the world, their effectiveness deterring large North American carnivores has not been scientifically evaluated. To the extent that LGDs deter depredation of livestock, and potentially reduce the need for lethal removal of carnivores, they are an asset to conservation efforts, increasing the sustainability of ranching and promoting good stewardship of natural resources. However, if LGDs currently used in the US are ineffective at deterring depredations from large carnivores, then they are of limited use to the rancher or the conservationist. The long tradition of LGD use in countries with wolves, brown bears, and large felids suggests that LGDs have the potential to be an effective deterrent to larger carnivores, but the supposition has gone largely untested.

Also lacking in the extant literature on LGDs is a direct comparison of LGD breeds. Internationally, there are 30-40 described breeds of LGD (Rigg, 2001). The Great Pyrenees is probably the most popular breed in the US, along with the Akbash, Maremma, Anatolian shepherd, and Komondor (Andelt and Hopper, 2000; Green et al., 1984; Green and Woodruff, 1980), although many LGDs in the US are genetic crosses of these and other breeds. Mongrel and mixed breed LGDs have been successfully used to guard livestock (Black and Green, 1984; R. Coppinger et al., 1985; González et al., 2012), although there is some evidence to suggest that they are more likely to injure livestock (C. Tepelli, unpublished) and they may be wholly ineffective when genetic origin is unknown (Khorozyan et al., 2017). Although limited, some research has sought to identify LGD breed differences. While self-report data was unable to detect any breed differences in LGD loss-prevention some specific behavioral differences were identified (Black and Green, 1984; R. Coppinger et al., 1988; Green and Woodruff, 1988; 1983).

Nevertheless, LGD breeds and crosses currently used in the US may not be well-suited to dealing with large carnivores (R. Coppinger et al., 1988; C. Urbigkit and J. Urbigkit, 2010). Accumulated anecdotal evidence gathered from ranchers suggest that the LGD breeds currently used may not be sufficient to defend sheep from larger carnivores like wolves and brown bears (C. Urbigkit and J. Urbigkit, 2010).

In addition to much-needed research on predator-specific effectiveness among LGD breeds, LGD research could be greatly improved through a more rigorous collection of data regarding their effectiveness at mitigating livestock depredations. Survey and self-report techniques have been useful for gauging LGD effectiveness in the past, but this kind of data suffers from recall bias (Bradburn et al., 1987). Further, discerning cause of death from livestock carcasses can be extremely difficult, especially if carcasses are not discovered immediately, making self-reports of cause-specific livestock mortality susceptible to bias from inexperience and prejudice towards certain carnivores (Hazzah et al., 2009). Especially when investigating predator-specific effectiveness of LGDs, an empirical approach to assessing livestock mortality is vital. Two chapters of this dissertation directly compare breeds. The first study herein investigates predator-specific efficacy of three LGD breeds and takes advantage of rigorous cause of death methodology (Chapter 1). The second study in this dissertation (Chapter 2) investigates behavior differences of four breeds of LGD that are directly relate to guarding ability and loss-prevention.

Another way in which my research addresses gaps in the LGD literature is by measuring responses of large carnivore species to the presence of LGDs. van Bommel et. al. (2016), were the first to investigate LGDs' effect on endemic species on the

landscape, but mostly on herbivores, and their work does not address LGDs' effect on large carnivores. For instance, it is generally accepted that LGDs are a non-lethal tool for predator control and thus a useful tool for bridging the gap between large carnivore conservation and livestock damage control (Shivik, 2006). However, while it is somewhat intuitive that LGDs should reduce the need for lethal control of predators, the impact of LGDs on carnivore ecology has been largely ignored. Presumably, grazing sheep act as an attractant to carnivores, but it is unclear whether the addition of LGDs ultimately attracts or displaces livestock predators. Through the collection of spatial and occupancy data on LGDs, sheep, and a host of North American carnivores, Chapter 3 sheds some light on the spatial impacts of LGDs and domestic sheep on endemic carnivore species.

Lastly, my study is novel in its use of socio-ecological constructs to investigate how LGDs fit into human-dimensions research on large carnivores. There have been a number of studies that have gauged livestock producers' attitudes towards LGDs (for instance Andelt and Hopper, 2000; Marker et al., 2005b; Rust et al., 2013; Scasta et al., 2017) or attitudes towards predators (Berry et al., 2016; Knopff et al., 2016; Miller et al., 2016a), but few have attempted to link these attitudes towards larger constructs of tolerance and acceptance for wildlife (see Bruskotter and Wilson, 2013). To the extent that past behaviors and attitudes influence behavioral intentions (Fishbein and Ajzen, 2009) it may be that a positive opinion of LGDs mitigates intolerance for large carnivores amongst pastoralists. Chapter 4 discusses the use of a small survey of North American pastoralists to compare how attitudes towards LGDs are related to attitudes towards wolves and brown bears.

Non-lethal management tools are somewhat unique, in that they may have the potential to bridge a divide between utilitarian and conservationist stakeholder groups. When optimized, non-lethal tools reduce livestock depredation and wildlife conflict. They also provide an alternative to lethal management of charismatic carnivores. However, absent the knowledge of how best to use a particular management tool, any tool is of limited use, regardless of the user. LGDs show great potential as a non-lethal management tool for reducing human-wildlife conflict, if for no other reason than their historical legacy, which extends back millennia. However, we still know very little about how LGDs work, in what contexts they work best, and the extent of their usefulness. In the following chapters I provide new evidence concerning (1) sheep survival as a function of both LGD breed and predator species, (2) breed-specific differences in LGD behavior related to guarding, (3) LGDs' effect on the space use of a host of North American carnivore species, and (4) pastoralists' attitudes towards LGDs, and whether or not they modify tolerance for large carnivores. Considered singly, each can inform ranchers and wildlife managers on how to make better use of LGDs as a loss-prevention or conservation tool. Taken summarily, this dissertation takes our scientific understanding of LGDs a considerable step further, and suggests a number of potential new research paths.

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CHAPTER 2

EVALUATING DOMESTIC SHEEP SURVIVAL WITH DIFFERENT BREEDS OF LIVESTOCK GUARDIAN DOGS[1]

Abstract

Livestock guard dogs (LGDs; *Canis familiaris*) have been widely adopted by domestic sheep (*Ovis aries*) producers because they reduce predation by wild carnivores. LGDs were originally used in the United States to reduce coyote (*Canis latrans*) depredations, but their efficacy against a suite of large carnivores, including wolves (*Canis lupus*), brown bears (*Ursus arctos*), black bears (*Ursus americanus*), and cougars (*Puma concolor*), and whether specific breeds perform better than others remains unclear. To assess breed-specific effectiveness at reducing depredations from a suite of livestock predators, we compared survival rates of sheep protected by different breeds of LGDs, including three breeds from Europe (Turkish kangal, Bulgarian karakachan, and Portuguese cão de gado transmontano) and mixed-breed LGDs, "whitedog," common to the U.S. With the help of participating sheep producers, we collected cause-specific mortality data from domestic sheep in Idaho, Montana, Oregon, and Wyoming between 2013 and 2016. All three of the novel breeds of LGD tested were associated with overall reductions in sheep depredation relative to whitedogs, ranging from 61 – 95% ($p < 0.05$). In terms of predator-specific effectiveness, the Turkish kangal was associated with decreases in depredation from cougars ($e^{\beta} = 0.31$, 95% CI = 0.10 – 0.94, $p = 0.04$), black

[1]Co-authored with Julie K. Young

bears (e^{β} = 0.33, 95% CI = 0.28 – 0.37, p < 0.01), and coyotes (e^{β} = 0.56, 95% CI = 0.35 – 0.90, p = 0.02). The Bulgarian karakachan was associated with a decrease in coyote depredations (e^{β} = 0.07, 95% CI = 0.01 – 0.49, p < 0.01). The Portuguese transmontano was not associated with significant reductions in depredation hazard for any specific predator. Although variations in breed-specific effectiveness were subtle and nuanced, these findings will help livestock producers and wildlife managers make tailored decisions about how best to incorporate different breeds of LGD into sheep grazing regimes.

Introduction

Livestock guardian dogs (LGDs) are domestic dogs (*Canis familiaris*) of a few dozen breeds that have been bred and trained to protect livestock from depredation, injury, and theft. LGDs are effective at reducing depredations by a number of carnivores, including coyotes (*Canis latrans*; Andelt and Hopper, 2000), dingoes (*Canis lupus dingo*; van Bommel and Johnson, 2012), black bears (*Ursus americanus*; Smith et al., 2000), and cheetahs (*Acinonyx jubatus*; Marker et al., 2005). They enjoy a rich tradition in European history that dates back at least 5,000 years (Coppinger and Coppinger, 2002; Gehring et al., 2010; Rigg, 2001; Smith et al., 2000) but were first imported to the United States (US) in the 1970s as a substitute for lethal predator control (Feldman, 2007). Scientific research on LGDs began at about the same time and indicates that LGDs are one of the few non-lethal management techniques that both reduce domestic sheep (*Ovis aries*) depredations (Andelt, 1992; Andelt and Hopper, 2000; Black and Green, 1984; Green et al., 1984; Hansen et al., 2002; Rigg, 2002; Smith et al., 2000; van Bommel and Johnson,

2012) and provide long-term results (Shivik, 2006). As such, it is generally concluded that LGDs are an effective tool for mitigation of livestock depredations, with reported declines in depredation between 11-100% (Smith et al., 2000). Consequently, the use of LGDs for reducing livestock depredations has been widely adopted by sheep producers in the USA.

LGD breeds initially selected for use in the USA were chosen at a time when wolves (*Canis lupus*) were almost entirely absent from the landscape (Bangs et al., 2005) and sheep depredations by brown bears (*Ursus arctos*) and cougars (*Puma concolor*) were rare or poorly documented (Gehring et al., 2010; Smith et al., 2000; Urbigkit and Urbigkit, 2010). Further, most of the literature on LGD use in the USA pre-dates the reintroduction of wolves and the expansion of brown bear and cougar populations in the Northern Rocky Mountains. Since then, depredations by large carnivores have allegedly caused some sheep ranchers to sell their remaining herds (National Agricultural Statistics Service, 2013; 2011), limiting the viability of rural communities that depend on agricultural competitiveness. In turn, declines in the number of livestock producers may impede conservation of large carnivores that rely on relatively undeveloped private rangelands, as the desertion of agriculture leads to increasing landscape fragmentation (Hobbs et al., 2008). Although pastoralists have used LGDs to guard against large carnivores for centuries, LGDs' effectiveness deterring large carnivores has not been scientifically evaluated outside of some work using LGDs to promote cheetah conservation (Marker et al., 2005). LGDs are sometimes killed by wolves (Bangs et al., 2005) and there is also evidence that LGDs sometimes kill wolves (Tepeli and Taylor, 2008), but beyond this, little is known about how effective LGDs are at deterring large

carnivores or whether efficacy varies among different breeds of LGDs.

Scientists have given little attention to potential LGD breed differences in predator-specific deterrence. Some researchers have sought to identify differences among LGD breeds – most commonly measured in terms of behavior (i.e., trustworthiness, attentiveness, and protectiveness) or rancher-reported depredation loss – and although significant differences in depredation were not detected, behavioral differences were identified (Black and Green, 1984; Coppinger et al., 1988; Green and Woodruff, 1988; 1983; Kinka and Young, 2017). These behavioral differences may extend into efficacy against large carnivores, but anecdotal evidence suggests LGD breeds and crosses currently used in the USA may not be well-suited to dealing with large carnivores (Coppinger et al., 1988; Urbigkit and Urbigkit, 2010). Meanwhile, there are LGD breeds in Europe and Asia that are currently underutilized in the US, and many of them have long histories of deterring large carnivores in their native countries (Rigg, 2001; Urbigkit and Urbigkit, 2010).

Despite this paucity of research regarding efficacy against large carnivores, LGDs continue to be accepted as a useful non-lethal management technique for bridging the gap between carnivore conservation and livestock damage control (Gehring et al., 2010; Shivik, 2006). In fact, they may have a mediating effect on tolerance for predators (Rust et al., 2013) and reduce the retaliatory killing of certain endangered carnivores (González et al., 2012; Marker et al., 2005). To the extent that LGDs deter depredation of livestock, and potentially reduce the need for lethal removal of carnivores, they are an asset to conservation efforts, increasing the sustainability of ranching and promoting good stewardship of natural resources. However, if LGDs currently used in the USA are

ineffective at deterring depredations from large carnivores, then they are of limited use to ranchers and conservationists. The long tradition of LGD use in European countries with wolves, brown bears, and large felids suggests that LGDs have the potential to be an effective deterrent to larger carnivores, but the supposition has gone largely untested.

To date, research suggesting LGDs reduce sheep depredations from a host of carnivores are almost exclusively based on the results of survey and self-report data (Andelt, 1992; Andelt and Hopper, 2000; Black and Green, 1984; Green et al., 1984; Hansen et al., 2002; Rigg, 2002; Scasta et al., 2017; van Bommel and Johnson, 2012). Both techniques suffer from recall bias and false reporting (Bradburn et al., 1987), as discerning cause of death from livestock carcasses can be difficult and subject to prejudices related to tolerance for large carnivores (Hazzah et al., 2009). When assessing the effectiveness of LGDs in the presence of a diverse guild of livestock predators (i.e., brown bears, wolves, cougars, black bears, coyotes, etc.), it is necessary to empirically determine cause of death.

The recent widespread use of LGDs in the US, their proven effectiveness against a host of smaller livestock predators, and their potential role in carnivore conservation illustrate the need for a large-scale investigation of LGD effectiveness, especially in places where conflict between livestock and large carnivores is growing. Here, we examined the relative effectiveness of three novel breeds compared with common mixed breeds, hereafter called “whitedogs,” in the USA. We defined effectiveness as a statistically significant reduction in sheep depredation from a diverse guild of carnivores associated with a particular LGD breed. Previous research has already established that LGD use provides significant reductions in livestock loss compared to operations that do

not employ LGDs (Smith et al., 2000). Currently in the US, as in other countries, the use of LGDs with free-ranging sheep is nearly ubiquitous. As such, there is little practical utility in comparing sheep survival between flocks with LGDs and those without. Instead, we placed three novel breeds of LGDs with long histories of use in areas of Europe with large carnivores (i.e., Turkish kangal, Bulgarian karakachan, and Portuguese cão de gado transmontano) directly with sheep producers throughout the Northwestern USA and compared these LGDs with whitedogs already in use. Brief histories and descriptions of each novel breed can be found in Rigg (2001), Urbigkit and Urbigkit (2010), and Kinka and Young (2017). Because of their longevity of use in countries with histories of coexistence between domestic sheep, LGDs, and large carnivores, we hypothesize that the novel breeds tested here will be more effective than common USA whitedogs at preventing depredations from large carnivores. We collected data in the field shortly after depredations occurred to address issues of recall bias and false reporting. Of particular interest is what effect LGD breed has on the survival of domestic sheep in the presence of competing risks. Results will help managers and ranchers make informed decisions about which breeds of LGD to use in areas with different assortments of carnivore species.

Methods

Livestock Guardian Dogs

Starting in 2012, we imported three breeds of LGDs to the USA and placed them on working ranches. These novel, imported breeds included the Turkish kangal, the Bulgarian karakachan, and the Portuguese cão de gado transmontano (henceforth "transmontano"), which were selected for their boldness towards large carnivores, history

of use in areas with wolves or brown bears, lack of aggression towards humans, and reported larger average size (Rigg, 2001; C. Urbigkit and J. Urbigkit, 2010). We imported most novel-breed LGDs from their countries of origin, but some kangals were sourced in the USA from reputable breeders who were able to trace their kangals' purebred status to their Turkish origins.

Once we placed LGDs with collaborating domestic sheep producers, they were cared for by the producers and their staff and bonded to their sheep using traditional practices (cf., Sims and Dawydiak, 2004). Collaborating sheep producers were selected based on willingness to participate in a study of novel LGDs, and a history or potential for conflict with wolves, brown bears, and cougars. We randomly distributed kangals, karakachans, or transmontanos among available collaborators at their time of arrival to the US, such that producers received three LGDs at a time, all of a single breed. Although most USA sheep producers are very familiar with LGD use, project staff provided continuous support by offering information concerning the proper handling and implementation of LGDs so as to maximize their effectiveness. All novel-breed LGDs were spayed or neutered at about one year of age to minimize problems of unintentional breeding and wandering.

In addition to the kangals, karakachans, and transmontanos, we also monitored extant mixed-breed LGDs belonging to collaborating sheep producers. These whitedogs include crosses of multiple LGD breeds and LGDs of unknown genetic origin, however, after discussions with collaborating producers we are confident that, at most, 1-2 whitedogs were purebred LGDs. For the purpose of comparison, we treated all whitedogs already in use in the USA as a single control breed. LGDs worked in teams of 2-8 dogs,

but were most in teams of 3-4. We evaluated different combinations of novel-breed LGDs with existing whitedogs to assess whether the substitution of kangals, karakachans, or transmontanos for whitedogs is associated with loss prevention. Due to the constraints of collaborating with working livestock ranches, we accounted for deviations from this study design at the time of analysis by including the specific combination of LGDs in our models.

Study Area

Study sites included parts of the Blue Mountains in Oregon; the western edge of Payette National Forest and the southern edge of Sawtooth National Forest in Idaho, from McCall to Ketchum; the Front Range in Montana, from Helena to Dillon; and parts of Bighorn National Forest in Wyoming (see Fig. 2.1). Because of the large geographic distribution of study sites, habitat characteristics varied. Sites included remote areas of public lands where livestock are grazed by permit through the Forest Service or Bureau of Land Management, as well as fenced and unfenced private lands. In many of these locations there is a history of conflict between sheep producers and large carnivores, while others were deemed to have the potential for conflict due to proximity to extant populations of wolves, brown bears, or cougars. We based such designations on input from state and federal wildlife officials, and area livestock producers. Relative abundances of each carnivore in each specific study area are not known. Instead we controlled for this through the use of nested random effects in our statistical models.

Data Collection

We collected cause-specific sheep mortality data from domestic sheep that died

during the summer grazing season (May – October, 2013 – 2016). We determined cause of death by investigating carcasses for a kill pattern that matched a known carnivore (generally from carcass location, amount of hemorrhaging, and teeth spacing), as well as investigating the area for tracks, scat, and evidence of scavenging, whenever possible. However, we also relied on evaluations conducted by USDA – Wildlife Services Specialists, and would defer to their expertise in determining cause of predation. For each sheep mortality discovered, we also received detailed oral and written reports from the shepherds who attended the sheep band. The shepherds were always the first, and sometimes the only individuals to see a carcass. Shepherds were also our primary source for identifying non-predator mortality (e.g., sickness, drowning, etc.). Due to the inherent subjectivity of field necropsy techniques to determine cause of death, we were conservative about ascribing cause of death and recorded some mortalities as "unknown predator" or "unknown" if non-predator mortality could not be ruled out.

To develop a survival database for sheep, we created a spreadsheet with an entry for every sheep from every sheep band monitored from 2013 – 2016. Because the exact number of sheep in a commercial sheep band is usually counted at the beginning and end of each grazing season, we were able to create a complete dataset for each band in most cases (rather than having to monitor a sample of the population). The total number of sheep counted at the end of the season were known to have survived and marked as censored on the last day of the grazing season. Known mortalities were marked as dead on the date which corresponded to the day the carcass was found minus the approximate age of the carcass in days. Unaccounted for sheep were assumed to have died from an unknown cause, and treated as a special case. We calculated time of death for

unaccounted sheep as the midpoint between the last day the sheep was counted as alive and the first day it was identified as missing. As such, we censored many unaccounted-for sheep exactly halfway between the start and end of the, approximately, 5 month grazing season for a particular band.

Each sheep record in the survival dataset also included the total number of LGDs (any breed) with the band, the number of sheep in the band, estimated average age of all LGDs in the band, as well as the number of kangals, karakachans, and transmontanos with the band. When, in some cases, LGDs were removed or added to a band, each sheep was censored at the time of the change and re-entered in the dataset with new covariate values corresponding to the number and breed of LGDs with the band. Ages for all kangals, karakachans, and transmontanos was known at the time of analysis, however specific ages could not be determined for 22 of 53 whitedogs. Rather than removing all records for sheep with a whitedog of unknown age, we set any unknown whitedog ages at the mean age for all whitedogs across the four years of the study. Substituting average whitedog age in the case of unknown ages, we subsequently averaged the age of all LGDs in a sheep band together, such that every sheep survival record included an estimate average age for all LGDs in the band. Mortality records from bands where the total number of sheep were unknown were removed. Further, mortality records from sheep bands where only the end-of-season headcount for sheep was known (i.e., the starting headcount of sheep was missing or unknown) were removed from the dataset before analysis unless their covariate structure matched another sheep band with complete records. In this way, neither mortality or survival was overrepresented for sheep with a unique covariate structures. We removed records of sheep grazed with very rare

LGD breed combinations (i.e., fewer than 10 records) as well so as not to bias survival estimates for underrepresented LGD pack structures.

Statistical Analyses

We first tested the effect of LGD breed against any type of predation. As the fate of any individual sheep in a monitored band was known to a high degree of certainty, we chose to analyze data within the context of time-to-event survival models (cf., Kleinbaum and Klein, 2005). Specifically, we utilized semi-parametric Cox Proportional Hazard (CPH; Cox, 1972) models, because they allow for the inclusion of covariates and do not require assumptions about the shape of the underlying mortality hazard (Wolfe et al., 2015). Instead, CPH models allow mortality hazard to vary by time, with covariates acting multiplicatively (i.e., proportionally) on the hazard at any point in time (Bradburn et al., 2003). We modeled the hazard of predation (all causes) as the outcome of interest, collapsing all other sources of mortality into the censored category. Primary covariates of interest were the number of kangals, karakachans, and transmontanos with a band. We also included fixed effects for total number of LGDs (any breed) with the band, number of sheep in the band, the interaction of number of sheep and number of LGDs in a band, the estimated average age of all LGDs in a band, whether the band was on open range or in a fenced pasture, and year (treated categorically). We included the number of whitedogs with a band in the total number of LGDs term, but we did not assess whitedogs as a unique breed in our models. Including the number of whitedogs in the model would have resulted in the sum of the kangal, karakachan, transmontano, and whitedog terms perfectly summing to the number of LGDs term. Instead, we treated

whitedogs as a baseline or generic breed in the models against which we tested the three other breeds. For instance, examining the global CPH equation (Table 2.1), we see that any examination of the "nLGD" term requires holding all other fixed effects constant at their mean values, such that any change in "nLGD" must be specifically attributed to the addition or subtraction of a whitedog from a hypothetical sheep band. We also employed a random effect structure of sheep band nested within producer nested within state to account for unmeasured differences in husbandry practices and potential differences in predator densities between bands. We consider all combinations of fixed effects to be biologically relevant, and therefore include all combinations of main effects as candidate models. Analysis was performed using the 'coxme' function (Therneau, 2015) available in R version 3.3.2 (R Core Team, 2016). Model selection for fixed effects was conducted using Akaike's Information Criterion (AIC).

To investigate potential differences in cause-specific hazard as a function of LGD breed, we analyzed the data using a competing risk (CR) framework, which allows for the consideration of multiple causes of death (Heisey and Patterson, 2006; Murray et al., 2010). In the CR framework each separate cause of death is mutually exclusive to the others, summing to the total probability of mortality. The CR framework is also more robust to bias estimates of cause-specific risk resulting from individuals being censored from observation before having a chance to succumb to a particular hazard (Kleinbaum and Klein, 2005). To assess the breeds one at a time we derived three new datasets from the original survival data. We created the kangal dataset by removing any data from bands with karakachans or transmontanos, the karakachan dataset by removing any data from bands with kangals or transmontanos, and the transmontano dataset by removing

any data from bands with karakachans or kangals. As such, each dataset contained data from whitedog-only bands, as well as data from bands to which one or more of the experimental breed of interest was added. First, we modeled survival using three types of risk – predation, sickness, and missing – but focused only on the probability of depredation. Next, we modeled survival for each potential cause of depredation, allowing for seven different types of risk -- non-predation, wolf, brown bear, cougar, black bear, coyote, and unknown predator. As fixed effects in each of the competing risk regression models, we included number of LGDs, number of sheep, and number of novel-breed LGDs with the band (depending on which data set was being used). CR models do not accommodate random effects, so we were unable to include a nested random term to account for differences in predator abundance or husbandry practices in these models. We performed CR analyses using the 'cmprsk' and 'riskRegression' functions (Gerds et al., 2017; Gray, 2015) available in R version 3.3.2 (R Core Team, 2016).

Results

In total, we worked with 12 producers and 35 sheep bands over the four years of the study to monitor 20 individual kangals, six karakachans, six transmontanos, 53 whitedogs (Table 2.2), and more than 88,000 sheep. After removing incomplete records from the dataset, we retained 88,073 records for analysis. Records show 181 sheep were depredated, 114 died from sickness or drowning, 13 died from unknown causes, eight were killed by an LGD, and 252 were missing and assumed dead from unknown causes. All sheep identified as missing were grazed on open range. The sample size of sheep kept with karakachans and transmontanos was smaller than for kangals and whitedogs (Table

2.2). Of the 31 documented wolf depredations, 19 occurred in a single band that included two kangals (Table 2.3). We analyzed competing risk data for kangals with and without this outlier event.

Cox Proportional Hazards Models

The best CPH model for sheep survival (by AIC rank) retained the fixed effects of number of sheep, number of LGDs, estimated average age of LGDs, number of kangals, number of karakachans, and number of transmontanos. There were only two models with a delta AIC ≤ 2.00, reaching a cumulative model weight of 0.80. Between the two top models every candidate fixed effect is represented except year (Table 2.1). We tested the utility of including a nested random effect (i.e., band within producer within state; a post-hoc control of relative predator abundance and varying husbandry methods) in our global model against an identical CPH model without the random effect using a likelihood ratio test and found the variance associated with the random effect was not likely to be due to chance ($\chi^2 = 218.71$, $p < 0.001$). We also tested for a possible correlation between number of LGDs and number of sheep and found them only weakly correlated (0.13). Currently, there is no supported method for calculating residuals from mixed-effect CPH models.

Examining only the top model, increasing the number of LGDs with a band increased the risk of predation for any given sheep in the band by approximately four times ($e^{\beta} = 4.14$, $p < 0.001$). However, the way the model is parameterized this term represents increasing the total number of LGDs by adding a whitedog (and not any other breed) to the band. For each additional sheep added to a band, the risk of depredation also

increased marginally ($e^{\beta} = 1.002$, $p < 0.001$). Increasing the average age of LGDs in the band by one month also marginally reduced the risk of sheep depredation, although the term is only weakly significant ($e^{\beta} = 0.94$, $p = 0.08$). Holding all other variables constant, the substitution of one kangal for one whitedog decreased the risk of sheep predation by nearly 60% ($e^{\beta} = 0.39$, $p = 0.02$). Likewise, the substitution of one karakachan for one whitedog decreased the risk of sheep predation by approximately 80% ($e^{\beta} = 0.20$, $p = 0.03$) and the substitution of one transmontano for one whitedog decreased the risk of sheep predation by approximately 95% ($e^{\beta} = 0.06$, $p < 0.01$). Both of the top models retained the number of LGDs, the number of sheep, estimated average LGD age, and all three novel breeds as predictor variables at similar magnitudes (Table 2.1). The second most likely model of sheep depredation (AIC weight = 0.35), also included the non-significant interaction term ($p > 0.1$) and the effect of fenced pastures versus open range (Table 2.4). This model predicts a nearly 720% increase in the risk of sheep predation on fenced pastures compared to sheep on open range ($e^{\beta} = 71.94$, $p = 0.02$).

Competing Risk Models, Kangals

Collapsing across all causes of predation, CR models for kangals indicate that each kangal substituted for a whitedog in a band does not significantly decrease the risk of sheep predation ($p > 0.1$). Holding the number of kangals constant while increasing the total number of LGDs (i.e., adding whitedogs) with a band may increase the risk of sheep predation, but the effect is only marginally significant ($e^{\beta} = 1.13$, $p = 0.08$). Increasing the number of sheep in a band also had a non-significant effect in the CR model ($p > 0.1$; Table 2.5). All three trends obfuscate those found in the top mixed effects CPH models.

Regarding specific predators, increasing the number of kangals in a band is associated with a 69% decrease in sheep predation risk from cougars ($e^{\beta} = 0.31$, p = 0.04), a 67% decrease in risk from black bears ($e^{\beta} = 0.33$, p < 0.001), and a 44% decrease in risk from coyotes ($e^{\beta} = 0.56$, p = 0.02). However, replacing a whitedog with a kangal is associated with a 31% increase in risk of wolf depredation ($e^{\beta} = 1.31$, p < 0.01). The effect of kangals on brown bears was non-significant (p > 0.1).

Because 19 of the 31 documented wolf depredations of domestic sheep occurred in a single sheep band with two kangals present, we also ran our kangal CR models without this data as it may represent an outlier. Using this abridged dataset and collapsing across all causes of predation, CR models for kangals indicate that each kangal substituted for a whitedog in a band does slightly decrease the risk of sheep predation, albeit only marginally significantly ($e^{\beta} = 0.84$, p = 0.1). Holding the number of kangals constant while increasing the total number of LGDs (i.e., adding whitedogs) with a band may still increase the risk of sheep predation, but the effect is still weakly significant ($e^{\beta} = 1.16$, p = 0.07). Increasing the number of sheep in a band still had a non-significant effect in the CR model (p > 0.1; Table 2.6). These findings are more in-line with the results from the CPH models. Regarding wolves, the abridged dataset for kangals shows a non-significant effect of kangals on wolf predation of sheep (p > 0.1; Table 2.6).

Competing Risk Models, Karakachans

Collapsing across all causes of depredation, CR models for karakachans indicate that substituting a karakachan for a whitedog decreased the risk of predation by 49% ($e^{\beta} = 0.51$, p = 0.02). Increasing the total number of LGDs (i.e., adding whitedogs) within a

band increased the risk of predation ($e^{\beta} = 1.69$, $p < 0.001$), as did increasing the number of sheep in a band ($e^{\beta} = 1.001$, $p < 0.01$). All three trends corroborate those found in the top mixed effects CPH models. Regarding specific predators, increasing the number of karakachans in a band was associated with a 93% decrease in risk of coyote depredation ($e^{\beta} = 0.07$, $p < 0.01$). Karakachans did not significantly affect the risk of wolf or cougar predation ($p > 0.1$; Table 2.7). The brown bear and black bear models failed to converge, as no brown bear killed a sheep in a band with at least one karakachan and only one sheep was killed by a black bear in a band with at least one karakachan (Table 2.2).

Competing Risk Models, Transmontanos

Collapsing across all causes of depredation, CR models for transmontanos indicate that substituting a transmontano for a whitedog decreased the risk of predation by 66% ($e^{\beta} = 0.34$, $p = 0.04$). Increasing the total number of LGDs (i.e., whitedogs) within a band increased the risk of predation ($e^{\beta} = 1.46$, $p < 0.01$), as did increasing the number of sheep in a band ($e^{\beta} = 1.001$, $p < 0.01$). All three trends corroborate those found in the top mixed effects CPH models. Regarding specific predators, substituting a transmontano for a whitedog was associated with a non-significant decrease in risk from coyotes ($p > 0.1$; Table 2.8). The wolf, brown bear, cougar, and black bear models failed to converge as no sheep was verified as killed by any of those predators in a band including at least one transmontano (Table 2.2).

Discussion

To better understand the contribution of different LGD breeds to sheep-loss

prevention in the Northwestern USA, we assessed overall and cause-specific predation in sheep as a function of the breed composition of LGDs used to guard domestic sheep. Ranked mixed effects CPH models indicate that all three novel-breed LGDs tested here – kangals, karakachans, and transmontanos – are associated with decreases in overall depredation hazard relative to the whitedogs traditionally used in the USA. Because our CPH models included a term for total number of LGDs with a band, these results can be best understood as the effect of swapping one of these novel-breed LGDs for a whitedog, all other fixed effects being held constant. CR models of overall depredation risk show similar decreases in depredation risk associated with each of the novel breeds, although the effect of kangals only becomes significant after an outlier incident is removed. Regarding predator-specific effectiveness of the novel breeds, replacing a whitedog with a kangal (i.e., increasing the number of kangals with a band while holding total number of LGDs constant) significantly reduced the risk of cougar, black bear, and coyote depredation. Similarly, replacing a whitedog with a karakachan significantly reduced the risk of coyote depredation. Interestingly, replacing a whitedog with a kangal is associated with a significantly elevated risk of wolf depredation, but only using the full dataset. When the outlier event for kangals is removed, their effect on wolf depredation becomes non-significant. For all other predator-breed combinations, there is no significant effect or too little data available to effectively model an effect on depredation hazard. Disregarding an outlier in the data for kangals, none of the novel breeds were significantly better or worse at preventing depredations by wolves or brown bears relative to whitedogs.

It is likely that the increased hazard of wolf depredation associated with kangals

in the full dataset was driven by a single sheep band grazed in central Idaho in 2014, which happened to be guarded by two kangals and one whitedog. The band incurred at least 19 wolf depredations throughout the season, nearly two thirds of all the wolf depredations detected throughout the study and included in our analyses. Clearly, this incidence represents a statistical outlier that can greatly skew the results of any survival model, thereby warranting its exclusion from the data. However, while wolf depredations of domestic sheep are infrequent, when they do occur wolves tend to kill many sheep at a time (Muhly and Musiani, 2009). In this way, this incident may be simultaneously biologically relevant and statistically irrelevant. Thus, we chose to model the data both with and without this incident in CR models. Excluding the outlier from the dataset caused the effect of kangals on wolves to become non-significant, but rather than clarifying the role of kangals in defending domestic sheep from wolf depredation, this example probably indicates that far more data would be necessary to properly model the effect of any LGD breed on the lethality of rare but costly wolf attacks. Interestingly, both shepherds in charge of this outlier band believed one of the kangals to be exceptionally good at deterring wolves, despite the unusually high numbers of wolf depredations that year.

In addition to breed-specific effects, most of our CPH and CR models of sheep survival indicate that increasing the number of sheep in a band increased the risk or predation. That each additional sheep added to a band would increase the risk of depredation for any sheep in that band (albeit by a small amount) is somewhat intuitive: a bigger band may simply be a bigger target. Indeed, wolves that fed exclusively on livestock were shown to target larger flocks (Vos 2000). In our system, large sheep bands

were probably easier for a predator to track and more detectable from a distance. While grouping behavior by wild ungulates has long been considered an antipredator strategy (e.g., Lazarus 1979), prey also decrease group size to avoid detection by predators. For example, elk (*Cervus elaphus*), a primary prey item of wolves, have been shown to keep group size low in high-risk habitat when wolves are present (Creel and Winnie 2005). Additionally, LGDs may become less effective as more and more sheep are added to a band, increasing the ratio of LGDs to sheep and, presumably, increasing the burden of guarding for each LGD. The magnitude of this effect is very small but also significant, which is not surprising considering that the addition of a single sheep to a band of 1,000 is unlikely to significantly impact the depredation hazard across the entire band. However, adding 500 sheep to the same band would multiply the effect magnitude to a level of practical significance. The sole exception to this effect for band size is the CR model for kangals and brown bears (Table 2.5), which indicates that each additional sheep added to a band with kangals reduced the risk of brown bear depredation by about 2%. It may be that a larger sheep band creates a larger disturbance as it moves through the landscape, which brown bears avoid the same way they seasonally avoid human disturbance (Ordiz et al., 2017). However, a lack of brown bear depredations in sheep bands with karakachans or transmontanos meant that we were unable to replicate this finding in other CR models.

Perhaps less intuitive are our results showing that increasing the number of LGDs with a band could increase the risk of depredation. As described above, this term also serves as a proxy for number of whitedogs. That is, holding all else constant in the model, increasing the number of LGDs in a band equates to adding a whitedog to the band. The

effect of adding any other breed to the band while also increasing the total number of LGDs was not explicitly tested, in that it requires the simultaneous manipulation of two model terms. Still, it is unclear why adding an LGD of any breed would increase the risk of depredation for a sheep in that band. LGDs did occasionally kill sheep when they were young or not properly bonded, but we relegated the eight LGD depredations in our final dataset to the "sick or other" category of mortality or as a special case in our analyses, so it did not drive any pattern of increased risk corresponding to number of LGDs. It is also possible that having too many LGDs with a sheep band leads to "boredom" and wandering behavior among LGDs, which would reduce guarding effectiveness (Zingaro et al. 2018). However, the average ratio of sheep to LGDs in our study was more than 679 to 1, and wandering behavior was seldom reported. What is more likely, is that by not explicitly modeling carnivore density associated with each sheep band (although we attempted to with nested random effects), the number of LGDs in a band was somewhat collinear with the un-modeled risk of predation risk. Predation risk is impacted by large carnivore presence and spatial density (Hebblewhite and Merrill 2015). In our study system, producers often responded to elevated risk that they perceive on the landscape by adding additional LGDs to a band. If producers are accurately gauging such risk, then increasing the number of LGDs in a band would be largely collinear with increasing depredation risk. That we were unable to control for this potential collinearity during data collection is an example of the constraints imposed on this study by collaborating with working sheep producers. Instead we attempted to correct for this through the use of nested random effect in our modeling exercise. Nevertheless, our nested random effect structure in the CPH models may have failed to capture all of this variance, and number

of LGDs may have served as a partial proxy for predation risk. We were unable to manipulate number of sheep or the number of LGDs with a band for the sake of this research, and only included the term in our models as a control. As such, results for number of sheep and number of LGDs presented here, and their respective effects on sheep survival, should not be considered prescriptive of ideal band size nor ideal ratio of LGDs to sheep. Future studies should investigate the optimal ratio of LGDs to sheep, as it is a salient question for producers and one that has not been adequately studied.

Because we mostly imported novel breeds from their countries of origin as puppies, the novel-breed LGDs tested here tended to be younger, on average, than their whitedog counterparts. Whitedogs included in the study ranged from very young to very old depending on which whitedogs producers were already using to guard their sheep (Table 2.2). LGDs less than two years of age may not be as effective as their adult counterparts (Sims and Dawydiak, 2004). Recent research also shows differences in LGD behavior before and after two years (van Bommel and Johnson, 2012). It is unclear at what age LGDs tend to senesce, but conventional wisdom among sheep producers suggests that LGDs become less effective starting at around eight years old. We did not include individual-level covariates for LGDs, such as age, in CPH and CR models as it is unclear how they could be integrated into our model structure and how the results would be interpreted, since multiple LGDs were present with each band. Further, the exact age of 25% of the whitedogs was unknown by their owners. Instead, we included a fixed effect of estimated average age of all LGDs with a band in our CPH modeling exercise. Results indicate that each additional month of average LGD age is associated with a statistically significant 5-6% reduction in depredation hazard. This corroborates findings

that older LGDs are more effective guardians than very young LGDs, and may continue to improve over time. Nevertheless, the fact that, despite their generally younger age, kangals, karakachans, and transmontanos were associated with decreased overall depredation risk as well as decreased risk in depredation from a number of specific predators compared to the generally older whitedogs, only adds strength to our findings of their greater effectiveness. In other words, the relatively inexperienced novel-breed LGDs seem to have outperformed an average whitedog.

Although only included in one of the top CPH models, fenced pastures are associated with a nearly 720% higher risk of depredation for domestic sheep. Similar to the way adding sheep to a band was generally associated with an increase in risk of depredation, sheep behind fenced pastures may simply be easier for predators to find because they do not move across the landscape, but are generally located in close proximity to a single ranch all year long. As pastures are typically more open and less topographically diverse than forested grazing allotments, sheep in these fenced pastures may also lack escape paths and escape terrain (cf., landscape of fear, Laundré et al. 2010). Alternatively, this higher risk could be an artefact of carcass detectability. Over the course of the study, more sheep went missing than were found and could be ascribed a cause of death. Although some proportion of missing sheep are likely to have been depredated, to be conservative, they were censored from our analyses halfway between the end of the season and the time at which they were last counted. However, all 252 sheep identified as missing were on open range. No sheep was ever classified as missing from a fenced pasture, which is to say every sheep in a fenced pasture could be accounted for. Thus, the effect of fenced versus unfenced pastures shown here likely indicates that

carcasses were more reliably located and necropsied on fenced pastures, not that risk of depredation was higher there.

The sheep that went missing on open range – nearly twice as many as we could confirm having been depredated – are perhaps a limiting factor for our study. Based on our known ratio of depredated sheep versus those that die from other causes (approximately 1.25:1), the majority of the missing sheep are likely to have been depredated, but it is impossible to know the exact proportion, or how those depredations would be distributed among covariate values (other than all missing sheep having been grazed on open range). Knowing the cause of death for these unaccounted-for sheep would have leant us far more statistical power, and future studies should consider methods to ensure that fewer mortalities go unaccounted.

Another limitation of our study was our inability to explicitly model variations in predation pressure between sheep bands. Keeping predation pressure constant across all carnivores and sheep bands (which is impossible) or somehow modelling predation pressure would more properly gauge the effectiveness of an LGD at reducing depredations. We attempted to model this latent variable through the inclusion of our nested random effect (band within producer within state) and a model term for study year. In this way, we hoped to capture most of the variance in predation pressure across the carnivore guild by focusing only on certain grazing pastures or allotments within a single grazing season. However, considering the surprising effect of more LGDs increasing depredation hazard (discussed above), it may be that the inclusion of the nested random effect of band and the fixed effect of year was insufficient to capture all of the variance in predation pressure, both within and between sheep bands. A preferred

alternative would have been to try and calculate relative carnivore densities between study sites as a proxy for predation pressure, but such data was not available and it was beyond the means of our research project to collect it.

Lastly, a small sample of sheep bands with karakachans or transmontanos resulted in a small sample of depredations on which to draw inference on predator-specific effectiveness of those breeds. As such, determining predator-specific effectiveness for those breeds was not possible for many carnivore species, but differences in overall risk of depredation were still identified. This suggests livestock producers should consider using these breeds but also sheds some light on the effort required to investigate differences in effectiveness between LGD breeds, and may suggest why it has not been well-studied to date.

Despite possible limitations, our findings are some of the first to show breed-specific differences in LGD effectiveness by direct comparison (but see Green and Woodruff, 1988; 1983). With over 30 unique breeds of LGDs to choose from (Rigg, 2001), sheep producers generally rely on anecdotes and shared experience when choosing a LGD breed to integrate into their operation. Here, we provide empirical evidence for three purebred LGD breeds, all of which show increased aptitude for preventing depredation of domestic sheep. Specifically, kangals outperformed whitedogs at preventing depredations from cougars, black bears, and coyotes, while karakachans outperformed whitedogs at preventing depredations from coyotes. In addition, we suggest that mature whitedogs already used by many sheep producers in the Northwest US, despite their often-uncertain genetic origin, are among the best options for protecting sheep from wolf or brown bear depredation, as there is no evidence to suggest that

replacing a whitedog with a kangal, karakachan, or transmontano reduces the risk posed by these carnivores. To date, most studies of LGD effectiveness have not accounted for breed. Considering, as we have shown here, that loss-prevention varies as a result of the interaction of LGD breed and predator species, the reported statistics on loss-prevention for LGDs should be considered minimums only (Andelt and Hopper, 2000). This may partially explain the large variance in effectiveness reported for LGDs as well (Eklund et al., 2017; Miller et al., 2016; Smith et al., 2000). Summarily, our findings expand the literature on using LGDs as an effective non-lethal management tool for reducing depredations of domestic sheep and provides information that might help livestock producers and wildlife managers make tailored decisions about how best to incorporate different breeds of LGD into sheep grazing regimes.

Implications

Wildlife managers, LGD breeders, and researchers are frequently asked which LGD breed would work best in a given situation or with a certain predator. Here we present findings that three novel breeds of LGD – kangals, karakachans, and transmontanos – are all associated with a reduced hazard of depredation for domestic sheep, compared with mixed-breed "whitedogs." Concerning predator-specific hazard, kangals were associated with a significant reduction in cougar, black bear, and coyote depredations, and karakachans were associated with a significant reduction in coyote depredation. We also present evidence that kangals may be less effective at reducing wolf depredations than whitedogs, although this may be an artefact of the uneven distribution of wolf depredations in our dataset. Overall, kangals appear to be a very useful breed of

LGD for most sheep producers, with karakachans and transmontanos also showing improvements over whitedogs. These findings will help livestock producers and wildlife managers make tailored decisions about how best to incorporate different breeds of LGD into sheep grazing regimes.

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Conflicts of Interest

None

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Tables

Table 2.1
Cox Proportional Hazard model selection based on ΔAIC. Only the top three models are shown (cumulative AIC weight = 0.842). Note that the third model is the global model. Number of parameters (np), AIC weights (w_i), and cumulative AIC weights (Cum. w_i) are also shown. In the model structure "LGD" is the number of LGDs (of any breed) in a band, "Sp" is the number of sheep in a band, "LGD:Sp" is the interaction term of number of LGDs and number of sheep in a band, "Kn" is the number of kangals in a band, "Kr" is the number of karakachans in a band, "Tr" is the number of transmontanos in a band, "eA" is the estimated average age of all LGDs in a band, "F" is whether or not the band was in a fenced pasture (1 = fenced, 0 = open range), and "Y" is the categorical effect of year (2013-2016). The number of whitedogs (if any) with a band were included in the "LGD" term, but were not assessed as a unique breed. All models share a common nested random error structure of sheep band within producer within state.

Model	*np*	ΔAIC	w_i	cum. w_i
LGD + Sp + Kn + Kr + Tr + eA	6	0.00	0.449	0.449
LGD + Sp + LGD:Sp + Kn + Kr + Tr + eA + F	8	0.48	0.353	0.802
LGD + Sp + LGD:Sp + Kn + Kr + Tr + eA + F + Y	9	4.84	0.040	0.842

Table 2.2
Number of individual LGDs by breed retained in dataset for analysis. Certain individuals were present in multiple years of the study, and the number of individual LGDs by year is shown. "#" denotes "number of." Mean age and standard deviation of age are shown as well. Note that ages were only known for 31 of the 53 whitedogs in the study, and mean age and standard deviation of age for whitedogs was calculated using that sample of the total population of whitedogs.

	# Individuals	# Individuals x Years	Mean Age (months)	SD of Age (months)
Kangal	20	37	22	16
Karakachan	6	8	14	9
Transmontano	6	7	11	4
Whitedogs	53	71	39	29
ALL BREEDS	85	123	29	25

Table 2.3
Number of sheep depredations by predator in sheep bands including at least one of each of the novel-breed LGDs. "All Predation" includes depredated sheep where predator could not be determined, and therefore may be greater than the sum of depredations identified as wolf, brown bear, cougar, black bear, and coyote. Note that some bands included LGDs from two of the novel breeds. Thus, rows 1 – 3 in the table are not mutually exclusive and the last row of the table does not indicate totals from the first four rows.

	n	All Predation	Wolf	Brown Bear	Cougar	Black Bear	Coyote
At least 1 kangal	45,581	90	28	14	4	13	12
At least 1 karakachan	9,848	11	1	0	5	1	1
At least 1 transmontano	6,924	15	4	1	0	3	6
Only whitedogs	30,304	76	7	1	6	3	51
All combinations	88,073	181	36	15	15	17	68

Table 2.4
Model results for all mixed effects Cox Proportional Hazards models with ΔAIC < 2.00. Results are shown as coefficient beta values for fixed effects (log hazard ratios) with standard error shown in parentheses below. All models share a common nested random error structure of sheep band within producer within state.

	Top Cox Proportional Hazards Models	
	1	2
Number of LGDs	1.421^{***}	2.014^{***}
	(0.308)	(0.744)
Number of Sheep	0.002^{***}	0.004^{**}
	(0.001)	(0.001)
Interaction of		-0.0003
num. of Sheep & num. of LGDs		(0.0004)
Number of Kangals	-0.931^{**}	-0.877^{**}
	(0.385)	(0.430)
Number of Karakachans	-1.590^{**}	-1.423^{*}
	(0.731)	(0.738)
Number of Transmontanos	-2.847^{***}	-2.966^{***}
	(0.730)	(0.698)
Estimated average age	-0.058^{*}	-0.055^{*}
	(0.033)	(0.031)
Fenced pasture vs. open range		4.276^{**}
		(1.867)
fitted log likelihood	-1852.0	-1852.0
ΔAIC	0.00	0.48
model weight	0.449	0.353

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 2.5
Model results for competing risk regression models for kangals. Includes data from whitedog-only bands and bands with at least one kangal dog present. Results are shown as coefficient beta values for fixed effects (log hazard ratios) with standard error shown in parentheses below. "#" denotes "number of."

		Competing Risk Regression Models for Kangals				
	All Predation (n = 155)	Wolf (n = 31)	Brown Bear (n = 14)	Cougar (n = 10)	Black Bear (n = 13)	Coyote (n = 61)
# LGDs	0.120*	-0.023	3.800***	0.993***	1.030***	0.231
	(0.069)	(0.101)	(1.260)	(0.377)	(0.121)	(0.160)
# Sheep	-0.0001	0.0010***	-0.0182***	-0.0001	0.0017***	0.0003
	(0.0001)	(0.0001)	(0.0060)	(0.0005)	(0.0002)	(0.0002)
# Kangals	-0.091	0.269***	0.220	-1.169**	-1.121***	-0.577**
	(0.091)	(0.058)	(0.234)	(0.564)	(0.070)	(0.239)

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table 2.6
Model results for competing risk regression models for kangals with outlier data removed. Includes data from whitedog-only bands and bands with at least one kangal dog present except for a single band of sheep that experienced unusually high wolf depredation in 2014. Results are shown as coefficient beta values for fixed effects (log hazard ratios) with standard error shown in parentheses below. "#" denotes "number of."

		Competing Risk Regression Models for Kangals *outlier band removed*
	All Predation (n = 130)	Wolf (n = 12)
# LGDs	0.146^{*}	-0.109
	(0.081)	(0.420)
# Sheep	-0.0001	0.0011^{***}
	(0.0001)	(0.0002)
# Kangals	-0.179^{*}	-0.103
	(0.107)	(0.124)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Table 2.7
Model results for competing risk regression models for karakachans. Includes data from whitedog-only bands and bands with at least one karakachan dog present. Results are shown as coefficient beta values for fixed effects (log hazard ratios) with standard error shown in parentheses below. “#” denotes “number of.” The brown bear and black bear models failed to converge, as no sheep was killed by a brown bear in a band with at least one karakachan and only one sheep was killed in a band with at least one karakachan.

		Competing Risk Regression Models for Karakachans		
	All Predation (n = 87)	Wolf (n = 8)	Cougar (n = 11)	Coyote (n = 52)
# LGDs	0.524^{***}	-0.312	1.0367^{**}	0.342^{***}
	(0.114)	(0.838)	(0.527)	(0.051)
# Sheep	0.0007^{***}	0.0011^{*}	0.0001	0.0009^{***}
	(0.0001)	(0.0006)	(0.0003)	(0.0001)
# Karakachans	-0.673^{**}	0.066	0.384	-2.659^{***}
	(0.294)	(0.845)	(0.481)	(0.990)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Table 2.8
Model results for competing risk regression models for transmontanos. Includes data from whitedog-only bands and bands with at least one transmontano dog present. Results are shown as coefficient beta values for fixed effects (log hazard ratios) with standard error shown in parentheses below. "#" denotes "number of." The wolf, brown bear, black bear, and cougar models failed to converge, as no sheep was killed by one of these predators in a band with at least 1 transmontano.

		Competing Risk Regression Models for Transmontanos
	All Predation (n = 80)	Coyote (n = 55)
# LGDs	0.379^{***}	0.337^{***}
	(0.080)	(0.047)
# Sheep	0.0007^{***}	0.0008^{***}
	(0.0001)	(0.00005)
# Transmontanos	-1.086^{**}	-0.620
	(0.534)	(0.543)

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

Figure

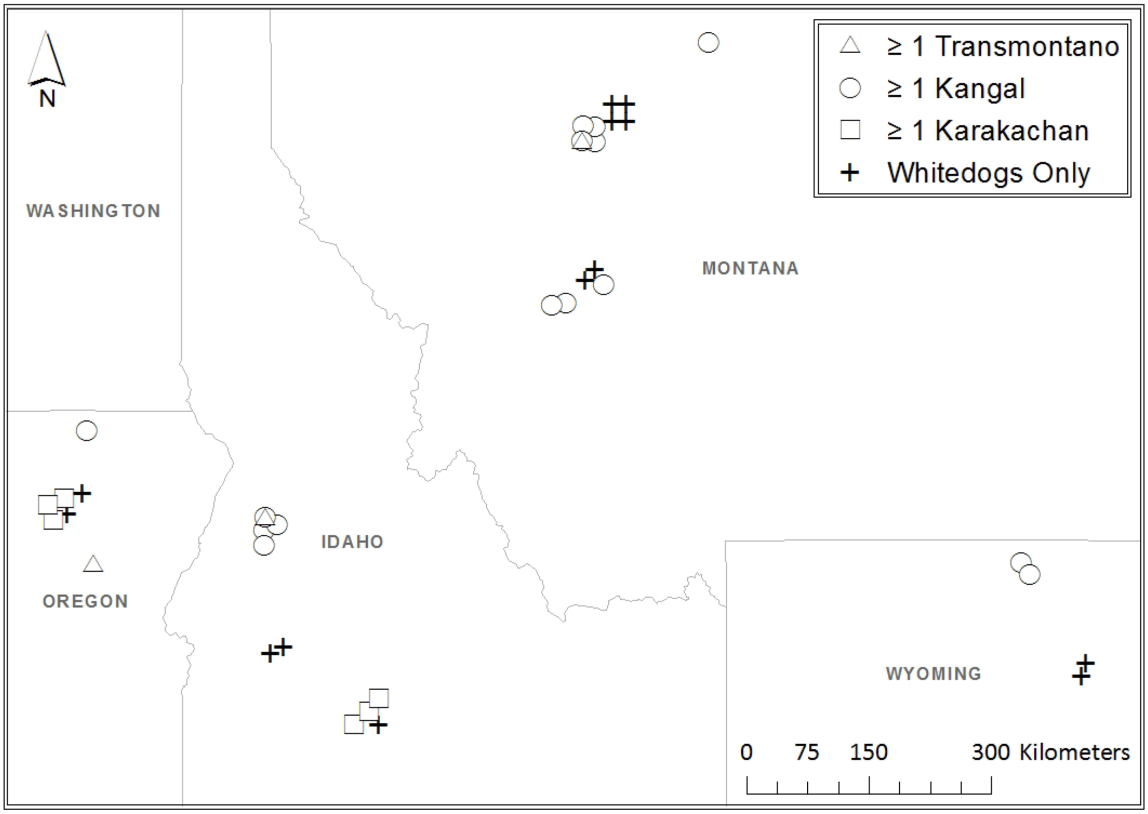

Figure 2.1
Extent of study site, with each symbol indicating the location of a monitored sheep band (N = 35 total sheep bands) in a single year of the study (2013 – 2016). Circles, squares, and triangles indicate the location of a monitored sheep band grazed with whitedogs and at least one kangal, karakachan, or transmontano, respectively. The two triangles inscribed inside circles indicate bands grazed with at least 1 kangal and 1 transmontano, in addition to whitedogs. Crosses indicate sheep bands with only whitedogs.

CHAPTER 3

AN LGD BY ANY OTHER NAME: SIMMILAR RESPONSES TO WOLVES ACCROSS LIVESTOCK GUARDIAN DOG BREEDS[2]

Abstract

Non-lethal tools for reducing livestock depredations, such as livestock guardian dogs (LGDs; *Canis familiaris*), reduce lethal management of livestock predators and have been widely adopted by domestic sheep (*Ovis aries*) producers in the United States. However, compared to their success in reducing coyote (*Canis latrans*) depredations, commonly used LGD breeds appear less effective against wolves (*Canis lupus*). With more than 30 distinct LGD breeds found throughout the world, certain breeds may be more effective at deterring specific threats. We compared LGD breeds commonly used in the United States, collectively called whitedogs, with three European breeds selected for boldness towards carnivores, history of use in areas with wolves, lack of aggression towards humans, and size. We collected data on LGD behavior with sheep herds in Idaho, Montana, Oregon, Washington, and Wyoming in 2015 and 2016. We also developed a test to examine LGDs' response to a simulated encounter with a wolf while on summer grazing range. Results from generalized linear mixed models of proportion of time spent in a given behavior indicate that few significant behavioral differences exist between tested breeds. Kangals tended to be more investigative when engaging a decoy, karakachans more vigilant, and transmontanos more able to decipher a threatening from unthreatening stimulus. Transmontanos also spent less time scanning than whitedogs and

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[2] Co-authored with Julie K. Young

there was a marginally significant effect of karakachans moving more than whitedogs. While these subtle behavioral differences may help livestock producers make tailored decisions in choosing the appropriate LGD for their needs and circumstance, our results suggest that behavioral differences among breeds may be less common than often suggested.

Introduction

Livestock guardian dogs (*Canis familiaris*; LGDs), also referred to as livestock protection dogs, have been utilized by humans to mitigate depredation of livestock for at least 5,000 years (Gehring et al., 2010). Contemporary research on LGDs indicates they are effective for reducing livestock loss (Andelt, 1992; Andelt and Hopper, 2000; Green et al., 1984; van Bommel and Johnson, 2012), although actual loss prevention varies from 11 to 100% (Smith et al., 2000). There are more than 30 distinct LGD breeds found throughout the world, most of them endemic to only a single country or region (Rigg, 2001). Likely the result of geographic isolation and selective breeding to meet the needs of local pastoralists, each breed adapted according to different circumstances and demands (R. Coppinger and L. Coppinger, 2002; Rigg, 2001). This diversity has led some to speculate as to whether certain breeds may be more effective at deterring specific threats (C. Urbigkit and J. Urbigkit, 2010).

Despite generations of use in Europe and Asia, the use of LGDs in other parts of the world is relatively new. In the United States, LGDs gained popularity as a non-lethal alternative to poison for predator control and began to be imported in the late-1970s (Gehring et al., 2010). The Great Pyrenees is the most popular breed in the United States,

along with the Akbash, Maremma, Anatolian shepherd, and Komondor (Andelt and Hopper, 2000; Green et al., 1984; Green and Woodruff, 1980), although many working LGDs are genetic crosses of these and other breeds. While mongrel dogs have been successfully utilized by the Navajo tribes of the southwestern United States as livestock guardians (Black and Green, 1985; R. Coppinger et al., 1985), there is no LGD breed endemic to North America.

Following the reintroduction of wolves (*Canis lupus*) to the Western United States, there has been a renewed interest in the relative effectiveness of LGD breeds among domestic sheep (*Ovis aries*) producers. LGD breeds initially selected for use in the United States were selected to reduce depredations by coyotes (*Canis latrans*) at a time when wolves were almost entirely absent from the landscape (Bangs et al., 2005). LGD breeds and crosses currently used in the United States may not be well-suited to dealing with large carnivores because deterring different predators requires different responses (R. Coppinger et al., 1988). However, there are LGD breeds in Europe and Asia that are currently underutilized in the United States, and many of them have long histories of deterring wolves in their native countries (Rigg, 2001). Variations in behavior between these European LGD breeds and LGDs bred in the United States may account for the differences in predator-specific effectiveness.

Minimizing depredation of livestock is the obvious goal of LGDs, but it is also important to understand the behavioral mechanisms that mediate their effectiveness. There were limited attempts to compare LGD breed effectiveness shortly after their use in the United States began, but findings were largely inconclusive (Green and Woodruff, 1988; 1983). A recent behavioral investigation of LGDs in Australia focused on their

space-use and activity patterns as measures of effectiveness (van Bommel and Johnson, 2014a; 2014b). For instance, van Bommel and Johnson (2014b) showed that maremma sheepdogs outfitted with GPS collars exhibited primarily crepuscular activity patterns, as well as lower levels of activity throughout the night, roughly corresponding to the activity patterns of predators in the area. Although van Bommel and Johnson (2014a) also documented the response of maremma sheepdogs to simulated dingo incursions into a sheep pasture, this recent investigation is limited in scale because it only examined the maremma sheepdog breed of LGD.

Here we examine the behavior of three European LGD breeds not commonly used in the United States and compare behavior to a number of domestically bred LGD crosses. To identify LGD behavior salient to guarding, we partnered with U.S. sheep producers working in wolf-occupied areas to quantify baseline LGD behavior as well as LGD response to a wolf encounter. Ethical and practical considerations preclude staging interactions of LGDs with wolves, so we developed a test to simulate a wolf encounter while LGDs were on grazing allotments. We analyzed all data with the intent to identify any behavioral differences that exist between LGD breeds, which could affect their ability to guard against large predators.

Methods

Livestock Guardian Dog Breeds

We imported three novel-breed LGDs from August 2012 – October 2016 and placed them with participating sheep producers in Idaho, Montana, Oregon, Washington, and Wyoming. Breeds include the Turkish kangal, the Bulgarian karakachan, and the

Portuguese cão de gado transmontano (henceforth “transmontano,” Fig. 3.1). Breeds were selected for their boldness towards large carnivores, history of use in areas with wolves, lack of aggression towards humans, and larger average size (Rigg, 2001; C. Urbigkit and J. Urbigkit, 2010). We imported most LGDs from their countries of origin, but some kangals were sourced in the United States from reputable breeders who were able to trace the purebred status to their Turkish origins. Novel-breed LGDs were placed with participating producers immediately after their arrival, at which time they were cared for by the producers and their staff and bonded to their sheep using traditional practices (Dawydiak and Sims, 2004). All novel-breed LGDs were spayed and neutered at about one year of age to minimize problems of unintentional breeding and wandering. We also monitored extant LGDs, already belonging to some of our participating producers. These “whitedogs” include crosses of multiple LGD breeds and LGDs of unknown genetic origin (see Fig. 3.1). For the purpose of comparison, we treated them as a single control breed. LGDs worked in teams of three dogs of the same breed per flock of sheep during the summer grazing season whenever possible. However, due to the constraints of working with working livestock ranches, we accounted for deviations from this study design at the time of analysis by including crossed random effects of individual LGD and trial.

Study Area

We collected data from May to October in 2015 and 2016. Study sites included parts of Wenatchee National Forest and lowland sections of Eastern Washington; the Blue Mountains in Oregon; the western edge of Payette National Forest and the southern

edge of Sawtooth National Forest in Idaho, from McCall to Ketchum; the front range in Montana, from Shelby to Dillon; and Bighorn National Forest in Wyoming (see Fig. 3.2). Because of the large geographic distribution of study sites, habitat characteristics varied. Sites were selected for the presence of domestic sheep on summer grazing pastures and the potential for depredation by wolves. This included remote areas of public lands where livestock are grazed by permit through the Forest Service or Bureau of Land Management, as well as fenced and unfenced private lands. In many of these locations there is a history of conflict between sheep producers and large carnivores, while others were deemed to have the potential for conflict due to proximity to extant populations of wolves. We based such designations on input from state and federal wildlife officials, and area livestock producers. All behavioral observations were done between 600 – 3,000 meters in elevation (most between 1,200 m – 1,400 m) and ≤ 500 meters from a grazing sheep band, during daylight hours between 06:00 – 23:00.

Baseline Behavior

To develop a baseline of typical LGD behavior by breed, dogs were observed and their behavior recorded up to once a week over two field seasons using a continuous focal sampling techniques (Altmann, 1974; Martin and Bateson, 2007). Generally, a single observer recorded continuous focal sampling after at least a week of training with a graduate student and co-workers. However, we collected observations in teams three to four times per month, with the graduate student assisting technicians to increase consistency and reduce inter-observer error. To maximize the amount of data collected, we recorded each behavioral observation as a four-component code: (1) activity, (2)

posture, (3) vocalization, and (4) proximity-to-sheep (Table 3.1). Each time a LGD changed states in any of the four components, an observer would record the time of the state change and a four-character code corresponding to the new behavioral state. At the time of analyses, we analyzed these four components of behavior separately. We observed 80 individual LGDs of four different breeds (kangal = 19, karakachan = 12, transmontano = 12, whitedog = 37), in a repeated measures design (kangal = 207, karakachan = 87, transmontano = 82, whitedog = 164). Observations lasted 20 minutes per LGD, but were occasionally shorter due to LGDs moving out of view. A total of 170 hours of observations were recorded across 540 trials. However, in three of the 540 trials, LGDs went out of view of the observers immediately after the test began and never came back into view. For an additional 27 trials, information on a whitedog's age or sex was unavailable, either because the whitedog could not be identified at the time of the test or because detailed records were not available for extant whitedogs. These trials were withheld from analysis, resulting in a sample size of 509 trials (Fig. 3.3).

Decoy Test

Although an important component of LGD effectiveness is how they respond during encounters with livestock predators, these encounters are infrequent and difficult to observe. Instead, we simulated an encounter between LGDs and a wolf using a decoy, and recorded the behavioral response. We constructed two decoys for the test to measure LGD response to a threatening wolf decoy and a non-threatening deer decoy. Decoys were constructed in the field using a pre-measured PVC frame skeleton. A mule deer (*Odocoileus hemionus*) hide was used for the deer decoy, and a wolf hide used with the

wolf decoy. We also paired each decoy with a remote-controlled call device that was programmed to play an elk bugle when paired with the deer decoy and a wolf howl when paired with the wolf decoy. In the field, decoys were constructed within 100 – 500 meters of sheep grazing with LGDs, but out of site of the LGDs. Once the decoy was constructed, observers hid out of sight in a nearby location with a clear view of the decoy and played the call device to alert the LGDs to the presence of the decoy. The call (i.e., howl or bugle, depending on decoy-type) was played for 2:00 minutes or until the first LGD arrived at the decoy (≤ 20 meters), whichever came first.

LGD response was recorded using instantaneous scan sampling (Altmann, 1974; Martin and Bateson, 2007) every 15 seconds, for all LGDs in view. At least two researchers were present for every decoy test, with one present for the majority of tests and responsible for all training of research participants, to increase consistency and minimize inter-observer error. We observed 84 individual LGDs of four different breeds (kangal = 19, karakachan = 8, transmontano = 9, whitedog = 48), in a repeated measures design (kangal = 57, karakachan = 19, transmontano = 17, whitedog = 118). Decoy tests lasted 5 – 30 minutes. We ended tests after two continuous minutes of inactivity or neutral behavior from the LGDs (usually returning to the sheep) with most tests lasting less than ten minutes. However, some tests lasted much longer and were ended at 30 minutes by the observer if the LGD never stopped engaging with the decoy. Individual LGDs were tested no more than twice per year (once with the deer decoy and once with the wolf decoy) to avoid habituating LGDs to potentially threatening environmental stimuli like wolf howls. The order in which the decoys were presented to each group of LGDs was randomized with a coin flip before the first test in each grazing year. Behavior

was recorded using the same four-character code as in the continuous focal sampling test. A total of 7,772 observations were collected across 214 trials in 64 tests. However, in 87 of the 214 trials LGDs remained out of view of the observers for the entirety of the test. These trials were withheld from analysis. For an additional 27 trials, information on a LGDs age or sex was unavailable. These trials were also withheld from analysis, resulting in a final sample size of 100 trials (Fig. 3.4).

Statistical Analysis

We focused analyses on behavior believed to be most relevant to guarding effectiveness. This included vigilant, investigate, scan, run, bark, move, lay, and with sheep (Table 3.1). While behavior like stalk, chase, fight, and growl are also likely to be related to LGD effectiveness, they were observed so rarely that we excluded them from analysis. Unlike the continuous focal observation dataset, which was ended or restarted when an LGD went out of view, it was possible for LGDs to be out of view for large proportions of the decoy test. As such, we included time spent out of view as a unique behavior to determine if time spent out of view was a random artefact of our test protocol, or if it varied systematically by one or more of our *a priori* predictor variables.

The proportion of time LGDs spent in each relevant behavioral state (i.e., vigilant, investigate, scan, run, bark, move, lay, and with sheep) was calculated for each trial and analyzed separately as the response variable of interest in a set of generalized linear mixed-models (GLMMs) with a binomial error structure (Broekhuis et al., 2014; Warton and Hui, 2011). Model sets for each behavior included a random effect of individual LGD to account for repeated measures of dogs across season and across year. To account

for overdispersion, we included a random variable of trial for continuous focal observations (i.e., unique for every observation) and a random variable of test for the decoy data set (i.e., all LGDs observed in a single test). As number and composition of individual LGDs varied by trial, the two random variables were treated as crossed random effects. Categorical predictor variables include LGD breed (kangal, karakachan, transmontano, "whitedog"), LGD sex (male, female), and LGD age category (juveniles < 2 years old, adults ≥ 2 years old). For the continuous focal data set we also included a categorical variable for time-of-day (morning: 07:00 – 11:59, mid-day: 12:00 – 16:59, evening: 17:00 – 22:00). For the decoy data set we also included as a categorical variable decoy-type (wolf, deer). As all combinations of *a priori* predictor variables were considered to have biological relevance, we treated all combinations of main effects as candidate models for proportion of time spent in each behavioral state. Including interaction terms generally caused models to fail to converge. Due to limited sample size, we did not test for interactions. For the decoy set, in addition to modeling all behavior observed during the test, we also modeled LGD behavior from only the first 60 seconds (up to four observations) after a LGD arrived at the decoy. These analyses were performed to determine if breed differences in LGD behavior during the decoy test might only be associated with initial response. Transmontanos had to be removed from this analysis because no transmontano ever engaged the deer decoy.

We also analyzed time-to-approach and time-to-leave for the decoy using a Cox proportional hazards analysis (Kleinbaum and Klein, 2005). Using proximity data from the decoy test, we calculated the time from the beginning of the test to the first time an LGD was ≤ 50 meters from the decoy (time-to-approach, n=140), and the time from the

first observation during which a LGD was ≤ 50 meters from the decoy to the last observation during which a LGD was ≤ 50 meters from the decoy (time-to-leave, n=43). As with the behavioral models of decoy data, categorical predictor variables include decoy, LGD breed, LGD sex, and LGD age category. A random effect was included for each individual LGD to account for repeated measures of dog across season and across year. To account for overdispersion, we included a random effect of test. We consider all combinations of these *a priori* predictor variables to be biologically relevant and therefore included all combinations of main effects as candidate models.

Analyses were run using the statistical software R 3.3.2 (R Core Team, 2016) with the lme4 package (version 1.1–12) for GLMMs (Bates et al., 2015) and the coxme package for Cox proportional hazards models containing random effects (Therneau, 2015). We tested for model convergence using the default bound optimization by quadratic approximation (BOBYQA) optimizer in lme4. We tested for overdispersion using the "overdisp_fun" function in R (available at http://bbolker.github.io/mixedmodels-misc/glmmFAQ.html). All models in each model set were ranked using Akaike Information Criterion for small samples (AICc). We considered all models with a delta AICc ≤ 2.0 top-models.

Results

Baseline Behavior

Two of seven top models indicate that transmontanos are about a third as likely to engage in scan behavior compared to whitedogs ($p < 0.04$, Table 3.2), with the same effect approaching significance in other top models. Additionally, in six of the seven top

models of scan behavior, scanning was more than twice as likely to occur in the evening compared to mid-day ($p < 0.02$, Table 3.2). Model sets for the move and lay postures indicate that laying was less common and moving more common in the morning and evening relative to mid-day ($p < 0.01$) in all top models from each model set (Tables 3.3 and 4). One of the top models for the move data set (ΔAICc = 1.71) indicates an effect of breed approaching significance ($p = 0.054$), which suggests that karakachans may be more likely to exhibit move posture than whitedogs (Table 3.3). For the behavior vigilant, investigate, run, with sheep, and bark, the null model was the highest-ranking model and no predictor variables reached a threshold of significance ($p < 0.05$) in any of the other top models. For some of the models using the continuous focal dataset as input, convergence problems were encountered in models that included time-of-day (Table A1), but all top models converged successfully except for model 5 of the scan behavior model set (max|grad| = 0.0036, tol = 0.001; see Table 3.2).

Decoy Test

Because models of out-of-view with a random effect of test showed significant evidence of overdispersion, we instead included a random effect for each LGD in a given test. The top model for out-of-view was the only model in the set with a delta AICc < 2.0 and it indicates a significant effect of age, with juvenile LGDs 2.7 times as likely to be out of view as their adult counterparts ($p = 0.03$). The only behavior in the decoy test with significant predictors was vigilant, where all three top models indicate that juvenile LGDs were about four times as likely to be vigilant during the decoy test relative to their adult counterparts ($p < 0.01$, Table 3.5). For behavior investigate, lay, with sheep, with

decoy, bark, and move, the null model was among the highest-ranking models and no predictor variables reached a threshold of significance in any of the other top models (Table A2). Observations of the run behavior were so infrequent in the decoy test dataset that most models failed to converge (Table A2).

Modeling only behavior observed in the first 60 seconds after a LGD engaged with the decoy we observed significant breed differences, but no difference between decoy types. Karakachans were approximately twenty times more likely to be observed vigilant than kangals in two of the six top models ($p < 0.05$, Table 3.6). Kangals were eight times more likely to have been observed investigating than whitedogs ($p < 0.05$, Table 3.7). Transmontanos had to be removed from the analysis because no transmontano ever engaged the deer decoy. For the behavior scan, run, bark, and move, the null model was among the highest-ranking models and no predictor variables reached a threshold of significance in any of the other top models (Table A3). Observations of the lay posture were so infrequent in the abbreviated decoy test dataset that we did not analyze the behavior.

Time-to-Approach and Time-to-Leave Decoy

For time-to-approach and time-to-leave decoy, neither top model set included predictor variables that reached significance. A trend was evident in the time-to-approach data of a marginally faster average response to the wolf decoy, but it does not reach statistical significance ($p < 0.05$). A table of all ranked models is included in supplemental material (Table A4).

Discussion

Our study found that kangals, karakachans, transmontanos, and whitedogs spent equivalent proportions of time in most behaviors during both baseline sampling and simulated wolf encounters. However, subtle behavioral differences relevant to guarding aptitude emerged. Behavioral divergence between breeds was documented for vigilance, investigation, scanning, and possibly, moving. Interestingly, for the decoy test, breed differences were only detected when the first minute of engagement with a decoy was considered, suggesting that while initial responses may vary among breeds, behavior is more consistent across time in this context. In addition to breed, we found that LGD age and time of day influenced LGD behavior and that sex had no effect on any LGD behavior, all of which corroborate earlier findings on LGD behavior (Leijenaar and Cilliers, 2015; van Bommel and Johnson, 2014b; 2012).

Regarding baseline LGD behavior, transmontanos were less likely to be scanning than whitedogs (which did not differ significantly from kangals or karakachans) as a proportion of baseline behavior. How this relates to transmontanos' effectiveness as guardians is unclear. It could mean they are less effective at guarding or they use other senses, such as smell and hearing, to detect threats. Our sample size of transmontanos was small relative to the other breeds, creating the possibility that this finding had more to do with the individual transmontanos in our study than the breed at large. There was also a marginally significant trend in baseline data of karakachans moving more than whitedogs. It is unclear whether simply being more active is associated with better guarding behavior, but this behavioral trend may be relevant to sheep producers who move their flocks often or require LGDs to guard large areas.

In the decoy test, neither breed nor decoy-type was a significant predictor of any LGD behavior associated with guarding when modeling all behavior observed during testing. In addition, we detected no significant differences in time-to-approach or time-to-leave the decoy as a function of breed, decoy, or other predictor variables. However, when modeling only the behavior observed in the first 60 seconds after a LGD engaged with a decoy, we found that kangals were significantly more likely to investigate the decoy than whitedogs (which did not significantly differ from karakachans). There is also evidence that karakachans are more likely to be vigilant than kangals but not whitedogs. Taken summarily, these findings suggest meaningful differences in how LGD breeds respond to potentially threatening stimuli. That kangals were more likely to investigate the decoy may imply a higher willingness for physical engagement. Conversely, karakachans seem to prefer guarding at a distance as indicated by their tendency towards vigilance. Which of these behavioral phenotypes is preferable for deterring predators is likely to be context dependent and will require additional study to disambiguate. Future work should also assess how LGD breed influences sheep survival, which will clarify the practical significance of breed differences in behavior.

That decoy-type was not a significant predictor of any of the LGD behavior implies that the LGDs responded to both decoys in the same way. It could mean that the two decoys were perceptually more similar to each other than they were to the animals they were intended to mimic. Anecdotally, LGDs' overall reaction to the decoy-types did seem to differ, with more aggressive behavior directed at the wolf decoy (see Fig. 3.4), but this observation is not supported by statistical analysis. It is difficult to rule-out the possibility of crossover interactions because we were unable to test for an interaction of

decoy by breed due to our small sample size. However, the main effects for kangals and karakachans discussed above may suggest some behavior switching based upon decoy type. Importantly, we never observed transmontanos engaging with the deer decoy (Fig. 3.4). Although initial response for transmontanos could not be modeled as a function of decoy type, it does imply a strong preference among transmontanos to respond to the wolf decoy, reinforcing our earlier hypothesis that transmontanos may identify threat differently than other breeds. It also suggests that, at least for some LGDs, the decoys were different enough to elicit separate responses. For kangals, karakachans, and whitedogs, decoy similarity could have prompted a general response to novelty rather than eliciting responses based upon perceived threat.

Because we imported most of the LGDs in the study as puppies, the majority of behavioral data came from juvenile LGDs (especially for karakachans and transmontanos). Rather than attempting to model only the limited data collected from adult LGDs, we included age as a predictor variable in all our modeling exercises. Conventional wisdom about LGDs suggests that until approximately two years of age most LGDs are not as effective as their adult counterparts (Dawydiak and Sims, 2004) and some recent research also shows differences in LGD behavior before and after two years (van Bommel and Johnson, 2012). Accordingly, we included a categorical variable of LGD age class in all our models to distinguish between juveniles (<2) and adults (≥2). Age was not a significant predictor of any of the baseline behavior we observed but did predict juvenile LGDs to be more vigilant and have a greater probability of being out of view during the decoy test. We assumed that vigilance would be associated with good guarding skills in LGDs and were somewhat surprised to find it more common among

juveniles. However, it may be that more experienced LGDs habituated to the stimulus presented during the decoy test more rapidly while inexperience caused the juveniles to attend to novel stimuli longer (Siwak, 2001). That juvenile LGDs were more likely to be out of view than adults may also be related to experience, or more specifically, confidence. Due to varying habitat characteristics and test protocol, any LGD out-of-view during a decoy test was greater than 50 meters from the decoy. Actual distance from the decoy was impossible to measure and varied by habitat characteristics, but an LGD could not be both proximate to the decoy and out of view. We believe the out-of-view behavior code may serve as a weak proxy of willingness to approach the decoy. Thus, it may be that juvenile LGDs lack the boldness or willingness of older LGDs to engage with potentially threatening stimuli. Alternatively, out-of-view may indicate younger LGDs' inexperience and inability to properly assess a threat by moving towards it. If so, our results provide further evidence that LGDs <2 years of age lack the ability of better performing, older LGDs.

Time-of-day was also a significant predictor of scanning and general locomotor activity during baseline sampling. These findings are somewhat intuitive and corroborate findings that LGDs are somewhat crepuscular in their activity patterns, or at least not as active during the hottest hours of mid-day and early afternoon (van Bommel and Johnson, 2014b). This pattern of mid-day inactivity also corresponds to the time-of-day in which wolf depredation is least likely (Ciucci and Boitani, 1998).

LGD sex was not a significant predictor of any LGD behavior. Although there exists a sentiment by some who breed and use LGDs that males are more aggressive than females (personal communications), we did not find this to be the case. We had all novel-

breed LGDs spayed and neutered at about one year of age to minimize problems of unintentional breeding and wandering. It is possible that intact LGDs may show more divergent behavior patterns between the sexes, but we were unable to test this hypothesis. Nevertheless, our findings corroborate other behavioral analyses of LGDs, which also find no effect of LGD sex on behavior (Leijenaar and Cilliers, 2015).

Due to dense vegetation and inconvenient topography, a number of potential observations had to be dropped from our behavioral analyses as certain LGDs remained out of view for the entirety of the decoy test. Although LGDs were always visible to the observer if they were proximate to the decoy, LGD behavior relevant to guarding that took place further from the decoy may have been missed. Although nearly all of the LGDs monitored during the decoy test were equipped with store-on-board GPS collars, those collars were not equipped with accelerometers. Had that been the case, it may have been possible to surmise LGD behavior, even while out of view, by analyzing locomotor activity recorded by the collars. Future field investigations of LGDs may consider employing such technology to partially account for difficulties in viewing behavior in wilderness settings.

Considering the range of behavior we observed, both in baseline sampling and a predator simulation, we found LGD behavior to be mostly the same across breeds. To the extent that the decoys properly modeled threatening and non-threatening species that LGDs would regularly encounter (i.e., a wolf-like canid and a deer-like ungulate), the data presented here suggest that there are no differences in response among kangals, karakachans, or whitedogs to threatening and non-threatening environmental stimuli. Due to a small sample size and the number of context-specific variables involved in field

studies of behavior, it may be more conservative to say that if behavioral differences in how these breeds respond to potentially threatening stimuli do differ, it is in subtle ways that are easily masked by noise in the data. In fact, disregarding decoy-type, we did detect subtle breed differences in initial response to the decoy and a significant breed difference in baseline behavior. Additional study will be necessary to determine to what extent these behavioral subtleties are relevant to loss prevention, and whether actual loss-prevention is a function of LGD breed. It is possible that the small behavioral differences we observed between breeds upon approaching the decoy would lead to increasingly divergent behavior if the stimulus was a living animal and not a decoy. For now, our results may help livestock producers make more-educated and tailored decisions in choosing the appropriate breed of LGD for their needs and circumstance.

Implications

Wildlife managers, LGD breeders, researchers, and others are frequently asked which LGD breed would work best in a given situation or with a certain predator. While an investigation of sheep mortalities to see which LGD breeds are associated with the greatest loss prevention could help answer this question, understanding behavioral differences among breeds provides information that may be less context dependent (Mehrkam and Wynne, 2014). For this study, we monitored LGD behavior, both passively and in response to a decoy, to determine if LGD breeds show behavioral differences. Our results indicate that few behavioral differences exist between the breeds tested, although kangals tended to be more investigative when engaging a decoy, karakachans more vigilant, and transmontanos more able to decipher a threatening from

unthreatening stimuli. While future study will be necessary to see if loss prevention varies by breed, the homogeneity of behavioral data for multiple LGD breeds suggests that regardless of breed, LGDs operate in much the same way. As such, breed may be a less important predictor of a "good dog" than often suggested.

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Conflicts of Interest

None

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Tables

Table 3.1
Behavioral codes used during continuous focal observations and the decoy test. Behavior is divided into four components and one behavior from each component was recorded at every observation. Note that the “decoy” behavior under proximity was only an option during the decoy test.

Behavioral Component	**Behavior**	**Description**
activity		
	vigilant	attention fixed
	investigate	sniffing an area or object
	scan	looking around or scanning an area
	run	running after another animal
	stalk	head, tail, and ears lowered; crouched pursuit
	chase	running after another animal
	fight	fighting with, or biting another animal
	play	playing with other dogs
	eat	eating or drinking
	hygiene	grooming, urinating, defecating
	no behavior	no behavior observed
posture		
	lay	lying or bedded-down (includes sleeping)
	up	sitting or standing stationary
	move	moving, any speed
vocalization		
	bark	barking
	growl	growling
	whine	whining
	no sound	no audible sound
proximity		
	sheep	≤ 50m from sheep
	away	> 50m from sheep (and decoy)
	decoy	≤ 50m from decoy (only during decoy test)
other		
	out-of-view	not visible to the observer

Table 3.2
Model results for all top models (ΔAICc ≤ 2.0) of the scan behavior observed during continuous focal observations. Results are shown as log odds ratios with standard error shown in parentheses below. Any models that failed to converge are indicated.

	Top Scan Models						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
morning	0.445	0.413	0.443	0.428	0.394	0.465	
vs. mid-day	(0.354)	(0.354)	(0.355)	(0.354)	(0.354)	(0.356)	
evening	0.852**	0.848**	0.828**	0.855**	0.853**	0.831**	
vs. mid-day	(0.349)	(0.350)	(0.350)	(0.349)	(0.350)	(0.350)	
kangal	0.163	0.087		0.033	-0.060		0.142
vs. whitedog	(0.422)	(0.432)		(0.447)	(0.454)		(0.422)
karakachan	0.746	0.683		0.532	0.435		0.622
vs. whitedog	(0.531)	(0.545)		(0.581)	(0.593)		(0.528)
transmontano	-1.045*	-0.907*		-1.270**	-1.180*		-1.118**
vs. whitedog	(0.540)	(0.548)		(0.592)	(0.604)		(0.539)
male	0.605*			0.575		0.369	0.586
vs. female	(0.360)			(0.365)		(0.380)	(0.359)
juveniles				0.339	0.398		
vs. adults				(0.356)	(0.359)		
model convergence					*failed*		
log likelihood	-3,308.37	-3,309.73	-3,312.88	-3,307.92	-3,309.11	-3,312.42	-3,311.41
ΔAICc	0.00	0.64	0.79	1.18	1.49	1.91	1.95
model weight	0.164	0.119	0.111	0.091	0.078	0.063	0.062

Note: *p<0.1, **p<0.05, ***p<0.01

Table 3.3
Model results for all top models (dAICc < 2.0) of the move behavior observed during continuous focal observations. Results are shown as log odds ratios with standard error shown in parentheses below. Any models that failed to converge are indicated.

	Top Move Models			
	(1)	(2)	(3)	(4)
morning vs. mid-day	1.670***	1.671***	1.705***	1.652***
	(0.482)	(0.482)	(0.483)	(0.483)
evening vs. mid-day	1.254***	1.287***	1.358***	1.255***
	(0.478)	(0.479)	(0.482)	(0.478)
juveniles vs. adults		0.464		
		(0.401)		
kangal vs. whitedog			0.653	
			(0.492)	
karakachan vs. whitedog			1.179*	
			(0.611)	
transmontano vs. whitedog			0.109	
			(0.633)	
male vs. female				-0.226
				(0.417)
model convergence				
log likelihood	-2,604.14	-2,603.47	-2,601.91	-2,603.99
ΔAICc	0.00	0.71	1.71	1.76
Model weight	0.305	0.214	0.130	0.127
Note:		*p<0.1; **p<0.05; ***p<0.01		

Table 3.4
Model results for all top models (dAICc < 2.0) of the lay behavior observed during continuous focal observations. Results are shown as log odds ratios with standard error shown in parentheses below. Any models that failed to converge are indicated.

	Top Lay Models	
	(1)	(2)
morning vs. mid-day	-1.641***	-1.639***
	(0.573)	(0.573)
evening vs. mid-day	-1.460***	-1.472***
	(0.565)	(0.566)
juveniles vs. adults		-0.208
		(0.498)
model convergence		
log likelihood	-2,831.52	-2,831.43
ΔAICc	0.00	1.87
model weight	0.428	0.168
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 3.5
Model results for all top models (dAICc < 2.0) of the vigilant behavior observed during the decoy test. Results are shown as log odds ratios with standard error shown in parentheses below. Any models that failed to converge are indicated.

	Top Vigilant Models		
	(1)	(2)	(3)
juveniles vs. adults	1.335^{***}	1.370^{***}	1.380^{***}
	(0.449)	(0.442)	(0.457)
wolf vs. deer decoy		-0.652	
		(0.623)	
male vs. female			-0.216
			(0.360)
model convergence			
log likelihood	-186.92	-186.39	-186.74
ΔAICc	0.00	1.16	1.85
model weight	0.409	0.229	0.162
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$		

Table 3.6
Model results for all top models (dAICc < 2.0) of the vigilant behavior observed within 60 seconds of intial engagement of a LGD with the decoy. Results are shown as log odds ratios with standard error shown in parentheses below. Any models that failed to converge are indicated.

	Top Vigilant Models (first 60 seconds)					
	(1)	(2)	(3)	(4)	(5)	(6)
wolf vs. deer decoy	-2.547	-2.248				-1.796
	(1.579)	(1.486)				(1.236)
juveniles vs. adults	2.052			2.085		
	(1.373)			(1.508)		
whitedog vs. kangal					1.380	1.377
					(1.124)	(1.065)
karakachan vs. kangal					3.245**	2.944**
					(1.549)	(1.440)
model convergence						
log likelihood	-44.72	-46.08	-47.44	-46.30	-45.31	-44.12
ΔAICc	0.00	0.15	0.43	0.60	1.19	1.52
model weight	0.147	0.137	0.119	0.109	0.081	0.069
Note:				*p<0.1; **p<0.05; ***p<0.01		

Table 3.7
Model results for all top models (dAICc < 2.0) of the investigate behavior observed within 60 seconds of intial engagement of a LGD with the decoy. Results are shown as log odds ratios with standard error shown in parentheses below. Any models that failed to converge are indicated.

	Top Investigate Models (first 60 seconds)		
	(1)	(2)	(3)
wolf vs. deer decoy		1.012	
		(0.949)	
male vs. female			-0.729
			(0.828)
kangal vs. whitedog	2.178**	2.091**	2.054**
	(0.878)	(0.863)	(0.864)
karakachan vs. whitedog	-0.360	-0.209	-0.184
	(1.346)	(1.346)	(1.358)
model convergence			
log likelihood	-32.39	-31.78	-32.00
ΔAICc	0.00	1.51	1.93
model weight	0.336	0.158	0.128
Note:			*p<0.1; **p<0.05; ***p<0.01

Figures

Figure 3.1
Livestock guardian dog breeds tested during this study. Clockwise from bottom left: Portuguese cão de gado transmontano, Bulgarian karakachan, Turkish kangal, American "whitedog."

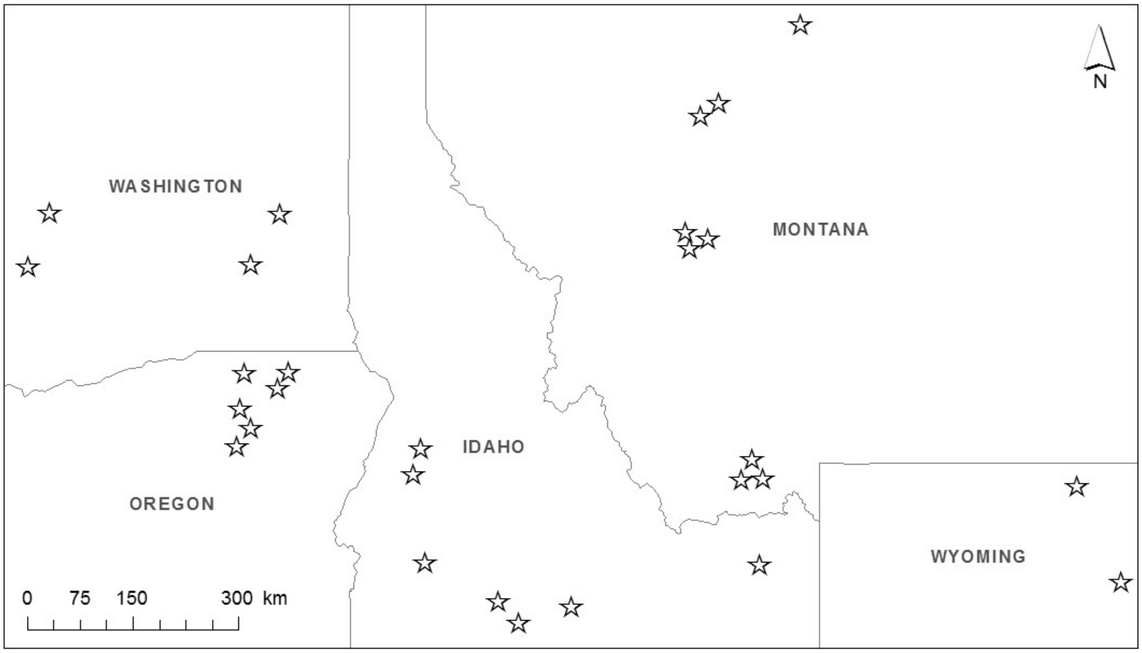

Figure 3.2
Study extent. Stars indicate the locations of monitored LGDs and sheep bands from 2015 – 2016.

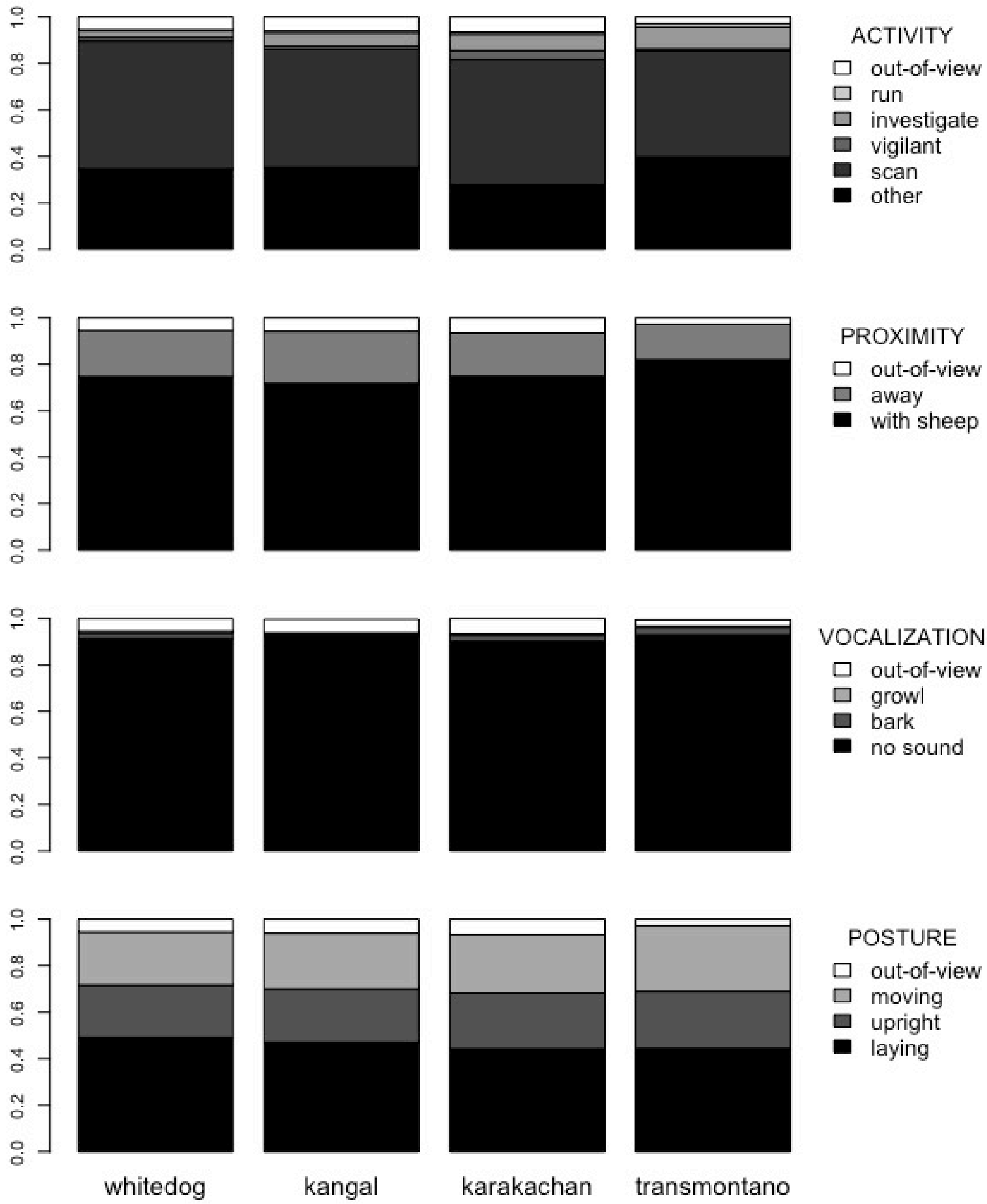

Figure 3.3
Proportion of time spent in each behavioral state, averaged across 540 tests of 80 individual LGDs. The four behavioral components (activity, proximity, vocalization, posture) are shown by row. Proportion of behavior is collapsed by breed (whitedog, kangal, karakachan, transmontano) and shown by column. Play, eat, hygiene, chase, stalk, fight, and no behavior are collapsed into a single “other” category in activity for readability.

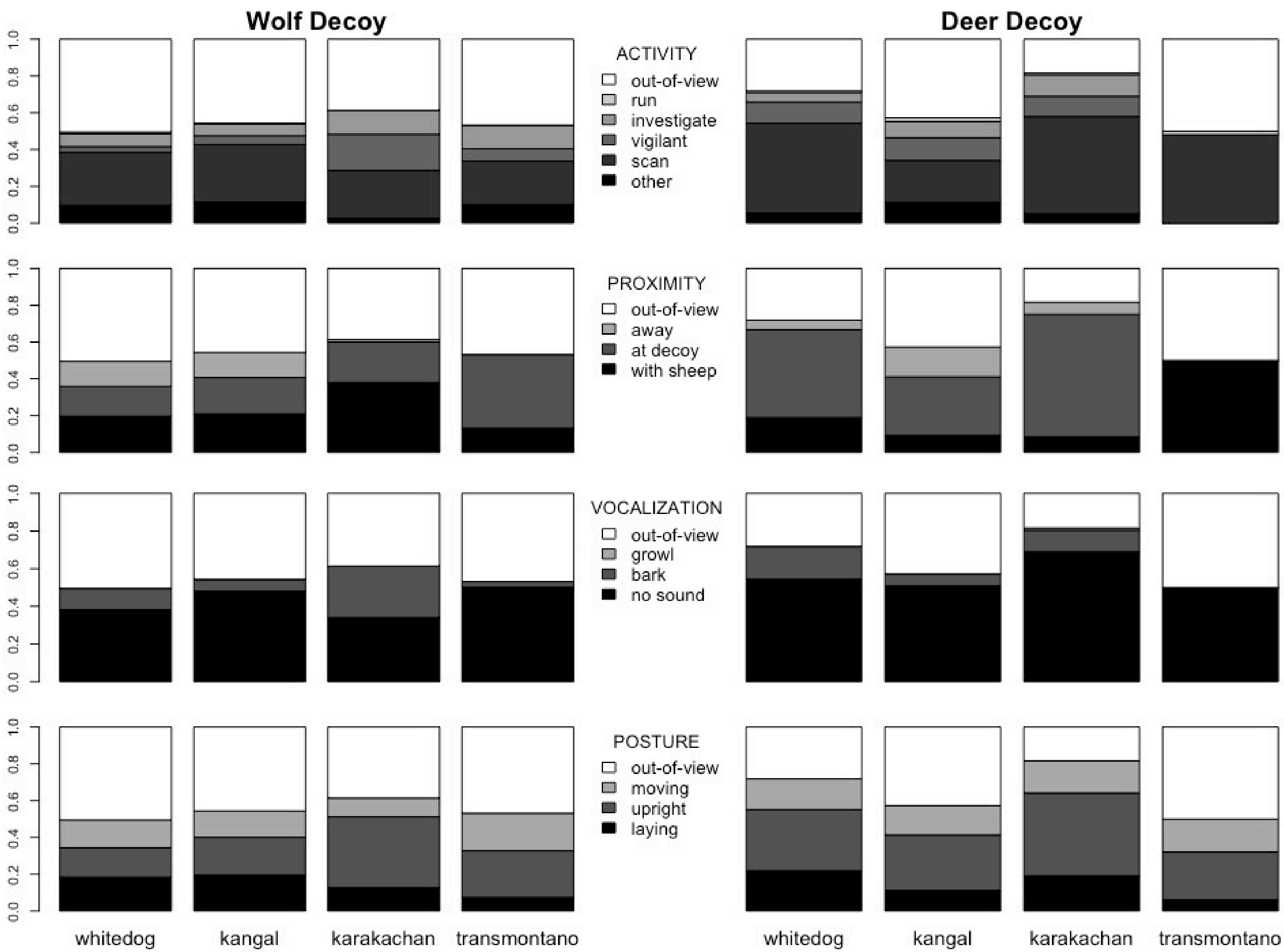
Wolf Decoy
Deer Decoy
ACTIVITY
out-of-view
run
investigate
vigilant
scan
other
PROXIMITY
out-of-view
away
at decoy
with sheep
VOCALIZATION
out-of-view
growl
bark
no sound
POSTURE
out-of-view
moving
upright
laying
0.0
0.2
0.4
0.6
0.8
1.0
whitedog
kangal
karakachan
transmontano
whitedog
kangal
karakachan
transmontano

Figure 3.4
Proportion of time spent in each behavioral state, averaged across 214 tests of 84 individual LGDs. The four behavioral components (activity, proximity, vocalization, posture) are shown by row. Decoy type (wolf, deer) is shown in the two major columns. Proportion of behavior is collapsed by breed (whitedog, kangal, karakachan, transmontano) and shown by sub column. Play, eat, hygiene, and no behavior are collapsed into a single "other" category in activity for readability.

CHAPTER 4

SHEEP BANDS AS SUPER PREDATORS: EFFECTS OF TRANSHUMANCE GRAZING SYSTEMS ON THE DETECTION PROBABILITY OF NORTH AMERICAN CARNIVORES[3]

Abstract

Although practiced for millennia, the effect that transhumance (i.e., moving livestock across open range) has on wildlife is poorly understood. Domestic sheep (*Ovis aries*) may act as an attractant to carnivores; however, sheep are traditionally accompanied by livestock guardian dogs (*Canis familiaris*) and shepherds (*Homo sapiens*), which defend prey and may displace carnivores. To test the effect of this multi-species assemblage – a sheep band – on detection probability of carnivores, we combined GPS-collar data with photos collected from 992 camera trap surveys and used these data to model the detection probability of carnivores relative to the presence of a sheep band. The presence of a sheep band reduced detectability of wolves (*Canis lupus*) by 75% in our top model ($p = 0.09$) but did not affect detectability of brown bears (*Ursus arctos*), black bears (*Ursus americanus*), or cougars (*Puma concolor*). Detectability for coyotes (*Canis latrans*), red foxes (*Vulpes vulpes*), and bobcats (*Lynx rufus*) increased when sheep bands were present ($p < 0.1$), suggesting displacement of wolves may result in mesopredator release. In demonstrating the species-specific effects of sheep-band presence, we suggest sheep bands serve as a super predator and trigger a non-

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[3] Co-authored with Julie K. Young

consumptive behavioral trophic cascade.

1. Introduction

How animals interact with one another is generally determined by their relative position in a trophic hierarchy and the level of territoriality between conspecifics and intraguild competitors. Prey respond to risk effects imposed on them by predators [1], dominant predators suppress and compete for resources with subordinate competitors [2,3], and conspecifics often protect resources from competing individuals by defending a territory [4,5]. These broad-scale generalizations about how animals interact in space provide a useful heuristic for ecologists and other wildlife professionals. The effect of multi-species assemblages on the space use of other species remains less understood, especially when species assemblages include domestic animals.

Foraging competition between wild and domestic herbivores has been studied [6,7] as well as some investigations of the effects of dogs (*Canis familiaris*) and humans (*Homo sapiens*) on wildlife [8-10]. Less studied is the effect that livestock assemblages have on predatory wildlife. Uniquely anthropogenic, sheep bands are dynamic assemblages of domestic sheep (*Ovis aries*), dogs, and people that travel throughout global landscapes in search of sheep forage. Following a practice known as transhumance [11], domestic sheep are herded to higher altitude pastures each summer to take advantage of forage resources. In North America, this tradition is typically practiced as sheep, shepherds, herding dogs, and livestock guardian dogs (LGDs; *Canis familiaris*) travel through and between undeveloped public lands each summer. This assemblage

(henceforth "sheep band") does not have an obvious analogue in other large-mammal systems but serves as a unique type of defended prey population.

Defended prey generally refers to a species which defends itself through weapon-like adaptations [12] or aposematism [13]. Another type of defended prey occurs when one species actively guards prey against another predator species. For example, certain varieties of ants (i.e., *Lasius niger*) guard food-producing aphids from predators [14] and multiple species of damselfish (e.g., *Plectroglyphidodon lacrymatus*) defend algae patches from other herbivorous fish [15]. In these cases, the guarding species successfully alters the behavior and space use of its competitor [14,16]. Despite the fact that invertebrates and fish may seem disparate examples of defended prey, there is no *a priori* reason to assume the basic ecological theory should not hold for a sheep band and native predators [17]. In fact, like aphids and algae, domestic sheep are largely defenseless to a host of potential predators and commonly killed when undefended [18].

Within the sheep band, shepherds, LGDs, and even herding dogs defend sheep from depredation [19]. While shepherds and herding dogs are generally only within the flock during the day, LGDs are present within the flock 24-hours a day and offer the first line of defense against predation. LGDs have been utilized by humans to mitigate depredation of livestock for at least 5,000 years [19]. Contemporary research on LGDs indicates they are effective for reducing livestock loss [20-24]. However, one recent meta-analysis found that their effectiveness may be weak relative to other non-lethal methods [25]. Only recently domesticated from wolves [19,26], LGDs are selectively bred to defend livestock from predators. LGDs are bonded to livestock when they are young, which enforces their natural instinct to protect [27]. Thus, LGDs may act as

intraguild competitors to sheep predators even though they do not kill and consume sheep. van Bommel and Johnson [28] showed that red foxes (*Vulpes vulpes*) avoided areas where LGDs were present. Foxes have been shown to avoid free-roaming dogs [29,30] while also being more detectable in areas frequented by dogs [31]. Bobcats (*Lynx rufus*) [31] and a host of ungulates [32] have been shown to avoid areas frequented by dogs. Further, while some large carnivores have been shown to depredate free-roaming dogs [33], the effect of LGDs on the space-use of larger carnivores is unknown [but see 34]. Coyotes (*Canis latrans*) remain the most common predator to kill sheep throughout the US. They were identified as the predator in 54.3% of all reported depredations events in 2014 [35] and most previous research on LGDs focused on sheep depredation by coyotes. Even so, a host of other carnivores also depredate sheep, including wolves (*Canis lupus*, 1.3%), bears (*Ursus sp.*, 5.0%), and cougars (*Puma concolor*, 5.6%) [35]. Interactions between LGDs and these large carnivores in North America have rarely been studied.

Lacking research on the topic, it is difficult to predict how LGDs might interact with native carnivores. Is an LGD simply a free-roaming dog or an intraguild competitor? It has been shown that distance to brown bears and other wolves is inversely related to the establishment of a new wolf pair [36], even though intraspecific competition among wolves does not seem to effect home range size [37]. If LGDs moving through the landscape as part of a sheep band are seen as competitors by nearby wolves, they could provoke intraspecific aggression just as an invading wolf pack might [but see 9]. However, because of the large number of animals in a sheep band and the presence of humans, wolves may respond to the sheep band as they would a more dominant pack

[10]. Allen et al. [38] showed that LGDs permitted many intrusions by other wild canids into sheep pastures while still preventing fine-scale interactions between predators and sheep, but whether this applies to sheep bands on open range is unclear. Likewise, it is unclear what effect, if any, a sheep band might have on bear or cougar space use. Wolves appear to avoid brown bears to some extent [36] even though they often outcompete brown bears for food resources [2]. Dogs, on the other hand, seem to displace brown bears [8], although this may be related to the association between dogs and humans [8,39,40]. Similarly, while LGDs can successfully defend livestock from black bears [23] and cougars [41], it is unclear whether this is via displacement or more direct interactions.

This study focuses on how transhumance sheep bands affect localized space use of endemic carnivores. We used detection probability as our metric of localized space use because camera-trap spacing optimized for sheep band home range is too close to ensure spatial independence for animals with large home ranges [28,42,43]. To the extent that species do not change their behavior when sheep bands are present in a way that makes them more or less detectable by camera, probability of detection can serve as a proxy for localized space use. To test the effect of a sheep band on the detection probability of medium- to large-bodied North American carnivores, we deployed trail cameras in grazed areas across the Northwestern US. As sheep, shepherds, and LGDs all remain closely proximate throughout the grazing season, the sheep band became the unit of analysis, but we assume LGDs are the dominant deterrent to carnivores within the sheep band. We hypothesize that LGDs, through their association with shepherds and as part of a sheep band, act as intraguild competitors to and temporarily displace brown bears,

wolves, black bears, and cougars on the landscape. We assume the effect is the same for smaller carnivores.

2. Materials and methods

2.1. Study area

We collected data from May to October of 2014 – 2016 in areas with a suite of mammalian carnivores and overlapping and adjacent to grazing sheep bands in five US states: Oregon, Washington, Montana, Idaho, and Wyoming. Study sites are detailed in Kinka and Young [44] and included remote areas where livestock are grazed on public land, as well as fenced and unfenced private land (Figure 4.1).

2.2. Livestock guardian dogs and sheep

The unit of interest for analysis is the sheep band, which typically consists of approximately 1,000 adult ewes with 1-2 lambs each and 2-8 LGDs at all times, with a shepherd, 1-2 herding dogs, and 0-2 horses also present during most daylight hours. The specific make-up of sheep bands is dynamic, so we were unable to control for the exact number of LGDs with the band, LGD breed, or sheep breed in analysis. LGD and sheep breeds are described in Kinka and Young [44].

2.3. Camera trapping

To measure the space use of carnivores in relation to LGDs and sheep, we deployed camera traps to collect presence/absence data for medium- to large-bodied mammals before, during, and after a sheep band was grazed through a given area (Figure 4.1). Bushnell Trophy Cam HD motion-triggered cameras were set-up along grazing

routes or around grazed areas of private land between 615 – 2,917 meters in elevation (most between 1,200 – 1,400 m). We spaced camera traps 2-4 km apart based on field observations that 4 km^2 roughly approximates the space used by a grazing sheep band within any 7-day period. We set cameras at a height of approximately 90-100 cm above the ground, generally along a path or game trail. A maximum of one photograph per second was captured when motion was detected in front of the camera.

2.4. Additional location data

All LGDs associated with the camera grid were outfitted with store-on-board GPS collars (Telonics or ATS), which recorded GPS locations for the LGDs every 2.5 or 5 hours throughout the grazing season. Three to five sheep from each sheep band were also fitted with store-on-board GPS collars (i-gotU GT-600) for 3-6 weeks at a time throughout the grazing season. If ranchers preferred that we not collar their sheep, we asked herders to carry handheld GPS devices and record locations for the sheep band three-times a day. Due to collar failure, collar loss, or the occasional relocation of LGDs from one band to another, there were gaps in the location data for certain individual LGDs at certain times. However, as the LGDs generally work as a unit, and are always proximate to the sheep, there was no reason to believe that these gaps in individual records biased the data for the entire sheep band. We also obtained GPS data from state wildlife agencies for a number of collared wolves and brown bears in Idaho and Montana. We obtained location data for 20 wolves and 5 brown bears in the vicinity of sheep bands in Montana, and for 20 wolves in the vicinity of sheep bands in Idaho. By also incorporating wolf and brown bear sightings and triangulating the location of VHF-

collared wolves and brown bears, we incorporated an additional 6 brown bear and 25 wolf locations.

2.5. Statistical analysis

To model the probability of detection for multiple carnivore species in the presence of sheep bands, we first created occupancy matrices for all species of interest based upon data collected from trail cameras. We defined surveys as a 7-day period in which a camera was deployed with each species either present or absent during the survey period. We then used information from wolf and brown bear sightings, as well as locations from LGDs, sheep, wolves, and brown bears fitted with GPS collars to fill-in gaps in occupancy matrices for these species. If a collar location or sighting fell within a 1-km radius of a trail camera during its deployment, we marked the species as present for the 7-day survey period in which the location was recorded (if the species had not already been detected by a camera trap) to create robust occupancy matrices. We combined robust occupancy data for LGDs and sheep to create a single encounter history for sheep bands. Cougar, black bear, coyote, red fox, and bobcat occupancy matrices were based on camera data alone. In cases where cameras were deployed <1 km of one another during overlapping trapping periods, the camera with the shorter deployment was excluded from analysis. We only included Montana study sites in occupancy models for brown bears as we never detected brown bears outside of Montana and they were not known to exist within other parts of our study area during the time of the study. Similarly, we removed Oregon and Washington field sites from the red fox data set as we never detected them at

those field sites and they were not known to exist in the Eastern parts of those states during the time of the study [45].

We analyzed brown bear, wolf, cougar, black bear, coyote, red fox, and bobcat data using single-species single-season occupancy models [43]. All models were constructed using the unmarked package [46] in program R [47]. We included state and year as possible predictors of occupancy probability in our modeling exercise to account for large-scale differences in species densities over space and time. We limited our interpretation of model output to probability of detection only because camera trap spacing was too close to ensure spatial independence for animals with large home ranges [28,42,43]. We used the encounter history of the sheep band as a survey-level covariate for probability of detection to account for sheep bands moving in and out of a trapping area [48]. We also included state and year as possible predictors of detection probability in our modeling exercise to account for differences in species densities over space and time. Since we only included Montana sites in our brown bear analysis, state was excluded as a predictor variable of probability of occupancy or probability of detection.

3. Results

We collected photographs from 185 camera locations over 992 trap surveys and detected all species of interest (Table 4.1). Vehicle and other human activity were also detected but infrequently. GPS data added 239 unique survey detections of LGDs and 93 of sheep for a total of 372 additional surveys where a sheep band (i.e., LGD, sheep, or both) was detected using GPS data. GPS data and live sightings combined added three additional survey detections for wolves and one additional survey detection for brown

bears.

Both sheep-band presence and year were significant predictors of detection probability for wolves in the highest-ranking occupancy model (Table 4.2). Across years, wolves were 0.27 times as likely to be detected when sheep bands were present ($p = 0.09$), as predicted by the top model (Table 4.2). Sheep band was not included in the second highest-ranking model for wolves (AIC = 1.40), which was the only other wolf model with a delta AIC ≤ 2.0. Year was included as a predictor of detection probability in both of the top wolf models, but only significant in the top model for differences between 2015 and 2016. Detection probability for wolves dropped by nearly an order of magnitude from 2015 to 2016, regardless of sheep band presence. However, sheep band presence reduced detection probability for wolves by approximately 75% in all three years of the study (Figure 4.2). One of the candidate models for wolves failed to converge and was not included in the model ranking exercise.

The null model was the highest-ranking occupancy model for both brown bears and cougars, both with approximately twice the AIC weight as the next best model (Tables 4.3 & 4.4). Sheep band was included as a predictor in the third and fifth highest-ranking models for brown bears and cougars (respectively), but neither term was significant (Tables 4.3 & 4.4). No predictors reached significance in any of the top brown bear or cougar models (ΔAIC ≤ 2.0). Three of the candidate models for cougars failed to converge and were not included in the model ranking exercise. Similarly, sheep-band presence was only included in one of three top models for black bears and the term was not significant. However, detection probability for black bears in Idaho, Oregon, and Washington was found to vary considerably (compared to Montana and Wyoming) in all

three top models, and one model also indicated a significant difference in detection probability between 2014 and 2016 (Table 4.5).

For the smaller carnivores, sheep-band presence increased detection probability, with most top models for coyotes, red foxes, and bobcats indicating a significant increase (Tables 4.6-8). Holding state and year constant, coyotes were 70-77% more likely to be detected when a sheep band was present, as predicted by all four top models for coyotes ($p < 0.01$; Table 4.6). The top two models for red fox indicated a marginally significant increase in detection probability of 114-117% when a sheep band was present ($p < 0.1$; Table 4.7). Two of the candidate models for bobcats failed to converge and were not included in the model ranking exercise. Even so, there was a significant increase in detection probability of 258-233% in 4 of the top 6 models when a sheep band was present ($p < 0.1$; Table 4.8). Certain top models also included significant effects of year on detection probability of coyotes, red foxes, and bobcats (Tables 4.6-8) and of state for coyotes (Table 4.6).

The models predicting occupancy probabilities are not reported here since camera traps were not spaced far enough apart to ensure spatial independence [28,42,43]. However, we did allow occupancy probability to vary by year in brown bear models, and state and year in all other species models. The best three of four brown bear models with a cumulative AIC weight of ≥0.75 did not include year as predictors of occupancy probability. All of the wolf models with a cumulative AIC weight of ≥0.75 included both state and year as predictors of occupancy probability. The inclusion of state and year as predictors of occupancy probability for other species varied.

4. Discussion

Our findings describe how defended multi-species assemblages moving across a landscape affect the localized space use of a number of different carnivores. We found that sheep bands in the Northwestern US may temporarily displace wolves. The presence of a sheep band reduced the probability of detection for wolves by about 75% (Table 4.2 and Figure 4.2). This result supports our hypothesis that domestic sheep in a sheep band function as a defended prey and that LGDs and shepherds, in turn, serve as intraguild competitors to wolves. The avoidance of the sheep band by wolves suggests that sheep bands constitute a dominant competitor on the landscape. Whereas the lack of a response in brown bears, black bears, and cougars may suggest a neutral or inverse relationship. Smaller carnivores were more detectable when a sheep band was present, suggesting the displacement of wolves may trigger mesopredator release [3,49,50]. Notably, although we found evidence that a sheep band may temporarily displace wolves, sheep band presence was not included in the second-best supported model and was only weakly significant ($p = 0.09$) in the first. Nevertheless, there is evidence that wolves are less likely to use small habitat patches occupied by sheep bands. How this effect on wolf behavior relates to actual loss prevention will require further study, but these findings may highlight a behavioral effect on wolves which contributes to LGDs success as a non-lethal management tool [19,20].

Unlike our results for wolves, the presence of a sheep band was not a significant predictor of detection probability for brown bears, black bears, or cougars. That sheep bands do not appear to affect the space use of these large carnivores suggests that LGD success is not facilitated by the spatiotemporal displacement of these species when a

sheep band is nearby. Our small sample of brown bear and cougar detections may have limited our ability to detect an effect of sheep bands. Cougars, being an ambush predator, are presumably less conspicuous than canids and ursids, and a more rigorous detection methodology might have been necessary to attain a large sample size for such a cryptic species. With brown bear populations expanding in the Northern Rocky Mountains [52], larger sample sizes may be attainable in the future. However, we were able to document more than 50 black bear detections throughout our study; enough to be fairly confident in our model outcomes. The non-effect of sheep band on black bears may serve as corroborating evidence of the same non-effect in their larger ursid cousin.

Counter to our original hypothesis, we found that smaller carnivores were more likely to be detected when a sheep band was present. For coyotes – the primary predators of domestic sheep [35] – it may have been that the attracting force of a vulnerable prey species like domestic sheep overwhelmed any displacing effect of LGDs or shepherds. Smaller carnivores have smaller home ranges [51] and unlike wolves may not be able to move to a different part of their territory when a sheep band arrives. Subsequently, these smaller predators may attempt to take advantage of the abundant food resource when sheep become available. Conceptualizing the sheep band as defended prey, wolves may choose to pursue more vulnerable prey in other parts of their territory, while smaller carnivores are incentivized to take advantage of what comes their way, and thus become more detectable. However, red foxes and bobcats are less common predators of domestic sheep [35], and red foxes have previously been shown to avoid LGDs [28]. It may be that by displacing wolves, a sheep band induces a temporary mesopredator release [3,49,50]; removing intraguild predation or competition pressure imposed by wolves, which results

in higher detection probability for coyotes, red foxes, and bobcats. Unlike van Bommel and Johnson [28], we showed that the presence of LGDs (as part of a sheep band) seemed to attract rather than repel red foxes. This disparity further supports the idea that sheep bands induce mesopredator release in North America. Because no apex predator was present in van Bommel and Johnson's [28] study of Australian LGDs, the LGDs themselves may have acted as a surrogate apex predator, displacing foxes instead of displacing wolves. Although we did not set out to investigate a potential mesopredator release imposed by sheep bands, these results highlight how novel anthropogenic scenarios can facilitate mesopredator release and the need for future work on this issue.

In addition to sheep-band presence, we modeled for a potential effect of year and state on probability of detection for all species (except state for brown bears). While there was no significant effect of year on detection probability of brown bears or cougars, year was a significant predictor in top models for wolf, black bear, coyote, red fox, and bobcat detectability. Specifically, probability of wolf detection was about 11 times higher in 2015 than in 2016. Although the difference is not significant, wolf detectability in 2015 was also higher than for 2014 (Table 4.2). Coyotes exhibited a similar increase in detectability in 2015, while black bears and red foxes show limited evidence of an increase in detectability in 2014. It is unclear what drove this effect. There is no *post hoc* reason to suspect that any species was more conspicuous in a given year, as an increased probability of detection might suggest. Our camera trapping protocol was well established and reinforced across sites throughout each field season, so it is unlikely that variation in specific placement by different study personnel explains yearly differences. The inclusion of state and year was also meant to capture variance in management

regimes between states and over time. The effect of wolf and coyote detectability in 2015, and black bear and red fox detectability in 2014, could be driven by differences in management, but then state should also be included as a predictor, as was the case for coyotes and black bears. State and year were retained in top models of occupancy probability for wolves, but only year appears in the top models for detection probability. A final, and perhaps most likely explanation for this effect in wolf and other carnivore models is fluctuations in primary prey abundance and distribution. Although we did not explicitly model abundance of primary prey sources for wolves such as elk (*Cervus canadensis*) and mule deer (*Odocoileus hemionus*) [53], we assumed that allowing state and year to serve as possible predictors of detection probability would capture variance in prey abundance between years and across states. Diet composition for wolves has been shown to vary based on prey abundance [54-56], suggesting that wolves should be detected where there is preferred or abundant food. Not exclusive to wolves, this type of prey switching has been documented in multiple carnivore species in response to anthropogenic food resources [57]. If environmental conditions in 2015 favored low ungulate densities or low rodent densities in 2014 across our study sites, it is possible that we saw a rise in detectability for certain carnivores near sheep bands as a result of less abundant wild prey resources.

Lastly, while we focus on the role of LGDs in defending domestic sheep from predation, the near ubiquity of shepherds, herding dogs, and LGDs among grazing sheep in North America makes their unique contributions to defense difficult to disambiguate. The role of humans in dictating carnivore behavior has been a recent topic of study [58] with some suggesting that humans may even impose a landscape of fear on area

carnivores [40] and serve as a super predator [59,60]. Ultimately, our data do not allow us to untangle the singular effects of humans, herding dogs, and LGDs, but it is worth mentioning that LGDs outnumbered people in every one of our monitored sheep bands and LGDs were active during the day and night, while shepherds and herding dogs were only active during the day. Further, the use of humans alone, typically called range riders, does not appear to significantly impact wolf space-use [61]. More research will be needed to identify the unique contributions of humans and LGDs on carnivore behavior and space use. Our study offers the first insight into the ecological mechanisms that prevent depredation of sheep by endemic carnivores during transhumance grazing seasons.

Ethics

All animal-handling procedures fulfilled ethical requirements and were approved by the relevant authorities (USDA-National Wildlife Research Center's Animal Care and Use Committee, permit number: QA-2062).

Data accessibility

Data available from online repository.

Authors' contributions

DK conducted data collection, carried out statistical analysis, and drafted the manuscript. JKY critically revised the manuscript and coordinated the study. DK and JKY conceived of the study, participated in the design of the study, and gave final approval for publication.

Competing interests

We have no competing interests. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Tables

Table 4.1
The total number of seven-day camera trap surveys with at least one detection (Survey Detections) and camera trapping sites with at least one detection (Site Detections) by species. Survey and site detections for LGDs, sheep, brown bears, and wolves include data gathered from GPS and VHF collars, and sightings, as well as camera trap data.

Species	Survey Detections	Site Detections
LGD	333	139
Sheep	226	102
Coyote	179	85
Black Bear	56	36
Red Fox	52	27
Bobcat	25	13
Wolf	17	13
Brown Bear	11	6
Cougar	7	4

Table 4.2
Beta coefficients for probability of detection (p) for the highest-ranking occupancy models (ΔAIC ≤ 2.0) of wolves. The standard error is shown in parentheses.

	Top wolf occupancy models	
	(1)	**(2)**
Sheep band	-1.327^{*}	
(present vs. absent)	(0.784)	
2014 vs. 2016	0.915	0.452
	(0.829)	(1.50)
2015 vs. 2016	2.399^{***}	2.220
	(0.817)	(1.53)
Constant	-3.753^{***}	-3.504^{**}
	(0.718)	(1.440)
ΔAIC	0.00	1.40
AIC weight	0.42	0.21

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 4.3
Beta coefficients for probability of detection (p) from the highest ranking occupancy models (ΔAIC ≤ 2.0) of brown bears. The standard error is shown in parentheses.

	Top brown bear occupancy models		
	(1)	**(2)**	**(3)**
Sheep band			0.223
(present vs. absent)			(0.701)
2014 vs. 2016		-8.007	
		(38.817)	
2015 vs. 2016		-0.764	
		(0.821)	
Constant		-1.227^{**}	-1.677^{***}
		(0.517)	(0.581)
ΔAIC	0.00	1.38	1.90
AIC weight	0.38	0.19	0.15

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 4.4
Beta coefficients for probability of detection (p) from the highest ranking occupancy models (ΔAIC ≤ 2.0) of cougars. Three of the 32 candidate models failed to converge and were excluded from the model ranking exercise. The standard error is shown in parentheses.

	Top cougar occupancy models				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Sheep band					0.257
(present vs. absent)					(0.872)
Idaho vs. Montana		9.025			
		(62.744)			
Oregon vs. Montana		10.443			
		(62.742)			
Washington vs. Montana		9.517			
		(62.750)			
Wyoming vs. Montana		-3.679			
		(517.969)			
2014 vs. 2016				-7.239	
				(44.482)	
2015 vs. 2016				0.854	
				(0.976)	
Constant		-11.720		-2.237***	-1.967***
		(62.741)		(0.762)	(0.682)
ΔAIC	0.00	0.79	1.22	1.88	1.91
AIC weight	0.22	0.15	0.12	0.08	0.08

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 4.5
Beta coefficients for probability of detection (p) from the highest ranking occupancy models (ΔAIC ≤ 2.0) of black bears. Standard error is shown in parentheses.

	Top black bears occupancy models		
	(1)	**(2)**	**(3)**
Sheep band		-0.321	
(present vs. absent)		(0.334)	
Idaho vs. Montana	1.432^{***}	1.390^{***}	1.476^{***}
	(0.516)	(0.514)	(0.498)
Oregon vs. Montana	1.598^{***}	1.566^{***}	1.760^{***}
	(0.488)	(0.485)	(0.488)
Washington vs. Montana	1.680^{**}	1.739^{**}	1.844^{***}
	(0.715)	(0.713)	(0.708)
Wyoming vs. Montana	-0.494	-0.496	-0.314
	(0.732)	(0.731)	(0.738)
2014 vs. 2016			1.119^{*}
			(0.676)
2015 vs. 2016			-0.122
			(0.517)
Constant	-2.910^{***}	-2.794^{***}	-3.088^{***}
	(0.456)	(0.465)	(0.501)
ΔAIC	0.00	1.06	1.21
AIC weight	0.30	0.17	0.16

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 4.6
Beta coefficients for probability of detection (p) from the highest ranking occupancy models (ΔAIC ≤ 2.0) of coyotes. The standard error is shown in parentheses.

	Top coyote occupancy models			
	(1)	**(2)**	**(3)**	**(4)**
Sheep band	0.562***	0.571***	0.562***	0.528***
(present vs. absent)	(0.196)	(0.195)	(0.197)	(0.198)
Idaho vs. Montana	0.186	0.933***	0.797**	0.359
	(0.298)	(0.326)	(0.360)	(0.329)
Oregon vs. Montana	0.559**	1.054***	0.928***	0.625**
	(0.274)	(0.284)	(0.329)	(0.290)
Washington vs. Montana	1.307***	1.946***	1.764***	1.427***
	(0.393)	(0.403)	(0.442)	(0.417)
Wyoming vs. Montana	-0.296	0.272	0.121	-0.254
	(0.309)	(0.327)	(0.373)	(0.321)
2014 vs. 2016		-0.023	-0.022	-0.139
		(0.402)	(0.371)	(0.371)
2015 vs. 2016		0.661***	0.494**	0.284
		(0.223)	(0.243)	(0.234)
Constant	-1.439***	-2.112***	-1.924***	-1.577***
	(0.199)	(0.225)	(0.295)	(0.247)
ΔAIC	0.00	0.16	1.86	1.96
AIC weight	0.29	0.26	0.11	0.11

Note: *p < 0.1, **p < 0.05, ***p < 0.01

Table 4.7
Beta coefficients for probability of detection (p) from the highest ranking occupancy models ($\Delta AIC \leq 2.0$) of red foxes. The standard error is shown in parentheses.

	Top red fox occupancy models		
	(1)	**(2)**	**(3)**
Sheep band	0.773^{*}	0.760^{*}	
(present vs. absent)	(0.402)	(0.409)	
Idaho vs. Montana		0.982	
		(0.607)	
Wyoming vs. Montana		-0.067	
		(0.624)	
2014 vs. 2016	1.263^{***}		0.994^{**}
	(0.488)		(0.462)
2015 vs. 2016	0.710		0.400
	(0.512)		(0.478)
Constant	-1.863^{***}	-0.689^{**}	-1.436^{***}
	(0.407)	(0.289)	(0.334)
ΔAIC	0.00	1.38	1.76
AIC weight	0.23	0.12	0.10

Note: $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 4.8
Beta coefficients for probability of detection (p) from the highest ranking occupancy models (ΔAIC ≤ 2.0) of bobcats. The standard error is shown in parentheses. Certain parameters did not resolve and are indicated by a very high standard error or "NaN" ("not a number," equivalent to 0/0). Two of the 32 candidate models failed to converge and were excluded from the model ranking exercise.

	Top bobcat occupancy models					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Sheep band	0.985*	1.203**		1.000**	0.947*	
(present vs. absent)	(0.515)	(0.538)		(0.492)	(0.490)	
Idaho vs. Montana	24.69	10.28	21.79			31.34
	(*NaN*)	(29.14)	(4843)			(9686)
Oregon vs. Montana	23.04	8.951	20.38			29.81
	(*NaN*)	(29.13)	(4843)			(9686)
Washington vs. Montana	23.82	9.901	20.81			30.31
	(*NaN*)	(29.14)	(4843)			(9686)
Wyoming vs. Montana	22.70	8.896	19.79			29.34
	(*NaN*)	(29.13)	(4843)			(9686)
2014 vs. 2016	21.34	9.504	18.63	-1.000	-3.590***	28.16
	(*NaN*)	(29.15)	(4843)	(1.413)	(1.053)	(9686)
2015 vs. 2016	-1.312*	-0.938	-1.010	-1.770**	-1.334	-0.165
	(0.715)	(1.111)	(0.710)	(0.696)	(1.039)	(1.040)
Constant	-25.21	-11.20	-21.96	-1.640***	-1.630***	-31.53
	(*NaN*)	(29.13)	(4843)	(0.375)	(0.378)	(9686)
ΔAIC	0.00	1.63	1.76	1.76	1.77	1.92
AIC weight	0.17	0.08	0.07	0.07	0.07	0.07

Note: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

Figures

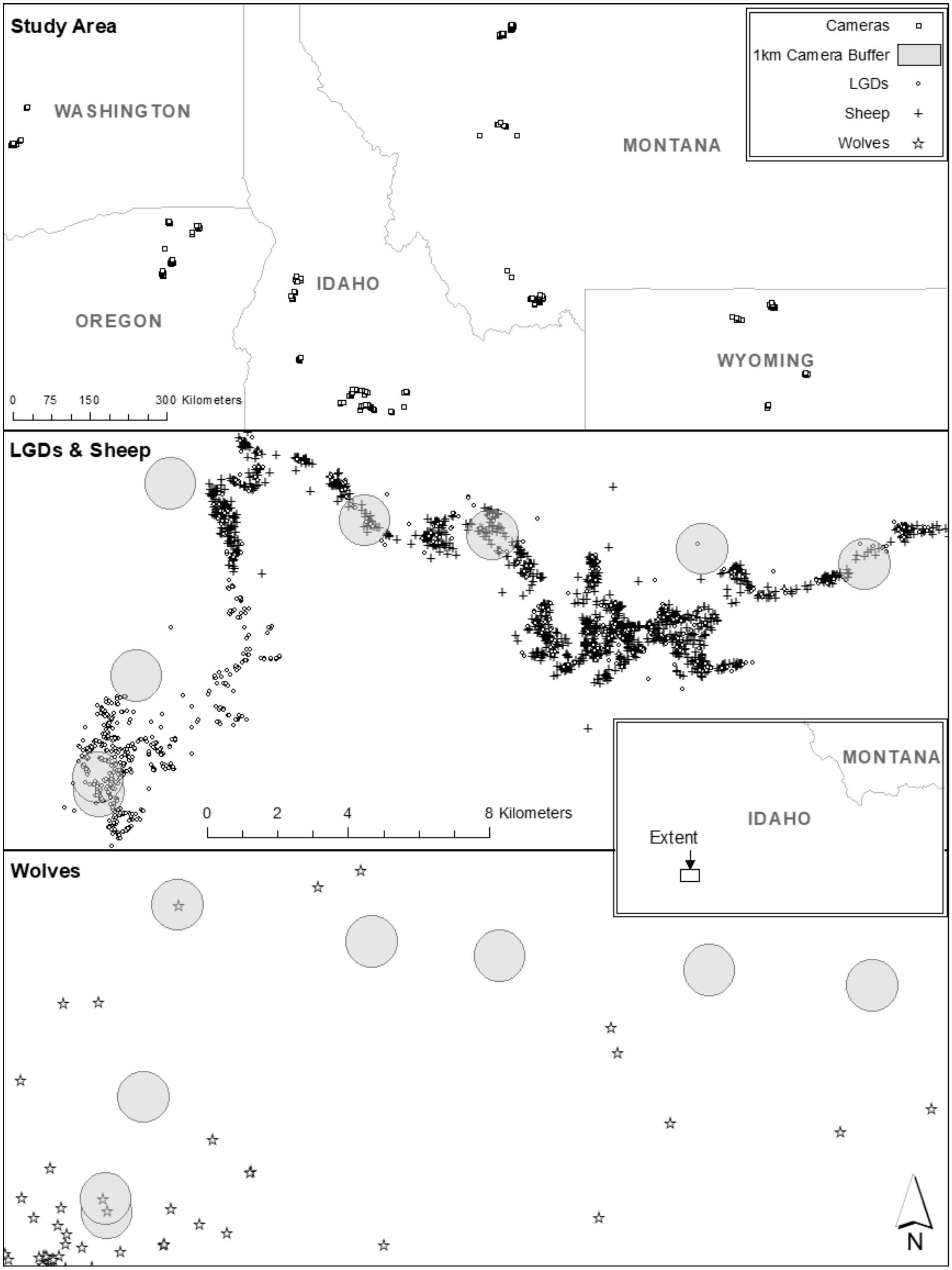
Study Area
Cameras
1km Camera Buffer
LGDs
Sheep
Wolves
WASHINGTON
MONTANA
IDAHO
OREGON
WYOMING
0 75 150 300 Kilometers
LGDs & Sheep
0 2 4 8 Kilometers
MONTANA
IDAHO
Extent
Wolves
N

Figure 4.1
Map of field sites and camera trap design. The top panel shows the location of all camera traps deployed during May – October 2014 - 2016. The middle and lower panels show the same trapping grid from Idaho's Sawtooth National Forrest in 2014. Grey circles indicate 1-km radium buffers around any camera trap active within the extent during the 2014 field season. Note that the overlapping buffers in the bottom left corner of the map indicate two sequential deployments of the same camera; they did not overlap temporally. The middle panel shows the locations of LGDs (small circles) and sheep (crosses) collected by GPS collar in relation to the camera trap buffers. The lower panel shows the locations of collared wolves (stars) collected via GPS and radio telemetry, as well as verified sightings of wolves, in relation to the camera trap buffers.

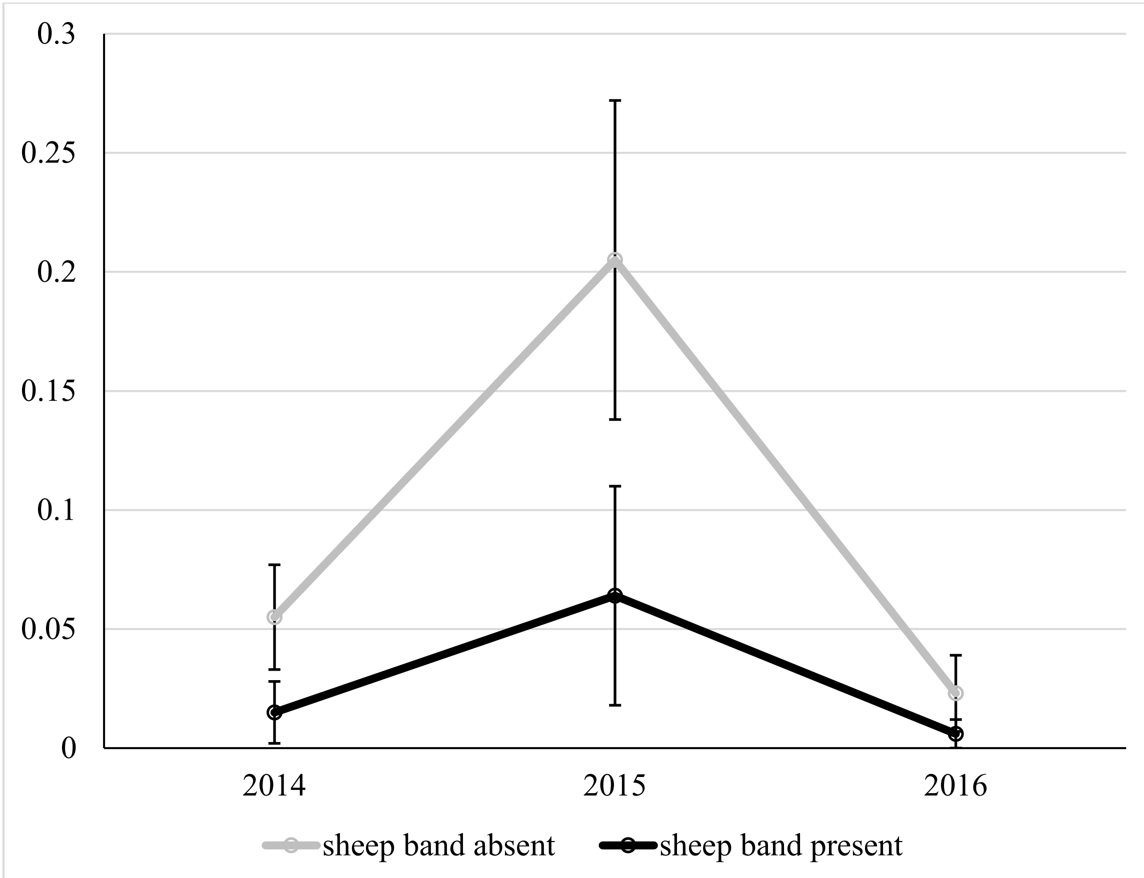

Figure 4.2
Probability of detection (p) for the highest ranked occupancy model of wolves as a function of the presence of a sheep band and year. Error bars represent standard error.

CHAPTER 5

THE TAIL WAGGING THE DOG: POSITIVE ATTITUDE TOWARDS LIVESTOCK GUARDIAN DOGS DO NOT MITIGATE PASTORALISTS' OPINIONS OF WOLVES OR GRIZZLY BEARS[4]

Abstract

While the re-establishment of grizzly bears (*Ursus arctos*) and gray wolves (*Canis lupus*) in the American West marks a success for conservation, it has been contentious among pastoralists. Livestock guardian dogs (LGDs; *Canis familiaris*) were widely adopted by domestic sheep (*Ovis aries*) producers in the United States to mitigate livestock depredation. We surveyed pastoralists to measure how experience with and attitudes towards LGDs related to attitudes towards livestock predators, and found positive responses regarding LGDs and negative responses regarding wolves and grizzly bears. The more respondents agreed that LGDs reduce the need for lethal management and prevent the spread of disease, the more positive their opinion of wolves as wild animals. Regarding wolves and livestock, the uncommon opinion that LGDs do more harm than good and the belief that LGDs reduce the need for lethal management both correlated with more positive attitudes towards wolves. Longer use of LGDs correlated with more negative opinions of grizzly bears. While experience was the greatest predictor of attitudes towards grizzly bears, attitudes towards wolves were correlated with the

[4] Co-authored with Julie K. Young

belief that LGDs offset the need for lethal management of carnivores. These results suggest that LGD use does not temper pastoralists' attitudes about livestock predators.

Introduction

Large carnivores are unique among other animals in terms of their ability to elicit strong emotions; they can be a contentious socioecological issue[1,2]. While the reintroduction of gray wolves (*Canis lupus*) and the re-establishment of grizzly bears (*Ursus arctos*) in the Northern Rocky Mountains of the United States (US) marked a success for conservationists, it also raised real and perceived concerns of risk among many pastoralists who cope with livestock depredation by wolves and grizzly bears[3]. Lethally managing carnivores to reduce livestock depredations is unpopular with the general public[4,5], questionable in its effectiveness[6], and not a broadly applicable option for species of concern like wolves and grizzly bears. This may partially explain the rapid adoption of non-lethal tools, such as livestock guardian dogs (LGDs), as a means of reducing livestock depredations in North America[2].

LGDs are domestic dogs (*Canis familiaris*) of a few dozen breeds that have been bred and trained to protect livestock from depredation, injury, and theft. LGDs are effective at reducing depredations by a suite of carnivores, including coyotes (*Canis latrans*)[7], dingoes (*Canis lupus dingo*)[8], black bears (*Ursus americanus*)[9], and cheetahs (*Acinonyx jubatus*)[10]. They enjoy a rich tradition in European history that dates back at least 5,000 years[2,9,11,12] but were first imported to the US in the 1970s as a substitute for lethal predator control outlawed by the Endangered Species Act[13]. Since that time, the use of LGDs as a non-lethal management tool for reducing livestock depredations has

been widely adopted by domestic sheep producers in the US because they are one of the few non-lethal management techniques that reduce domestic sheep (*Ovis aries*) depredations[7-9,14,15] and provide long-term results[1], despite some recent evidence to the contrary[16]. With the reintroduction of wolves to the Rocky Mountains and the recovery of other large carnivore populations, new breeds of LGDs are being introduced in the US for use deterring larger predators as well[17].

One aspect of LGD use that has gone largely unstudied is whether their use mediates pastoralists' tolerance for livestock predators. For instance, Rust, et al. detected an increase in reported tolerance for cheetahs in 11 of 14 South African farmers after they began using LGDs[18]. Other studies have evaluated the perceived effectiveness of LGDs, and while they were able to show that perceptions of LGD effectiveness were high or moderate, they did not test for a mediating effect of LGDs on tolerance for large carnivores[19,20]. There have also been a number of studies on human attitudes towards large carnivores that do not address LGDs[21-27]. For instance, encounter rate is the strongest predictor of perceived depredation risk from wolves[25], while willingness to adopt non-lethal management strategies and coexist with wolves is correlated with length of exposure and experience with wolves[27]. However, some of these studies lack a well-developed framework for assessing tolerance of large carnivores, failing to incorporate psychosocial theory on how attitudes arise and persist[28-33]. Thus, there is a need for research on how non-lethal management tools like LGDs do or do not affect attitudes towards large carnivores that is robust enough to draw on existing theories about tolerance.

We set out to measure experience with LGDs and perceptions about their

effectiveness to determine if they are positively correlated with attitudes towards large carnivores. Our target populations was individuals in pastoralist communities of the Northern Rocky Mountains who would be familiar with LGD use and livestock depredation from large carnivores. While reducing depredations has generally been the focus of LGD research, the human dimensions of LGD use are also important in predicting the adoption of best management practices for LGDs, and whether or not management tools can influence acceptance of large, wild carnivores. To the extent that perceptions of LGDs are correlated with tolerance for wolves and grizzly bears, they may play an important role in conservation of large carnivores. To test the hypothesis that positive attitudes towards LGDs among pastoralists predict more positive attitudes about wolves and grizzly bears, we developed a survey to gauge participants' attitudes towards all three. We modeled survey questions loosely around a Hazard-Acceptance model for tolerance of large carnivores[30,34], but centered our analysis around determining how experience with and attitudes towards LGDs correlates with general attitudes towards large carnivores. Rather than strictly defining attitude towards wolves and grizzly bears, we used factor analysis to identify underlying metrics of attitudes based on grouping responses to our survey, and then used a series of questions related to LGDs to model those underlying composite metrics in a linear regression framework. While the results may not directly address whether LGDs temper pastoralists' acceptance of risks imposed by large carnivores, our findings provide generalizable lessons on how the use of non-lethal management tools and the belief in their efficacy (broadly defined) affects general attitudes towards large carnivores.

Results

Survey. We distributed 234 surveys and 50 were returned for a response rate of 21.4%. Of that total, 45 participants responded using the English-language survey (out of 203 distributed) and 5 participants responded using the Spanish-language (out of 31 distributed). Thirty-three of the respondents reported as male and 16 female; one did not respond to the question. Most respondents (n = 16) reported as being between 56 and 65 years of age. The average respondent had at least a bachelor's degree (n = 20) and earned between $50,000 and $99,999 per year (n = 21), of which 75 – 100% came from livestock (n = 14). Of the 46 participants who responded to the wolf encounter question, 35% of respondents (n = 16) reported encountering wolves while grazing livestock at least once a year, with an additional 13% (n = 6) encountering wolves at least once a month. The rest (52%) reported never encountering wolves. Losing livestock to wolves was less common than encountering them, with 21% (n = 9) of the 43 participants who responded to the wolf depredation question reporting losing livestock to wolves at least once a year, and an additional 9% (n = 4) reporting losing livestock to wolves at least once a month. The rest (70%) reported never losing livestock to wolves.

Experience with grizzly bears was less common than for wolves. Four percent of respondents (n = 2) reported encountering grizzly bears while grazing livestock at least once a year, with an additional 4% (n = 2) encountering grizzly bears at least once a month. The rest (92%) reported never encountering grizzly bears. Four percent of respondents (n = 2) reporting losing livestock to grizzly bears at least once a year, and an additional 2% (n = 1) reporting losing livestock to grizzly bears at least once a month. The rest (94%) reported never losing livestock to grizzly bears.

Factor Analysis. Results of parallel analyses used to calculate the number of interpretable factors that should be extracted from each question set indicated that three factors could be identified in the wolf question set, and two each in the grizzly bear and LGD question set. Although questions were nearly identical for wolves and grizzly bears, respondents' answers clustered slightly different by species in factor analysis (Tables 5.1 and 5.2). For wolves, we identified three distinct factors (Table 5.1). Seven questions loaded onto the first factor identified for wolves (i.e., $\geq |0.500|$), four on the second, and two on the third. With the exception of wolf question six (W6, Table 5.1) all of the wolf questions with strong loadings on the first factor reference wolves' role within a wild ecosystem (μ = -0.61, SD = 0.96, α = 0.87; Table 5.1). The second wolf factor is comprised largely of questions which reference how wolves interact with livestock, ranching, and ranchers (μ = -1.01, SD = 0.93, α = 0.82; Table 5.1). The third wolf factor was comprised of two questions that reference revenue generated from wolves (α = 0.82; Table 5.1). We used raw averages of scores in wolf factors one and two as dependent variables in linear modeling.

Factor loadings for grizzly bear questions had two salient factors emerge (Table 5.2). Six questions loaded onto the first factor (i.e., $\geq |0.500|$), all of which reference general attitudes towards grizzly bears or grizzly bears' role within an ecosystem (μ = -0.18, SD = 0.89, α = 0.84; Table 5.2). Five other grizzly bear questions loaded heavily onto a second factor, all of which reference how grizzly bears interact with livestock, ranching, and ranchers, except grizzly bear question 2 (G2, Table 5.2) which loaded nearly equally on both factors and seems more associated with the first (μ = -0.58, SD = 1.20, α = 0.90; Table 5.2). We used raw averages of scores in grizzly bear factors one

and two as dependent variables in linear modeling.

Factor loadings for LGD questions had two salient factors emerge (Table 5.3). Eight questions loaded onto the first factor (i.e., ≥ |0.500|), all of which have to do with LGDs' usefulness to pastoralists ($\alpha = 0.91$). Only one question loaded onto the second LGD factor at a significant threshold (≥ |0.500|), which asked participants to weigh whether they thought LGDs did more harm than good. Three other LGD questions did not load significantly on to either LGD factor (L12 –L14; Table 5.3), nor are they related to one another ($\alpha = 0.12$).

Linear Regression Models. For the model set related to the first wolf factor, both top models (i.e., ΔAICc ≤ 2.0) indicate that level of concurrence with LGD questions 13 and 14 (L13 and L14, Table 5.3) is predictive of more positive attitudes toward wolves (Table 5.4). That is, the more respondents agreed that LGDs reduce the need for lethal management ($p < 0.01$) and prevented the spread of disease ($p < 0.05$), the more positive their opinion of wolves. For the model set related to the second wolf factor, all four top models (i.e., ΔAICc ≤ 2.0) indicate that level of concurrence with LGD questions 9 and 13 (L9 and L13, Table 5.3) is predictive of more positive attitudes toward wolves (Table 5.5). That is, the more respondents agreed that LGDs do more harm than good ($p < 0.05$) and reduce the need for lethal management ($p < 0.001$), the more positive their opinion of wolves.

For grizzly bear factor one, we identified seven top models (ΔAICc ≤ 2.0), but only LGD question 12 (L12, Table 5.3) was a significant predictor of attitudes towards grizzly bears ($p < 0.05$), and only in the second highest ranking model (Table 5.6). For grizzly bear factor two, nine top models were identified (Table 5.7). However, only

experience question 1 (E1, Table 5.3) was a significant predictor of attitudes towards grizzly bears. Consistently across all nine top models, respondents with up to ten years' experience using LGDs had more negative attitudes towards grizzly bears on this metric ($p < 0.01$) and respondents with more than ten years' experience using LGDs had the most negative attitudes towards grizzly bears ($p < 0.001$; Table 5.7).

Discussion

While LGDs may effectively deter livestock predators[2], experience using LGDs alone does not temper pastoralists' attitudes about livestock predators. Instead, longer use of LGDs correlated with more negative attitudes about grizzly bears. General attitudes about LGDs (i.e., L7, Table 5.3) and opinions about their usefulness (i.e., L5 and L6, Table 5.3) were largely positive amongst our respondents, but the metric we chose to represent general attitude towards LGDs (i.e., L1 and L2, Table 5.3) did not predict attitudes towards large carnivores. The LGD perceptions which significantly predicted attitudes towards wolves concerned lethal removal of predators (i.e., L13, Table 5.3), spread of disease (i.e., L14, Table 5.3), and overall benefits (i.e., L9, Table 5.3). For grizzly bears, the only LGD question which significantly predicted attitude referenced reliance on government agencies (i.e., L12, Table 5.3), and only in the second highest ranked model.

While these results may suggest LGDs have some ability to increase tolerance for wolves and grizzly bears, the causal order of these effects is difficult to discern. It may be that a more positive attitude for wolves and grizzly bears to begin with predicts a more optimistic attitudes about LGDs and their capacity to reduce human-wildlife conflict and,

more specifically, reduce the need for lethal management of large carnivores. The strongest predictor of both composite metrics of attitudes towards wolves was level of concurrence with the statement “livestock guardian dogs reduce the need for lethal removal of predators.” Interestingly, this statement has as much to do with LGDs as respondents’ general feelings towards lethal management. That is, a respondent might feel that, while LGDs are a very effective tool (which was the general pattern in our data), their purpose is not to replace or reduce the need for lethal management, nor is that a relevant measure of LGD efficacy. So, to suggest that believing LGDs reduce the need for lethal management of wolves is predictive of more positive attitudes towards wolves may be the tail wagging the dog. Although, this should be tested explicitly.

Surprisingly, using LGDs for any length of time predicted more negative attitudes towards grizzly bears. Using LGDs for up to 10 years significantly predicted more negative views of grizzly bears (compared to no use of LGDs), and more than 10 years’ experience with LGDs predicted even more negative attitudes towards grizzly bears. We did not find the same effect for wolves. Viewed as a proxy of experience dealing with livestock predators, length of time using LGDs may corroborate other findings that attitudes towards predators deteriorate after prolonged exposure to them[21,26], even though length of exposure is also correlated with self-reported acceptance and interest in coexistence[27]. Encounter rate by pastoralists was the strongest predictor of perceived risk from wolves[25], which we did not find to be a significant predictor of attitudes toward wolves or grizzly bears in this study. Nor did actual experience losing livestock to wolves or grizzly bears significantly predict participants’ attitudes towards those carnivores. That actual experience losing livestock to large carnivores did not significantly predicted a

more negative attitudes is somewhat surprising. We would assume that pastoralists' who regularly lose livestock to large carnivores would view them more negatively[23,25,26,35]. However, this may simply be an artefact of how rare the experience of losing livestock to wolves ore grizzly bears was amongst our respondents. In fact, the majority of respondents did not have losses to these carnivores; only 6% of respondents reported losses to grizzly bears and 30% reported losses to wolves. Both populations continue to expand in this area, so more livestock depredation is likely. This evolving scenario may alter attitudes in the future.

Interestingly, despite having different socio-political histories, and how strongly politicized wolves have become in the Northern Rocky Mountains[22,36,37], respondents' answers to wolf and grizzly bear questions mapped onto very similar dimensions in factor analysis. With the exception of two questions (W11, Table 5.1; and G2; Table 5.2), responses for each species seemed to map clearly and consistently along at least two factors, the first strongly associated with wolves and grizzly bears as wild animals in non-human systems (e.g., W5, Table 5.1; and G5, Table 5.2) and the second having more to do with the practicality and economics of raising livestock alongside large carnivores (e.g., W8, Table 5.1; and G8, Table 5.2). A third factor, relating to revenue-generation (i.e., W12 and W13, Table 5.1; and G12 and G13, Table 5.2) also emerged for wolves and may have for grizzly bears with more data, but we chose not to investigate this latent factor for wolves to maintain consistency in our analysis of the two large carnivore species and because revenue generation involves many other factors and beliefs outside this scope of this study. Respondents seemed to be able to readily differentiate their beliefs about wolves and grizzly bears as abstract components of wilderness and natural

systems, and as tangible threats to pastoralism and intersecting areas of wilderness and anthropogenic utilization. While average responses to both composite metrics for wolves and grizzly bears were negative, average responses to the wolf and grizzly metric regarding livestock were both lower than for the metrics related to wild systems. While one LGD question was a significant predictor of both composite metrics of attitudes towards wolves (i.e., L13, Table 5.3), and the most predictive of wolf attitudes overall, the predictors of the two composite grizzly bear metrics were largely dissimilar. Thus, LGDs seem to have a similar impact on pastoralists' views of wolves (as wild animals or livestock predators), while LGDs and their use are linked to attitudes towards grizzly bears in different ways depending on context.

LGDs have been shown to be effective and reduce depredations from many different carnivores[2,8]. Even so, increasing tolerance for wolves and grizzly bears, especially among pastoralists, may be a task LGDs are poorly suited for. Consider, for instance, practical versus substantive threat[29]. Generally more objective and easier to quantify, practical threats from wolves and grizzly bears would include livestock depredation. These threats are easily understood[38] and direct action can be taken to try and mitigate them using tools such as LGDs[2,8]. Substantive threats, however, involve navigating a constellation of morals and ideas about how the world should be, having less to do with an individual's pragmatic interests as with their values[29]. The substantive threat of wolves and grizzly bears must be thought of in terms of competing values – not the danger of the animals themselves, but what they represent. Regarded as a substantive threat, neither wolves nor grizzly bears would be expected to be viewed more favorably just because LGDs remove some of the practical threats associated with each. Indeed, the

economic cost of wolf depredation to the livestock industry as a whole is marginal[38], and our respondents reported that losses to wolves and grizzly bears were uncommon. Yet negative attitudes towards wolves and grizzly bears were frequently observed. Thus, while non-lethal management tools like LGDs can be extremely useful in addressing practical threats to the livestock industry, addressing the substantive threat carnivores represent for pastoralists may require a different set of tools.

While our small sample size prohibited a more nuanced look at these data and limited the inference, this study is the largest of LGDs' effect on attitudes towards large carnivores to date. Future work may seek to establish causality or directionality between attitudes towards non-lethal management tools and attitudes for contentious carnivores. In addition, future work should seek to further disentangle the substantive and practical threats of large carnivores to pastoralists, in hopes of improving coexistence on shared landscapes. Regardless, the evidence we present here does not seem to support the hypothesis that using LGDs, nor beliefs in their efficacy and usefulness, tempers attitudes towards wolves or grizzly bears.

Conclusions. We present evidence that LGDs, though undeniably effective at reducing livestock depredation, do not seem to strongly influence pastoralists' attitudes towards wolves or grizzly bears. These results suggest that pastoralists' attitudes about large carnivores are dictated by more than just the practical and economic threats they pose to the ranching industry. While a small sample size prohibits a more nuanced look at these data and limits inference, this study is the largest of LGDs' effect on attitudes towards large carnivores to date. Future work may seek to further disentangle the substantive and

practical threats of large carnivores to pastoralists, in hopes of improving coexistence on shared landscapes.

Materials and Methods

Survey methods. We developed a 113-question survey, loosely based around a Hazard-Acceptance framework of human tolerance for wildlife[30,34], and designed to compare respondents' attitudes towards LGDs, wolves, and grizzly bears. Some questions were adapted from other surveys of large carnivores that also employed a Hazard-Acceptance model of tolerance[32,33]. The initial portion of the survey consisted of questions related to participants' experience with livestock and LGDs and was designed to help correlate attitudes with experience and exposure to livestock (sheep and cattle), LGDs, wolves, grizzly bears, and other common livestock predators. Respondents were also asked to answer demographic questions at the end of the survey. The majority of the survey questions gauged attitudes and perceptions and consisted of three sections concerning wolves, grizzly bears, and LGDs, respectively. Questions in the wolf and grizzly bear sections were designed to assess attitudes towards each species relative to tolerance. Questions in the LGD section were designed to assess attitudes towards LGDs specific to their usefulness. Two questions asked participants to evaluate the size of the wolf and grizzly bear populations in their state on a 3-point Likert scale (i.e., too small, appropriate, too large)[39]. All other questions in these three sections asked participants to rank their level of concurrence with a statement on a 5-point Likert scale (i.e., strongly disagree, somewhat disagree, neither or agree or disagree, somewhat agree, strongly agree). The wolf and grizzly bear sections consisted of 33 identical questions with only

the name of the subject animal changed. The only exception was question 24, which asks about the appropriateness of reintroduction of wolves in the wolf section, and the appropriateness of continued Federal management in the grizzly bear section. The LGD section consisted of 22 questions. The full survey document is available as supplementary material.

The survey was pre-tested by university graduate students to examine question clarity, subject relevance, general flow, and approximate completion time[40]. It was translated into Spanish with help from a bilingual technician and proofread by two native speakers for clarity. The Institutional Review Board for the protection of human participants at Utah State University approved the survey for distribution (Protocol #6001). The survey was formatted for distribution as part of a printed packet that could be distributed by mail or in-person and returned anonymously via an included pre-paid return envelope. No compensation was offered for participation in the study.

Our primary focus was to survey individuals in pastoralist communities of the Northern Rocky Mountains who would be familiar with LGD use and livestock depredation from large carnivores. However, as a pseudo-control on exposure to wolves and grizzly bears while grazing livestock we also solicited responses from individuals in pastoralist communities outside of wolf and grizzly bear habitat. The survey was initially distributed to sheep producers in Idaho, Montana, Oregon, Wyoming, and Washington with whom the authors had been collaborating on a separate study of LGD effectiveness[17]. We invited approximately twenty livestock operators, their spouses, and their employees to consider participating in the survey. Then, through a snowball sampling methodology, we asked these rancher collaborators and other collaborators with

USDA Wildlife Services to solicit interest in the survey amongst their community. Surveys were also distributed at livestock association meetings, non-lethal management workshops conducted by the USDA's Wildlife Services, and at the conference of the Western Section of the Wildlife Society's annual conference in Reno, NV. In total, the survey was disseminated to 234 individuals between 2014 and 2017. The survey response rate was calculated as the number of completed surveys divided by the initial number of surveys disseminated. To minimize non-response bias amongst our collaborators we continually reminded them in person to complete and return the survey, if they had not already done so. In addition, we sent multiple, mixed-media reminders to our collaborators.

Statistical analyses. Because of our small sample size, we chose to examine only a subset of the questions in the wolf, grizzly bear, and LGD sections of the survey deemed most relevant to the current investigation of attitudes towards wolves, grizzly bears, and LGDs (Tables 5.1-3). We analyzed these subsets of the wolf, grizzly bear, and LGD sections of the survey using exploratory maximum likelihood factor analysis. We used parallel analysis to calculate the number of interpretable factors that should be extracted, and varimax rotation was used to identify how the survey questions in each section grouped based on participants' responses. Only questions with loadings greater than or equal to $|0.500|$ were selected for use as components of a composite measure of attitudes towards wolves and grizzly bears in our linear modeling exercise. We used Cronbach's α coefficient to assess the internal reliability of these composite measures. Responses to the selected questions were reverse coded if necessary, averaged within each factor and carried forward as dependent variables in linear regression analyses. Factor analysis of

questions in the LGD section of the survey were used to inform our choice of predictor variables in subsequent linear regression modeling. Candidate predictor variables in the linear regression models were chosen based upon relevance to the question of whether or not attitude towards LGDs predicts attitudes towards wolves or grizzly bears and how questions clustered during factor analysis. To avoid collinearity in our models, we selected only LGD questions with distinct factor loadings, to ensure that each question addressed a specific component of attitudes towards LGDs. Unlike for wolves and grizzly bears, instead of using factor analysis to generate a composite metric for attitudes towards LGDs, we chose the single LGD question with the highest loading on each factor (Table 5.3) as a predictor variable in linear regression. Thus, LGD questions 1 or 2, 9, 12, 13, and 14 (Table 5.3) were used as predictor variables in all linear modeling exercises. In addition, we identified five questions from the experience section of the survey we believed might influence participants' attitudes towards wolves or grizzly bears (Table 5.3). For LGD and experience questions relating specifically to either wolves of grizzly bears, only the question relating to the same species as the dependent variable was included in the model (Tables 5.4 – 7). We considered all combinations of predictor variables to be relevant before running analyses, and therefore included all combinations of predictors as candidate models. Analyses were performed using the 'psych' package[41] and 'lm' function available in R version 3.3.2[42]. Model selection for fixed effects was conducted using Akaike's Information Criterion for small sample sizes.

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Author Contributions

D. Kinka and J. K. Young conceptualized the study. D. Kinka created the survey and was in charge of survey distribution. D. Kinka analyzed the data. D. Kinka and J. K. Young collaborated to fit results in to a theoretical framework.

Additional Information

Supplementary information accompanies this paper

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Tables

Table 5.1
The subset of survey questions concerning wolves deemed, *a priori*, most relevant to this analysis. Respondents ranked their level of concurrence with each of the following statements along a 5-point Likert scale (i.e., strongly negative, somewhat negative, neither positive nor negative, somewhat positive, strongly positive) except for the second statement which was ranked on a 3-point Likert scale (i.e., too small, appropriate, too large). Mean response, standard deviation (SD), and number of respondents (n) are shown for each question, along with factor loadings determined from maximum likelihood exploratory factor analysis. The responses to question in italics were reverse coded before factor analysis. Loadings less than |0.300| are hidden for clarity. Cronbach's α is shown for each factor, which includes only those questions which mapped most strongly onto the factor (in bold). Questions with factor loadings less than |0.500| were not used to calculate Cronbach's α. Note that question W6 loaded approximately equally onto both factors.

	Mean	SD	n	Factor 1	Factor 2	Factor 3
***W1.** Wolves reduce the amount of game available to hunters.*	1.10	1.33	50	**0.92**		
***W2.** Wolves have a negative impact on the populations of their prey.*	0.80	1.31	49	**0.77**		
***W3.** The size of the current wolf population in this state is…*	0.57	0.58	47	**0.70**		
W4. Wolves are part of the natural heritage of this state.	-0.27	1.30	49	**0.67**		
W5. Wolves contribute to a healthy ecosystem.	-0.30	1.40	48	**0.66**	0.34	0.33
***W6.** Wolves are putting livestock owners out of business.*	0.52	1.49	48	**0.61**	0.57	
W7. I enjoy seeing wolves.	-0.73	1.34	49	**0.56**		
***W8.** Livestock can not be successfully grazed in areas with wolves.*	0.29	1.40	49		**0.72**	
***W9.** Wolves cause livestock owners to lose money.*	1.41	0.96	49	0.36	**0.68**	
***W10.** Wolves will always be a problem for livestock owners.*	1.33	0.93	48		**0.61**	0.34
W11. How would you describe your feelings about wolves?	-0.98	1.21	48	0.50	**0.58**	0.36
W12. Wolves generate tourism revenue for this state.	-1.22	1.56	49	0.35		**0.92**
W13. Wolves generate hunting revenue for this state.	-1.02	1.22	49			**0.73**
***W14.** I am afraid of wolves.*	-0.26	1.42	47		0.45	
***W15.** Wolves are a threat to human safety.*	0.13	1.21	48		0.41	0.39
sums of squared loadings				4.14	2.69	2.02
proportion of variance explained				0.28	0.18	0.14
cumulative variance explained				0.28	0.46	0.59
Cronbach's α				0.87	0.82	0.80

Table 5.2
The subset of survey questions concerning grizzly bears deemed, *a priori*, most relevant to this analysis. Respondents ranked their level of concurrence with each of the following statements along a 5-point Likert scale (i.e., strongly negative, somewhat negative, neither positive nor negative, somewhat positive, strongly positive) except for the second statement which was ranked on a 3-point Likert scale (i.e., too small, appropriate, too large). Mean response, standard deviation (SD), and number of respondents (n) are shown for each question, along with factor loadings determined from maximum likelihood exploratory factor analysis. The responses to question in italics were reverse coded before factor analysis. Loadings less than |0.300| are hidden for clarity. Cronbach's α is shown for each factor, which includes only those questions which mapped most strongly onto the factor (in bold). Questions with factor loadings less than |0.500| were not used to calculate Cronbach's α. Note that question G2 loaded approximately equally onto both factors.

Grizzly Bear Questions	**mean**	**SD**	**n**	**Factor 1**	**Factor 2**
G5. Grizzly bears contribute to a healthy ecosystem.	0.08	1.29	39	**0.82**	
G11. How would you describe your feelings about grizzly bears?	-0.27	1.00	41	**0.81**	0.40
G4. Grizzly bears are part of the natural heritage of this state.	0.05	1.28	40	**0.73**	
G7. I enjoy seeing grizzly bears.	0.43	1.20	40	**0.62**	0.31
G1. *Grizzly bears reduce the amount of game available to hunters.*	0.33	1.38	40	**0.62**	0.42
G3. *The size of the current grizzly bear population in this state is…*	0.26	0.55	39	**0.59**	
G6. *Grizzly bears are putting livestock owners out of business.*	0.21	1.55	42		**0.94**
G9. *Grizzly bears cause livestock owners to lose money.*	1.04	1.18	42		**0.83**
G10. *Grizzly bears will always be a problem for livestock owners.*	0.95	1.12	41		**0.77**
G8. *Livestock cannot be successfully grazed in areas with grizzly bears.*	0.12	1.53	42		**0.76**
G2. *Grizzly bears have a negative impact on the populations of their prey.*	0.35	1.31	40	0.55	**0.59**
G15. *Grizzly bears a threat to human safety.*	0.80	1.11	40	0.32	0.44
G12. Grizzly bears generate tourism revenue for this state.	-0.75	1.24	40	0.34	-0.34
G13. Grizzly bears generate hunting revenue for this state.	-0.73	1.30	40		0.33
G14. *I am afraid of grizzly bears.*	0.83	1.22	40		
sums of squared loadings				3.65	4.09
proportion of variance explained				0.24	0.27
cumulative variance explained				0.52	0.27
Cronbach's α				0.84	0.90

Table 5.3
Survey questions considered as predictor variables in linear modeling. Mean response is shown for questions with continuous response options, and mode is shown for categorical responses. Standard deviations (SD) are shown for questions with continuous response options, along with factor loadings determined from maximum likelihood exploratory factor analysis. Number of respondents (n) is shown for each question. The responses to question in italics were reverse coded before factor analysis. Loadings less than |0.300| are hidden for clarity. Cronbach's α is shown for each factor, which includes only those questions which mapped most strongly onto the factor (in bold). Questions with factor loadings less than |0.500| were not used to calculate Cronbach's α.

Question Text	Mode/Mean	SD	n	Factor 1	Factor 2
E1. How many years have you used livestock guardian dogs to protect livestock? *	10 or more		48		
E2. How often do you encounter wolves while grazing livestock? †	never		46		
E3. How often do you encounter grizzly bears while grazing livestock? †	never		47		
E4. How often have you lost livestock to wolves while grazing livestock? †	never		46		
E5. How often have you lost livestock to grizzly bears while grazing livestock? †	never		45		
L1. Livestock guardian dogs are a necessary tool for protecting sheep from wolves. §	1.06	1.23	48	**0.90**	0.33
L2. Livestock guardian dogs are a necessary tool for protecting sheep from grizzly bears. §	0.77	1.26	44	**0.84**	0.40
L3. Using livestock guardian dogs is a good idea for most livestock owners. §	1.23	1.03	47	**0.82**	
L4. Using livestock guardian dogs with my own livestock is a good idea. §	1.62		47	**0.82**	
L5. Livestock guardian dogs are a useful tool for protecting sheep from grizzly bears. §	0.94	1.16	49	**0.70**	0.53
L6. Livestock guardian dogs are a useful tool for protecting sheep from wolves. §	1.78	0.55	50	**0.66**	0.54
L7. Livestock guardian dogs are a vital part of any livestock operation. §	1.32	1.08	50	**0.64**	-0.45
L8. The costs associated with keeping livestock guardian dogs are worth the economic benefits they provide. §	1.49	0.69	47	**0.57**	
L9. *Livestock guardian dogs do more harm than good.* §	-1.65	0.78	49		**-0.60**
L10. *Livestock guardian dogs are a threat to human safety.* §	-1.47	0.81	50		-0.39
L11. Livestock guardian dogs	0.65	1.11	49		0.39

prevent livestock being stolen by other people. §					
L12. Livestock guardian dogs reduce livestock owners' reliance on government agencies to manage and control predators. §	0.78	1.25	46		
L13. Livestock guardian dogs reduce the need for lethal removal of predators. §	0.36	1.52	47		
L14. Livestock guardian dogs prevent the spread of disease between wild animals and livestock. §	0.58	1.11	48		
sums of squared loadings				4.60	1.80
proportion of variance explained				0.33	0.13
cumulative variance explained				0.33	0.46
Cronbach's α				0.91	*na*

*none, less than 1, 1-5, 6-10, 10 or more

†never, at least once a year, at least once a month, at least once a week, at least once a day

§strongly disagree, somewhat disagree, neither or agree or disagree, somewhat agree, strongly agree

Table 5.4
Model results for all linear models of attitudes towards wolves with ΔAICc ≤ 2.00 (n = 35). Results are shown as coefficient values with standard error shown in parentheses below. The dependent variable in all models was a composite measure of general attitude for wolves, composed of an average of scores for 6 survey questions about wolves that loaded on to a single factor with a loading of |0.500| or more. The factor upon which all questions comprising the dependent variable loaded is best described as "wolves in the wild."

Top Wolf Attitude Models, Factor 1 – *"wolves in the wild"*
Global Model: lm(Wolf Factor 1 ~ E1 + E2 + E4 + L1 + L9 + L12 + L13 + L14)

	1	2
L13. Livestock guardian dogs reduce the need for lethal removal of predators.	0.31^{**} (0.10)	0.29^{**} (0.13)
L14. Livestock guardian dogs prevent the spread of disease between wild animals and livestock.	0.28^{*} (0.13)	0.29^{*} (0.13)
E4. How often have you lost livestock to wolves while grazing livestock? At least once a year (vs. never)		-0.50 (0.33)
Intercept	-0.89 (0.18)	-0.74 (0.20)
adjusted R-squared	0.30	0.33
ΔAICc	0.00	0.31
model weight	0.11	0.10

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 5.5

Model results for all linear models of attitudes towards wolves with ΔAICc ≤ 2.00 (n = 36). Results are shown as coefficient values with standard error shown in parentheses below. The dependent variable in all models was a composite measure of general attitude for wolves, composed of an average of scores for 6 survey questions about wolves that loaded on to a single factor with a loading of |0.500| or more. The factor upon which all questions comprising the dependent variable loaded is best described as "wolves and livestock."

Top Wolf Attitude Models, Factor 2 – *"wolves and livestock"* Global Model: lm(Wolf Factor 2 ~ E1 + E2 + E4 + L1 + L9 + L12 + L13 + L14)				
	1	**2**	**3**	**4**
L9. Livestock guardian dogs do more harm than good.	0.50^{*} (0.22)	0.57^{*} (0.23)	0.47^{*} (0.22)	0.52^{*} (0.22)
L13. Livestock guardian dogs reduce the need for lethal removal of predators.	0.35^{***} (0.09)	0.33^{***} (0.07)	0.33^{***} (0.09)	0.33^{***} (0.33)
E4. How often have you lost livestock to wolves while grazing livestock? At least once a year (vs. never)		-0.35 (0.31)		
L14. Livestock guardian dogs prevent the spread of disease between wild animals and livestock.			0.12 (0.12)	
L1. Livestock guardian dogs are a necessary tool for protecting sheep from wolves.				0.09 (0.11)
Intercept	-0.19 (0.41)	0.03 (0.45)	-0.32 (0.43)	-0.22 (0.41)
adjusted R-squared	0.38	0.38	0.38	0.37
ΔAICc	0.00	1.28	1.45	1.93
model weight	0.13	0.07	0.06	0.05

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 5.6

Model results for all linear models of tolerance for grizzly bears with ΔAICc ≤ 2.00 (n = 32). Results are shown as coefficient values with standard error shown in parentheses below. The dependent variable in all models was a composite measure of general attitude for wolves, composed of an average of scores for 6 survey questions about wolves that loaded on to a single factor with a loading of |0.500| or more. The factor upon which all questions comprising the dependent variable loaded is best described as "grizzly bears in the wild."

Top Grizzly Bear Attitude Models, Factor 1 – *"grizzly bears in the wild"*
Global Model: lm(Grizzly Bear Factor 1 ~ E1 + E3 + E5 + L2 + L9 + L12 + L13 + L14)

	1	**2**	**3**	**4**	**5**	**6**	**7**
L12. Livestock guardian dogs reduce livestock owners' reliance on government agencies to manage and control predators.	0.23 (0.13)	0.26* (0.13)		0.19 (0.13)		0.22 (0.13)	
L14. Livestock guardian dogs prevent the spread of disease between wild animals and livestock.		0.21 (0.14)				0.19 (0.14)	0.17 (0.15)
L13. Livestock guardian dogs reduce the need for lethal removal of predators.			0.17 (0.10)	0.13 (0.10)		0.11 (0.10)	
Intercept	-0.35 (0.18)	-0.54 (0.22)	-0.22 (0.16)	-0.37 (0.18)	-0.15 (0.15)	-0.54 (0.22)	-0.28 (0.19)
adjusted R-squared	0.07	0.11	0.05	0.09	na	0.11	0.01
ΔAICc	0.00	0.19	0.66	0.93	0.94	1.75	2.00
model weight	0.07	0.06	0.05	0.04	0.04	0.03	0.02

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 5.7
Model results for all linear models of tolerance for grizzly bears with $\Delta AICc \leq 2.00$ ($n = 36$). Results are shown as coefficient values with standard error shown in parentheses below. The dependent variable in all models was a composite measure of general attitude for wolves, composed of an average of scores for 6 survey questions about wolves that loaded on to a single factor with a loading of |0.500| or more. The factor upon which all questions comprising the dependent variable loaded is best described as "grizzly bears and livestock."

Top Grizzly Bear Attitude Models, Factor 2 – *"grizzly bears and livestock"* Global Model: lm(Grizzly Bear Factor 2 ~ E1 + E3 + E5 + L2 + L9 + L12 + L13 + L14)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
E1. How many years have you used livestock guardian dogs to protect livestock?									
0–10 years (vs. never)	-2.15** (0.61)	-1.99** (0.63)	-2.13** (0.63)	-1.98** (0.62)	-1.80** (0.62)	-1.85** (0.64)	-1.83** (0.65)	-1.99** (0.62)	-2.04** (0.63)
10+ years (vs. never)	-2.52*** (0.57)	-2.17*** (0.57)	-2.21*** (0.56)	-2.42*** (0.58)	-2.40*** (0.58)	-2.13*** (0.57)	-2.14*** (0.57)	-2.50*** (0.57)	-2.12*** (0.57)
L9. Livestock guardian dogs do more harm than good.	-0.45 (0.25)			-0.37 (0.26)	-0.43 (0.26)			-0.48 (0.25)	
L14. Livestock guardian dogs prevent the spread of disease between wild animals and livestock.	0.28 (0.16)		0.23 (0.16)					0.25 (0.16)	

L12. Livestock guardian dogs reduce livestock owners' reliance on government agencies to manage and control predators.					-0.21 (0.15)	-0.17 (0.15)		-0.16 (0.15)	
E5. How often have you lost livestock to grizzly bears while grazing livestock? At least once a year (vs. never)							-0.69 (0.66)		
L13. Livestock guardian dogs reduce the need for lethal removal of predators.									0.12 (0.12)
Intercept	0.67 (.60)	1.38 (0.52)	1.26 (0.52)	0.91 (0.61)	0.94 (0.60)	1.46 (0.53)	1.38 (0.52)	0.73 (0.60)	1.32 (0.53)
adjusted R-squared	0.33	0.27	0.29	0.29	0.31	0.27	0.27	0.34	0.26
ΔAICc	0.00	0.18	0.60	0.60	1.36	1.55	1.69	1.79	1.90
model weight	0.07	0.06	0.05	0.05	0.04	0.03	0.03	0.03	0.03

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

CHAPTER 6

CONCLUSION

Non-lethal management tools are unique, because they have the potential to bridge a divide between utilitarian and conservationist stakeholder groups. When optimized, non-lethal tools reduce livestock depredation and wildlife conflict, which benefits the rancher and the wildlife manager. They also provide an alternative to lethal management of charismatic carnivores, which is good for the environmentalists and the general public, who have shown an increasing distaste for lethal management. Perhaps chief among all non-lethal tools, is the livestock guardian dog (LGD). Unlike technological solutions to carnivore management problems, I have found that LGDs resonate with pastoralists in the United States. Indeed, what is an LGD but another animal on a ranch? And I've never met a rancher who didn't pride herself on her animal husbandry practices. Likewise, LGDs have been heralded by some in the conservation community as an old-world solution to promote human-carnivore coexistence. Nevertheless, even a cursory glance at the literature on LGD use quickly reveals that there is very little scientific evidence comparing LGD breeds or their aptitude for dealing with different carnivore species. With this dissertation, I have attempted to take a first step towards disambiguating LGD breeds and investigating their cause-specific effectiveness. In addition, I investigated the effect that LGDs and free-ranging sheep have on resident carnivore communities, and surveyed ranchers to see if LGDs can improve tolerance for carnivores in pastoralist communities.

In Chapter 1, I presented findings that three novel breeds of LGD are associated

with reduced depredation compared with mixed-breed whitedogs. Turkish kangals were associated with a significant reduction in cougar, black bear, and coyote depredations. Similarly, Bulgarian karakachans were associated with a significant reduction in coyote depredation. Transmontanos were also associated with a reduction in livestock depredation across all predators types. Kangals were also shown to be less effective at reducing wolf depredations than whitedogs, but this may have been due to an outlier in the data. Results were mixed, but strong evidence is presented that purebred kangals can be a very effective addition to most sheep bands. This corroborates the sentiment of many of the ranchers and shepherds we worked with throughout the study – everybody likes kanagals. Even the shepherds who lost 19 sheep in a single grazing season to wolves claimed that one of their kangals regularly chased off wolves, and speculated that losses would have been much higher without her.

In Chapter 2, I presented results that few behavioral differences exist between the breeds tested, although kangals tended to be more investigative when engaging a decoy, karakachans more vigilant, and transmontanos more able to decipher a threatening from unthreatening stimuli. Transmontanos also spent less time scanning than whitedogs and there was a marginally significant effect of karakachans moving more than whitedogs. Perhaps the most interesting finding was the difference between kangals and karakachans; kangals preferring to investigate and karakachans preferring to keep their distance from a decoy. Ranchers and LGD breeders will occasionally mention the observation that some LGDs tend to stay close to sheep at all times while others are more likely to patrol. In future analyses, we hope to use GPS data collected from LGDs to parse whether these patterns of space use are breed-specific. Nevertheless, the difference

we observed between kangals and karakachans in terms of willingness to engage may confirm (as many of our collaborators would attest) that kangals are more of a “patrol dog” and karakachans more of a “sheep-tending dog.” Also worth mentioning, is that karakachans were very unpopular with our collaborators throughout the study. Even the most practiced and tenacious sheep producers often had difficulty getting sheep to bond to their karakachans, and thus have their karakachans successfully integrate with the flock. This may have been a result of karakachans’ generally darker coat and squatter build – unfamiliar to most U.S. sheep – but the supposition was not tested. Regardless, despite their being unpopular amongst our collaborators, karakachans were found to be better than whitedogs at defending against coyote depredation. All of which suggests that perceptions about LGD effectiveness may not always mirror reality, and that the success of any new breed of LGD will hinge on more than its guarding abilities alone.

In Chapter 3, I presented evidence that sheep grazed with LGDs act as a mild deterrent to wolves, decreasing the likelihood that they will be detected near a sheep band by about 75%. No effect of sheep and LGD presence was found for brown bears, black bears, or cougars. However, interestingly, there was an increase in detection of smaller carnivores when a sheep band was present, including coyotes, red foxes, and bobcats. As red foxes and bobcats are less common predators of domestic sheep, their increased detectability may have more to do with a short-term mesopredator release accompanying the decrease in wolf detectability when sheep were present. It may also have been an effect of scale. That is, for wolves it is possible to simply move to another part of their home range when sheep and LGDs are present. Smaller carnivores with smaller home ranges may have been more inclined to try and take advantage of an abundant food

source that appeared within their home range, defended or no. With the exception of one other paper out of Australia that investigated the effect of LGDs on space use of herbivores and foxes, these results are novel in the LGD literature. They also mark an attempt to discuss LGDs and livestock grazed on open range in the context of ecological theory. In terms of loss-prevention, how spatial interactions influence LGD effectiveness against brown bears, black bears, cougars, and coyotes will require further study, but effectiveness does not seem to be mediated by intraguild space use interactions. With wolves however, LGDs seem to be effective deterrents.

In Chapter 4, I presented evidence that, although LGDs are undeniably effective at mitigating livestock depredation, experience using LGDs alone does not temper pastoralists' attitudes about livestock predators. Instead, longer use of LGDs correlated with more negative attitudes about grizzly bears. In addition, the more respondents agreed that LGDs reduce the need for lethal management, the more positive their opinion of wolves. While these results may suggest LGDs have some ability to increase tolerance for wolves, the causal order of these effects is difficult to discern. It may be that an existing positive attitude towards wolves predicts a more optimistic attitudes about LGDs and their capacity to reduce human-wildlife conflict and, more specifically, reduce the need for lethal management of large carnivores. This suggests that pastoralists' attitudes about large carnivores are dictated by more than just the practical and economic threats they pose to the ranching industry. This marks an attempt to discuss LGDs and non-lethal management tools in the context of psychosocial theories of tolerance, acceptance, and decision making. While a small sample size prohibited a more nuanced look at the data, and limited its potential inference, it is still the largest study of LGDs' effect on attitudes

towards large carnivores to date. With a larger sample size, structural equation modeling could have been used to investigate the Hazard-Acceptance model of wildlife tolerance, and it is still a potential avenue for further investigations.

This dissertation provides useful insight to ranchers and wildlife managers on the strengths and weakness of different breeds of LGDs and facilitates more informed use of LGDs to reduce livestock depredations. It also provides ranchers and wildlife managers and initial investigation of carnivore responses to sheep bands grazing on open range. For conservationists, especially any concerned about facilitating recovery of large carnivore populations by increasing tolerance, it suggests that LGDs are not a panacea. Hopefully it also draws attention to future research opportunities concerning LGDs that go beyond loss-prevention. Overall, this dissertation advances the scientific understanding of LGDs, how they work, when they work, and what else they can do.

APPENDICES

APPENDIX A: SUPPLEMENTARY TABLES

Table A1. Summary of model selection statistics for generalized linear mixed models analysing proportion of time spent in a specific behaviour during continuous focal sampling. Predictor variables include LGD breed (breed = kangal, karakachan, transmontano, or whitedog), LGD age category (age = juvenile or adult), LGD sex (sex = male or female), and hour category (hour = morning, mid-day, or evening). All sixteen possible combinations of these four predictors are shown. The identity of the individual LGD (ID) and specific observation (trial) were included as random variables in all models. Models are ranked according to AICc differences (Δ_i) based on the Akaike Information Criterion for small samples (AICc). Also included are the number of parameters (K), the log likelihood, and Akaike weights (*w*j).

Response Variable	Model	K	log likelihood	AICc	Δ_i	w_i
vigilant	(ID) + (trial)	3	-397.6	801.25	0	0.34
	(ID) + (trial) + age	4	-397.17	802.41	1.164	0.19
	(ID) + (trial) + sex	4	-397.59	803.26	2.011	0.124
	(ID) + (trial) + hour	5	-396.97	804.05	2.798	0.084
	(ID) + (trial) + age + sex	5	-397.14	804.4	3.149	0.07
	(ID) + (trial) + age + hour	6	-396.57	805.3	4.047	0.045
	(ID) + (trial) + breed	6	-396.93	806.02	4.768	0.031
	(ID) + (trial) + sex + hour	6	-396.95	806.08	4.825	0.03
	(ID) + (trial) + breed + age	7	-396.06	806.35	5.099	0.027
	(ID) + (trial) + age + sex + hour	7	-396.54	807.3	6.047	0.017
	(ID) + (trial) + breed + sex	7	-396.9	808.02	6.774	0.011
	(ID) + (trial) + breed + age + sex	8	-396.03	808.35	7.096	0.01
	(ID) + (trial) + breed + hour	8	-396.1	808.49	7.236	0.009
	(ID) + (trial) + breed + age + hour	9	-395.47	809.3	8.053	0.006
	(ID) + (trial) + breed + sex + hour	9	-396.09	810.54	9.291	0.003
	(ID) + (trial) + breed + age + sex + hour	10	-395.32	811.07	9.822	0.003
investigate	(ID) + (trial)	3	-1038.74	2083.54	0	0.247
	(ID) + (trial) + hour	5	-1036.77	2083.66	0.119	0.232
	(ID) + (trial) + sex	4	-1038.56	2085.21	1.671	0.107
	(ID) + (trial) + sex + hour	6	-1036.61	2085.39	1.849	0.098
	(ID) + (trial) + age	4	-1038.7	2085.49	1.95	0.093
	(ID) + (trial) + age + hour	6	-1036.71	2085.58	2.047	0.089
	(ID) + (trial) + age + sex	5	-1038.51	2087.14	3.604	0.041
	(ID) + (trial) + age + sex + hour	7	-1036.52	2087.25	3.718	0.038
	(ID) + (trial) + breed + hour	8	-1036.21	2088.7	5.165	0.019

	(ID) + (trial) + breed	6	-1038.43	2089.04	5.5	0.016
	(ID) + (trial) + breed + sex	7	-1038.2	2090.62	7.08	0.007
	(ID) + (trial) + breed + age	7	-1038.43	2091.07	7.538	0.006
	(ID) + (trial) + breed + age + sex + hour	10	-1035.97	2092.37	8.836	0.003
	(ID) + (trial) + breed + age + sex	8	-1038.19	2092.67	9.132	0.003
	(ID) + (trial) + breed + age + hour	9	-1037.4	2093.16	9.628	0.002
	(ID) + (trial) + breed + sex + hour	9	-1039.22	2096.8	13.269	0
scan	(ID) + (trial) + breed + sex + hour	9	-3308.37	6635.1	0	0.164
	(ID) + (trial) + breed + hour	8	-3309.73	6635.74	0.641	0.119
	(ID) + (trial) + hour	5	-3312.88	6635.89	0.79	0.111
	(ID) + (trial) + breed + age + sex + hour	10	-3307.92	6636.28	1.179	0.091
	(ID) + (trial) + breed + age + hour	9	-3309.11	6636.58	1.485	0.078
	(ID) + (trial) + sex + hour	6	-3312.42	6637.01	1.908	0.063
	(ID) + (trial) + breed + sex	7	-3311.41	6637.05	1.95	0.062
	(ID) + (trial) + age + hour	6	-3312.51	6637.19	2.096	0.058
	(ID) + (trial) + breed	6	-3312.69	6637.55	2.452	0.048
	(ID) + (trial)	3	-3315.76	6637.57	2.475	0.048
	(ID) + (trial) + breed + age + sex	8	-3310.97	6638.22	3.12	0.035
	(ID) + (trial) + breed + age	7	-3312.09	6638.41	3.312	0.031
	(ID) + (trial) + age + sex + hour	7	-3312.13	6638.48	3.382	0.03
	(ID) + (trial) + sex	4	-3315.36	6638.79	3.694	0.026
	(ID) + (trial) + age	4	-3315.47	6639.02	3.92	0.023
	(ID) + (trial) + age + sex	5	-3315.13	6640.38	5.278	0.012
run	(ID) + (trial)	3	-239.6	485.25	0	0.415
	(ID) + (trial) + age	4	-239.53	487.14	1.886	0.162
	(ID) + (trial) + sex	4	-239.59	487.26	2.001	0.153
	(ID) + (trial) + hour	5	-239.13	488.37	3.118	0.087
	(ID) + (trial) + age + sex	5	-239.51	489.14	3.882	0.06
	(ID) + (trial) + age + hour	6	-239.04	490.24	4.985	0.034
	(ID) + (trial) + sex + hour	6	-239.11	490.4	5.142	0.032
	(ID) + (trial) + breed	6	-239.59	491.35	6.099	0.02
	(ID) + (trial) + age + sex + hour	7	-239.02	492.26	7.006	0.013
	(ID) + (trial) + breed + age	7	-239.53	493.27	8.02	0.008
	(ID) + (trial) + breed + sex	7	-239.57	493.37	8.114	0.007
	(ID) + (trial) + breed + hour	8	-239.09	494.47	9.216	0.004
	(ID) + (trial) + breed + age + sex	8	-239.5	495.29	10.031	0.003
	(ID) + (trial) + breed + age + hour	9	-239.02	496.41	11.151	0.002
	(ID) + (trial) + breed + sex + hour	9	-239.07	496.51	11.255	0.001
	(ID) + (trial) + breed + age + sex + hour	10	-240.98	502.4	17.147	0

bark	(ID) + (trial)	3	-454.99	916.03	0	0.405
	(ID) + (trial) + sex	4	-454.97	918.02	1.993	0.15
	(ID) + (trial) + age	4	-454.98	918.04	2.005	0.149
	(ID) + (trial) + hour	5	-454.42	918.97	2.935	0.093
	(ID) + (trial) + age + sex	5	-454.96	920.03	4.002	0.055
	(ID) + (trial) + sex + hour	6	-454.4	920.98	4.945	0.034
	(ID) + (trial) + age + hour	6	-454.42	921	4.974	0.034
	(ID) + (trial) + breed	6	-454.53	921.23	5.2	0.03
	(ID) + (trial) + age + sex + hour	7	-454.4	923.02	6.99	0.012
	(ID) + (trial) + breed + age	7	-454.5	923.22	7.188	0.011
	(ID) + (trial) + breed + sex	7	-454.53	923.28	7.254	0.011
	(ID) + (trial) + breed + hour	8	-453.82	923.93	7.895	0.008
	(ID) + (trial) + breed + age + sex	8	-454.5	925.28	9.249	0.004
	(ID) + (trial) + breed + sex + hour	9	-453.82	926	9.967	0.003
	(ID) + (trial) + breed + age + sex + hour	10	-453.78	928	11.973	0.001
	(ID) + (trial) + breed + age + hour	9	-459.02	936.4	20.373	0
move	(ID) + (trial) + hour	5	-2604.14	5218.39	0	0.305
	(ID) + (trial) + age + hour	6	-2603.47	5219.1	0.707	0.214
	(ID) + (trial) + breed + hour	8	-2601.91	5220.1	1.707	0.13
	(ID) + (trial) + sex + hour	6	-2603.99	5220.15	1.758	0.127
	(ID) + (trial) + age + sex + hour	7	-2603.26	5220.74	2.341	0.095
	(ID) + (trial) + breed + age + hour	9	-2601.69	5221.74	3.349	0.057
	(ID) + (trial) + breed + sex + hour	9	-2601.9	5222.15	3.757	0.047
	(ID) + (trial) + breed + age + sex + hour	10	-2601.74	5223.92	5.523	0.019
	(ID) + (trial)	3	-2611.3	5228.64	10.25	0.002
	(ID) + (trial) + age	4	-2610.74	5229.56	11.161	0.001
	(ID) + (trial) + sex	4	-2611.03	5230.14	11.743	0.001
	(ID) + (trial) + age + sex	5	-2610.4	5230.91	12.517	0.001
	(ID) + (trial) + breed	6	-2609.55	5231.27	12.874	0
	(ID) + (trial) + breed + age	7	-2609.25	5232.72	14.327	0
	(ID) + (trial) + breed + sex	7	-2609.48	5233.18	14.788	0
	(ID) + (trial) + breed + age + sex	8	-2609.16	5234.6	16.205	0
lay	(ID) + (trial) + hour	5	-2831.52	5673.15	0	0.428
	(ID) + (trial) + age + hour	6	-2831.43	5675.02	1.874	0.168
	(ID) + (trial) + sex + hour	6	-2831.51	5675.19	2.041	0.154
	(ID) + (trial) + breed + hour	8	-2830.04	5676.37	3.224	0.085
	(ID) + (trial) + age + sex + hour	7	-2831.42	5677.07	3.915	0.06
	(ID) + (trial) + breed + age + hour	9	-2829.99	5678.33	5.181	0.032
	(ID) + (trial) + breed + sex + hour	9	-2830	5678.35	5.204	0.032

	(ID) + (trial)	3	-2837.06	5680.17	7.016	0.013
	(ID) + (trial) + breed + age + sex + hour	10	-2830	5680.44	7.286	0.011
	(ID) + (trial) + age	4	-2837	5682.08	8.928	0.005
	(ID) + (trial) + sex	4	-2837.03	5682.13	8.981	0.005
	(ID) + (trial) + breed	6	-2835.7	5683.57	10.418	0.002
	(ID) + (trial) + age + sex	5	-2836.96	5684.03	10.882	0.002
	(ID) + (trial) + breed + age	7	-2835.61	5685.44	12.291	0.001
	(ID) + (trial) + breed + sex	7	-2835.69	5685.6	12.453	0.001
	(ID) + (trial) + breed + age + sex	8	-2835.6	5687.49	14.343	0
with sheep	(ID) + (trial)	3	-860.77	1727.59	0	0.429
	(ID) + (trial) + age	4	-860.67	1729.42	1.83	0.172
	(ID) + (trial) + sex	4	-860.77	1729.61	2.025	0.156
	(ID) + (trial) + hour	5	-860.52	1731.15	3.566	0.072
	(ID) + (trial) + age + sex	5	-860.66	1731.44	3.858	0.062
	(ID) + (trial) + age	6	-860.43	1733.04	5.45	0.028
	(ID) + (trial) + sex + hour	6	-860.51	1733.2	5.61	0.026
	(ID) + (trial) + breed	6	-860.54	1733.26	5.668	0.025
	(ID) + (trial) + age + sex + hour	7	-860.43	1735.08	7.497	0.01
	(ID) + (trial) + breed + age	7	-860.52	1735.26	7.675	0.009
	(ID) + (trial) + breed + hour	8	-860.31	1736.91	9.327	0.004
	(ID) + (trial) + breed + age + sex	8	-860.52	1737.33	9.739	0.003
	(ID) + (trial) + breed + age + hour	9	-860.31	1738.98	11.392	0.001
	(ID) + (trial) + breed + age + sex + hour	10	-860.3	1741.04	13.454	0.001
	(ID) + (trial) + breed + sex	7	-872.1	1758.42	30.829	0
	(ID) + (trial) + breed + sex + hour	9	-944.64	1907.65	180.06	0

Table A2. Summary of model selection statistics for generalized linear mixed models analysing counts of specific behaviours during the decoy test. Predictor variables include decoy type (decoy = deer or wolf), LGD breed (breed = kangal, karakachan, transmontano, or whitedog), LGD age category (age = juvenile or adult), and LGD sex (sex = male or female). All sixteen possible combinations of these four predictors are shown. The identity of the individual LGD (ID) and test group (test) were included as random variables in all models except for the out of view model set, which treats each LGD within a test group (trial) instead of test group as a random variable to account for overdisperssion. Models are ranked according to AICc differences (Δ_i) based on the Akaike Information Criterion for small samples (AICc). Also included are the number of parameters (K), the log likelihood, and Akaike weights (*w*j).

Response variable	Model	K	log likelihood	AICc	Δ_i	w_i
vigilant	(ID) + (test) + age	4	-186.92	382.26	0	0.409
	(ID) + (test) + decoy + age	5	-186.39	383.42	1.158	0.229
	(ID) + (test) + age + sex	5	-186.74	384.11	1.851	0.162
	(ID) + (test) + decoy + age + sex	6	-186.17	385.25	2.993	0.092
	(ID) + (test) + breed + age	7	-186.02	387.25	4.993	0.034
	(ID) + (test)	3	-191	388.24	5.984	0.021
	(ID) + (test) + decoy + breed + age	8	-185.7	388.98	6.722	0.014
	(ID) + (test) + breed + age + sex	8	-185.91	389.4	7.146	0.011
	(ID) + (test) + decoy	4	-190.78	389.98	7.725	0.009
	(ID) + (test) + sex	4	-190.98	390.38	8.118	0.007
	(ID) + (test) + decoy + breed + age + sex	9	-185.57	391.14	8.877	0.005
	(ID) + (test) + decoy + sex	5	-190.76	392.16	9.897	0.003
	(ID) + (test) + breed	6	-189.69	392.28	10.017	0.003
	(ID) + (test) + decoy + breed	7	-189.55	394.32	12.065	0.001
	(ID) + (test) + breed + sex	7	-189.66	394.53	12.268	0.001
	(ID) + (test) + decoy + breed + sex	8	-189.51	396.61	14.35	0
investigate	(ID) + (test)	3	-201.83	409.91	0	0.253
	(ID) + (test) + age	4	-200.75	409.92	0.013	0.251
	(ID) + (test) + decoy	4	-201.57	411.56	1.65	0.111
	(ID) + (test) + decoy + age	5	-200.59	411.81	1.9	0.098
	(ID) + (test) + age + sex	5	-200.7	412.05	2.138	0.087
	(ID) + (test) + sex	4	-201.83	412.08	2.169	0.086
	(ID) + (test) + decoy + sex	5	-201.57	413.77	3.865	0.037
	(ID) + (test) + decoy + age + sex	6	-200.54	413.99	4.078	0.033
	(ID) + (test) + breed + age	7	-200.34	415.9	5.988	0.013
	(ID) + (test) + breed	6	-201.58	416.06	6.153	0.012
	(ID) + (test) + decoy + breed	7	-201.3	417.82	7.91	0.005

	(ID) + (test) + decoy + breed + age	8	-200.17	417.93	8.019	0.005
	(ID) + (test) + breed + age + sex	8	-200.29	418.17	8.258	0.004
	(ID) + (test) + breed + sex	7	-201.57	418.36	8.455	0.004
	(ID) + (test) + decoy + breed + sex	8	-201.3	420.17	10.265	0.001
	(ID) + (test) + decoy + breed + age + sex	9	-200.13	420.26	10.35	0.001
scan	(ID) + (test) + age	4	-297.32	603.05	0	0.262
	(ID) + (test)	3	-298.66	603.58	0.521	0.202
	(ID) + (test) + decoy + age	5	-296.95	604.54	1.488	0.124
	(ID) + (test) + decoy	4	-298.1	604.62	1.561	0.12
	(ID) + (test) + age + sex	5	-297.3	605.24	2.182	0.088
	(ID) + (test) + sex	4	-298.66	605.75	2.692	0.068
	(ID) + (test) + decoy + age + sex	6	-296.94	606.78	3.723	0.041
	(ID) + (test) + decoy + sex	5	-298.1	606.83	3.777	0.04
	(ID) + (test) + breed + age	7	-296.51	608.23	5.175	0.02
	(ID) + (test) + breed	6	-298.43	609.77	6.716	0.009
	(ID) + (test) + decoy + breed + age	8	-296.1	609.78	6.721	0.009
	(ID) + (test) + breed + age + sex	8	-296.51	610.59	7.54	0.006
	(ID) + (test) + decoy + breed	7	-297.77	610.76	7.71	0.006
	(ID) + (test) + breed + sex	7	-298.42	612.06	9.005	0.003
	(ID) + (test) + decoy + breed + age + sex	9	-296.1	612.19	9.138	0.003
	(ID) + (test) + decoy + breed + sex	8	-297.76	613.1	10.041	0.002
run	(ID) + (test)	3	-69.24	144.73	0	0.253
	(ID) + (test) + decoy	4	-68.48	145.39	0.658	0.182
	(ID) + (test) + sex	4	-68.85	146.11	1.385	0.127
	(ID) + (test) + age	4	-68.98	146.39	1.657	0.11
	(ID) + (test) + decoy + sex	5	-68.03	146.69	1.965	0.095
	(ID) + (test) + decoy + age	5	-68.18	147.01	2.278	0.081
	(ID) + (test) + age + sex	5	-68.49	147.62	2.887	0.06
	(ID) + (test) + decoy + age + sex	6	-67.61	148.12	3.39	0.046
	(ID) + (test) + breed	6	-68.95	150.81	6.081	0.012
	(ID) + (test) + decoy + breed	7	-68.19	151.6	6.875	0.008
	(ID) + (test) + breed + sex	7	-68.39	151.99	7.261	0.007
	(ID) + (test) + breed + age	7	-68.63	152.47	7.741	0.005
	(ID) + (test) + decoy + breed + sex	8	-67.59	152.75	8.026	0.005
	(ID) + (test) + decoy + breed + age	8	-67.76	153.1	8.374	0.004
	(ID) + (test) + breed + age + sex	8	-67.99	153.57	8.843	0.003
	(ID) + (test) + decoy + breed + age + sex	9	-67.09	154.18	9.451	0.002
bark	(ID) + (test)	3	-182.6	371.46	0	0.178
	(ID) + (test) + breed	6	-179.62	372.14	0.68	0.127

	(ID) + (test) + sex	4	-182.08	372.58	1.126	0.102
	(ID) + (test) + breed + sex	7	-178.94	373.1	1.646	0.078
	(ID) + (test) + decoy	4	-182.37	373.17	1.709	0.076
	(ID) + (test) + age	4	-182.48	373.38	1.921	0.068
	(ID) + (test) + decoy + breed	7	-179.09	373.39	1.937	0.068
	(ID) + (test) + breed + age	7	-179.31	373.83	2.377	0.054
	(ID) + (test) + decoy + sex	5	-181.87	374.37	2.915	0.042
	(ID) + (test) + decoy + breed + sex	8	-178.46	374.5	3.042	0.039
	(ID) + (test) + age + sex	5	-182	374.65	3.189	0.036
	(ID) + (test) + decoy + breed + age	8	-178.54	374.66	3.205	0.036
	(ID) + (test) + decoy + age	5	-182.15	374.93	3.473	0.031
	(ID) + (test) + breed + age + sex	8	-178.71	375	3.539	0.03
	(ID) + (test) + decoy + breed + age + sex	9	-178.02	376.04	4.577	0.018
	(ID) + (test) + decoy + age + sex	6	-181.71	376.32	4.867	0.016
move	(ID) + (test) + age	4	-288.83	586.07	0	0.225
	(ID) + (test)	3	-289.97	586.19	0.122	0.212
	(ID) + (test) + age + sex	5	-288.65	587.94	1.866	0.089
	(ID) + (test) + decoy	4	-289.9	588.22	2.147	0.077
	(ID) + (test) + sex	4	-289.92	588.26	2.185	0.076
	(ID) + (test) + decoy + age	5	-288.81	588.26	2.186	0.075
	(ID) + (test) + breed + age	7	-286.62	588.46	2.386	0.068
	(ID) + (test) + breed	6	-288.41	589.73	3.655	0.036
	(ID) + (test) + decoy + age + sex	6	-288.64	590.18	4.106	0.029
	(ID) + (test) + breed + age + sex	8	-286.33	590.23	4.162	0.028
	(ID) + (test) + decoy + sex	5	-289.85	590.33	4.259	0.027
	(ID) + (test) + decoy + breed + age	8	-286.62	590.82	4.75	0.021
	(ID) + (test) + breed + sex	7	-288.28	591.77	5.697	0.013
	(ID) + (test) + decoy + breed	7	-288.39	591.99	5.92	0.012
	(ID) + (test) + decoy + breed + age + sex	9	-286.32	592.65	6.574	0.008
	(ID) + (test) + decoy + breed + sex	8	-288.25	594.09	8.02	0.004
lay	(ID) + (test) + age	4	-244.47	497.37	0	0.278
	(ID) + (test)	3	-245.87	497.99	0.619	0.204
	(ID) + (test) + decoy + age	5	-244.24	499.12	1.753	0.116
	(ID) + (test) + age + sex	5	-244.46	499.57	2.196	0.093
	(ID) + (test) + sex	4	-245.73	499.88	2.506	0.079
	(ID) + (test) + decoy	4	-245.78	499.98	2.61	0.075
	(ID) + (test) + decoy + age + sex	6	-244.24	501.38	4.009	0.037
	(ID) + (test) + decoy + sex	5	-245.64	501.93	4.556	0.028
	(ID) + (test) + breed	6	-244.64	502.18	4.813	0.025

	(ID) + (test) + breed + age	7	-243.52	502.25	4.882	0.024
	(ID) + (test) + decoy + breed + age	8	-243.26	504.1	6.733	0.01
	(ID) + (test) + decoy + breed	7	-244.52	504.25	6.881	0.009
	(ID) + (test) + breed + sex	7	-244.59	504.39	7.018	0.008
	(ID) + (test) + breed + age + sex	8	-243.52	504.61	7.244	0.007
	(ID) + (test) + decoy + breed + age + sex	9	-243.26	506.52	9.15	0.003
	(ID) + (test) + decoy + breed + sex	8	-244.47	506.52	9.151	0.003
with sheep	(ID) + (test)	3	-198.83	403.92	0	0.204
	(ID) + (test) + age	4	-197.82	404.06	0.139	0.19
	(ID) + (test) + decoy + age	5	-197.09	404.82	0.902	0.13
	(ID) + (test) + decoy	4	-198.21	404.84	0.921	0.129
	(ID) + (test) + age + sex	5	-197.34	405.31	1.389	0.102
	(ID) + (test) + sex	4	-198.61	405.64	1.718	0.086
	(ID) + (test) + decoy + age + sex	6	-196.6	406.1	2.181	0.069
	(ID) + (test) + decoy + sex	5	-197.98	406.6	2.684	0.053
	(ID) + (test) + breed + age	7	-197.53	410.27	6.352	0.009
	(ID) + (test) + breed	6	-198.73	410.37	6.447	0.008
	(ID) + (test) + decoy + breed + age	8	-196.86	411.3	7.377	0.005
	(ID) + (test) + decoy + breed	7	-198.17	411.56	7.642	0.004
	(ID) + (test) + breed + age + sex	8	-197.09	411.75	7.835	0.004
	(ID) + (test) + breed + sex	7	-198.52	412.25	8.329	0.003
	(ID) + (test) + decoy + breed + age + sex	9	-196.4	412.79	8.873	0.002
	(ID) + (test) + decoy + breed + sex	8	-197.95	413.48	9.563	0.002
with decoy	(ID) + (test)	3	-198.67	403.59	0	0.254
	(ID) + (test) + sex	4	-197.65	403.72	0.124	0.239
	(ID) + (test) + decoy	4	-198.65	405.72	2.126	0.088
	(ID) + (test) + age + sex	5	-197.56	405.75	2.159	0.086
	(ID) + (test) + age	4	-198.67	405.76	2.168	0.086
	(ID) + (test) + decoy	5	-197.63	405.9	2.305	0.08
	(ID) + (test) + breed + sex	7	-196.11	407.44	3.845	0.037
	(ID) + (test) + decoy + age	5	-198.65	407.93	4.34	0.029
	(ID) + (test) + decoy + age + sex	6	-197.53	407.97	4.381	0.028
	(ID) + (test) + breed	6	-197.64	408.18	4.588	0.026
	(ID) + (test) + decoy + breed + sex	8	-196.06	409.7	6.105	0.012
	(ID) + (test) + breed + age + sex	8	-196.11	409.8	6.205	0.011
	(ID) + (test) + decoy + breed	7	-197.58	410.39	6.795	0.009
	(ID) + (test) + breed + age	7	-197.59	410.4	6.807	0.008
	(ID) + (test) + decoy + breed + age + sex	9	-196.06	412.11	8.518	0.004

	(ID) + (test) + decoy + breed + age	8	-197.54	412.66	9.07	0.003
out of view	(ID) + (trial) + age	4	-351.29	710.99	0	0.388
	(ID) + (trial) + decoy + age	5	-351.23	713.1	2.101	0.136
	(ID) + (trial)	3	-353.47	713.19	2.198	0.129
	(ID) + (trial) + age + sex	5	-351.28	713.21	2.213	0.128
	(ID) + (trial) + decoy	4	-353.22	714.86	3.861	0.056
	(ID) + (trial) + sex	4	-353.39	715.2	4.202	0.047
	(ID) + (trial) + decoy + age + sex	6	-351.22	715.35	4.354	0.044
	(ID) + (trial) + breed + age	7	-350.75	716.71	5.715	0.022
	(ID) + (trial) + decoy + sex	5	-353.1	716.85	5.853	0.021
	(ID) + (trial) + decoy + breed + age	8	-350.72	719.03	8.037	0.007
	(ID) + (trial) + breed + age + sex	8	-350.75	719.07	8.078	0.007
	(ID) + (trial) + breed	6	-353.09	719.08	8.085	0.007
	(ID) + (trial) + decoy + breed	7	-352.9	721.01	10.019	0.003
	(ID) + (trial) + breed + sex	7	-353.04	721.29	10.298	0.002
	(ID) + (trial) + decoy + breed + age + sex	9	-350.72	721.44	10.449	0.002
	(ID) + (trial) + decoy + breed + sex	8	-352.82	723.23	12.237	0.001

Table A3. Summary of model selection statistics for generalized linear mixed models analysing counts of specific behaviours during the first 60 seconds after an LGD approached the decoy for the first time (<50 meters) in the decoy test. Predictor variables include decoy type (decoy = deer or wolf), LGD breed (breed = kangal, karakachan, transmontano, or whitedog), LGD age category (age = juvenile or adult), and LGD sex (sex = male or female). All sixteen possible combinations of these four predictors are shown. The identity of the individual LGD (ID) and test group (test) were included as random variables in all models. Models are ranked according to AICc differences (Δ_i) based on the Akaike Information Criterion for small samples (AICc). Also included are the number of parameters (K), the log likelihood, and Akaike weights (*w*j).

Response Variable	Model	K	log likelihood	AICc	Δ_i	w_i
vigilant	(ID) + (trial) + decoy + age	5	-44.720	101.05	0.000	0.147
	(ID) + (trial) + decoy	4	-46.080	101.20	0.149	0.137
	(ID) + (trial)	3	-47.440	101.49	0.433	0.119
	(ID) + (trial) + age	4	-46.300	101.65	0.600	0.109
	(ID) + (trial) + breed	5	-45.310	102.25	1.192	0.081
	(ID) + (trial) + decoy + breed	6	-44.120	102.58	1.522	0.069
	(ID) + (trial) + sex	4	-47.010	103.08	2.024	0.054
	(ID) + (trial) + decoy + sex	5	-45.800	103.22	2.163	0.050
	(ID) + (trial) + decoy + breed + age	7	-43.130	103.47	2.415	0.044
	(ID) + (trial) + breed + age	6	-44.570	103.48	2.428	0.044
	(ID) + (trial) + decoy + age + sex	6	-44.600	103.54	2.486	0.043
	(ID) + (trial) + age + sex	5	-46.020	103.66	2.604	0.040
	(ID) + (trial) + breed + sex	6	-45.160	104.65	3.593	0.024
	(ID) + (trial) + decoy + breed + sex	7	-44.040	105.28	4.230	0.018
	(ID) + (trial) + breed + age + sex	7	-44.460	106.13	5.075	0.012
	(ID) + (trial) + decoy + breed + age + sex	8	-43.110	106.46	5.404	0.010
investigate	(ID) + (trial) + breed	5	-32.380	76.39	0.000	0.336
	(ID) + (trial) + decoy + breed	6	-31.780	77.90	1.511	0.158
	(ID) + (trial) + breed + sex	6	-31.990	78.32	1.931	0.128
	(ID) + (trial) + breed + age	6	-32.240	78.81	2.422	0.100
	(ID) + (trial) + decoy + breed + sex	7	-31.550	80.30	3.911	0.048
	(ID) + (trial) + decoy + breed + age	7	-31.570	80.34	3.947	0.047
	(ID) + (trial) + breed + age + sex	7	-31.880	80.97	4.576	0.034
	(ID) + (trial)	3	-37.190	81.00	4.611	0.034
	(ID) + (trial) + sex	4	-36.130	81.31	4.920	0.029
	(ID) + (trial) + decoy	4	-36.190	81.42	5.033	0.027
	(ID) + (trial) + decoy + sex	5	-35.440	82.49	6.103	0.016
	(ID) + (trial) + decoy + breed + age + sex	8	-31.380	83.00	6.608	0.012
	(ID) + (trial) + age	4	-37.110	83.27	6.878	0.011

	(ID) + (trial) + decoy + age	5	-36.070	83.76	7.369	0.008
	(ID) + (trial) + age + sex	5	-36.120	83.86	7.471	0.008
	(ID) + (trial) + age + sex	6	-35.410	85.16	8.770	0.004
scan	(ID) + (trial) + age	4	-46.340	101.74	0.000	0.154
	(ID) + (trial) + breed	5	-45.120	101.85	0.114	0.145
	(ID) + (trial)	3	-47.630	101.88	0.141	0.143
	(ID) + (trial) + sex	4	-46.720	102.49	0.750	0.106
	(ID) + (trial) + decoy + age	5	-45.750	103.12	1.382	0.077
	(ID) + (trial) + decoy	4	-47.040	103.14	1.400	0.076
	(ID) + (trial) + age + sex	5	-45.980	103.59	1.853	0.061
	(ID) + (trial) + decoy + breed	6	-44.790	103.91	2.175	0.052
	(ID) + (trial) + decoy + sex	5	-46.340	104.29	2.555	0.043
	(ID) + (trial) + breed + sex	6	-45.020	104.36	2.627	0.041
	(ID) + (trial) + breed + age	6	-45.070	104.48	2.740	0.039
	(ID) + (trial) + decoy + age + sex	6	-45.530	105.39	3.656	0.025
	(ID) + (trial) + decoy + breed + age	7	-44.730	106.65	4.914	0.013
	(ID) + (trial) + decoy + breed + sex	7	-44.730	106.66	4.918	0.013
	(ID) + (trial) + breed + age + sex	7	-44.990	107.18	5.443	0.010
	(ID) + (trial) + decoy + breed + age + sex	8	-44.680	109.60	7.863	0.003
run	(ID) + (trial)	3	-4.580	15.77	0.000	0.257
	(ID) + (trial) + decoy	4	-3.950	16.96	1.186	0.142
	(ID) + (trial) + age	4	-4.050	17.16	1.384	0.129
	(ID) + (trial) + sex	4	-4.080	17.22	1.446	0.125
	(ID) + (trial) + decoy + age	5	-3.350	18.32	2.551	0.072
	(ID) + (trial) + breed	5	-3.630	18.88	3.103	0.055
	(ID) + (trial) + decoy + sex	5	-3.650	18.92	3.150	0.053
	(ID) + (trial) + age + sex	5	-3.670	18.97	3.197	0.052
	(ID) + (trial) + decoy + breed	6	-2.970	20.27	4.499	0.027
	(ID) + (trial) + breed + sex	6	-3.100	20.53	4.760	0.024
	(ID) + (trial) + decoy + age + sex	6	-3.180	20.69	4.917	0.022
	(ID) + (trial) + breed + age	6	-3.440	21.22	5.445	0.017
	(ID) + (trial) + decoy + breed + sex	7	-2.700	22.61	6.836	0.008
	(ID) + (trial) + decoy + breed + age	7	-2.760	22.73	6.954	0.008
	(ID) + (trial) + breed + age + sex	7	-3.010	23.23	7.457	0.006
	(ID) + (trial) + decoy + breed + age + sex	8	-2.580	25.39	9.613	0.002
bark	(ID) + (trial)	3	-48.100	102.81	0.000	0.370
	(ID) + (trial) + sex	4	-47.810	104.67	1.863	0.146
	(ID) + (trial) + decoy	4	-47.990	105.04	2.229	0.121
	(ID) + (trial) + age	4	-48.090	105.23	2.428	0.110
	(ID) + (trial) + breed	5	-47.460	106.54	3.732	0.057
	(ID) + (trial) + decoy + sex	5	-47.730	107.09	4.285	0.043

	(ID) + (trial) + age + sex	5	-47.800	107.23	4.421	0.041
	(ID) + (trial) + decoy + age	5	-47.990	107.60	4.795	0.034
	(ID) + (trial) + breed + age	6	-47.210	108.76	5.951	0.019
	(ID) + (trial) + breed + sex	6	-47.300	108.93	6.122	0.017
	(ID) + (trial) + decoy + breed	6	-47.390	109.12	6.313	0.016
	(ID) + (trial) + decoy + age + sex	6	-47.730	109.80	6.993	0.011
	(ID) + (trial) + breed + age + sex	7	-47.070	111.34	8.531	0.005
	(ID) + (trial) + decoy + breed + age	7	-47.180	111.55	8.745	0.005
	(ID) + (trial) + decoy + breed + sex	7	-47.250	111.70	8.890	0.004
	(ID) + (trial) + decoy + breed + age + sex	8	-47.050	114.34	11.536	0.001
move	(ID) + (trial) + sex	4	-45.120	99.29	0.000	0.263
	(ID) + (trial)	3	-46.720	100.07	0.776	0.179
	(ID) + (trial) + age + sex	5	-44.790	101.20	1.907	0.101
	(ID) + (trial) + age	4	-46.090	101.24	1.950	0.099
	(ID) + (trial) + decoy + sex	5	-45.070	101.76	2.468	0.077
	(ID) + (trial) + decoy	4	-46.540	102.12	2.835	0.064
	(ID) + (trial) + breed + sex	6	-43.960	102.24	2.956	0.060
	(ID) + (trial) + decoy + age	5	-45.860	103.35	4.061	0.035
	(ID) + (trial) + breed + age + sex	7	-43.290	103.77	4.484	0.028
	(ID) + (trial) + decoy + age + sex	6	-44.720	103.78	4.488	0.028
	(ID) + (trial) + breed	5	-46.330	104.29	5.002	0.022
	(ID) + (trial) + decoy + breed + sex	7	-43.840	104.88	5.595	0.016
	(ID) + (trial) + breed + age	6	-45.660	105.65	6.361	0.011
	(ID) + (trial) + decoy + breed + age + sex	8	-43.110	106.45	7.162	0.007
	(ID) + (trial) + decoy + breed	6	-46.080	106.49	7.203	0.007
	(ID) + (trial) + decoy + breed + age	7	-45.280	107.77	8.479	0.004

Table A4. Summary of model selection statistics for Cox proportional hazards models analysing time to engage and time to leave decoy. Predictor variables include decoy type (decoy = deer or wolf), LGD breed (breed = kangal, karakachan, transmontano, or whitedog), LGD age category (age = juvenile or adult), and LGD sex (sex = male or female). All sixteen possible combinations of these four predictors are shown. The identity of the individual LGD (ID) and test group (test) were included as random variables in all models. Models are ranked according to AICc differences (Δ_i) based on the Akaike Information Criterion for small samples (AICc). Also included are the number of parameters (K), the integrated partial likelihood, and Akaike weights (*w*j).

Response Variable	Model	K	integrated partial likelihood	AICc	Δ_i	w_i
engage	(ID) + (test)	2	-190.40	384.89	0.000	0.221
	(ID) + (test) + sex	3	-189.66	385.49	0.599	0.163
	(ID) + (test) + decoy	3	-189.70	385.55	0.666	0.158
	(ID) + (test) + decoy + sex	4	-189.01	386.28	1.396	0.110
	(ID) + (test) + age	3	-190.16	386.48	1.593	0.099
	(ID) + (test) + age + sex	4	-189.31	386.89	2.005	0.081
	(ID) + (test) + decoy + age	4	-189.47	387.21	2.320	0.069
	(ID) + (test) + decoy + age + sex	5	-188.67	387.74	2.850	0.053
	(ID) + (test) + breed	5	-190.19	390.78	5.895	0.012
	(ID) + (test) + decoy + breed	6	-189.46	391.48	6.594	0.008
	(ID) + (test) + breed + sex	6	-189.54	391.65	6.766	0.007
	(ID) + (test) + decoy + breed + sex	7	-188.87	392.51	7.620	0.005
	(ID) + (test) + breed + age	6	-189.98	392.54	7.649	0.005
	(ID) + (test) + breed + age + sex	7	-189.27	393.29	8.409	0.003
	(ID) + (test) + decoy + breed + age	7	-189.27	393.30	8.411	0.003
	(ID) + (test) + decoy + breed + age + sex	8	-188.60	394.19	9.308	0.002
leave	(ID) + (test)	2	-107.39	219.04	0.000	0.364
	(ID) + (test) + age	3	-106.97	220.48	1.433	0.178
	(ID) + (test) + decoy	3	-107.36	221.24	2.200	0.121
	(ID) + (test) + sex	3	-107.37	221.27	2.230	0.119
	(ID) + (test) + age + sex	4	-106.90	222.70	3.655	0.059
	(ID) + (test) + decoy + age	4	-106.90	222.70	3.658	0.058
	(ID) + (test) + decoy + sex	4	-107.33	223.56	4.517	0.038
	(ID) + (test) + breed	5	-106.77	224.94	5.899	0.019
	(ID) + (test) + decoy + age + sex	5	-106.80	224.99	5.948	0.019
	(ID) + (test) + breed + sex	6	-106.53	227.06	8.012	0.007
	(ID) + (test) + breed + age	6	-106.67	227.34	8.297	0.006
	(ID) + (test) + decoy + breed	6	-106.68	227.37	8.325	0.006

(ID) + (test) + decoy + breed + sex	7	-106.34	229.42	10.374	0.002
(ID) + (test) + breed + age + sex	7	-106.41	229.55	10.501	0.002
(ID) + (test) + decoy + breed + age	7	-106.57	229.87	10.828	0.002
(ID) + (test) + decoy + breed + age + sex	8	-106.18	231.96	12.919	0.001

APPENIX B: LETTERS OF INFORMATION

UtahState University
Department of Wildland Resources
5230 Old Main Hill
Logan UT 84322-5230
Telephone: (435) 797-1348

LETTER OF INFORMATION

Livestock Guardian Dogs and Livestock Predators

Protocol # 6001

Introduction/ Purpose Dr. Julie K. Young and her graduate student Daniel Kinka in the Department of Wildland Resources at Utah State University are conducting a research study to find out more about attitudes towards wolves, grizzly bears, and livestock guardian dogs. You have been asked to take part because of your experience with livestock. There will be approximately 300 total participants in this research.

Funding This study is funded by USDA-APHIS-Wildlife Services and Utah State University

Procedures If you agree to be in this research study, we ask that you respond to a series of questions about your attitudes towards wolves, grizzly bears, and livestock guardian dogs, as well as your experience with livestock and some basic demographic information. The complete survey is attached. The survey should take 15-20 minutes to complete. Once you have completed the survey, please return it using the pre-paid envelope included with this packet. Using the pre-paid envelope helps us to assure your anonymity and the confidentiality of your answers.

Risks Participation in this research study may involve some slight psychological discomfort associated with thinking about your attitudes towards large carnivores and livestock guardian dogs. There is also a small risk of loss of confidentiality but we have taken steps to reduce this risk.

Benefits There are no direct benefits to you for participating in this study. However, your answers to these questions will help determine the most appropriate use of livestock guardian dogs. Ultimately the findings of this research will be made available to those in the livestock-producing community who stand to benefit from an improved understanding of how to best utilize livestock guardian dogs.

Explanation & offer to answer questions The introductory letter of this survey has hopefully explained this research study to you and answered any questions you may have had. If you have other questions or research-related problems, you may reach Dr. Julie K. Young at (435) 797-1348 or julie.k.young@aphis.usda.gov.

Extra Cost There is no cost to you for participating in this study. Postage for the return of this survey has already been paid for if you use the included return envelope.

Payment/Compensation There is no monetary compensation for participating in this study.

Utah State University
Department of Wildland Resources
5230 Old Main Hill
Logan UT 84322-5230
Telephone: (435) 797-1348

Full AAHRPP Accreditation

LETTER OF INFORMATION

Livestock Guardian Dogs and Livestock Predators

Protocol # 6001

Voluntary nature of participation and right to withdraw without consequence Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits. You may be withdrawn from this study without your consent by the investigator.

Confidentiality Research records will be kept confidential, consistent with federal and state regulations. Only the investigators will have access to the data which will be kept in a locked file cabinet or on a password protected computer in a locked room. To protect your privacy, personal, identifiable information will be removed from study documents and destroyed. We are attempting to gauge general attitudes towards large carnivores and livestock guardian dogs with this survey, so it is not necessary for us to collect or retain any identifiable information from you.

IRB Approval Statement The Institutional Review Board for the protection of human participants at Utah State University has approved this research study (Protocol# 6001). If you have any questions or concerns about your rights or a research-related injury and would like to contact someone other than the research team, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu to obtain information or to offer input.

Investigator Statement "I certify that the research study has been explained to the individual, by me or my research staff, and that the individual understands the nature and purpose, the possible risks and benefits associated with taking part in this research study. Any questions that have been raised have been answered."

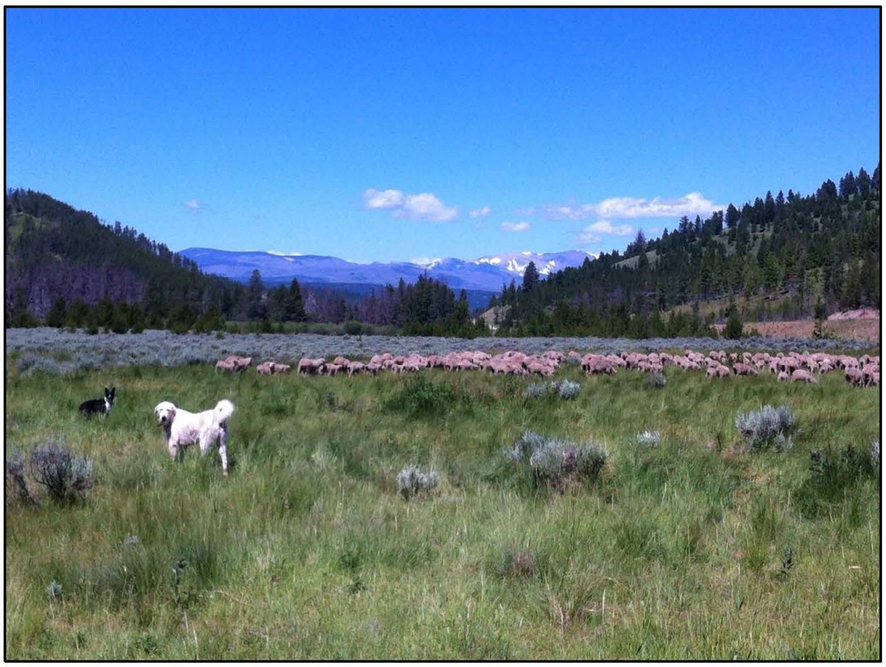
Signature of Researchers

Dr. Julie K. Young
Principal Investigator
(435) 797-1348
julie.k.young@aphis.usda.gov

Daniel Kinka
Student Researcher
(919) 995-1149
kinkadan@gmail.com

APPENDIX C: SURVEY

Livestock Guardian Dogs and Livestock Predators



Department of Wildland Resources
Quinney College of Natural Resources
Utah State University
Logan, Utah 84322-0730
IRB Protocol # 6001

Hello,

I am writing to invite you to participate in a study to evaluate human perspectives of livestock guardian dogs. The study is being conducted by the United States Department of Agriculture's National Wildlife Research Center in collaboration with Utah State University. Livestock guardian dogs are used to protect livestock from wild predators. This study has two components. One is to assess the performance of livestock guardian dogs in the field, and the other is to learn from you about your knowledge, concerns, and experiences with respect to livestock guardian dogs in areas with wolves and grizzly bears. The survey is designed to capture the experiences of people who work with livestock and your answers will help determine the most appropriate use of livestock guardian dogs.

Participation in the study is completely voluntary. We hope that you will consider sharing your opinions with us. There are no right or wrong answers, and responses to this survey are completely anonymous and confidential. More information about protecting the privacy and anonymity of individuals who complete the survey is attached in the Letter of Information.

If you choose to participate, please fill out all the information in this questionnaire to the best of your knowledge. The questionnaire should take 15-20 minutes to complete. After you have completed the survey please return the questionnaire using the pre-paid envelope included in your survey packet.

I thank you for your participation in advance. Please do not hesitate to contact me with questions.

Julie K. Young, Ph.D.

Principal Investigator
Supervisory Research Wildlife Biologist
USDA-WS-NWRC Predator Research Facility
julie.k.young@aphis.usda.gov

Daniel Kinka

Graduate Student Researcher
Utah State University
Department of Wildland Resources
kinkadan@gmail.com

EXPERIENCE

*Please answer the following questions about your experience with **livestock** and **livestock guardian dogs**.*

	None	Less than 1	1-5	6-10	10 or more
1. How many years have you raised livestock?	☐	☐	☐	☐	☐
2. How many years have you used livestock guardian dogs to protect livestock?	☐	☐	☐	☐	☐

	None	1-99	100-999	1,000-4,999	5,000-9,999	10,000 or more
3. How many SHEEP are you currently raising (include lambs)?	☐	☐	☐	☐	☐	☐
4. How many CATTLE are you currently raising (include calves)?	☐	☐	☐	☐	☐	☐

	None	1-3	4-9	10-19	20-29	30 or more
5. How many livestock guardian dogs are you using to protect SHEEP?	☐	☐	☐	☐	☐	☐
6. How many livestock guardian dogs are you using to protect CATTLE?	☐	☐	☐	☐	☐	☐

	No	Yes
7. Do you OWN PRIVATE grazing land?	☐	☐
8. Do you LEASE PRIVATE grazing land?	☐	☐
9. Do you LEASE PUBLIC grazing land?	☐	☐

EXPERIENCE

Please answer the following questions about your experience with ***large carnivores****.*

	Never	At least once a year	At least once a month	At least once a week	At least once a day
10. How often do you ENCOUNTER each of the following while grazing livestock?					
Coyotes	☐	☐	☐	☐	☐
Wolves	☐	☐	☐	☐	☐
Black Bears	☐	☐	☐	☐	☐
Grizzly Bears	☐	☐	☐	☐	☐
Mountain Lions	☐	☐	☐	☐	☐
11. How often have you LOST LIVESTOCK to each of the following while grazing livestock?					
Coyotes	☐	☐	☐	☐	☐
Wolves	☐	☐	☐	☐	☐
Black Bears	☐	☐	☐	☐	☐
Grizzly Bears	☐	☐	☐	☐	☐
Mountain Lions	☐	☐	☐	☐	☐

WOLVES

*Please answer the following questions about **wolves**.*

	Strongly Negative	Somewhat Negative	Neither Positive or Negative	Somewhat Positive	Strongly Positive
1. How would you describe your feelings about wolves?	☐	☐	☐	☐	☐

	Too Small	Appropriate	Too Large
2. The size of the current wolf population in this state is…	☐	☐	☐

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
3. I enjoy seeing wolves.	☐	☐	☐	☐	☐
4. I am afraid of wolves.	☐	☐	☐	☐	☐
5. Wolves contribute to a healthy ecosystem.	☐	☐	☐	☐	☐
6. Wolves are a threat to human safety.	☐	☐	☐	☐	☐
7. Wolves are part of the natural heritage of this state.	☐	☐	☐	☐	☐
8. Wolves have a negative impact on the populations of their prey.	☐	☐	☐	☐	☐
9. Wolves generate tourism revenue for this state.	☐	☐	☐	☐	☐
10. Wolves generate hunting revenue for this state.	☐	☐	☐	☐	☐
11. Wolves reduce the amount of game available to hunters.	☐	☐	☐	☐	☐
12. Livestock owners have a right to defend their livestock from wolf attacks.	☐	☐	☐	☐	☐

WOLVES

*Please answer the following questions about **wolves**.*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
13. Current state and federal laws prevent livestock owners from protecting their livestock from wolves.	☐	☐	☐	☐	☐
14. Livestock can not be successfully grazed in areas with wolves.	☐	☐	☐	☐	☐
15. Wolves cause livestock owners to lose money.	☐	☐	☐	☐	☐
16. Wolves are putting livestock owners out of business.	☐	☐	☐	☐	☐
17. Wolves will always be a problem for livestock owners.	☐	☐	☐	☐	☐
18. Protecting livestock from wolves is the responsibility of the livestock owner.	☐	☐	☐	☐	☐
19. The FEDERAL government…					
is responsible for livestock killed by wolves	☐	☐	☐	☐	☐
is managing wolf populations effectively	☐	☐	☐	☐	☐
should be in charge of managing wolf populations	☐	☐	☐	☐	☐
20. The STATE government…					
is responsible for livestock killed by wolves	☐	☐	☐	☐	☐
is managing wolf populations effectively	☐	☐	☐	☐	☐
should be in charge of managing wolf populations	☐	☐	☐	☐	☐

WOLVES

*Please answer the following questions about **wolves**.*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
21. I have the ability to influence wildlife management decisions concerning wolves at…					
the FEDERAL level	☐	☐	☐	☐	☐
the STATE level	☐	☐	☐	☐	☐
22. Lethal management of wolves is preferable to non-lethal methods.	☐	☐	☐	☐	☐
23. Wolf populations do not need to be managed.	☐	☐	☐	☐	☐
24. Reintroducing wolves to the western United States was a mistake.	☐	☐	☐	☐	☐
25. A wolf should be killed if…					
it is seen in a rural area	☐	☐	☐	☐	☐
it is seen around people	☐	☐	☐	☐	☐
it kills a dog	☐	☐	☐	☐	☐
it kills livestock	☐	☐	☐	☐	☐

GRIZZLY BEARS

*Please answer the following questions about **grizzly bears**.*

	Strongly Negative	Somewhat Negative	Neither Positive or Negative	Somewhat Positive	Strongly Positive
1. How would you describe your feelings about grizzly bears?	☐	☐	☐	☐	☐

	Too Small	Appropriate	Too Large
2. The size of the current grizzly bear population in this state is…	☐	☐	☐

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
3. I enjoy seeing grizzly bears.	☐	☐	☐	☐	☐
4. I am afraid of grizzly bears.	☐	☐	☐	☐	☐
5. Grizzly bears contribute to a healthy ecosystem.	☐	☐	☐	☐	☐
6. Grizzly bears are a threat to human safety.	☐	☐	☐	☐	☐
7. Grizzly bears are part of the natural heritage of this state.	☐	☐	☐	☐	☐
8. Grizzly bears have a negative impact on the populations of their prey.	☐	☐	☐	☐	☐
9. Grizzly bears generate tourism revenue for this state.	☐	☐	☐	☐	☐
10. Grizzly bears generate hunting revenue for this state.	☐	☐	☐	☐	☐
11. Grizzly bears reduce the amount of game available to hunters.	☐	☐	☐	☐	☐
12. Livestock owners have a right to defend their livestock from grizzly bear attacks.	☐	☐	☐	☐	☐

GRIZZLY BEARS

*Please answer the following questions about **grizzly bears**.*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
13. Current state and federal laws prevent livestock owners from protecting their livestock from grizzly bears.	☐	☐	☐	☐	☐
14. Livestock can not be successfully grazed in areas with grizzly bears.	☐	☐	☐	☐	☐
15. Grizzly bears cause livestock owners to lose money.	☐	☐	☐	☐	☐
16. Grizzly bears are putting livestock owners out of business.	☐	☐	☐	☐	☐
17. Grizzly bears will always be a problem for livestock owners.	☐	☐	☐	☐	☐
18. Protecting livestock from grizzly bears is the responsibility of the livestock owner.	☐	☐	☐	☐	☐
19. The FEDERAL government…					
is responsible for livestock killed by grizzly bears	☐	☐	☐	☐	☐
is managing grizzly bear populations effectively	☐	☐	☐	☐	☐
should be in charge of managing grizzly bear populations	☐	☐	☐	☐	☐
20. The STATE government…					
is responsible for livestock killed by grizzly bears	☐	☐	☐	☐	☐
is managing grizzly bear populations effectively	☐	☐	☐	☐	☐
should be in charge of managing grizzly bear populations	☐	☐	☐	☐	☐

GRIZZLY BEARS

*Please answer the following questions about **grizzly bears**.*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
21. I have the ability to influence wildlife management decisions concerning grizzly bears at…					
the FEDERAL level	☐	☐	☐	☐	☐
the STATE level	☐	☐	☐	☐	☐
22. Lethal management of grizzly bears is preferable to non-lethal methods.	☐	☐	☐	☐	☐
23. Grizzly bear populations do not need to be managed.	☐	☐	☐	☐	☐
24. Maintaining federal protections for grizzly bears in the western United States is a mistake.	☐	☐	☐	☐	☐
25. A grizzly bear should be killed if…					
it is seen in a rural area	☐	☐	☐	☐	☐
it is seen around people	☐	☐	☐	☐	☐
it kills a dog	☐	☐	☐	☐	☐
it kills livestock	☐	☐	☐	☐	☐

LIVESTOCK GUARDIAN DOGS

To what extent do you agree or disagree with the following statements about ***livestock guardian dogs****?*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
1. Livestock guardian dogs are a vital part of any livestock operation.	☐	☐	☐	☐	☐
2. Livestock guardian dogs do more harm than good.	☐	☐	☐	☐	☐
3. Livestock guardian dogs prevent the spread of disease between wild animals and livestock.	☐	☐	☐	☐	☐
4. Livestock guardian dogs are a threat to human safety.	☐	☐	☐	☐	☐
5. Livestock guardian dogs prevent livestock being stolen by other people.	☐	☐	☐	☐	☐
6. Livestock guardian dogs are a *useful* tool for protecting SHEEP from:					
Coyotes	☐	☐	☐	☐	☐
Wolves	☐	☐	☐	☐	☐
Grizzly Bears	☐	☐	☐	☐	☐
7. Livestock guardian dogs are a *necessary* tool for protecting SHEEP from:					
Coyotes	☐	☐	☐	☐	☐
Wolves	☐	☐	☐	☐	☐
Grizzly Bears	☐	☐	☐	☐	☐

LIVESTOCK GUARDIAN DOGS

To what extent do you agree or disagree with the following statements about ***livestock guardian dogs****?*

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
8. Livestock guardian dogs are a *useful* tool for protecting CATTLE from:					
Coyotes	☐	☐	☐	☐	☐
Wolves	☐	☐	☐	☐	☐
Grizzly Bears	☐	☐	☐	☐	☐
9. Livestock guardian dogs are a *necessary* tool for protecting CATTLE from:					
Coyotes	☐	☐	☐	☐	☐
Wolves	☐	☐	☐	☐	☐
Grizzly Bears	☐	☐	☐	☐	☐
10. Livestock guardian dogs reduce livestock owners' reliance on government agencies to manage and control predators.	☐	☐	☐	☐	☐
11. The costs associated with keeping livestock guardian dogs are worth the economic benefits they provide.	☐	☐	☐	☐	☐
12. Livestock guardian dogs reduce the need for lethal removal of predators.	☐	☐	☐	☐	☐
13. Using livestock guardian dogs is a good idea for most livestock owners.	☐	☐	☐	☐	☐
14. Using livestock guardian dogs with my own livestock is a good idea.	☐	☐	☐	☐	☐

DEMOGRAPHIC INFORMATION

Please fill out the demographic information below.
As a reminder, all the information that you provide will remain anonymous.

	Female	Male
1. What is your gender?	☐	☐

	18-25	26-35	36-45	46-55	56-65	66+
2. What is your age?	☐	☐	☐	☐	☐	☐

	Did not complete High School	High School diploma	Bachelor's degree	Graduate degree(s)
3. What is the highest level of formal education you have completed?	☐	☐	☐	☐

	Idaho	Montana	Oregon	Washington	Wyoming	Other (please specify)
4. What state do you raise livestock in?	☐	☐	☐	☐	☐	__________

	Less than $30,000	$30,000-$49,999	$50,000-$99,999	$100,000-$149,999	$150,000-$199,999	$200,000 or more
5. What is your annual household income before taxes?	☐	☐	☐	☐	☐	☐

	None	1-25%	26-50%	51-75%	76-100%
6. What percentage of your household income comes from livestock?	☐	☐	☐	☐	☐

Thank You!

Thank you for completing the survey! Your responses are extremely valuable to our research. Please put your completed survey in the mail using the pre-paid envelope included in your survey packet. If you would like to make any comments or share additional opinions about and experiences with wolves, grizzly bears, or livestock guardian dogs, please use the space provided below. If you have questions, please contact Dr. Julie Young directly (julie.k.young@aphis.usda.gov; 435-890-8204).

CURRICULUM VITAE

DANIEL KINKA

816 West 4th Street, Anaconda, MT 59711
kinkadan@gmail.com | (919) 995-1149
https://danielkinka.wordpress.com

EDUCATION

2019 Ph.D. in Ecology, Utah State University
Advised by Julie K. Young
Dissertation: Efficacy of livestock guardian dogs: Ecology, Attitudes, and Management

2010 M.A. in Psychology, University of Richmond
Advised by Cindy Bukach
Thesis: Shared features and similarity: Implications for category specificity and normal recognition

2008 B.S. in Psychology with minors in Biology and Chemistry, Florida State University Advised by Carlos Bolaños
Thesis: Effects of adult treatment with nicotine and the antidepressant fluoxetine on male rats exposed to nicotine during adolescence

PUBLICATIONS

2019 Kinka, D., J.K. Young. Evaluating Domestic Sheep Survival with Different Breeds of Livestock Guardian Dogs. *Rangeland Ecology & Management (in press).*

2019 Young, J., Draper, J. P., & Kinka, D. Spatial associations of livestock guardian dogs and domestic sheep. *Human–Wildlife Interactions*, 13(1), 6.

2018 Kinka, D., J.K. Young. A livestock guardian dog by any other name: similar response to wolves across livestock guardian dog breeds. *Rangeland Ecology & Management, 71(4), 509-517*.

2015 Mahoney, P.J., K.H. Beard, A.M. Durso, A.G. Tallian, A.L. Long, R.J. Kindermann, N.E. Nolan, D. Kinka, & H.E. Mohn. Introduction effort, climate matching and species traits as predictors of global establishment success in non-native reptiles. *Diversity and Distributions*, 21(1), 64–74.

2012 Bukach, C.M., T. Vickery, D. Kinka, & I. Gauthier. Training experts: Individuation without naming is worth it. *Journal of Experimental Psychology: Human Perception and Performance,* 38(1), 14–17.

2008 Bolaños, C.A., M.D. Willey, M.L. Maffeo, K.D. Powers, D.W. Kinka, K.B. Grausam, & R.P. Henderson. Antidepressant treatment can normalize adult behavioral deficits induced by early-life exposure to methylphenidate. *Biological Psychiatry,* 63(3), 309–316.

PRESENTATIONS

2017 Kinka, D., J.K. Young. Hidden wolves & apathetic bears: Effects of livestock guard dogs on carnivore detectability (poster). The Ecological Society of America annual meeting, Portland, OR. August 11.

2017 Kinka, D., J.K. Young. How Livestock Guard Dogs Work (invited talk and panel discussion). The Western Section of the Wildlife Society annual meeting, Reno, NV. February 10.

2017 Kinka, D. Ranching with Carnivores Symposium (invited panel discussion). Yale University, New Haven, CT. February 3.

2016 Kinka, D. What am I doing with my life and how did I get here? (invited talk). Student Chapter of the Wildlife Society Meeting, Utah State University. November 15.

2016 Kinka, D. Non-lethal Carnivore Management: Livestock Guard Dogs (invited talk). Initiative to Bring Science Programs to the Incarcerated (INSPIRE), Salt Lake County Jail, Salt Lake City, UT. October 31.

2016 Kinka, D., J.K. Young. Effect and effectiveness of livestock guard dogs (poster). The Wildlife Society annual meeting, Raleigh, NC. October 18.

2016 Kinka, D. Non-lethal Carnivore Management: Livestock Guard Dogs (guest lecture). WILD3810: Plant and Animal Populations, Utah State University. April 18.

2016 Kinka, D. Non-lethal Carnivore Management: Livestock Guard Dogs (guest lecture). ENVS3600: Living with Wildlife, Utah State University. April 14.

2016 Kinka, D. Livestock Guard Dogs (invited talk). Non-lethal predator damage management workshop, Pinetop, AZ. February 18.

2015 Kinka, D., J.K. Young. Effect and effectiveness of livestock guard dogs (poster). The Wildlife Society annual meeting, Winnipeg, MB. October 19.

2015 Young, J.K., D. Kinka. How to assess the efficiency of LGDs – update on research in the USA (invited talk). Workshop on LGDs - From tradition to modernity: How to assess, improve and innovate. Castelo Branco, Portugal. October 19-21.

2015 Kinka, D. Evaluating the efficacy of livestock guardian dogs (talk). Quinney College of Natural Resources Graduate Research Symposium, Utah State University. April 17.

2015 Kinka, D., J.K. Young. Evaluating the efficacy of livestock guardian dogs (poster). Student Research Symposium, Utah State University. April 9.

2014 Kinka, D. The Chimerical Wolf (TED-style talk). Ignite USU speaker series, Utah State University.
April 11.

2014 Kinka, D., J.K. Young. Evaluating the efficacy of livestock guardian dogs (poster). Student Research Symposium, Utah State University. April 10.

2014 Kinka, D. Public Speaking for Scientists (talk). EcoLunch, Utah State University.
February 21.

2013 Kinka, D. Evaluating the effectiveness of livestock guard dogs: Loss-prevention, ecology, and sociology (talk). Quinney College of Natural Resources Graduate Research Symposium, Utah State University. April 19.

2010 Kinka, D., K. Roberts, C.M. Bukach. The interaction of structural and conceptual
information determines object confusability (poster). Vision Sciences Society annual conference, Naples, FL.

2010 Kinka, D., K. Roberts, C.M. Bukach. The interaction of structural and conceptual information determines object confusability (poster). University of Richmond Arts & Sciences, graduate symposium, Richmond, VA.

2010 Kinka, D., K. Roberts, C.M. Bukach. The interaction of structural and conceptual information determines object confusability (poster). College of William & Mary Arts & Sciences, graduate symposium, Williamsburg, VA.

2009 Kinka, D., M.R. Grovola, C.M. Bukach. Does shared dimensionality inhibit object recall? (poster). Society for Neuroscience annual conference, Chicago,

IL.

2009 Kinka, D., C.M. Bukach, I. Gauthier. Are label association necessary for the acquisition of expertise? (poster). Vision Sciences Society annual conference, Naples, FL.

2009 Kinka, D., M. Grovola, C.M. Bukach. The effect of shared dimensionality on object recall (poster). College of William & Mary Arts & Sciences, graduate symposium, Williamsburg, VA.

2009 Butt, E.W., J. Ubiwa, D. Kinka, C.M. Bukach. The effect of attitude on the other race effect (poster). Southeastern Psychological Association annual conference, New Orleans, LA.

2009 Kinka, D., M. Grovola, C.M. Bukach. The effect of shared dimensionality on object recall (poster). University of Richmond Arts & Sciences, graduate symposium, Richmond, VA.

2008 Bolaños, C.A., D.W. Kinka. Effects of adult treatment with nicotine and the antidepressant fluoxetine on male rats exposed to nicotine during adolescence (talk). ACC Meeting of the Minds Conference, Tallahassee, FL.

2007 Bolaños, C.A., M.L. Maffeo, D.W. Kinka. Nicotine exposure during regulates adult behavioral responsiveness to mood- stimuli in male rats (poster). Society for Neuroscience annual conference, San Diego, CA.

PROFESSIONAL POSITIONS

2016-17 Science Reporter
Utah Public Radio, Logan, UT | January – *present*
Duties: Schedule, conduct, and record interviews. Produce audio content for broadcast on National Public Radio affiliate Utah Public Radio.
Supervisor: Kerry Bringhurst

2012 Ranger Naturalist
U.S. National Park Service, Grand Teton National Park | April – August
Duties: Develop and lead interpretive programs including ranger-led hikes and educational talks. Provide visitor services.
Supervisor: Elizabeth Maki

2012 Research Technician: Study of Gray Wolf Predation
U.S. Fish & Wildlife Service, Grand Teton National Park | January – April
Duties: Track and monitor gray wolves via track identification; perform carcass dissection and analysis; manage remote cameras; travel in backcountry (ski, snowmobile, snowshoe); manage research database.

Supervisor: Mike Jimenez

2011 Naturalist
Grand Teton Association, Grand Teton National Park | August – September
Duties: Provide visitor services. Develop and lead interpretive programs including ranger-led hikes and educational talks.
Supervisor: Dan Greenblatt

2011 Research Technician: Study of Gray Wolf Predation
U.S. National Park Service, Grand Teton National Park | April – July
Duties: Track and monitor gray wolves via GPS and track identification; perform carcass dissection and analysis; manage remote cameras; travel in backcountry (hike, mountain bike); manage research database.
Supervisor: John Stephenson

2011 Research Technician: Study of Gray Wolf Predation
U.S. Fish & Wildlife Service, Grand Teton National Park | January – April
Duties: Track and monitor gray wolves via radio telemetry and track identification; perform carcass dissection and analysis; manage remote cameras; travel in backcountry (ski, snowshoe); manage research database.
Supervisor: Mike Jimenez

2010 Research Technician: Study of Ungulate Response to Pathway
Colorado State University, Grand Teton National Park | June – October
Duties: Conduct ungulate (elk, moose, pronghorn antelope and mule deer) behavior surveys; conduct human activity surveys; manage research database.
Supervisor: Amanda Hardy

2008–09 Research Technician: Study of Disadvantaged Youth Resources
Clark-Hill Institute, Virginia Commonwealth University
Duties: Recruit participants; conduct interviews; administer survey materials.
Supervisors: Anne Y. Greene, Jennifer Elswick, Dana Andrew

2006–07 Student Researcher: Study of Juvenile Depression Modeled in Rats
Florida State University
Duties: Perform data management and analysis; prepare and inject serum; handle laboratory animals; conduct behavioral tests.
Supervisors: Carlos Bolaños, Melissa Maffeo

GRANTS & FELLOWSHIPS

2015 Ecology Center, Utah State University, graduate research grant | $4,000
2014 Ecology Center, Utah State University, graduate research grant | $3,000
2012 Quinney Foundation Doctoral Fellowship | $80,000

2010	University of Richmond thesis research grant | $2,800
2009, 08	University of Richmond research grant | $1,100

TEACHER'S ASSISTANTSHIPS

2016	Plant and Animal Populations | Utah State University
2010	Cognitive Neuroscience | University of Richmond
2010	Psychopathology | University of Richmond
2009	Methods & Analysis | University of Richmond
2009	Cognitive Science | University of Richmond
2009	Methods & Analysis | University of Richmond
2008	Cognitive Neuroscience | University of Richmond
2007	Physiological Psychology | Florida State University

VOLUNTEER ACTIVITIES

2016	Assist with Coyote Capture and Relocation | National Wildlife Research Center
2014	Bobcat GPS Collar Retrieval | Dallas, TX
2011	Bighorn Sheep Population Survey | Grand Teton National Park
2011	Osprey and Bald Eagle Nest Survey | Grand Teton National Park
2010	Bighorn Sheep Radio Collar Retrieval | Grand Teton National Park

TRAINING & CERTIFICATIONS

2016	Audience Engagement Workshop | Utah State University
2016	Interviewing & Recording Workshop | The Kitchen Sisters
2016	Wilderness First Aid Certification | Desert Mountain Medicine
2016	Hunting Awareness & Conservation Course | Conservation Leaders for Tomorrow
2014	Research Integrity Training | Utah State University
2014	Science Communication Workshop | Utah State University
2013	Grant Writing Workshop | Utah State University
2013	Software Carpentry Bootcamp | Utah State University
2012	Human Research Training | Collaborative Institutional Training Initiative
2012	Wildlife Capture and Handling Workshop | Utah State University

SKILLS

FIELD	Camera trapping, animal tracking, radio telemetry, field necropsy, backcountry navigation, 4x4 truck operation, ATV operation,

	snowmobile operation, skiing, snowshoeing, backpacking, hiking.
ANALYSIS	Occupancy modeling, GPS data analysis, home range modeling, survival modeling, behavioral analysis.
SOFTWARE	R, ArcGIS, MARK, PRESENCE, Microsoft Office, Evernote, WordPress, Adobe Audition, Papers, Mendeley, SPSS, social media.
LANGUAGE	English: Native speaker. Spanish: Good reading comprehension, intermediate conversation and writing.
GENERAL	Science communication, science writing, public speaking, public radio, music, prose, poetry, theatre.

SELECT MEDIA

2016 The Science of Beer. Utah Public Radio. December 27. (Winner: Best Use of Sound. Society of Professional Journalists, Utah Chapter.) http://upr.org/post/science-beer

2015 Mesas and Sky. High Country News. January 19. (Runner-up: Bell Prize. High Country News.) http://www.hcn.org/issues/47.1/mesas-and-sky

2015 Young Leaders Changing the West. High Country News. January 13. http://www.hcn.org/articles/ten-people-under-30-changing-the-west

2014 The Chimerical Wolf. Ignite, Utah State University. April 11. https://www.youtube.com/watch?v=Jpbkr6tDzeM

PROFESSIONAL AFFILIATIONS

2017–*present*	The Ecological Society of America
2017–*present*	American Association for the Advancement of Science
2015–*present*	The Wildlife Society
2014–*present*	The Berryman Institute, Utah State University
2009–10	Vision Sciences Society
2007–09	Society for Neuroscience