Efficacy of gray wolf (*Canis lupus*) rendezvous site mapping for predicting the spatiotemporal risk of domestic cattle-wolf encounters

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Authorization to Submit Thesis

This thesis of Darrel Joseph Chigbrow, submitted for the degree of Master of Science with a Major in Natural Resources and titled “Efficacy of gray wolf (*Canis lupus*) rendezvous site mapping for predicting the spatiotemporal risk of domestic cattle-wolf encounters,” has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

During 2009-2011, resource selection patterns of cattle (*Bos tarsus*) on mountainous terrain among four allotments in western Idaho was determined. Within these rangelands gray wolves (*Canis lupus*) have been documented and known to harass and prey on livestock. Using GPS location data on cattle, along with wolf presence data which correlates with Ausband et al. (2010) wolf rendezvous prediction model, resource selection patterns of cattle were overlaid on top of predicted wolf rendezvous habitat to find areas where cattle-wolf encounters may occur. Areas of likely cattle-wolf encounters can then be more intensely managed by producers to reduce possible harassment and depredation by wolves, along with narrowing the focus for finding missing and depredated cattle.

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Chapter 1. Overview of Interactions Between Wolves and Domestic Livestock

Introduction

Conflicts often arise between predators and domestic livestock that occupy a shared landscape. These conflicts have both economic and political implications (Graham et al., 2005). Gray wolves (*Canis lupus*) were reintroduced to the Northern Rocky Mountain (NRM) region of the United States (US) in 1995 after being absent for nearly 70 years (USFWS et al., 2015). Uncertainties and controversies continue to surround this wolf reintroduction despite the 20 years since its implementation. Some believe wolves are a detriment to the economic stability of livestock operations, while others believe this economic problem is overstated and that wolf reintroduction will actually increase the economic viability of rural areas through tourism and increased land values (Clark and Johnson, 2009). Many ranchers, farmers, and other rural residents who directly experience livestock depredation, decreased nutrition and reduced immunity to diseases (Carroll and Forsberg, 2007), and other documented or perceived effects of wolves, tend to view wolf reintroductions unfavorably (Fritts et al., 2003). These negative views exist even when repopulation happens naturally, as in Minnesota, through recolonization from surrounding areas (Chavez et al., 2005).

Following gray wolf reintroduction to Yellowstone National Park and central Idaho in 1995, wolf populations have greatly increased and expanded into surrounding areas (Fig. 1.1; USFWS et al., 2015). As of December 31, 2014 the minimum estimated population was 1,657 wolves (Fig. 1.2) in 313 packs and 85 breeding pairs. These population trends have remained fairly constant since 2008 (USFWS et al., 2015).

Home ranges for wolf packs in Montana cover an average of 518 km² of territory each with some packs occupying territories over 770 km² (Sime et al., 2011). Given the requirement for territories to provide enough resources to sustain an individual pack, growing wolf populations have resulted in wolves occupying the available habitat within the original three recovery areas and have since expanded into surrounding areas. Currently, the NRM wolf population occupies a range within Idaho, Montana, Wyoming, eastern portions of Washington and Oregon, and a small part of north central Utah (USFWS et al., 2015).

As the NRM wolf population has increased and expanded, livestock depredation by wolves has also increased in number and spatial extent (Muhly and Musiani, 2009). In 1994, prior to wolf reintroduction, Montana was the only state in the Northwestern U.S. with a known wolf population. Montana had six confirmed wolf depredations of beef cattle (*Bos taurus;* Table 1.1, USFWS et al., 2015). The number of confirmed wolf depredations on cattle in the NRM region has increased since reintroduction with an average of 176/year during 2008-2014 (USFWS et al., 2015). During 2014, of 355 wolf packs to have existed at some time during 2014, 62 were involved in at least one confirmed cattle depredation (USFWS et al., 2015).

Wolf depredation losses in 2014 amounted to compensation payments of $274,886 within the NRM region excluding Idaho and Washington, which did not report compensation payments, with an additional $530,306 spent on preventing livestock depredation and compensation to affected livestock owners through the Wolf-Livestock Demonstration Project Grant Program (USFWS et al., 2015). Generally, across the NRM region, death losses resulting from wolf depredation may be relatively small compared to livestock deaths caused by birthing problems, disease/health problems, weather, and accidents. Nationally, according to the United States Department of Agriculture's National Agricultural Statistics Service report on cattle death loss for 2010, wolf depredation accounts for 3.7% of cattle deaths, while calving, disease/health problems, weather related, and accidents (lameness/injury) account for 13.1%, 49.4%, 13.0%, and 3.7%, respectively (NASS -USDA2011). For instance, in Idaho only 6.56% of cattle losses were due to predators, with 30% of those depredations due to wolves (NASS -USDA2011). However, some individual ranching operations experience comparatively high depredation rates and suffer substantial economic impact (Breck and Meier, 2004).

One problem hindering management of wolf-livestock interactions in the NRM region is that the majority of wolf depredations likely go undetected. In a wolf depredation study on calves in Lemhi County, Idaho, Oakleaf et al. (2003) estimated documented wolf depredation on cattle accounted for only about 12.5% of the cattle actually killed by wolves. Oakleaf's study also theorized that detection rates were dependent on terrain and vegetation characteristics within a grazing allotment. Consequently, allotments with more rugged and forested range would likely have lower depredation detection rates.

Depredation losses are not the only costs borne by livestock producers as a consequence of increasing wolf populations and interaction with livestock. These producers spend money for predation prevention measures, such as hiring additional personnel as watchmen; fladry (posted flagging) and electronic fladry incorporating scare devices (irritating sounds, flashing lights, predator collars with electroschoking devices), guard dogs, and biofences (biologically produced barriers; Shivik et al., 2003; Lance, 2009; Ausband, 2011). Wolf presence can also require substantial management changes such as early weaning, grazing schedule changes, and fencing and facility changes. Conflict with wolves may also result in losses in usable grazing acreage, thus, increasing feeding costs to producers (Shelton, 2004).

There are also increased costs and lost revenue resulting from the lasting effects of harassment or injury to livestock from wolf encounters and pursuit events (Lemkuhler et al., 2007). Wolf-caused stress may lead to livestock reproductive problems, including abortion, failure or delayed conception, increased susceptibility to diseases, decreased weight gain due to increased vigilance, and/or reductions in meat quality (Bruscino and Cleveland, 2004; Lemkuhler et al., 2007). Livestock may also exhibit different range-use habits under the chronic threat of wolf depredation. Livestock may selectively change the habitat types they occupy when wolf presence is high as opposed to low and these differences in habitat use may impact livestock health and fitness (Lind and Cresswell, 2005).

When cattle become aware of a wolf's presence they tend to form groups and increase the sinuosity of their travel path as an anti-predator response (Laporte et al., 2010). This can lead to changes in habitat selection causing cattle to expend more energy avoiding predators than when walking directly from one area to the next, i.e., from a food source to water (Clark and Johnson, 2009), which could ultimately decrease the health and productivity of livestock (Laporte et al., 2010). It has also been suggested that livestock have lost some of their innate anti-predator responses, which can increase stress due to erratic and inconsistent responses to predators (Laporte et al., 2010), while increasing the likelihood that domestic animals may experience higher depredation than wild animals (Mignon-Grasteau et al., 2005). As wolves continue to expand into available habitats throughout western North America, their interactions with livestock and consequent depredations losses, stress-related livestock, disease, and reproductive problems will likely increase (Muhly and Musiani, 2009).

Cattle Resource Selection for Cattle

Resource selection functions (RSF) are statistically derived models classified to be proportional to the probability of use of a resource unit by an organism (Manly et al., 1993; Boyce et al. 2002). Resource selection functions are built using abiotic (e.g., elevation, slope, man-made structures) and biotic (e.g., plant and animal community dynamics) environmental characteristics' which affect an organism's distribution. With the collection of presence/absence data (i.e., cattle locations) within a study area, correlated to environmental characteristics, RSF models can be produced which predict the probability of habitat use by cattle (Turner et al., 2000; Bailey and Provenza, 2008).

Cattle distribution is largely influenced by abiotic factors, which in turn determine biotic factors (i.e., slope, distance to water, etc. affecting plant species presence) (Bailey et al., 1996; Ganskopp and Bohnert, 2009). Ganskopp and Bohnert (2009) showed cattle will selectively graze relatively small portions of the available range land. Cattle are also known to primarily focus on grasses for forage and they prefer grazing on grasslands sites (McInnis and Vavra, 1987; Ganskopp and Bohnert, 2009).

Wolf Resource Selection

Wolf rendezvous sites are areas used by wolf packs throughout their territory where wolf pups can rest while the adults forage for food (Mech, 2000). Wolf rendezvous site prediction maps can be a useful tool in predicting cattle-wolf interactions as Oakleaf et al. (2003) and Bradley and Pletscher (2005) reported that cattle herds that had the greatest spatial overlap with a wolf pack's home territory were subject to more depredations, compared to cattle herds which had less spatial overlap. The summer grazing season is when the majority of livestock are killed by predators, which coincides with when wolf rendezvous locations are used, generally from late spring to early fall (Peterson and Ciucci, 2003).

Ausband et al., (2010) generated a map which predicted the most likely wolf rendezvous sites for the state of Idaho (Fig. 1.3). Rendezvous site predictions were calculated using characteristics of 122 known historical rendezvous sites from wolf populated Game Management Units (GMU) in Central Idaho. In Idaho, rendezvous sites are best classified by elevated levels of green leaf biomass associated with grasses along with concave and gentle topography which retains water. The rendezvous prediction map used LANDSAT 7 imagery from July 2002, which was processed through ERDAS Imagine v.9.3.2 to calculate green leaf biomass NDVI; while ArcMap v.9.3 was used to calculate surface roughness, and profile curvature. Both surface roughness and profile curvature indicate landscapes that collect and hold water, while profile curvature characterizes topographic features e.g., flat meadows.

Resource selection functions' where then used to model predicted rendezvous sites using ArcMap. The resulting wolf rendezvous RSF raster had agricultural areas masked from the wolf rendezvous prediction model because they were categorized as good rendezvous habitat but are not viable sites due to high frequency of human activity. Finally, the wolf rendezvous RSF raster was divided into ten predictive classifications, with the first class the least likely to have wolf rendezvous' and the tenth class the most likely to have wolf rendezvous' (C. Tobalski, Montana Cooperative Wildlife Research Unit, personal communication, April 2012). The top two wolf rendezvous classifications where then used to map the most likely areas to have wolf rendezvous locations, across Idaho.

Since, both cattle and wolves select grassland habitats for foraging and rendezvous sites, respectively; it is reasonable to assume both cattle and wolves will have overlapping RSF's. By comparing both cattle and wolf RSF's and finding those areas of overlap, areas of likely cattle-wolf interaction emerges. This is especially true when comparing the highest wolf rendezvous prediction sites in wolf populated regions of Idaho (Fig. 1.3) as developed by Ausband et al., (2010), which represents wolf resource selection for this study.

Monitoring Techniques

Since wolf scat samples correlate well with predicted rendezvous sites (Ausband, et al., 2010), the combination of these wolf monitoring/prediction tools can help predict areas where cattle-wolf interactions may occur in a given area. Scat route surveys rely on the behavior of canids to scent-mark their territory by depositing scented secretions in the environment (Barrette and Messier, 1980). Wolves are known for using secondary roads (unpaved) and trails as travel routes. These roads are usually scent-marked and have been shown to represent the boundaries between wolf territories (Fritts et al., 2003). Along territory boundaries wolves are known to leave twice as many marks, compared to markings in the core of the territory, creating an "olfactory bowl" (Peters and Mech, 1975). This behavior to leave a visual and olfactory territorial mark, especially along roads enables the use of scat routes to be an effective low cost survey tool to estimate relative abundance of canids within an area as reported by Kunkel and colleagues (2005).

Other inexpensive methods that are less reliable for monitoring wolves include questionnaires, tracking surveys, harvest data, and evaluating relationships between prey densities to predict predator densities. Questionnaires are often biased depending on the attitudes towards wolves of the people polled, ability of public to identify wolves or their sign, and the novelty of sighting a wolf may increase the frequency of reporting (Kunkel et al., 2005). Tracking surveys can also provide information on wolf movements but are generally only reliable in snow covered areas during winter when tracks can easily be distinguished by non-expert trackers (Kunkel et al., 2005). Harvest data and prey-predator relationships can be unreliable because they primarily show only the extent and general location of wolves (Kunkel et al., 2005) and harvesting can be inconsistent depending on whether or not there is a public hunt and by how many confirmed depredations lead to removal of an animal(s) by wildlife control.

Project Objectives

The main goal of this project was to evaluate efficacy of wolf rendezvous site mapping for predicting the spatiotemporal risk of cattle to wolf depredation. Cattle GPS collar data and predicted wolf rendezvous sites were used to develop a predictive map of the wolf depredation risk within four US Forest Service (USFS) cattle grazing allotments in western Idaho. Data for cattle-wolf interaction sites derived from GPS telemetry analysis will be used to validate the predictive map. Specific objectives of this project include:

1) Predict the resource-selection patterns of cattle on these 4 study areas over 3 grazing seasons;

2) Evaluate the performance an existing wolf rendezvous site habitat-quality model (Ausband et al., 2010) using wolf presence data, such as scat and telemetry locations, confirmed cattle depredations, and actual rendezvous sites documented within and nearby these 4 study areas during the rendezvous period (June-August);

3) Identify areas of overlap between patterns in predicted cattle resource selection and in predicted wolf rendezvous-site habitat quality to thus locate areas where cattle-wolf encounters might likely to occur during the rendezvous period;

4) Evaluate the efficacy of spatial cattle-wolf encounter risk maps, derived from these overlaps, by applying case study at one of the study areas where actually cattle-wolf encounters were documenting using GPS tracking.

By knowing where possible interactions among cattle and wolves may occur, ranchers can invest more resources and intensify husbandry practices to discourage wolf activity in specific areas (Muhly et al., 2010). In cases where depredation has occurred and cattle are missing, ranchers can use predicted areas of cattle-wolf interaction to better determine where the depredation may have occurred. Initial searches for missing cattle can focus on areas of higher probability of cattle-wolf interaction before moving on to less likely areas.

Chapter 2. Efficacy of Gray Wolf (*Canis lupus*) Rendezvous Site Mapping for Predicting the Spatiotemporal Risk of Domestic Cattle-wolf Encounters

Introduction

Gray wolves (*Canis lupus*) were reintroduced to the Northern Rocky Mountain (NRM) region of the United States (US) in 1995 after being extirpated from the Western US by the 1930's (USFWS et al., 2015). With an increase in population and a need for territories providing enough resources to sustain an individual pack, wolves have come to occupy the available habitat within the original three recovery areas (central Idaho, western Montana, and Yellowstone National Park) and have since expanded into these surrounding territories as of 2014. Currently, the NRM wolf population occupies a range within Idaho, Montana, Wyoming, eastern portions of Washington and Oregon, and a small part of north central Utah; with a minimum wolf population of 1,600 individuals since 2008 (USFWS et al., 2015).

As wolf populations increasingly inhabit the shared space of livestock on rangelands, the interactions between wolves and livestock increased. These wolf-livestock interactions have both direct and indirect costs that result in both a financial and time management burden on individual ranchers who have limited resources to make a living and be productive ranchers. As a result, tools that allow ranchers to more effectively reduce depredation and cattle injury, in addition to finding maimed or depredated livestock more quickly is beneficial to the ranching community as a whole.

The following study attempts to use low cost wolf monitoring methods and tools to determine the space shared by wolves and cattle during the wolf rendezvous period.

Monitoring methods such as radio telemetry and GPS tracking collars are very effective in providing spatial data, especially with wild secretive species (Coelho et al., 2007). However, tracking collars can be costly and difficult to manage over a large landscape, due to the high numbers of individual wolf packs in an area. Low cost methods that do not rely on trapping, collaring, and tracking of wolf packs may be a more efficient way of using limited funds to learn which areas wolves currently inhabit and predict future pack sites. The low cost method of wolf scat route surveys of the study sites (Barrette and Messier, 1980; Kunkel et al., 2005; Broseth et al., 2010) in conjunction with a wolf rendezvous site prediction map developed by Ausband et al. (2010) will help determine areas of wolf presence.

A rendezvous site prediction map generated by Ausband et al. (2010) was used for determining the wolf rendezvous sites within Idaho. Wolf rendezvous sites are generally flat areas near water where sub-adults of a wolf pack watch over wolf pups as the adults hunt, until the pups have grown enough to travel with the pack full time. Ausband's model selected for green leaf biomass indicated by Normalized Difference Vegetation Index (NDVI), surface roughness, and profile curvature. Both surface roughness and profile curvature indicate landscapes that collect and hold water, while profile curvature characterizes topographic features e.g., flat meadows. Wolf rendezvous site prediction maps can be a useful tool in predicting cattle-wolf encounters because Oakleaf et al. (2003) and Bradley and Pletscher (2005) similarly found that cattle herds that had the greatest spatial overlap with a wolf pack's home territory were subject to more depredations, compared to cattle herds which had less spatial overlap.

Since wolf scat samples correlate well with predicted rendezvous sites (Ausband, et al., 2010), the combination of these tools can help predict areas where cattle-wolf encounters may occur in a given area. Scat route surveys rely on the behavior of canids to scent-mark their territory by depositing scented secretions in the environment (Barrette and Messier, 1980). Wolves are known for using secondary roads (unpaved) and trails as travel routes. These roads are usually scent-marked and have been shown to represent the boundaries between wolf territories (Fritts et al., 2003).

The summer grazing season (June-August) is when the majority of livestock are killed by predators, which coincides with when wolf rendezvous locations are used, generally from late spring to early fall (Peterson and Ciucci, 2003). Since wolf rendezvous areas happen to coincide with grazing areas preferred by cattle, knowing how frequently cattle select for these rendezvous areas will help provide knowledge on where possible cattle-wolf encounters occur.

Project Objectives

The main goal of this project was to evaluate efficacy of wolf rendezvous site mapping for predicting the spatiotemporal risk of cattle-wolf encounters. Cattle GPS collar data and a wolf rendezvous habitat model were used to develop predictive maps of the wolf depredation risk within four study areas (i.e., USFS cattle grazing allotments) in western Idaho. Data for actual cattle-wolf encounters, derived from GPS telemetry analysis, were then used to validate the predictive risk maps. Specific objectives of this project were to:

1) Predict the resource-selection patterns of cattle on these 4 study areas over 3 grazing seasons;

2) Evaluate the performance an existing wolf rendezvous site habitat-quality model (Ausband et al., 2010) using wolf presence data, such as scat and telemetry locations, confirmed cattle depredations, and actual rendezvous sites documented within and nearby these 4 study areas during the rendezvous period (June-August);

3) Identify areas of overlap between patterns in predicted cattle resource selection and in predicted wolf rendezvous-site habitat quality to thus locate areas where cattle-wolf encounters might likely to occur during the rendezvous period;

4) Evaluate the efficacy of spatial cattle-wolf encounter risk maps, derived from these overlaps, by applying case study at one of the study areas where actually cattle-wolf encounters were documenting using GPS tracking.

By understanding where; within extensive, rugged and remote rangelands, encounters between cattle and wolves are most likely to occur, ranchers can more effectively invest resources and intensify husbandry practices to discourage wolf depredation (Muhly et al., 2010). For example, increased human presence (e.g., range riders) in areas of high probability of cattle-wolf encounters may reduce wolf depredation or allow wolf depredations to be discovered and confirmed in a timely manner. When cattle are missing and wolf depredation is suspected, ranchers can likely use predicted cattle-wolf encounter risk maps to improve search efficiency. Initial searches for missing cattle can thus focus on the areas of higher probability of cattle-wolf encounters first, before moving on to less likely areas.

Materials and Methods

Study Areas

This research was conducted during 2009-2011 in four study areas, each within a different US Forest Service grazing allotments, located on the Payette National Forest (PNF) in western Idaho. Habitat types in this region range from dry canyon grasslands along the Snake River-Hells Canyon in the west to moist, cool coniferous forests among snow-capped peaks in the east. The regional climate is influenced by Pacific air masses resulting in cold, wet winters which provide the majority of annual precipitation. Pacific high pressure systems promote warm, dry summers (Doerner and Carrara, 1999). Soils in this region are generally classified as fine-loamy, mixed Dystric Cryochrepts produced from basalt residuum, consisting of weakly developed reddish-colored subsoil (Barker et al., 1983). Soil depth can be 152 cm or greater, which is well drained along a topography of gentle slopes to steep uplands (Barker et al., 1983).

Description of regional vegetation follows Johnson and Simon (1987), however, species nomenclature follows the USDA Plants Database (USDA-NRCS, 2015). The canyon grasslands in the western portion of this region are vegetated by bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love) and Idaho fescue (*Festuca idahoensis* [Elmer]) associations with perennial forbs such as arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.), parsnipflower buckwheat (*Eriogonum heracleoides* Nutt.), Cusick’s milkvetch (*Astragalus cusickii* A. Gray), and Snake River phlox (*Phlox colubrine* Wherry & Constance) occurring occasionally as co-dominants. Eastward and upslope, mid-elevation landscapes are dominated by Ponderosa pine (*Pinus ponderosa*

Lawson & C. Lawson) associations which can form a savanna with bunchgrasses (e.g., Idaho fescue) under the pine overstory or an open woodland with a shrub layer of common snowberry (*Symphoricarpos albus* [L.] S.F. Blake) and/or white spirea (*Spiraea betulifolia* Pall.) and an herb layer of pinegrass (*Calamagrostis rubescens* Buckley) and Geyer's sedge (*Carex geyeri* Fernald*)* on mesic aspects or Idaho fescue on drier aspects. At higher, forest vegetation is dominated by Douglas-fir (*Psedotsuga menziesii* [Mirb.] Franco) and grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.) associations with forest openings vegetated by ninebark (*Physocarpus malvaceus* [Green] Kuntze) and common snowberry associations and, farther eastward, mountain big sagebrush associations (*Artemisia tridentata* [Nutt.] ssp. *vaseyana* [Rybd.] Beetle). Besides native graminoids like Geyer's sedge and mountain brome (*Bromus marginatus* Nees ex Steud.); seeded, introduced grasses (e.g., orchardgrass [*Dactylis glomerata* {L.}] and timothy [*Phleum pretense* {L.}]) can also occur in the herb layer of these forests. Ridge-top grasslands are dominated by bluebunch wheatgrass and Idaho fescue associations. Kentucky bluegrass (*Poa pratensis* [L.]) and California oatgrass (*Danthonia californica* Bol.) occur on dry meadows. Moist meadows are dominated by tufted hairgrass (*Deschampsia cespitosa* [L.] P. Beauv.), Hood's sedge (*Carex hoodia* Boott), and thick-head sedge (*Carex pachystachya* Cham. Ex Steud.). Aspen (*Populus tremuloides* Michx.) communities may occur near springs and other moist areas. Stream riparian areas are dominated by black cottonwood (*Populus balsamifera* [L.] spp. Trichocarpa [Torr. & A. Gray ex Hook.] Brayshaw), willow (*Salix* spp. [L.]), and Kentucky bluegrass at lower elevations and willow and sedges (*Carex* spp. [L.]) at higher elevations. Subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) associations dominate forested areas and fescues (*Festuca* spp.[L.]) and upland sedges vegetate open areas at the highest elevations reached by these four study areas.

Study Area 1 encompasses 73.1 km² east of Council, ID occupying the western slope of an uplifted mountain ridge with one principal peak. Terrain is moderately complex with elevations ranging from 1,082 to 2,478 m, slopes 0-57°, and all aspects well represented. Vegetation is typical of the mid- and higher-elevation conifer forests, openings, and dry meadows mentioned in the regional description above. Long-term (1982- 2015) mean annual precipitation, recorded at the Squaw Flat Snow Telemetry (SNOTEL) site (NRCS, 2015) was 1,080 mm. Total precipitation amounts for 2009 (1,113 mm) and 2010 (1,100 mm) water years (e.g., October 2008-September 2009) were similar to the long-term mean but 2011 was much wetter, having about 258 mm more precipitation than average. This relationship where 2009 and 2010 tended to be average precipitation years while 2011 was much wetter was consistent across all four study areas. Long-term mean, maximum and minimum annual air temperatures were 3.9, 12.0, and -2.7 °C, respectively. Mean temperature for the summer period (June-August) was 13.9 °C over the long term. Mean summer temperatures during 2009, 2010, and 2011 were 14.0, 13.0, and 13.3 °C, respectively.

Study Area 2 is 48.0 km² and located west of Council, ID. Topography is a dissected plateau with slopes ranging from flat to 53° and elevations extending from 1,011 to 1,865 m. Dry grasslands occur on the canyon walls, Ponderosa pine savanna and ridgetop grasslands occupy the mid-elevations, and Douglas-fir and grand fir forests occur at higher elevations and on moister aspects. Long-term (1988 to 2015) mean annual precipitation at the West Branch SNOTEL site (NRCS, 2015) was 1052 mm. About 1041, 1039, and 1242 mm of precipitation fell during the 2009, 2010, and 2011 water years, respectively. Long-term mean, maximum and minimum air temperatures were 5.2, 12.4, and 0.5 °C, respectively. Mean summer temperature was 15.4 °C over the long term and 14.7, 14.0, and 14.3 °C during 2009, 2010, and 2011, respectively.

Study Area 3 encompasses 112.4 km² south of Cuprum, ID along the Snake River Breaks north and adjacent to Study Area 2. Setting is a dissected plateau rising to highlands in the northeast of the extent. Elevations range from a low of 568 m to 1,834 m, with slopes varying from 0 to 45°. Vegetation occurs as dry grasslands in the canyons on the western extent, Ponderosa pine savanna eastward and upslope, and transitioning into mixed conifer stands at higher elevations. Given their proximately, both Study Area 2 and 3 share the same SNOTEL site and thus the precipitation and air temperature data reported for Study Area 2 applies here as well.

Study Area 4 occupies 82.8 km² northeast of New Meadows, ID. Topographic setting is a rugged, uplifted mountain range trending north-northeast with elevations ranging 1,252 to 2,581 m and slopes 0 to 45°. Open woodlands of ponderosa pine occur on the drier aspects at the lowest elevations while fir forests and shrub-dominated openings occur on moister aspects and at higher elevations. Small, moist mountain meadows occur in flatter areas at these higher elevations. Subalpine fir forests occur at the highest elevations in the north where open areas are often only sparsely-vegetated but in some cases do support ample stands of fescues and sedges. Long-term mean annual precipitation (1987-2015) was 1,239 mm at the Brundage Reservoir SNOTEL site (NRCS, 2015). Total precipitation during the 2009, 2010, and 2011 water years was 1,270, 1,209, and 1,516 mm, respectively. Long-term mean, maximum and minimum air temperatures were 3.5, 10.0, and -2.4 °C, respectively. Mean summer temperature for this period of record was 13.9 °C. During 2009, 2010, and 2011, mean summer temperatures were 13.0, 12.7, and 12.3 °C, respectively.

GPS Data Collection for Cattle

Cattle entered each of the four study areas as mature, lactating cows with calves on about 15 June of each year. There was, however, some difference among study areas in terms of calf age at entry. Calves in study areas 1, 2, and 4 were about three months of age by 15 June while calves in study area 3 were only about 1.5 month of age on this date. Cattle herds entering each study area were about 341-411 cow-calf pairs in size.

Generally, the intent of this study was to track the spatial behavior of these herds using custom GPS collars (Clark et al. 2006) which collected GPS position data at 5-min intervals throughout the 2009, 2010, and 2011 grazing seasons. These GPS data were then used to develop resource selection functions (RSF) for predicting population-level, cattle-use patterns on mountainous landscapes in western Idaho. The best performing of these cattle RSF models were then compared to spatial results from a wolf RSF model, developed by Ausband et al. (2010), to evaluate whether predicted cattle use patterns overlapped with areas identified as high-quality wolf rendezvous site habitat within the four study areas.

Specifically, GPS collars were installed on 10 cows from each study area during each of the three study years. Consequently, this effort involved 40 collared cows per year and potentially yielded 120 data sets by the end of the study. However, due to malfunctions, only 109 collars acquired usable data. Of these 109 collars, three from each study area/year combination (n = 36 collar data sets) were selected for further analysis based on their having the most complete GPS location collections with the fewest GPS positional errors during the 15 June-15 August summer period. This time period represents when wolf rendezvous sites are most likely to be occupied by wolves (Schullery, 2003). While some study areas had additional GPS collar data sets that could have been used, for consistency, only three collar sets per year were used for cattle RSF modeling in an attempt to represent cattle use equally, i.e., similar numbers of accurate GPS locations across all four study areas.

These 36 GPS data sets were initially screened to remove gross positioning errors (i.e., > 1 km outside of bounding fences or limiting perimeter features [e.g., rivers]). Further error screening was accomplished using the fix quality parameters included in the data sentences (i.e., National Marine Electronics Association [NMEA]) output by the GPS receiver on each collar. Locations with a Positional Dilution of Precision (PDOP) value greater than or equal to 10 were flagged as potentially having poor spatial accuracy. Instantaneous speeds exceeding 5 knots or 9.3 kilometers per hour (km/h) were flagged since past experience indicated cattle do not move this fast while grazing or walking. Compiled data were also used to derive parameters such as net displacement or straight-line travel distance between consecutive GPS locations. Travel distances of greater than 500 m between GPS locations separated by the 5-min sampling interval were also flagged as potentially erroneous. The 500-m threshold was chosen because it was considered very unusual for cattle to travel more than 500 m in 5 min or in other words, sustain a velocity of greater than 6 km/h for 5 min or more (P. Clark, USDA-Agricultural Research Services, personal communication, May 2012).

The Kinetic Resource and Environmental Spatial System v.4 (KRESS) software package was used to determine whether each error-flagged location was actually erroneous.

Within KRESS, GPS locations were displayed sequentially in an animated fashion, overlain on top of high-resolution, remote-sensing imagery, thus allowing the observer to visually track the movement path of each collared cow across the virtual landscape. Special attention was paid to flagged locations to make sure their contribution to the movement path was logical given preceding and subsequent movement steps and underlying terrain and vegetation features. Flagged locations were retained in the data set if they appeared to be accurate, otherwise, they were removed. The majority of GPS locations flagged and subsequently removed were locations which had failed the instantaneous speed criterion. The editing process removed an average of 3.4% of the original locations from each collar data set thus about 96.6% of the locations were retained for statistical analysis.

None of the study areas had a completely intact bounding fence perimeter. In some places, drift fences and/or rough terrain were relied upon by managers to confine cattle movement. Consequently, this porous perimeter could not be used to define the choice space or study area extent available to collared cattle. Alternatively, a minimum convex polygon (MCP) (Tinkle et al., 1962) was created from all nine edited GPS collar data sets per study area. An additional 500 m external buffer was added to the area of each MCP to account for available habitat not sampled by the GPS locations but could conceivably have been used by collared cattle. The MCP was then clipped to any intact bounding fence boundaries and thus provided the areal extent of each study area described above.

Resource Selection Analysis for Cattle

The GPS location data sets were used to develop cattle resource selection functions (Manly et al., 2002) with the five-step method described by Nielson and Sawyer (2013).

First, habitat variables were measured within circular plots randomly distributed within each study area. Second, cattle GPS locations within each circular plot were counted. Third, from these cattle GPS location counts, negative binomial regression (NB) was used to estimate the probability of cattle use as a function of the habitat attributes occurring within the plots. Fourth, data from individual cattle collars were bootstrapped to estimate standard errors (SEs) and 90% confidence intervals (CI) for the population model coefficients. Fifth, predicted use probability maps were then created for each study area using these population models.

The following equations (1) and (2) were used to estimate model coefficients (Nielson and Sawyer, 2013):

$$(1)\ \ln[E(t_i)] = \ln(T) + \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} \ldots + \beta_\rho x_{\rho i}\ ,$$

which is equivalent to

$$(2)\ \ln[E(t_i/T)] = \ln[E(\text{Relative frequency}_{\ i})]$$
$$= \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} \ldots + \beta_\rho x_{\rho i}$$

where, t_i is the number of GPS locations within a sampling unit i $(i = 1, 2, \ldots, x)$, T is the total number of GPS locations within the entire study area, β_0 is an intercept term, $\beta_1, \ldots, \beta_\rho$ are unknown coefficients for the predictor or habitat attribute variables $x_{1i}, \ldots, x_{\rho i}$, and E[.] is the expected value. An offset term, ln(T) converts the integer counts of the response variable into relative frequency values. These NB models estimate the true probability of use and, by strict definition, can be termed resource selection probability functions (RSPF) according to Manley et al. (2002). For consistency, however, the more general acronym, RSF, was retained and used throughout this document.

Details of this modeling process follow herein. Within each study area, sets of randomly-located, circular plots were created using Geospatial Modeling Environment (GME) v.7.2. About 1,500 plots each were created in study areas 1, 2, and 4 while 2,500 plots were created in study areas 3. Study area 3 received a greater number of plots as a reflection of its greater areal extent. Each circular plot was 500 m in diameter. Plot size was determined as being both small enough to differentiate variations in cattle habitat selection while large enough to ensure the number of GPS locations contained within the plots followed a negative binomial distribution (Nielson and Sawyer, 2013). Selecting a plot size was an iterative process. If too many of the plots (e.g., > 50%) do not contain any GPS locations then the plot size was considered too small and was, consequently, enlarged and reevaluated.

Nine habitat variables were used in creating the cattle RSF models. These nine habitat variables were chosen based on their ability to represent the landscape and factors affecting cattle behavior on that landscape. These nine variables were: aspect, elevation, distance to nearest roads, distance to nearest perennial streams, normalized difference vegetation index (NDVI), normalized surface roughness index, profile surface curvature index, slope, and classified vegetation cover type (with 18 type classes). The variables NDVI, normalized surface roughness index, and profile surface curvature index were chosen since they were the three variables used in Ausband et al. (2010) wolf rendezvous site RSF model. The remaining six variables were selected based on their demonstrated potential to influence cattle resource selection on western Idaho rangelands (Clark et al., 2014). An U.S.

Geological Survey (USGS) digital elevation model (DEM; 10 x 10 m cell size) was processed in ArcMap v.10.0 to provide plot attribute values for the elevation (m), aspect (bearing degrees), normalized surface roughness, profile curvature and slope (degrees) variables. Road and stream GIS layers sourced from the PNF were used to calculate distance measurements (m) between each plot centroid and the nearest road and stream in ArcMap v.10.0. The NDVI layer which was resampled from 30-m to 10-m cell size to correspond with the terrain variables, was provided by C. Tobalski (Montana Cooperative Wildlife Research Unit). The plots were then attributed with values from each of the nine habitat variables using GME. For the continuous raster variables (e.g., elevation) the mean value of raster cells intercepting the plot perimeter were recorded as attribute values for the plot. Vegetation-type cover was a thematic raster, consequently, the areal percentages of each of the different vegetation type represented inside the plot was recorded in this case. The area percentages were henceforth referred to as plot coverages by type (e.g., 78% of the plot area was covered by the Ponderosa pine type and the remainder by the grand fir type). Although aspect was initially a continuous variable in bearing degrees, this plot attribute was subsequently converted to a categorical variable with four levels representing the cardinal directions.

For each study area/year combination, a random sample of 25% of the cattle GPS locations were reserved for model validation. The remaining 75% of GPS locations were used for model development. Models were developed using R Statistical Computing software v2.15.2 and R scripts originally written by Ryan M. Nielson (Western EcoSystems Technology, Inc., Laramie, Wyoming). Following Nielson and Sawyer (2013) modeling procedures, a Pearson’s pair-wise correlation analysis was performed to screen for multicollinearity among predictor variables (e.g., elevation and distance from perennial streams). Pairs of variables found to be correlated (|r| > 0.60) were noted and not permitted within the same model.

Model development proceeded in a multi-step process. First, an *a priori* set of 50 models, starting with the variables used to predict wolf rendezvous locations along with additional models containing from three to five variables and their quadratic forms as applicable, was created. Fifty *a priori* models were believed to be sufficient to provide enough model variability while not introducing problems (e.g., data dredging) that a stepwise multiple regression approach might introduce (Burnham and Anderson, 2002). The *a priori* set of models was initially fitted to data from Study Area 1 only. Each year was modeled separately using pooled data from all three collars per year. Study Area 1 was selected for initial model development because this area was thought to have a relatively low level of wolf presence compared to the other three study areas. The intent was to test the relative importance of the different predictor variables in the initial model set without the additional, confounding influence of high wolf presence and predation threat on cattle resource-selection patterns. Fits of each of the 50 *a priori* models to the pooled data from Study Area 1 were determined using Akaike Information Criterion (AIC) scores. Ranking of these AIC scores was then used to select the ten top-performing models for each of the three study years (Burnham and Anderson, 2002). The following five predictor variables: aspect, slope, distance to roads, distance to streams, and ponderosa pine cover were found to consistently occur within this initial short-list of models.

These five variables, including their quadratic forms, were then used to build an exhaustive list of refined models containing combinations of three, four, and all five of these important variables. These refined models were then fitted to data from each of the four study areas for each of the three study years. The AIC scores were used to select the top five models in each of the following categories: best 5-variable models, best 4-variable models, and best 3-variable models. Bootstrapping of individual collar data sets was then applied to these top 3-, 4-, and 5-variable models to determine SE and 90% CI for model coefficient estimates (McDonald et al., 2006).

Model validation was conducted using the randomly-selected cattle GPS locations previously reserved for this purpose. Spearman's rank correlations were calculated by counting the number of GPS locations occurring in 20 equal-sized bins representing the ordered probability of cattle use from very low to very high as predicted by each of the 15 models in the stratified short-list above. Finally, four models with the best overall predictive performance were selected, based on Spearman scores, and retained for further analysis:

Model #1 Probability of Use = Intercept + Slope + Slope^2 + Distance to Roads + Distance to Roads^2 + Distance to Streams + Distance to Streams^2;

Model #2 Probability of Use = Intercept + Slope + Slope^2 + Distance to Roads + Distance to Roads^2 + Distance to Streams + Distance to Streams^2 + Aspect;

Model #3 Probability of Use = Intercept + Slope + Slope^2 + Distance to Roads + Distance to Roads^2 + Distance to Streams + Distance to Streams^2 + Ponderosa Pine Coverage;

Model #4 Probability of Use = Intercept + Slope + Slope^2 + Distance to Roads + Distance to Roads^2 + Distance to Streams + Distance to Streams^2 + Aspect + Ponderosa Pine Coverage;

Note that models #1, #2, and #3 are simply reduced forms of model #4. These top four cattle RSF models were then applied in ArcMap v.10.0 to build raster maps of predicted cattle resource selection patterns. Predicted probably of cattle use was categorized into 10 equal-sized classes ordered from very low to very high.

Mapping Predicted Wolf Rendezvous Site Habitat Quality

Once their pups are mobile enough to leave the den site, gray wolves use rendezvous sites as places to keep their pups while the adults of the pack make extensive hunting and territorial maintenance forays. As such, a rendezvous site forms a strong anchor affecting the distribution patterns of the adult wolves, some of which remain at the site to tend and protect the pups and those adults that depart must return frequently (every 2-9 hrs) to feed the pups and take over pup-sitting chores (Potvin et al., 2004). For gray wolves in the Northern Rockies, this period of rendezvous site usage generally occurs between 15 June and 15 August.

Wolves tend to select very distinctive habitats for use as rendezvous sites. Ausband et al. (2010) found a relatively simple RSF model could be used to accurately predict the type of habitat wolves tended to use as rendezvous sites. This wolf RSF model was evaluated throughout much Idaho and found to be quite robust. Just three predictor variables; green leaf biomass, profile curvature, and surface roughness were included in this logistic regression model. Green leaf biomass was estimated as NDVI derived from Landsat 7 satellite imagery from July 2002. Profile curvature and surface roughness were derived from USGS DEMs. Raster maps developed from this wolf RSF were used to illustrate the spatial distribution of predicted wolf use as 10 ordered, equal-sized classes from very low to very high predicted use (Ausband et al., 2010). In the present study, raster maps covering the four study areas were created using the wolf RSF model and NDVI data sourced from C. Tobalski (Montana Cooperative Wildlife Research Unit). The 10 prediction classes illustrated in these maps were interpreted as an ordered classification of habitat quality for wolf rendezvous sites. In other words, classes indicating very low predicted wolf use were interpreted as being very poor habitat quality for rendezvous sites and so on. Although Ausband et al. (2010) had conducted an extensive validation of their wolf RSF model and associated predicted use map, further validation of the model on the four study areas was desirable to conservatively confirm performance using several forms of wolf presence data.

Wolf Presence Data Collection

Wolf presence data, including known rendezvous sites, telemetry tracking locations (Very High Frequency [VHF] radio and GPS), confirmed livestock or herding dog depredation sites, and wolf scat locations were sourced or collected for each of the study areas. Rendezvous site location and radio telemetry data were sourced from Idaho Department of Fish and Game (IDFG). The GPS tracking data were collected for one adult male wolf (member of a pack of 11 wolves) collared on Study Area 3 during 2009. This wolf was tracked at 15-min intervals from May-Dec 2009. Depredation data were acquired from USDA-Animal and Plant Health Inspection Service (APHIS) Wildlife Services and from IDFG.

The distance was measured between each known rendezvous site and the boundary of the nearest patch of high-quality wolf rendezvous site habitat. High-quality habitat was defined as habitat from the top two predicted use classes (i.e., classes 9 and 10) from the

Ausband et al. (2010) wolf RSF model. A similar approach was applied to measure the nearest distance to high-quality rendezvous site habitat for radio and GPS telemetry and depredation locations. Scat routes were established along forest roads within all four study areas. Observed scats greater than or equal to 2.5-cm dia. were considered wolf scats (Weaver and Fritts, 1979). A geo-tagged photograph with scale reference was acquired for each wolf scat to record its condition and the time and geographic location of the observation.

While the paucity of rendezvous site, telemetry, and depredation data allowed only a qualitative assessment of these responses, it was possible to conduct statistical analyses using the scat location data. The proximity of observed scat locations to high-quality wolf rendezvous site habitat was contrasted with that of random locations along the scat survey route. This contrast was conducted with mixed models developed using the Generalized Linear Mixed Model (GLIMMIX) procedure in the Statistical Analysis System (SAS) software package (SAS, 2013). Separate models were fit for each study area using a Poisson distribution with location type (i.e., observed scat and random) as the fixed effect. A residual-type random component was used to adjust the model error term for under or over dispersion relative to the Poisson distribution. For each study area, sample sizes of the random locations were held equal to those of observed scat locations to avoid bias induced by the spatial positioning of the survey route relative to high-quality habitat.

Cattle RSF-Wolf Rendezvous Correlation

Overlap between areas with high predicted cattle use during summer and areas predicted to contain high-quality wolf rendezvous site habitat could inform cattle producers and natural resource managers regarding the spatial risk for cattle-wolf encounters. Logically, areas favored by both cattle and wolves during the 15 June-15 August rendezvous usage period would be at higher risk for cattle-wolf encounters than areas where common use is less likely. The intent of this analysis was to quantify the degree of spatial overlap between predicted cattle use and high-quality rendezvous site habitat and map these overlaps within each study area.

For each study area, spatial correlation was evaluated between predictive use maps derived from the top cattle RSF models and maps of wolf rendezvous site habitat quality created using the Ausband et al. (2010) model. Specifically, Spearman's rank correlation analysis was used to compare how well the ordering of the 10 prediction classes in a cattle RSF model matched that of the wolf RSF model. For example, strong positive correlations would indicate: 1) areas where cattle were predicted to avoid or use very little were also areas predicted to have very poor rendezvous habitat quality; and 2) areas exhibiting very high predicted cattle were also predicted to have very high habitat quality. In the former case, strong positive correlation would also indicate areas where cattle and wolves, based strictly on habitat selectivity, would be less likely to interact as neither species would prefer to be there. In the latter case, areas with high relative potential for cattle-wolf encounter would thus be identified. Conversely, strong negative correlations would signify a reversal of the example above and generally indicate a strong avoidance of high-quality wolf rendezvous site habitat by cattle.

Raster maps were created to illustrate the patterns of spatial correlation between predicted cattle use and wolf rendezvous site habitat quality and to identify areas where the potential for cattle-wolf encounters, based solely on habitat selectivity, was elevated. Raster layers for both the cattle and wolf RSF models were selected for this analysis. ArcMap Mosaic was used to combine these cattle and wolf layers and then sliced into five categories/classes of predicted cattle-wolf encounters ranked from “Very Low” to “Very High”; thus illustrating the areas of where the least to highest likelihood for cattle-wolf encounters may occur across each study area.

Evaluating the efficacy of these maps for predicting spatial risk of cattle-wolf encounters would be challenging, if not impossible, given the rarity of spatial data for cattle-wolf encounters. However, the concurrent GPS data sets acquired for cattle and wolves in Study Area 3 during 2009 offered a unique opportunity to make a limited efficacy evaluation in the form of a case study. The cattle and wolf GPS data sets were compared to identify encounter events where wolf locations were less than 500 m from cattle locations and occurred less than 15 min before or after the cattle locations were acquired. The 500-m distance threshold was selected based on the assumption that wolves and cattle would become aware of each by sight, sound, or smell at this distance after accounting for terrain and vegetation occlusion effects. The15-min threshold ensured temporal synchrony between wolf and cattle locations involved in encounter events. Wolf locations involved in the identified encounters events were plotted over the spatial risk maps described above for Study Area 3. A SAS logistic regression model was used to describe the relationship between these documented cattle-wolf encounters and the predicted encounter classes.

Results

Cattle Resource Selection Models

Generally, model #4 proved to be quite robust at accurately predicting cattle resource selection across most study areas during most years, being the top model based on AIC scores in 9 of the 12 cases. Whereas, models #2 (without Ponderosa pine), #1 (without aspect and Ponderosa pine), and #3 (without aspect) were selected in 2011 at Study Area 1, and 2009 and 2010 at Study Area 3, respectively. At Study Areas 2 and 4, model #4 was the best predictor of cattle resource selection for all study years.

In a practical sense, however, performance of the four top models did not differ markedly among study areas and years, with all models having quite high Spearman's correlation scores ranging from 0.81 to 0.99. Consequently, rather than provide a lengthy, detailed discussion of all models and all years, the data were pooled across study years and reanalyzed using a single top model, Model #4 for each study area (Table 2.1). Validation of Model #4 yielded Spearman's rank correlation scores of 0.96, 0.96, 0.99, and 0.97 for Study Areas 1, 2, 3, and 4, respectively. These high Spearman's correlations indicate that model #4 was highly effective for predicting cattle resource-selection patterns at all four study areas when data from all years were pooled.

Model #4 Predictions by Study Area

At Study Area 1 (Fig. 2.1), generally cattle were predicted to select for areas of low to moderately steep terrain. Predicted cattle use tended to peak around slopes of about 10° with use declining in a curvilinear fashion for both flatter and steep slopes. Predicted cattle use increased with increasing distance from roads and streams, peak at around 1,800 m from roads and 1,600 m from streams, then declining with distance thereafter in both cases. Aspect and Ponderosa pine cover did not significantly affect cattle resource selection (Table 2.1).

Predicted cattle use at Study Area 2 focused on very flat areas, yet generally avoided areas near and quite distant from roads and streams (Fig. 2.1). Cattle use was very tightly confined to slopes less than 5° thus presenting a markedly different response than predicted for the other three study areas. Predicted use responses relative to distance to roads and streams were generally similar to those at Study Area 1. However, use relative to roads tended to peak more sharply and at a further distance (2,200 m) at Study Area 2. Predicted cattle use relative to streams tend to peak at a somewhat shorter distance (1,400 m) that at Study 1. Here again, aspect and Ponderosa pine cover did not influence of cattle selectivity (Table 2.1).

In contrast to the previous two study areas, cattle use at Study Area 3 (Fig. 2.1) declined gradually with increasing slope up to about 18° and then the rate of decline tended to flatten. Predicted use declined quite sharply with increasing distance from roads and streams in very distinct contrast to predictions at both Study Areas 1 and 2. As before, aspect and Ponderosa pine cover did not play a significant role in cattle resource selection (Table 2.1).

Predicted cattle resource selection in Study Area 4 was affected by slope, distance from streams, aspect, and Ponderosa pine cover (Table 2.1). Notably, Study Area 4 was the only study area where distance from roads did not significantly affect cattle behavior. Cattle use decreased exponentially with increasing slope (Fig. 2.1). Predicted use increased with increasing distance from streams, peaked at around 400 m from streams, and then gradually declined with additional distance. Study Area 4 was the only study area where aspect and Ponderosa pine cover were influential factors of cattle selection (Table 2.1). Predicted cattle use tended to decline on north, south, and western aspects relative to east-facing slopes. Predicted use increased markedly with increasing Ponderosa pine coverage.

Wolf Presence

None of the eight rendezvous sites documented during 2005-2009 were located within study area boundaries. All of these rendezvous sites, however, were found to be located within 90 m of high-quality (i.e., classes 9 and 10) rendezvous habitat as predicted by the Ausband et al. (2010) model. Depredations of livestock and hunting dogs were recorded at seven locations during 2007-2013 and these ranged from 5 to 182 m from the high-quality rendezvous habitat. None of these depredations occurred within high-quality rendezvous habitat and where not recorded during the study period, 2009 to 2011. Because GPS locations were not recorded for the majority of agency-confirmed depredations occurring within the study areas. A considerable amount of depredation data could not be used in this analysis.

Only at Study Area 3 did the mean distance of observed scat from high-quality rendezvous site habitat differ from that of random locations along the survey route (Table 2.2). Observed scats were a mean distance of 15.0 m from high-quality rendezvous habitat while random locations were 32.8 m away. A total of 149 scat locations were observed at Study Area 3 with 138 (92.6%) of these scats located within 50 m of high-quality wolf rendezvous habitat, and all 149 scats were within 100 m of these habitat areas.

The lack of differences in proximity to high-quality rendezvous habitat between observed scat and random locations at the three other study areas indicates at least a couple of things. First, the placement and/or orientation of the survey routes within the landscapes of these three study areas were the principal factor influencing the proximity of observed scat to high-quality rendezvous habitat. Second, wolves were present but they were not responding to variations in rendezvous site habitat quality occurring along the survey routes.

Correlations between Cattle RSF and Wolf Rendezvous models

Spearman’s rank correlation analyses between outputs from the top-performing cattle RSF (model #4) and the wolf rendezvous habitat quality outputs from the Ausband et al. (2010) model yielded correlation scores 0.55, 0.07, 0.70, 0.55 at Study Areas 1, 2, 3, and 4, respectively, using data pooled across all three study years. All four Spearman’s correlations had significant p-values ≤ 0.0001. Except for Study Area 2, the cattle RSF predicted by model #4 was strongly ($r_s \geq 0.6$) and positively correlated with patterns of wolf rendezvous habitat quality. Areas predicted to have both very high probability of cattle use and very high wolf rendezvous habitat quality were identified. These areas of overlap were assumed to have a higher likelihood of cattle-wolf encounters than other areas during the rendezvous usage period. Generally, these overlaps or areas of potentially higher risk to cattle-wolf encounters tended to occur in flat, meadow areas containing habitat characteristics (e.g. abundant tall grass cover) useful to both cattle and wolves (Figs. 2.2-2.5). The landscape position of these higher risk areas, however, differed among study areas. At Study Area 1, areas classified as very high encounter risk class (Fig. 2.2) do not seem to be associated with near-stream riparian areas rather they occurred as highland meadows. At the other three study areas, these areas of very high risk tended to occur in more concave terrain (e.g., stream valleys) but were not necessary located within near-stream riparian areas. Furthermore, not all stream valleys contained areas of very high risk, Study Area 3 provides a good example of this situation (Fig. 2.4).

Efficacy Evaluation -- Case Study

Based on the cattle and wolf GPS data acquired at Study Area 3 during 2009, 89 of 165 (53.94%) cattle-wolf encounter locations occurred within the very high encounter risk class (Fig. 2.6) and 70 of 165 (42.42%) occurred within the high risk class. In other words, only 3.64% of the observed cattle-wolf encounters were located outside of either the high or very high predicted encounter risk classes. Ordering of the predicted encounter risk classes corresponded well with counts of observed cattle-wolf encounters. The following logistic regression equation well illustrated the relationship between observed cattle-wolf encounters and predicted cattle-wolf encounter risk class:

$$F(x) = \frac{1}{1 + e^{-(\beta 0 + \beta 1 x)}}$$

where, $F(x)$ is the probability a dependent variable (observed cattle-wolf encounters) fall within a particular predicted cattle-wolf risk encounter class. Generally, as cattle moved from areas of low to very high classes of predicted risk, observed encounters increased exponentially. The largest increase in observed encounters occurred between areas of medium and high predicted risk of cattle-wolf encounter.

Discussion

Drivers of Cattle Resource Selection

Slope and distance from perennial streams were generally found to be very influential predictors of cattle resource selection at these four study areas in western Idaho. In most cases, distance from roads was also an important predictor of cattle use patterns. It is quite clear, however, that neither aspect nor Ponderosa pine coverage were broadly useful as predictors. Only at Study Area 4 were aspect and Ponderosa pine shown to significantly influence cattle selection. Given the available data, it was difficult to determine whether this exceptional case was due to some uniqueness at this study area or happenstance. Some explanations can, however, be provided for the differing responses to slope, distance from roads, and distance from streams which were observed among the study areas (Fig. 2.1).

While generally cattle in all four study areas selected for slope less than 20-25^o, predicted use at Study Area 1 peaked at about 10^o which is a departure from the selectivity for flat slopes predicted for the other study areas (Fig. 2.1). Study Area 1 occurs on the upper slope of a mountain range with steep, headwater stream canyons with very few wide, flat-bottomed valleys or stream terraces. Consequently, it is reasonable to speculate that predicted cattle use peaked at 10^o rather than 0^o at Study Area 1 simply because of the scarcity of flat terrain there compared to the other study areas.

Three different responses to roads were evident in this study. Cattle use at Study Areas 1 and 2 was predicted to peak at a substantial distance from roads, while at Study Area 3, cattle selected for areas near to roads and cattle use patterns at Study Area 4 were not influence by distance from roads. Differences in road density and placement among study areas may provide an explanation for these differing responses. Study Area 1 had the lowest road density of all the study areas and most of these roads traversed along steep, canyon slopes. Consequently, most of the study area extent was located at substantial distance from roads. If cattle were not attracted to roads for some reason (e.g., as lower-energy travel corridors through steep terrain), then low road density alone would tend to explain why predicted cattle use peaked at substantial distance from roads. At Study Area 2, cattle were predicted to select for flatter terrain which tended to be located along a major stream drainage and atop a dissected plateau. Most roads in this study areas, however, were located in moderately steep terrain. Consequently, it seemed the cattle response was more a reflection of road placement rather than a behavioral avoidance of the roads themselves. In contrast to Study Areas 1 and 2, most of the road network within Study Area 3 was located within flatter areas along or near streams. Cattle were predicted to select for these flatter slopes. Consequently, cattle selectivity for areas near roads could again be explained by road placement and thus the apparent cattle response had more to do with slope than distance from roads. When viewed in composite, the importance of distance from roads in the RSF models appears to be a matter of happenstance related to road placement relative to terrain slope and less about cattle preference or avoidance of roads as a habitat feature.

Across most study areas, response curves for distance from perennial streams were roughly similar in shape to those for distance from roads (Fig. 2.1). An exception being that distance from streams did significantly influence cattle resource selection at Study Area 4 but distance from roads did not. Regardless of this exception, the landscape-position explanation presented above regarding the variably in responses to roads likely can also explain the differing responses among study areas to distance from streams. Headwater streams in Study Area 1 occurred in steep, v-shaped canyons with very little flat terrain (e.g., riparian or stream-terrace meadows) available to cattle for foraging and/or resting activities. Ridgetops, benches, and other low-slope terrain were located substantial distances from perennial streams. Much of the stream network in Study Area 2 occurred as tributaries located in steep-walled side canyons. A relatively broad, flat stream valley did occur elsewhere in this study area but a substantial proportion of the meadows and other near-stream habitat in this valley was located within a fenced, private land in-holding from which cattle were excluded (Fig. 2.3). As mentioned above, much of the flatter terrain in Study Area 2 was located atop a plateau and was thus a substantial distance from perennial streams. Similar to Study Area 2, a portion of the stream network at Study Area 3 was located in steep, v-shaped canyons and the remainder in flatter terrain. Cattle were predicted to select for near-stream habitat in the flatter areas but strongly avoid this habitat in the steep canyons. Almost all of the stream network in Study Area 4 was located in steep canyons. Much of the flatter areas, consequently, occurred as benches on the canyon slopes or as ridge crowns rather than as near-stream meadows. Predicted cattle use peaked about 400 m from streams and this distance tends to correspond with relative location of the benches.

Cattle grazed away from roads, in that cattle were grazing areas of either mountainous terrain (Study Area 1) and on a large plateau (Study Area 2); areas a couple thousand meters from streams. At Study Area 3, cattle grazed along larger, flat meadow areas coinciding with the stream networks of that location. At Study Area 4 cattle utilization increased a short distance from streams, but after 400 m grazing decreased. Cattle selected areas that were close to streams but did not graze riparian areas as they did at Study Area 3. When combined with the responses predicted in the other study areas, cattle use patterns relative to streams may be more a function of landscape position relative to areas of flat or low slopes rather than avoidance or attraction to the streams or associated near-stream habitats. Simply put, slope is likely the overriding factor influencing cattle resource selection in these four study areas. There is substantial support for this conclusion in the rangeland livestock literature (Mueggler 1965; Cook, 1966; Ganskopp and Vavra, 1987). Effects of roads, streams, and, perhaps, aspect and Ponderosa pine coverage may be interacting with slope. Unfortunately, interactions terms were not included in any of the models of the original *a priori* candidate set. Consequently, it was not possible to conclusively determine how much influence came directly from roads, streams, etc. and how much may have stemmed from interactions with slope.

Adequacy of Wolf RSF Model

Analysis of wolf scat survey data at Study Area 3 tended to confirm the efficacy of the Ausband et al. (2010) wolf RSF model for classifying habitat quality for rendezvous sites. Wolves depositing scat along the survey route demonstrated selectivity for high-quality rendezvous site habitat at Study Area 3 (Table 2.2). At the other study areas, however, proximity of observed scat to areas of high-quality rendezvous site habitat did not differ from that of random locations along the survey routes. There could be a number of explanations for this disparity in response but perhaps the most likely was that although wolves demonstrated a presence in these study areas, they were not selecting for rendezvous site habitat in the surveyed area because they already had established rendezvous sites outside of the surveyed area. Another explanation could be that the wolves which deposited the scat along the survey routes were not interested in establishing or using rendezvous sites because these wolves were not associated with a pack with pups of the year or came from a pack in which reproduction had failed or all pups had been lost. Still another explanation might simply be that the wolf RSF model just was not accurately classifying rendezvous habitat quality in these three study areas. However, given the results obtained in Study Area 3 and the robust validation conducted by Ausband et al. (2010) in landscapes similar to all four study areas, it is probably reasonable to discount this last explanation.

Cattle/Wolf RSF Correlations and Encounter Risk Classifications

At Study Areas 1, 3, and 4, predicted cattle use patterns were strongly and positively correlated with predicted patterns in wolf rendezvous site habitat quality. Correlations between these patterns, however, was much weaker at Study Area 2. Predicted high and very high quality wolf rendezvous habitat occurred almost exclusively in concave terrain in Study Area 2 while predicted cattle use was focused in two areas, one characterized by a concave terrain profile (i.e., a stream valley) and one by a convex profile (i.e., a plateau). Predicted cattle selectivity for this convex terrain thus tended to decrease the correlation with predicted wolf rendezvous habitat quality. Cattle seemed to be attracted to highly productive grasslands occurring on the plateau yet, because the terrain tended to be convex rather than concave, the wolf RSF model classified this plateau as low quality wolf rendezvous site habitat.

Generally, areas classified to the very high encounter risk class occurred on flatter, smoother slopes within concave terrain such stream terrace meadows and, at higher elevation, small headwater basins containing springs or seeps where graminoid productivity would tend to be quite high (Figs. 2.2-2.5). Not all of these very high risk areas where located near surface water. Some areas were located in gently-sloping forest openings rather than in broad meadows. Areas classified to the very low encounter risk class were generally steeply sloping.

Responding to Spatial Risk

The case study conducted at Study Area 3 using concurrent cattle and wolf GPS tracking data indicated observed cattle-wolf encounters increased as the predicted encounter risk increased from very low to very high. Most areas in the high and very high risk classes were located in stream terrace meadows which are important to cattle producers as these areas can provide considerable amounts of palatable, high-quality cattle forage. The importance of these meadows increases as the summer grazing season progresses and upland forages begin to dry and lose quality. However, as demonstrated by this case study, cattle grazing in these predicted high and very high risk areas are indeed much more likely to have encounters with wolves than cattle in areas of lower risk classes, assuming wolves are present in the general area. Although not tested in this study, it is reasonable to predict that as cattle-wolf encounters increase, the likelihood that cattle will suffer consequent stress from predation threat or even injury or death from wolf depredation events. Stress, injury, and death loss all have impact on ranch economics and range management planning. Consequently, understanding the spatial risk of cattle-wolf encounter across extensive, rugged and remote landscapes can obviously be an important aid for decision making by cattle producers and natural resource managers. The cost/benefits of grazing cattle in certain areas can be effectively evaluated and informed decision making can thus respond dynamically as wolf presence levels in the grazing area varies over time.

This case study clearly illustrates that mapping the spatial risk of cattle-wolf encounters for individual grazing areas (e.g., USFS grazing allotments) can serve as a valuable management tool. There was a distinct increase in actual encounters between areas of the medium and high risk classes. This clear demarcation in spatial risk would allow producers and managers to efficiently concentrate their management attention and effort to specific areas of the landscape (i.e., those in the high and very high risk classes). For example, knowledge of spatial risk can allow producers to proactively mitigate cattle depredation by concentrating human presence (e.g., range riders) in areas classified as high or very high encounter risk. Even if depredations did occur, it is in these areas of high and very high risk where producers should concentrate their search for missing cattle. Narrowing the search could allow more depredations to be found and agency confirmed thus promoting more complete compensation to the producer for wolf-caused livestock losses.

Management Implications

Knowing where possible encounters among cattle and wolves are likely to occur, producers and managers can be more effective in applying resources, husbandry practices, and mitigation techniques. For example, well-targeted use of range riding (Muhly et al., 2010), guard dogs, scare devices, fladry (Shivik et al., 2003; Lance, N.J., 2009), biofences (Ausband, D., 2011) could discourage wolf activity in specific areas. Often the problem with many depredation mitigation techniques is that they are place-based and have limited spatial scope. They cannot be used effectively to protect the whole of an extensive grazing allotment. These techniques can become effective if specific high risk areas can be identified and mitigation effort is then concentrated in these specific areas.

In addition, by identifying areas of high cattle-wolf encounter risk, producers and natural resource managers can work to adjust cattle distribution and pasture rotation schedules to avoid placing cattle where they may come in conflict with wolves during the June-August rendezvous period. This knowledge can also help producers respond dynamically to perplexing situations which crop up during the grazing season. For example, if it appears cattle will not stay where they are placed within a pasture or are avoiding an area which they should prefer, knowing that such areas were classified as high cattle-wolf encounter risk could clearly help the producer to avoid inadvertently causing a depredation problem by herding cattle back into a wolf-occupied area.

Simply put, having knowledge of spatial encounter risk can help ensure proper steps are taken to reduce actual cattle-wolf encounters, minimize any harmful interactions, and thus optimize cattle distribution across the rangeland to the benefit of both cattle production and sustainable wolf management. Reducing cattle-wolf encounters is beneficial to both the ranching communities and wildlife conservationists. The issue of wolf-livestock relations is complex, highly controversial and polarizing. Pitched feelings and poorly-founded rhetoric about the issue tend to complicate and confound effective management and decision making. Understanding and managing spatial encounter risk to thus decrease harmful interactions and wolf-caused depredations may lead to better relations between opposing parties within this issue. Such efforts would serve to foster greater cooperation in finding management strategies and solutions that are beneficial to both cattle and wolves.

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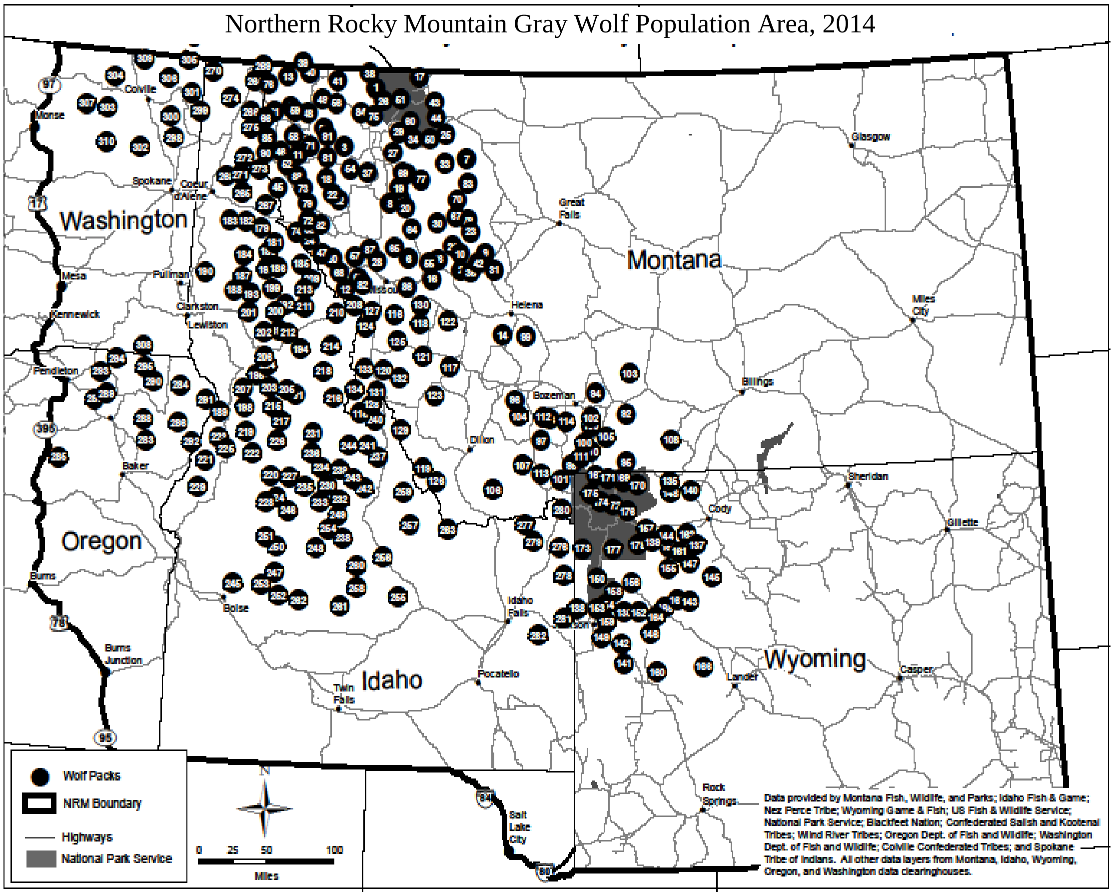

Data provided by Montana Fish, Wildlife, and Parks; Idaho Fish & Game; Nez Perce Tribe; Wyoming Game & Fish; US Fish & Wildlife Service; National Park Service; Blackfeet Nation; Confederated Salish and Kootenai Tribes; Wind River Tribes; Oregon Dept. of Fish and Wildlife; Washington Dept. of Fish and Wildlife; Colville Confederated Tribes; and Spokane Tribe of Indians. All other data layers from Montana, Idaho, Wyoming, Oregon, and Washington data clearinghouses.

Figure 1.1. Established wolf packs in the Northern Rocky Mountain region, as of December 2014. Each numbered circle represents a pack, with a total of ≥ 313 packs shown. Figure reproduced from U.S. Fish and Wildlife Service Northern Rocky Mountain Wolf Recovery Program Update 2014.

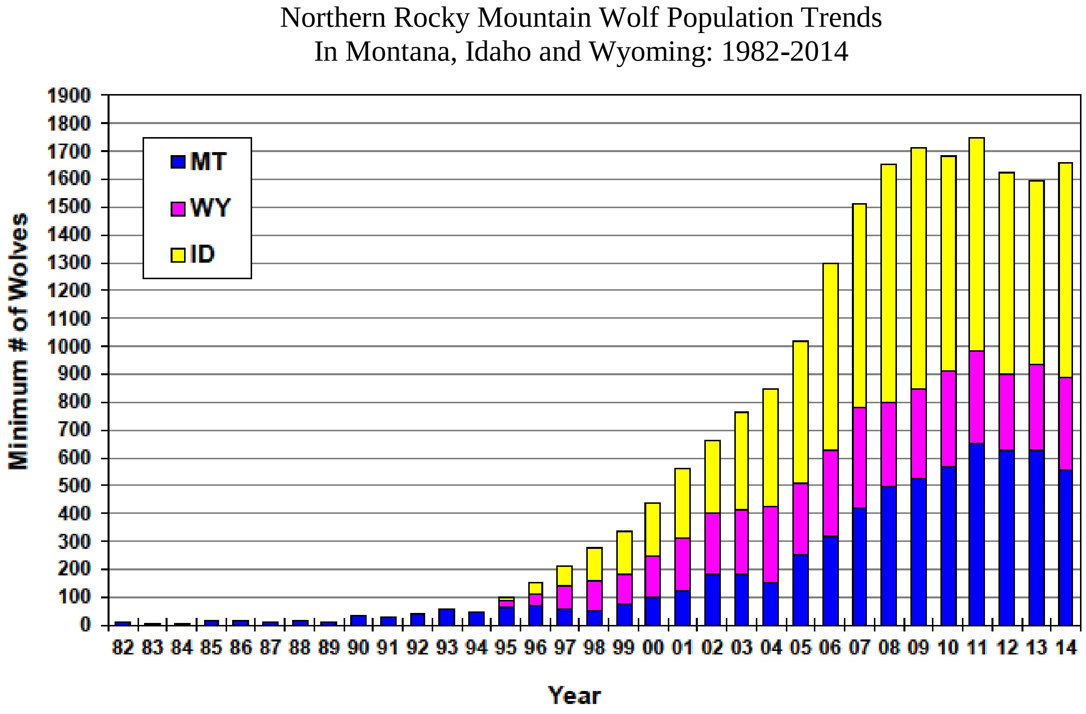

Figure 1.2. Northern Rocky Mountain Wolf Population Trends by Recovery Area, 1982-2014, not including Oregon and Washington; as of December 2014. Recovery areas include Central Idaho, Greater Yellowstone N.P. Area, and Northwest Montana. Figure reproduced from U.S. Fish and Wildlife Service Northern Rocky Mountain Wolf Recovery Program Update 2014.

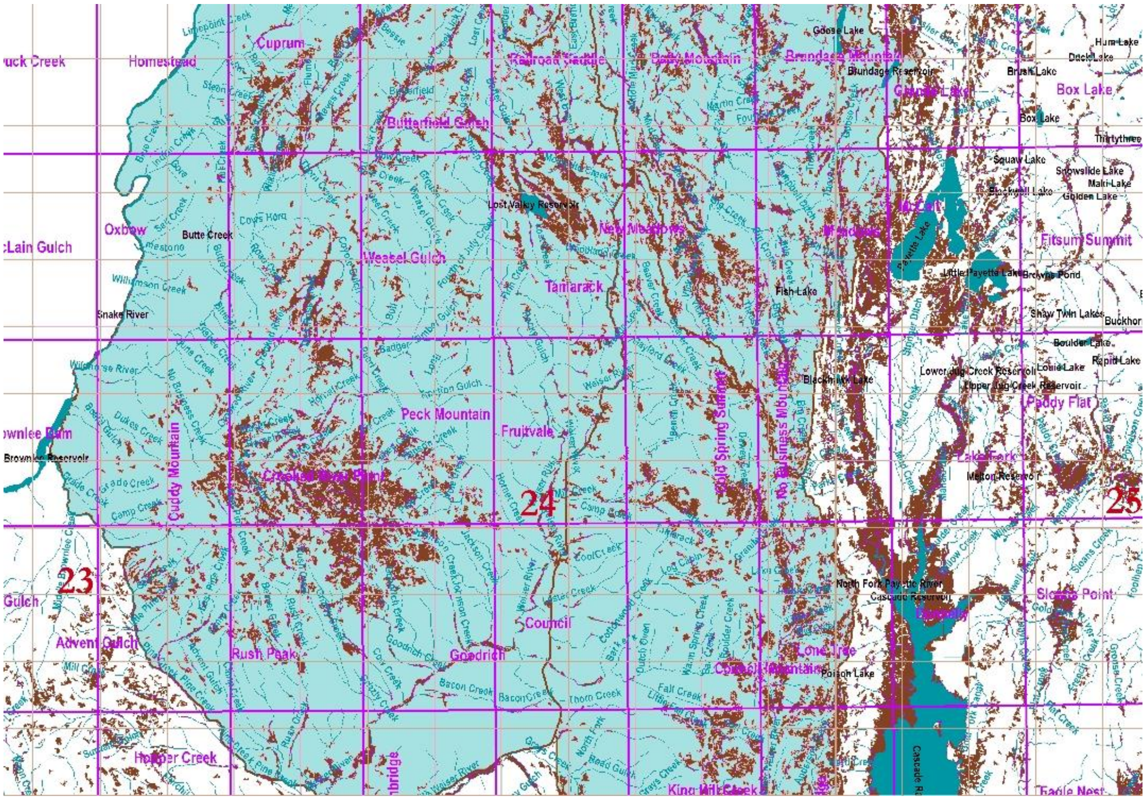

Figure 1.3. West-central Idaho section of Ausband et al. (2010) wolf rendezvous site prediction map where study areas occurred. Potential wolf rendezvous sites depicted as dark polygons across landscape.

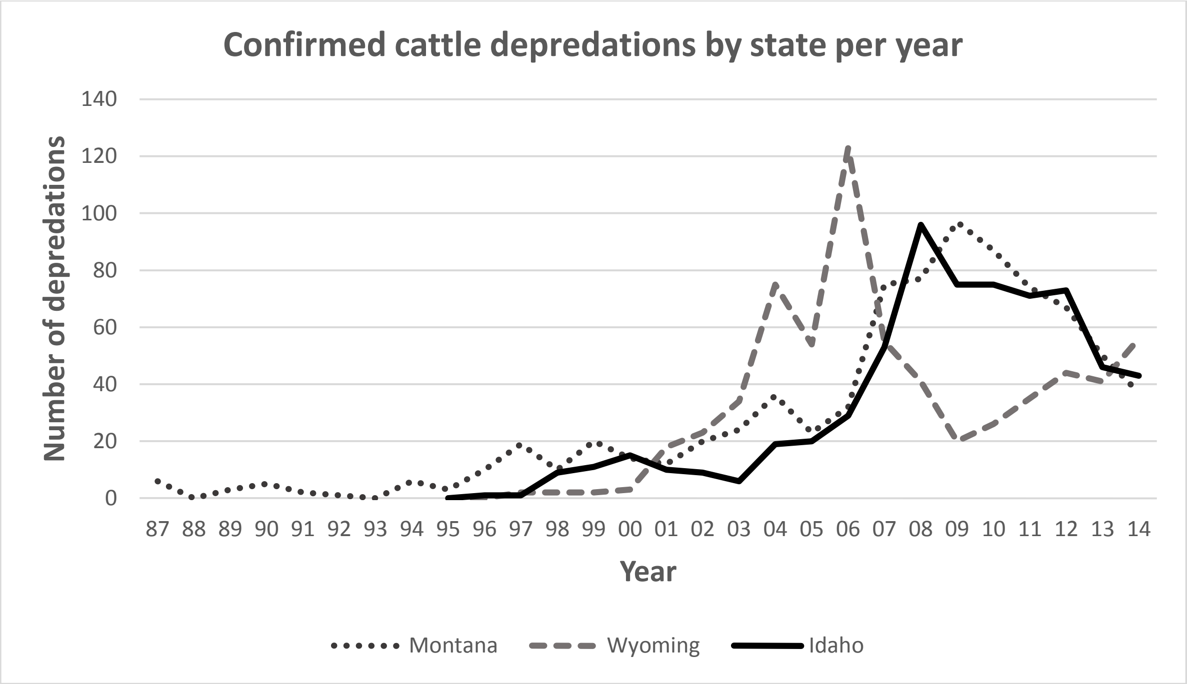

Figure 1.4. Number of confirmed livestock killed by wolves in Northern Rocky Mountain by State, 1987-2014; excluding Oregon, Washington and Utah; as of December 2014. Data from U.S. Fish and Wildlife Service Northern Rocky Mountain Wolf Recovery Program Update 2014.

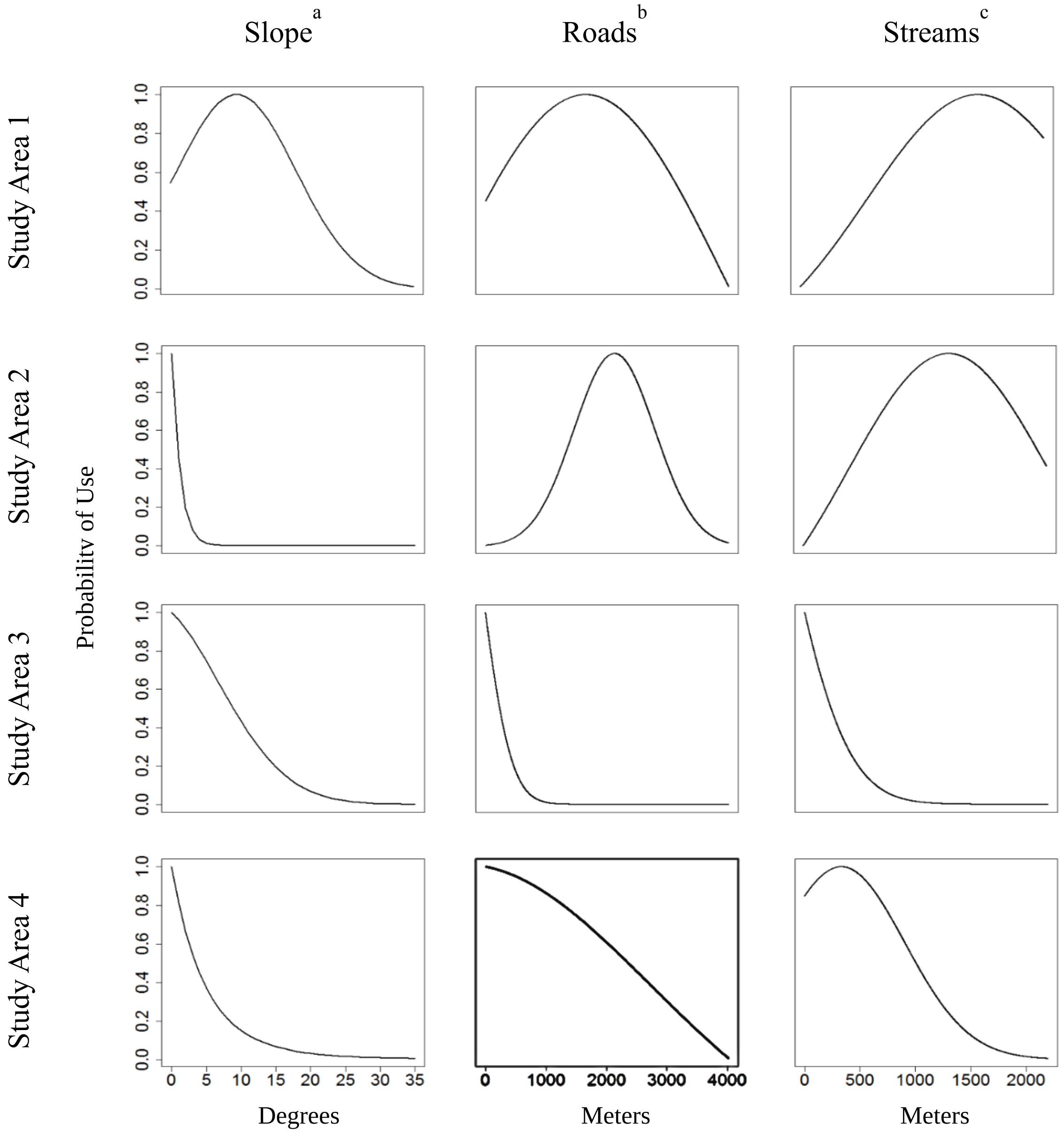

Figure 2.1. Marginal plots of the probability of cattle use, within four study areas in western Idaho, as functions of three continuous predictors; slope (degrees), distance from nearest road (m), and distance from nearest perennial stream (m) where, each predictor is a combination of linear and quadratic variable forms. Highlighted marginal plot for Roads at Study Area 4 indicates distance to roads not being a significant variable at Study Area 4, all other marginal plots indicate significant variables.

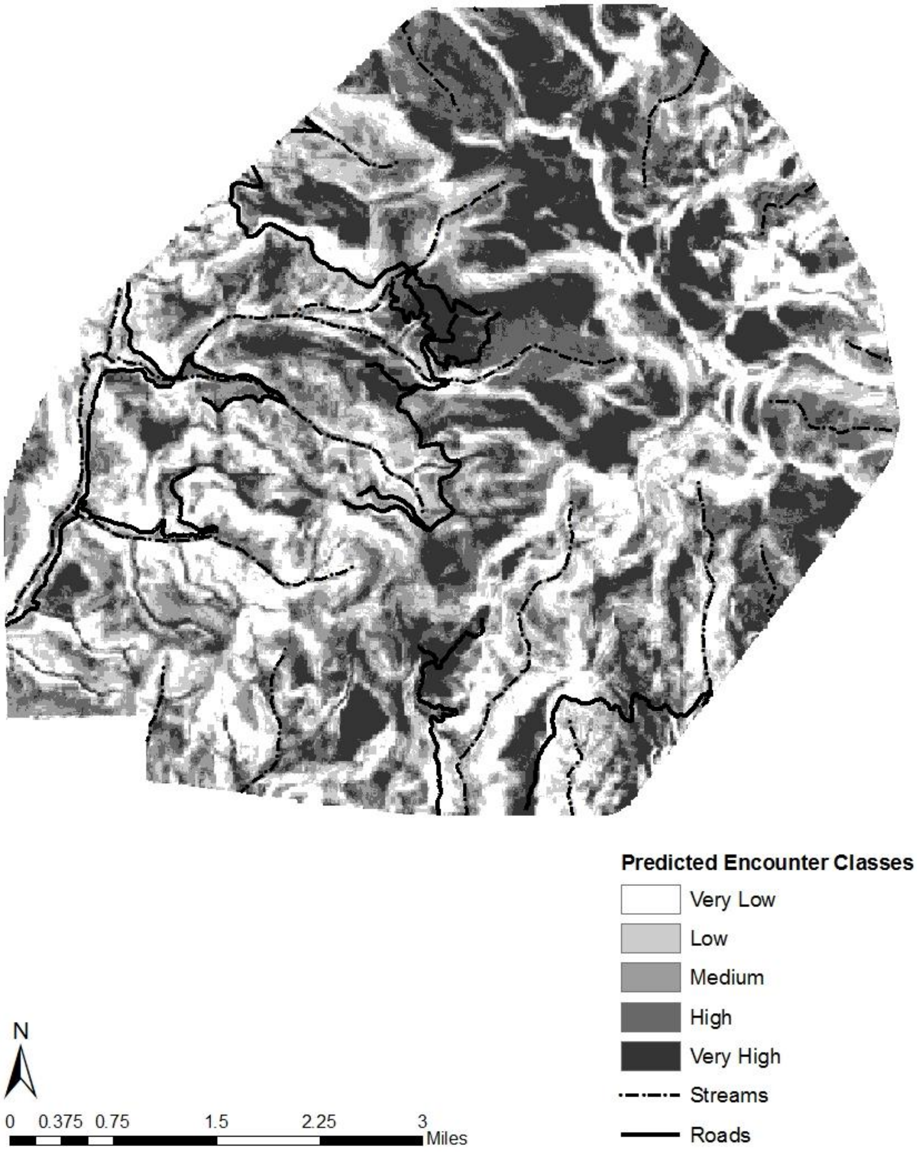

Figure 2.2. Spatial risk map for Study Area 1 illustrating the predicted risk of cattle-wolf encounters as derived by combining the mapped outputs of a cattle resource selection (RSF), developed from GPS tracking data pooled from three grazing seasons (2009-2011), and the mapped outputs of a wolf rendezvous site RSF originally developed by Ausband et al. (2010).

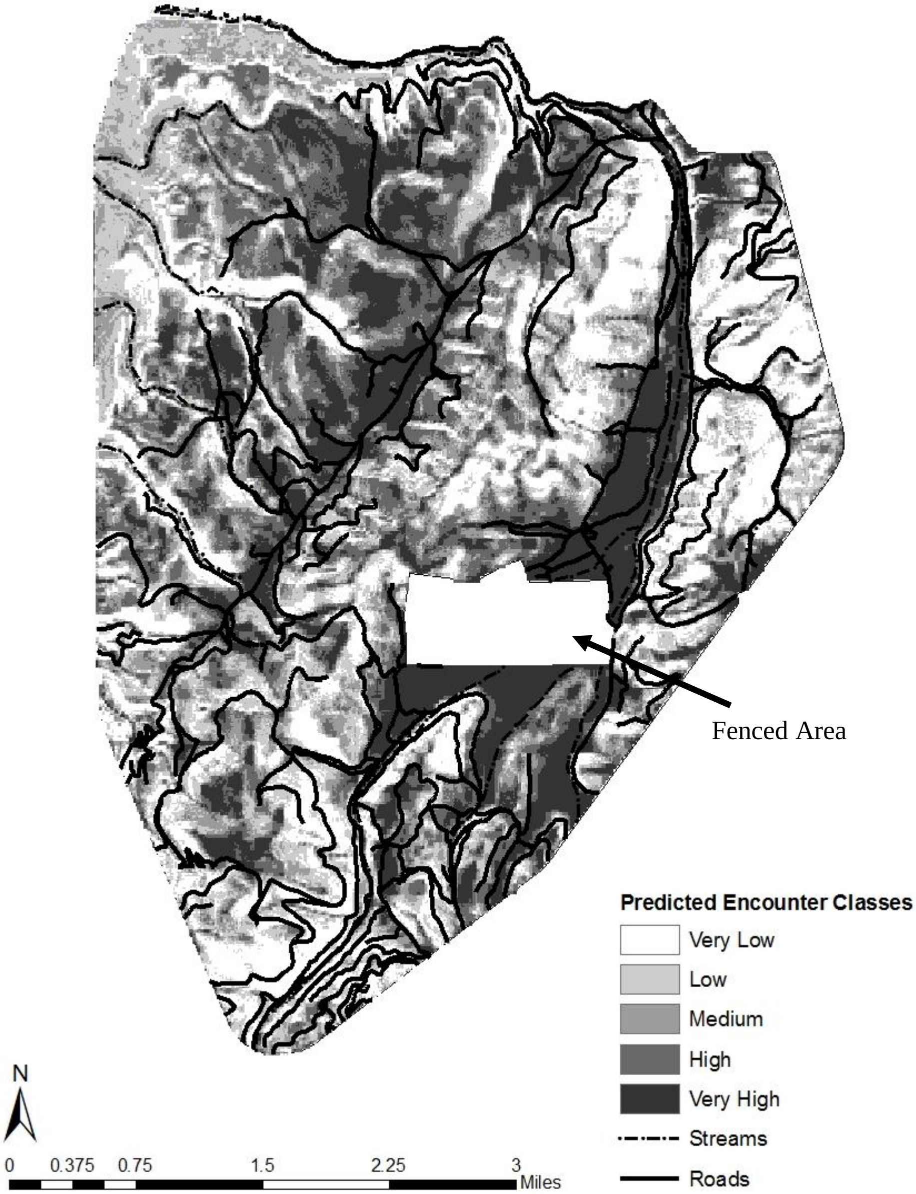

Figure 2.3. Spatial risk map for Study Area 2 illustrating the predicted risk of cattle-wolf encounters as derived by combining the mapped outputs of a cattle resource selection (RSF), developed from GPS tracking data pooled from three grazing seasons (2009-2011), and the mapped outputs of a wolf rendezvous site RSF originally developed by Ausband et al. (2010). Rectangular, white area within study area boundary represents private land which was fenced off, excluding livestock grazing.

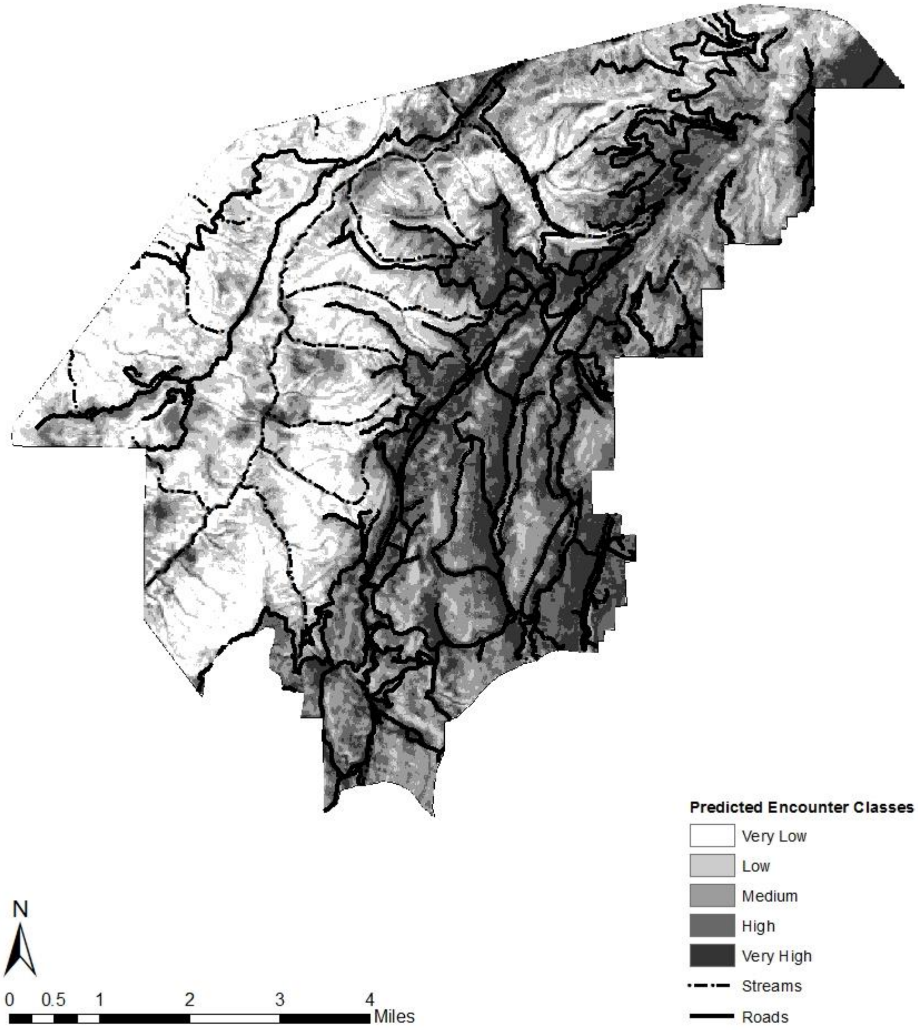

Figure 2.4. Spatial risk map for Study Area 3 illustrating the predicted risk of cattle-wolf encounters as derived by combining the mapped outputs of a cattle resource selection (RSF), developed from GPS tracking data pooled from three grazing seasons (2009-2011), and the mapped outputs of a wolf rendezvous site RSF originally developed by Ausband et al. (2010).

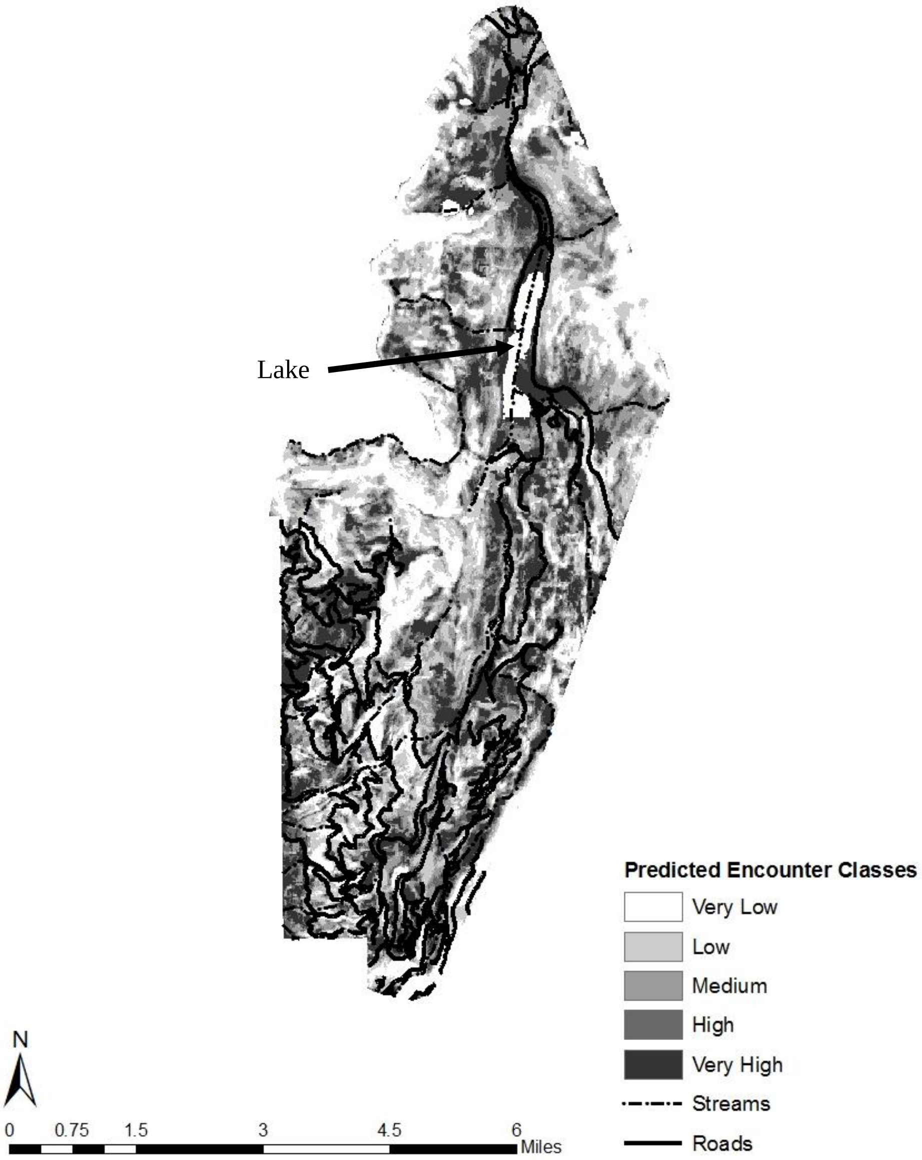

Figure 2.5. Spatial risk map for Study Area 4 illustrating the predicted risk of cattle-wolf encounters as derived by combining the mapped outputs of a cattle resource selection (RSF), developed from GPS tracking data pooled from three grazing seasons (2009-2011), and the mapped outputs of a wolf rendezvous site RSF originally developed by Ausband et al. (2010).

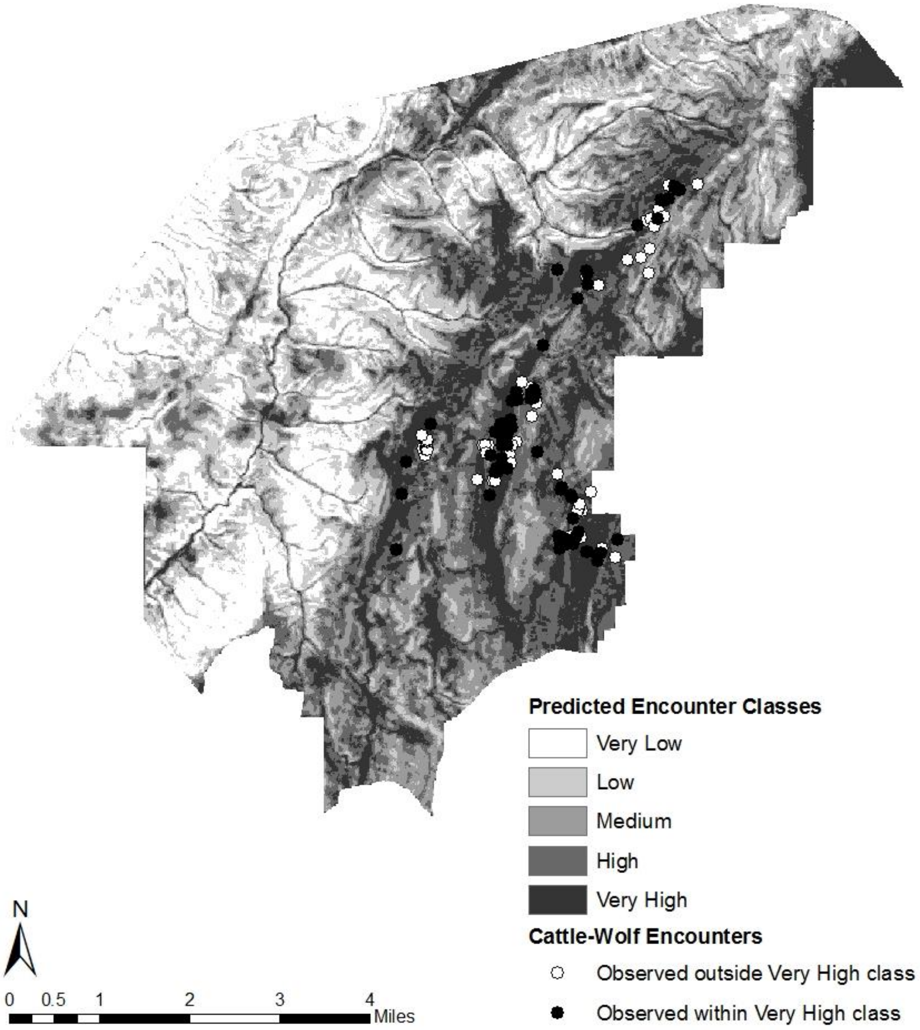

Figure 2.6. Spatial risk map for Study Area 1 illustrating the predicted risk of cattle-wolf encounters and the spatial relationship between observed cattle-wolf encounter locations and the distribution of areas classified to the “Very High” predicted risk class where, black dots represent cattle-wolf encounter locations occurring within areas of this risk class and white dots represent encounter locations occurring outside this class.

Table 2.1. Predictor coefficient estimates, standard errors, t-values and P-values for cattle resource selection function (RSF) Model #4 which was applied at four study areas (1-4) in western Idaho using GPS tracking data pooled across three grazing seasons (2009-2011).

Study Area	Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
1	**(Intercept)[a]**	-6.657	0.560	-11.880	**< 0.001**
	Slope[b]	0.128	0.060	2.146	**0.032**
	Slope^2	-0.007	0.002	-4.242	**< 0.001**
	Dist. to Roads[c]	3.2E-04	1.3E-04	2.398	**0.017**
	Dist. to Roads^2	-9.7E-08	4.1E-08	-2.377	**0.018**
	Dist. to Streams[d]	0.002	4.5E-04	3.552	**< 0.001**
	Dist. to Streams^2	-5.0E-07	4.3E-07	-1.153	0.249
	Aspect-south[e]	-0.047	0.098	-0.474	0.636
	Aspect-west	-0.040	0.448	-0.089	0.929
	Ponderosa Pine[f]	0.333	0.233	1.434	0.152
2	**(Intercept)**	-2.698	0.320	-8.447	**< 0.001**
	Slope	-0.768	0.053	-14.559	**< 0.001**
	Slope^2	0.024	0.002	10.654	**< 0.001**
	Dist. to Roads	0.005	0.001	5.180	**< 0.001**
	Dist. to Roads^2	-1.1E-06	1.2E-06	-0.961	0.337
	Dist. to Streams	0.002	4.4E-04	3.610	**< 0.001**
	Dist. to Streams^2	-6.1E-07	2.4E-07	-2.511	**0.012**
	Aspect-south	-0.131	0.144	-0.909	0.364
	Aspect-west	1.248	0.885	1.411	0.159
	Ponderosa Pine	0.331	0.304	1.091	0.276
3	**(Intercept)**	-4.531	0.301	-15.060	**< 0.001**
	Slope	-0.033	0.040	-0.817	0.414
	Slope^2	-0.005	0.001	-3.605	**< 0.001**
	Dist. to Roads	-0.002	0.001	-4.572	**< 0.001**
	Dist. to Roads^2	2.2E-06	3.6E-07	6.165	**< 0.001**
	Dist. to Streams	-0.003	0.001	-4.438	**< 0.001**
	Dist. to Streams^2	1.7E-06	4.8E-07	3.500	**< 0.001**
	Aspect-south	-0.112	0.141	-0.791	0.429
	Aspect-west	-1.147	1.631	-0.703	0.482
	Ponderosa Pine	0.201	0.285	0.703	0.482
4	**(Intercept)**	-4.041	0.311	-13.016	**< 0.001**
	Slope	-0.207	0.046	-4.470	**< 0.001**
	Slope^2	0.002	0.002	1.125	0.261
	Dist. to Roads	3.9E-05	2.6E-04	-0.147	0.883
	Dist. to Roads^2	5.2E-08	1.5E-07	0.340	0.734
	Dist. to Streams	0.001	4.4E-04	2.279	**0.023**
	Dist. to Streams^2	-1.5E-06	4.0E-07	-3.766	**< 0.001**
	Aspect-north	-1.889	0.371	-5.092	**< 0.001**
	Aspect-south	-0.300	0.092	-3.275	**0.001**
	Aspect-west	-0.922	0.320	-2.884	**0.004**
	Ponderosa Pine	1.765	0.250	7.048	**< 0.001**

[a] Coefficients in bold face were significantly different from zero at the 0.05 alpha level

[b] Slope (deg)

[c] Nearest distance to roads (m)

[d] Nearest distance to water (m)

[e] Aspect (factor variable)

[f] Ponderosa Pine (frequency)

Table 2.2. Least-squared mean distance of wolf scat locations and random locations from high-quality wolf rendezvous site habitat as sampled along scat survey routes (i.e., forest roads) in four study areas in western Idaho.

Study Area	Pr > F	DF	Location Type	LS Means[a]	Std. Errors
1	0.556	52	Scat	19.721	1.286
			Random	24.105	1.255
2	0.090	472	Scat	23.427	1.082
			Random	19.192	1.091
3	<0.001	296	Scat	**14.986**[b]	1.149
			Random	**32.842**	1.098
4	0.598	96	Scat	32.766	1.164
			Random	29.140	1.175

[a] Least-squared means and standard error values were back transformed for presentation, those means highlighted in bold face were significantly different from zero at the 0.05 alpha level.

[b] Coefficients in bold face were significantly different from zero at the 0.05 alpha level model p-value.