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ABSTRACT: Cattle grazing lands in the mountainous western United States are rugged, complex, and extensive. Terrain, vegetation, and other landscape features vary greatly across space. Risk of wolf-cattle encounters and potential for depredation loss certainly differ spatially as consequence of this variability. Yet, our understanding of this spatial risk is quite poor and this knowledge gap severely hampers our abilities to manage wolf-livestock interactions and mitigate conflicts. During 2009-2011, a research study was conducted at four study areas (USFS cattle grazing allotments) in western Idaho to evaluate and predict risk of wolf-cattle encounters. Each year, a random sample of 10 lactating beef cows from each study area was instrumented with GPS collars that logged positions at 5-minute intervals throughout the summer grazing season. Cattle resource selection was modeled using these GPS data and negative-binomial regression. An existing model was used to classify habitats within the study areas in terms of probability of use by wolves as rendezvous sites. Efficacy of this model was confirmed using scat, telemetry, and rendezvous site data. Spatial overlaps in the predicted selectivity of wolves and cattle were assessed and study area landscapes were then classified into five encounter-risk classes (very low to very high). Concurrent wolf and cattle GPS tracking data were used to document wolf-cattle encounters and thus evaluate the accuracy of this classification. About 94% of observed wolf-cattle encounters occurred within either the high or highest encounter-risk classes. Areas classified to the highest risk class were located on smooth, relatively flat slopes in concave terrain (e.g., stream terrace meadows) but not all were associated with surface water. Having this predictive understanding of where wolf-cattle encounters are most likely to occur will allow livestock producers and wildlife managers to more effectively apply resources, husbandry practices, and mitigation techniques to reduce conflict.

KEY WORDS: *Bos taurus*, *Canis lupus*, cattle, encounter risk, mapping, resource selection, wolf

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INTRODUCTION

Gray wolf (*Canis lupus*) populations in the have expanded considerably in size and range extent since reintroduced into the northern Rocky Mountains in 1996. As wolves have come to occupy cattle (*Bos taurus*) grazing lands throughout much of this and other regions in the mountainous western US, cattle depredation losses to wolves have also increased. The rugged complexity, vast extent, and remoteness typical of these grazing lands make it difficult to mitigate and manage wolf-cattle conflict. Commonly, such conflict goes undetected until long after the fact and mitigation efforts are consequently belated and ineffective. Furthermore, we lack an adequate understanding of how wolves and cattle spatially interact, which thus hinders our abilities to proactively plan and apply management to reduce wolf-cattle encounters and associated conflict in free-ranging production systems. The objectives of this research study were to: 1) develop an improved understanding of resource selection by wolves and cattle during the summer grazing season; 2) identify areas of spatial overlap in the selection patterns of these species; and 3) apply this knowledge to develop and validate maps of spatial risks for wolf-cattle encounters in cattle grazing lands of the northern Rocky Mountains.

METHODS

This research was conducted during 2009-2011 at four USDA Forest Service (USFS) cattle grazing allotments (48-112 km^2 in extent) in western Idaho where gray wolves were generally present at moderate to higher levels. These study areas (A, B, C, D) were selected to represent the broad range in environmental and livestock management variability typical of extensive, public-land grazing areas in the northern Rocky Mountains. Study area landscapes generally graded upward from low-elevation, steep-walled canyon lands vegetated by native bunchgrass, to dissected plateaus with pine savanna and open woodlands, topping out on relatively high-elevation mountain slopes vegetated by mixed conifer forest (Clark et al. 2017).

Herds of about 350-400 cow-calf pairs occupied each study area during the summer grazing season (June-October). Ten mature cows were randomly selected from each study area and equipped with GPS tracking collars which recorded positions at 5-minute intervals during the grazing season. As is typical of telemetry studies, the individual tracking data sets acquired varied in completeness due to collar malfunction and a number of other factors. For this study, three of the most complete data sets from each study area for each of the three study years (i.e., 36 data sets total) were selected for analysis. Cattle resource-selection patterns were modeled using the negative-binomial regression approach described by Nielson and Sawyer (2013). A candidate set of 50 models developed *a priori* and consisting of up to five predictor variables derived from nine environment data sets were fitted to the GPS position data (Chigbrow 2016). Model fits were ranked by AIC scores (Akaike 1973, Burnham and Anderson 2002) and predictive performance of top models was evaluated using Spearman rank correlation and GPS data reserved for model validation (Boyce et al. 2002, Sawyer et al. 2009). Based on these top models, the relative probability of cattle use was spatially mapped as 10 ranked classes (lowest to highest predicted use) for each study area-year combination using a 30-m raster grid cell size.

Wolf presence was monitored on the study areas using a combination of telemetry tracking (radio and GPS), scat surveys, camera traps, den/rendezvous site surveys, direct observation, and depredation reporting. Presence was generally at moderate levels for all study areas although there was variability among months within years (Clark et al. 2017). Wolf resource selection during the rendezvous period (15 June to 15 August; Schullery 2003) was mapped using an existing logistic regression model developed and validated by Ausband et al. (2010) throughout central and western Idaho. This simple model included three predictor variables: 1) Normalized Difference Vegetation Index (NDVI) derived from Landsat 7 imagery, plus 2) normalized surface roughness and 3) profile curvature, both of which were derived from USGS digital elevation models (DEM). Relative probability of wolf use during the rendezvous period was then mapped as 10 ranked classes on a 30-m raster grid using this existing model. Model efficacy was confirmed using documented wolf rendezvous site locations, telemetry tracking, and other presence data acquired in or near the four study areas.

Spatial overlap of predicted cattle and wolf use during the rendezvous period was evaluated by conducting Spearman rank correlation analyses between the cattle and wolf resource selection maps: areas with positive correlation would indicate spatial overlap of cattle and wolf use patterns, while negative correlation values would indicate area avoided by both species. Wolf-cattle encounter risk would thus be expected to increase with increasing spatial overlap of predicted wolf and cattle use patterns. Based on this correlation analysis, predicted encounter risk was then mapped as five ranked classes from lowest to highest risk on a 30-m raster grid for each study area-year combination.

A case study was conducted in Study Area A to evaluate the efficacy of the encounter risk map for predicting actual encounters during the 2009 grazing season between 10 GPS-collared cows representing a herd of 350 cow-calf pairs and a GPS-collared adult male wolf representing a pack (n = 11) with pups of the year. Wolf GPS data were acquired at 15-minute intervals. For the purposes of this case study, concurrent wolf and cattle GPS positions (±15 min) located within 200 m of each other were considered wolf-cattle encounters. These documented encounters were overlain on the encounter risk map created for this study area-year combination. Encounters were tallied for each of the five risk classes and then reported as percentages of the total encounters.

RESULTS

Spearman rank scores for the top performing cattle resource-selection models were quite high for all four study areas (r_s = 0.96 to 0.99) indicating very good to excellent prediction accuracy and general robustness within the study domain. The best overall model contained five predictor variables (not counting the intercept and quadratic terms): [Refer to Chigbrow (2016).]

Relative probability of use = Intercept + Slope + Distance from Roads + Distance from Roads^2 + Distance from Streams + Distance from Streams^2 + Aspect + Ponderosa pine

Cattle were predicted to select for areas of flat to moderate terrain slopes and close to or at a moderate distance from roads and streams. The influence of the remaining to predictor variables; terrain aspect and proportional Ponderosa pine coverage, on predicted cattle use patterns differed among study areas. Other top models were simply 3- and 4-variable derivatives of 5-variable, best model where the aspect and/or Ponderosa pine variable(s) were excluded.

General efficacy of the Ausband et al. (2010) model for the study domain was confirmed. There were eight documented wolf rendezvous sites located within or near the four study areas. All eight sites were located within 0-90 m of areas classified to either the high or highest wolf use probability class based on this existing resource-selection model. Wolves were predicted to select for areas with relatively high vegetation greenness values (e.g., grassy meadows), smooth terrain surface, and concave terrain shape (e.g., valley bottoms, toe slopes).

Mapping of spatial overlap between predicted wolf and cattle use patterns revealed that both species tended to select for relatively flat, grassy meadows during the rendezvous period but these selected areas were not necessarily associated with riparian meadows or other near-stream habitats (Figure 1). Wolf-cattle encounter risk was thus expected to be highest in these mutually-selected areas. Both wolves and cattle tended avoided steep slopes and sparsely-vegetated ridge tops and encounter risk should be lowest in these areas.

During the 2009 case study, 165 GPS-based wolf-cattle encounter events were recorded in Study Area A during the rendezvous period (Figure 1). Events varied in duration with some involving only a single pair of concurrent wolf-cattle positions and others potentially involving many consecutive position pairs. Encounter events could simultaneously involve more than 1 GPS-collared cow. In one case, six of the ten collared cows were involved in single encounter event. More than 54% of wolf-cattle encounters occurred in areas mapped to the very high

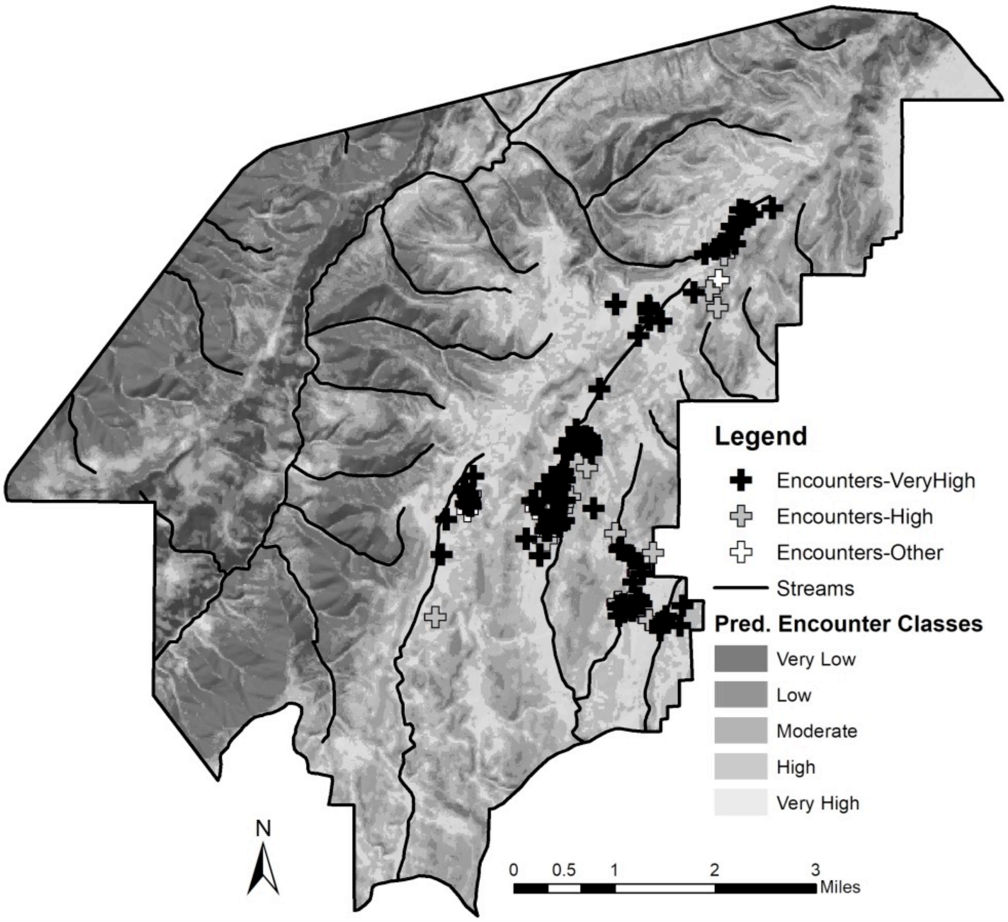

Figure 1. Classified wolf-cattle encounter risk map derived from cattle and wolf resource-selection models for a study area (USFS cattle grazing allotment) in western Idaho. Actual wolf-cattle encounters (n = 165 events) identified by GPS tracking are overlain on the map and color coded to represent the mapped encounter class (Very high, high, and other (includes medium, low, and very low classes) in which each encounter event occurred.

risk class. About 42% of encounters occurred areas of the high risk class. Consequently, all but about 4% of the wolf-cattle encounters were located in areas of these two highest risk classes. The relationship between counts of observed wolf-cattle encounters and the ordering of predicted encounter risk classes tended to follow an exponential curve of the following equation form (Chigbrow 2016):

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

As such, the largest increase in observed encounters occurred between areas of medium and high predicted encounter risk.

DISCUSSION

Relatively simple models of five variables or less were found to be very effective for accurately predicting cattle resource-selection patterns on four rugged, complex, and extensive study areas in the western Idaho. Efficacy of the wolf resource-selection model, which had been previously validated by Ausband et al. (2010) through much of western and central Idaho, was confirmed for these four study areas. Tests of correlation between wolf and cattle resource selection revealed distinct overlapping areas of predicted use and thus areas which likely had elevated risk of wolf-cattle encounters. A case study conducted in one of the study areas (A) using concurrent cattle and wolf GPS data to document actual wolf-cattle encounters clearly confirmed that spatial risk mapping could accurately predict where within a rugged, complex, and extensive landscape these encounters were most likely to occur. Although encouraging, the reader should note this apparent confirmation of efficacy is limited to the scope of this case study and its associated conditions, extent, and scope. The robustness of this spatial risk mapping approach, consequently, requires further testing at other sites in the northern Rocky Mountains as well as in other regions where wolves and cattle occupy the same range.

An underlying assumption for encounter risk mapping is that increased wolf-cattle encounters would likely lead to increased depredations of cattle by wolves. While this assumption is generally supported by predation theory (Gerritsen and Strickler 1977), it remains untested as a rationale for wolf-cattle encounter risk mapping. Therefore, our next step in this line of research is to develop and evaluate wolf-cattle encounter risk maps for a study area in central Idaho, where general terrain characteristics (high glacial valleys and alpine peaks) differ from western Idaho (riverine canyons and dissected plateaus); where we have been GPS-tracking cattle herds since 2005; and where we have also recorded spatial coordinate data for cattle depredation sites. Research in central Idaho will provide the opportunity to evaluate whether encounter risk mapping can spatially predict where cattle depredations are most likely to occur.

Findings from the present study and anticipated future work will provide cattle producers and natural resource managers with an improved understanding of how wolf and cattle spatially interact; predictive technologies to determine where wolf-cattle encounters and potential depredation events are most likely to occur; and a means to proactively plan and apply wolf and cattle management on extensive grazing lands. Spatial risk mapping will allow producers and managers to more effectively apply resources, husbandry practices, and mitigation techniques to reduce wolf-cattle conflict.

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