DETERMINING THE RELATIONSHIP BETWEEN PACKSTOCK AND SIERRA NEVADA BIGHORN SHEEP IN SEQUOIA-KINGS CANYON NATIONAL PARKS: ARE THERE NEGATIVE EFFECTS?

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Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*) are a federally endangered subspecies. They are native to the Sierra Nevada and use open habitats that provide forage adequate to meet their nutritional demands. Bighorn sheep are recognized as grazers but their diets include abundant shrubs and forbs as well (Wehausen 1980, Schroeder et al. In press). During summer, Sierra bighorn primarily use alpine and subalpine habitats. Given the low density of vegetation in the arid landscape in the Sierra Nevada, bighorn sheep use meadows that provide a high density of nutritious forage. The integrity of meadows in the Sierra Nevada is likely important for the recovery of Sierra Nevada bighorn sheep.

Of the herd units identified in the Recovery Plan for Sierra Nevada bighorn sheep, 10 of 16 (62.5%) lie partially or wholly within Sequoia-Kings Canyon National Park (SEKI; Figure 1). Consequently, preserving the integrity of habitats within SEKI is essential for recovery of Sierra bighorn. Meadows are focal vegetation communities for both wildlife and human activities. Yet meadows occupy only 1-2% of the landscape in the alpine and subalpine of the Sierra Nevada.

Activity by humans has the potential to disturb bighorn sheep and illicit behavioral responses that may have negative consequences (Papouchis et al. 2001).

However, Hicks and Elder (1979) concluded that activity by hikers and backpackers using alpine summer range in the Sierra Nevada did not adversely affect bighorn sheep.

The National Park Service has received concerns that pack stock that use habitats used by Sierra Nevada bighorn sheep may negatively impact their recovery. Negative impacts could result from behavioral displacement, excessive consumption of forage, habitat destruction, or disease transmission. Consideration of impacts should include a determination of the likelihood of population level effects (i.e., demographic rates).

Recreational pack stock also use subalpine and alpine habitats in proximity to trail systems within SEKI (McClaren 1989). Currently, 219 meadows (753 ac) are open to grazing, and additional meadows are open to smaller pack animals (llamas, burrows; Figure 2).

Packstock, with the exception of goats, are unlikely to pose a disease risk to Sierra bighorn. Experimental studies that examined the co-pasturing of bighorn sheep with llamas and horses did not identify disease transmission or morbidity and mortality associated with such contact (Foreyt 1994, Foreyt and Lagerquist 1996). Conversely, domestic goats have been associated with negative effects of disease following contact with bighorn sheep (Jansen et al. 2006). The risk associated with the use of packing goats is recognized and has resulted in the exclusion of goats from SEKI and much of Sierra bighorn range, therefore this discussion will assume that they are not a form of packstock in SEKI.

In SEKI, effects by packstock are most likely to be associated with influences on the foraging efficiency and forage supply for Sierra bighorn. Grazing herbivores may modify the foraging environment through removal of biomass and by exerting pressure on the ground. Meadows are a limited resource in the Sierra Nevada and a sought after destination by backcountry users. Trampling by packstock may have numerous effects on the ecology of meadows through a combination of soil compaction, erosion, and damage to vegetation (Cole et al. 2004).

Packstock may exert negative effects on bighorn through behavioral interactions. Ostermann-Kelm (2008) observed that desert bighorn avoided water sources with horses nearby. Brown et al. (2010) noted that bighorn sheep foraged less efficiently in the presence of livestock, specifically cattle. Shrestha and Wegge (2008) observed that grazing by livestock using overlapping habitats, likely resulted in competition for forage with wild sheep.

Cole et al. (2004) noted that horses and mules (equids) preferred graminoids and consequently modified the species composition in Sierra Nevada meadows that were grazed. While Sierra Nevada bighorn sheep consume a combination of grasses, forbs, and shrubs, graminoids typically compose the largest proportion of the diet during summer (Wehausen 1980) and winter (Schroeder et al. In Press). Because both bighorn sheep and equids exhibit a preference for graminoids the potential exists for packstock to compete with bighorn sheep for forage when using the same areas. Grazing may exert positive or negative effects on plant growth and forage production depending on the level of removal (McNaughton 1983, Belsky 1986). In order for bighorn sheep to be negatively affected by packstock, there must be spatial overlap in habitat use that negatively affects forage acquisition.

Our objectives are to: (1) quantify the degree of current and potential spatial overlap between Sierra Nevada bighorn sheep and areas grazed by packstock; (2)

determine the effect of packstock on vegetation structure and species composition, with special focus on forage resources that are jointly used by bighorn and packstock; (3) refine our understanding of diet and foraging behavior of Sierra bighorn on alpine and subalpine summer range; (4) use resource selection functions (RSF's) to develop bighorn distribution models. Achieving these objectives will allow us to evaluate the potential behavioral, nutritional, distributional, and demographic effects of packstock on bighorn sheep.

METHODS

Objective 1: Quantifying spatial overlap

We will use two approaches to quantify spatial overlap in habitat use between bighorn sheep and packstock. The first approach will be based on incidence data of bighorn sheep and packstock in meadows, and the second on the proportion of meadows used by bighorn sheep relative to the proportion available that are used or not by packstock. The first approach will allow us to evaluate overlap in meadow use at the landscape level while the second approach will allow us to evaluate overlap at the herd level while accounting for variation in availability of different habitat types for each herd. We are concentrating on meadows because this is the vegetation type in bighorn sheep summer range where packstock use would have the greatest potential impact (see introduction).

First, data from GPS locations on bighorn sheep and GIS layers for vegetation and packstock use in SEKI will be used to calculate a simple χ^2 coefficient of association (Legendre and Legendre 1998). The number of meadows within the cumulative range of the ten bighorn herd units within SEKI will be identified, then we will tabulate those that are used by both bighorn sheep and packstock, those used by bighorn sheep or packstock but not the other, and those where neither bighorn sheep or packstock occur. If the χ^2 value is significant ($P \leq 0.05$), the direction of the association (positive or negative) will be evaluated by inspection of the ratio between observed and expected values.

For the second approach we will use GPS location data to estimate a "herd home range" (minimum convex polygon; see below) for each of the ten bighorn herds within SEKI. GIS layers will be used to estimate the proportion of five habitat classes within each herd home range; meadows without packstock use, meadows with packstock use, conifer, shrub, and barren (includes rock and sparsely vegetated alpine). The number of locations within each habitat class for each herd will then be tabulated. An analysis of habitat selection using a Manly Type 1 approach (Manly et al. 2002) will then be performed for each herd unit. Evaluation of overlap will be conducted by inspection of 95% confidence intervals (CI's). CI's for meadows with packstock use that do not overlap the proportion available would indicate positive associations (use is greater than availability) or negative associations (use is less than availability).

Objective 2: Relationship between meadow vegetation structure and species composition and herbivory by packstock and bighorn sheep

We will select six meadows in each of four conditions (N = 24 meadows total); those used by bighorn sheep and packstock, those used by bighorn sheep but not packstock, those used by packstock but not bighorn sheep, and those used by neither bighorn sheep nor packstock. Within each meadow we will locate three 0.25 ha plots (N = 72 plots total). Each plot will consist of four 25-m transects originating from a center point, with each transect oriented in one of the cardinal directions. Height measurements and ocular estimates of cover will be made for all herbaceous species (forb, grass, and sedge) in 5 randomly selected 1-m^2 quadrats along each transect. Cover and height of woody and herbaceous species and cover of rock will be estimated with point-intercept sampling (points evenly spaced at 0.5-m intervals) along each transect. Woody plants will be identified to species level, while herbaceous species will be placed in one of three classes; forb. grass, or sedge. Density of woody species will be estimated from counts done in a 5-m belt (2.5 m on either side of the transect). Herbaceous biomass (identified to species) will be collected from three 100-cm^2 sub-plots on each transect and used to estimate the amount and quality of forage (see Objective 3 below).

The cover data will be used to derive Hill's series of indices of diversity (Hill 1973, Jost 2006) for (1) all herbaceous species, (2) all woody species, and (3) all forage species. Hill's series is considered to be a particularly useful way to quantify diversity (Magurran 2004, Jost 2006). First, it spans different measures of diversity, from those that are most sensitive to rare species (species richness) to those most sensitive to changes in the more abundant species (e.g. Simpsons index). Next, it is not sensitive to differences in sample size. Finally, its values are interpreted as the effective number of species. Using Hill's series will allow us to quantify if differences in overall vegetation diversity as well as forage species diversity occur in meadows with different degrees of use by bighorn sheep and packstock, then evaluate if this is due to differences in the number of species, the relative abundance of less common species, or the relative abundance of more common species. The biomass data will be used to derive Hill's series of indices of diversity for all.herbaceous forage species and to analyze differences in the total amount of forage in the four meadow conditions (those used by bighorn sheep and packstock, those used by bighorn sheep but not packstock, those used by packstock but not bighorn sheep, and those used by neither bighorn sheep nor packstock). We will analyze the diversity and total biomass data with mixed effects models (Zuur et al. 2009), with meadow condition as a fixed effect and plot and meadow as two levels of random effects. The identity of forage species will be based on Wehausen (1980).

Meadows may not differ in diversity among the four conditions but they could differ in species composition. Therefore, we will analyze differences in species composition among the four meadow conditions with Distance-based Redundancy Analysis (DbRDA; Legendre and Anderson 1999). DbRDA is a constrained version of principal components analysis that is conducted on a distance or dissimilarity matrix. Fixed and random effects can be partitioned in the analysis, and interactions included as factors. The importance of variables and ordination axes are evaluated from permutation tests, and the proportion of variance accounted for by the different gradients can be calculated. We will use cover data to derive a Bray-Curtis matrix of dissimilarities and factor out variation due to topography by including elevation, slope, and aspect as covariates. Meadow will also be included as a covariate (random effect). The DbRDA will allow us to determine if there are overall differences in species composition among the four meadow conditions and which forage species tend to be associated with which meadow condition.

Objective 3: Diet composition and Forage Quality

Diet quality will be assessed by measuring digestible energy and digestible protein of forage samples. Diets will be determined by microhistological analysis of fecal samples. Forage samples will be collected monthly during the growing season (see Objective 2 above), air dried, and stored for analysis. In vitro dry matter digestibility and bomb calorimetry will be used to estimate digestible energy. Nitrogen (protein) will be quantified using a TruSpec nitrogen analyzer.

Objective 4: Resource Selection Functions and Bighorn Distribution Model

We will develop a resource selection function model to examine the current and likely potential distribution of Sierra bighorn. We will use a modeling approach to define the potential distribution of bighorn because current distribution is limited given their limited population size and endangered status. Following recovery, it is expected that bighorn sheep will occupy a much broader distribution that is dictated by habitat variables that we will use to predict their future range extent.

Global positioning system (GPS) collars will be deployed on male and female bighorn sheep in multiple herd units within SEKI. We will model resource selection on a seasonal basis. We will sub-sample locations recorded by GPS collars to obtain 24 locations/animal/day, collected hourly.

We will compare values of habitat predictor variables at GPS locations to values at random "available" locations, selected using stratified random sampling. We define available habitat as habitat within the 100% annual minimum convex polygon (MCP) home ranges of bighorn sheep included in each model, with an additional 1 km buffer (Bleich et al. 1997; Nielson et al. 2002). We will generate random locations within the MCP for local populations. Model precision is often improved by including more available locations than used locations, since available locations usually include more variation in habitat characteristics (Fielding and Haworth 1995; Gross et al. 2002).

We will develop digital raster layers for seven habitat predictor variables associated with bighorn sheep habitat; elevation, slope, hillshade, aspect, distance to escape terrain, terrain ruggedness, vegetation, greenness (NDVI), and snow cover (Festa-Bianchet et al. 1988; McKinney et al. 2003, DeCesare and Pletscher 2006; Bleich et al. 2008). We will use a 30 x 30 m USGS Digital Elevation Model (DEM) to derive values for slope, hillshade, and aspect coverages. To create the hillshade thematic layer, we will set the aspect at 225º and the angle of the sun at 45º, such that higher values represent xeric southwest slopes and lower values represent mesic northeast slopes (Nielson et al. 2002).

Aspect will be converted to a continuous surface based on heat load index (McCune and Grace 2002), using the conversion formula:

$$\text{Aspect Surface} = (1-\cos(\theta-45))/2$$

where θ is equivalent to aspect in degrees east of true north (McCune and Grace 2002). The heat load index rescales aspect about the northwest-southeast axis from a scale of zero to one, with zero being the coolest slope (northeast) and one being warmest slope (southwest). We will convert values to radians for processing in a geographic information system (GIS) environment.

Bighorn sheep prefer open habitats with high visibility and access to steeper slopes to successfully evade predators (Risenhoover and Bailey 1985; Etchberger et al. 1989; Bleich et al. 2008). We will calculate distance to escape terrain for each pixel in the study area, where escape terrain was defined as any pixel having >60% slope (Smith et al. 1991; McKinney et al. 2003). We also will develop a terrain ruggedness surface using a Vector Ruggedness Measure (VRM) based on local variation measures that are independent of slope and developed for bighorn sheep (Sappington et al. 2007).

We will use thematic vegetation layers provided by SEKI to classify vegetation by type. To identify habitat and topographic characteristics important in describing bighorn sheep habitat selection, we will develop a set of *a priori* candidate models for every variable combination. We will screen habitat variables for multicollinearity using Pearson's correlation coefficient to determine that no two variables are highly correlated using a cutoff of $r \leq 0.7$ (Green 1979). We will determine whether the continuous variables were curvilinear, and include second order polynomial terms where appropriate (Hosmer and Lemeshow 1989).

We will use multiple logistic regression to estimate model coefficients (Hosmer and Lemeshow 2000). Values of habitat predictor variables will be compared between "used" (i.e. GPS) locations and randomly selected "available" locations. We will use Akaike's Information Criterion (AIC) to compare candidate models (Akaike 1973; Burnham and Anderson 1998).

We will use regression coefficients from the best fit model to calculate the RSF using the formula:

$$w(x) = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p)$$

where, x_i are the independent habitat predictor variables, and β_i represent the coefficients of those variables from the logistic regression model (Manly et al. 2002; Pearce and Boyce 2006).

The RSF's will then be used to calibrate a species distribution model (Franklin 2009) by applying the RSF to each 30 x 30 m pixel across our study area. Since values produced by the RSF are relative, we will standardize the resulting surface by scaling pixel values from 0-1. We will validate the habitat model using a sample validation procedure utilizing 30 % testing data withheld from model development (Howlin et al. 2004).

By intersecting the resource selection function model with packstock use areas, we will compare the likelihood of bighorn sheep using habitats that are also used by species of packstock. We will also determine whether bighorn sheep tend to avoid habitats associated with packstock by comparing expected use with actual use by bighorn that wear GPS collars.

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Table 1. Budget

Item	Year 1	Year 2
GPS Collars	$71,400	$71,400
Helicopter capture	$28,500	$28,500
Vegetation Technician	$19,980	$19,980
Annual Cost	$119,880	$119,880
Total Cost (2 years)		$239,760

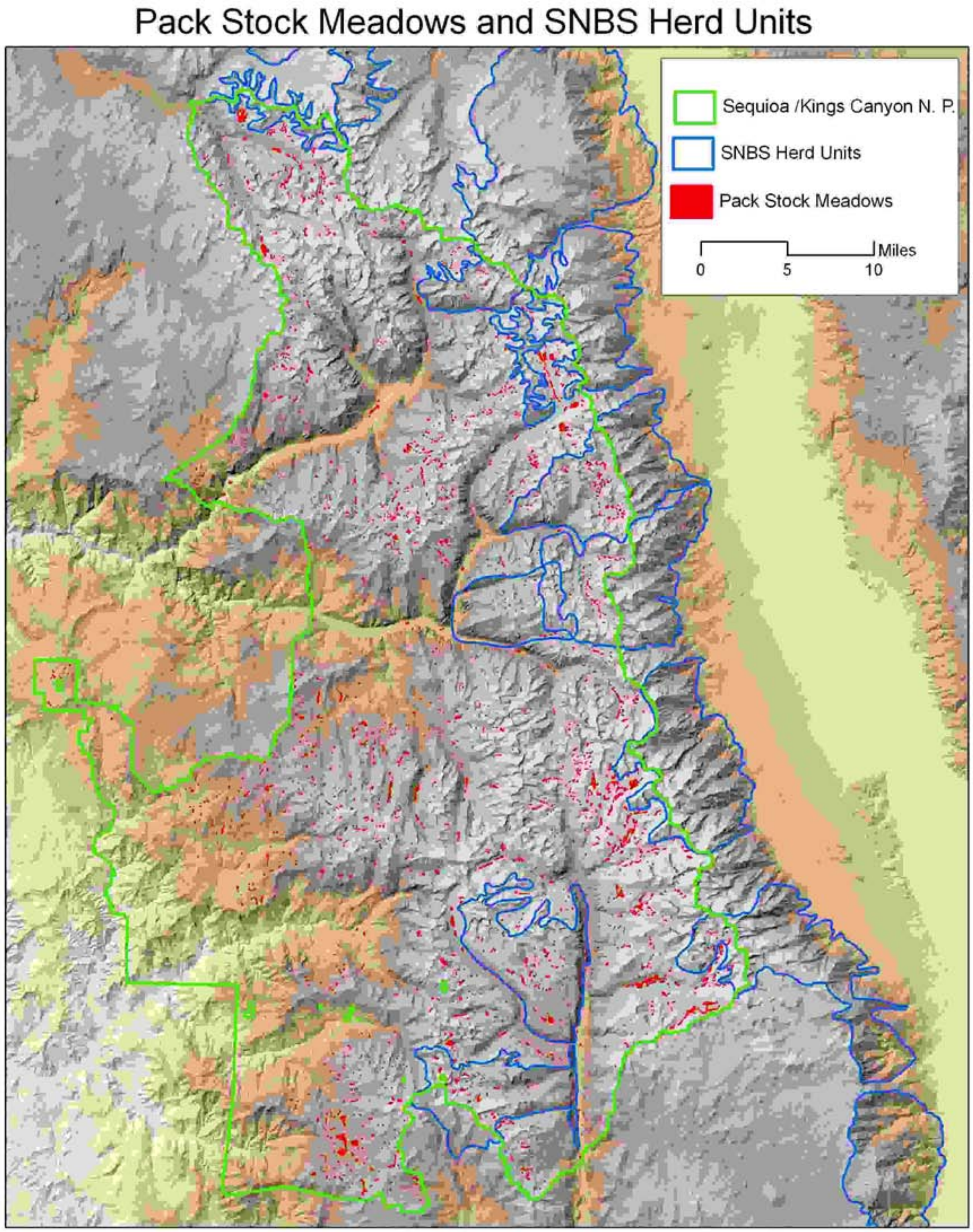

Figure 1. Distribution of meadows that are open to grazing by packstock in Sequoia-Kings Canyon National Park. Herd units that are identified in the Recovery Plan are indicated for Sierra Nevada bighorn sheep.