Change Detection Using Historical Aerial Photography in Bighorn Sheep Habitat of the Sierra Nevada

Erin Latham[1], Lacey Greene[2], Tom Stephenson[3], Greg McDermid[4], and Mark Hebblewhite[5]

1 Foothills Facility for Remote Sensing and GIScience, Geography, University of Calgary, els.latham@ucalgary.ca
2 College of Forestry and Conservation, University of Montana, Missoula, MT, lacey.eva@gmail.com
2 Foothills Facility for Remote Sensing and GIScience, Geography, University of Calgary, mcdermid@ucalgary.ca
4 California Fish and Wildlife Department, McGill University, Bishop, California, Tom.Stephenson@dfg.ca.gov
5 Geography, College of Forestry and Conservation, University of Montana, Missoula, MT, Mark.Hebblewhite@cfc.umt.edu

Abstract

This research project evaluates the changes in Sierra-Nevada bighorn sheep habitat over the past 75 years using historical aerial photography.

Background and Relevance

The bighorn sheep population in the Sierra Nevada (*Ovis canadensis sierrae*) was listed endangered in 2000 (65 FR 20, 2000). The causes of the population decline have been attributed to illegal hunting (Advisory Group 1997, Wehausen and Hansen 1988), disease (Buechner 1960), and the direct and indirect effects of predation (Wehausen 1996). The vulnerability of the population may be exasperated by low nutrition, environmental stochasticity, and anthropogenic disturbance (65 FR 20, 2000). The recovery effort on behalf of the California Department of Fish and Game and the Sierra Nevada Bighorn Sheep Recovery Program (SNBSRP) may be further impeded by changes in the landscape over the last century. Bighorn sheep tend to prefer open terrain allowing for better visibility of predators (65 FR 20, 2000), and tree encroachment, specifically by single-leaf piñon (*Pinus monophylla*), has been documented in the Sierra Nevada (Burwell 1999, Miller and Rose 1999, Gruell 2001, Romme et al. 2009). The scale of tree encroachment in bighorn sheep habitat has not been directly investigated

The principal goal of this research project was to evaluate the changes in Sierra-Nevada bighorn sheep habitat over the past 75 years using historical aerial photography. We hypothesized that changes in bighorn sheep habitat could be characterized by spatial and terrain-related variables such as low elevations, northern aspects, and north latitudes. Our analysis specifically focused on winter habitat ranges with substantial low elevation forest. The application of geographic information science and remote sensing will be useful for managers of the SNBSRP in restoring lost or vulnerable habitat to further aid the recovery of the subspecies.

Methods and Data

The study area is based in the Sierra Nevada mountain range of California, and is focused on four of the bighorn sheep herd units that have been identified as priorities for recovery (Figure 1). A total of 92 historical aerial photographs of the study area from 1929 and 1944 were found in hard-copy archives. Approximately 36000 hectares of sheep habitat were covered by the historical imagery, although the extent of the imagery was limited to the eastern front of the sheep's range. The imagery was scanned, orthorectified, and made available by the SNBSRP. True-colour and colour-infrared aerial photographs from 2005 with 1-meter spatial resolution were collected as digital orthophoto quadrangles from the online Cal-Atlas database (http://atlas.ca.gov/). A 10-meter digital elevation model (DEM) and shape files of the herd units were also provided by the SNBSRP.

A manual interpretation of the imagery was performed using a multi-stage sampling design. Semivariogram analysis was initially performed on a 2005 classified air photograph of tree cover to aid in determining the coarse level of analysis. The study area for each herd unit was then stratified by the results of the semivariogram analysis to 600 meter by 600 meter (0.36-km^2) grids, and was sub-sampled systematically by eight 50-meter plots (2500 m^2). The sampling design needed to be non-biased in evaluating tree encroachment across bighorn sheep habitat, but it also required sampling flexibility in order to avoid major distortions and shadows in both the old and new imagery sets. The sampling design allowed for discretion in choosing alternate plots based on major distortions or shadows in the grid. The DEM was resampled to 50 meters using window averaging, and slope, cosine aspect, and elevation were recorded at each plot after resampling. Sampling also occurred across a range of elevations, but due to the variation of seasonal habitat use by the herd units and the extent of the historical imagery, only winter habitat is included in the analysis. The 2005 colour-infrared imagery was initially classified in the object-based software, Definiens Developer 7.0, and change was calculated as a difference of vegetation cover between the historical and current dataset by area (m^2). Overall, 58- 600-meter grids were identified in the four study area units resulting in 421 50-meter interpreted plots

Linear mixed model regression in R was used to predict change with the terrain variables of slope, aspect, and elevation. The authors chose not to model the loss of vegetation or negative change because it was assumed that the variables affecting vegetation loss would be different than tree encroachment. Due to zero-inflation of the data, we initially modeled change as a binary categorical response in a generalized mixed model under the binomial family, and then proceeded to model positive change as a linear mixed model. Models were evaluated based on residual plots, and significance values were used to evaluate the predictor variables. A validation assessment was also performed on the change areas.

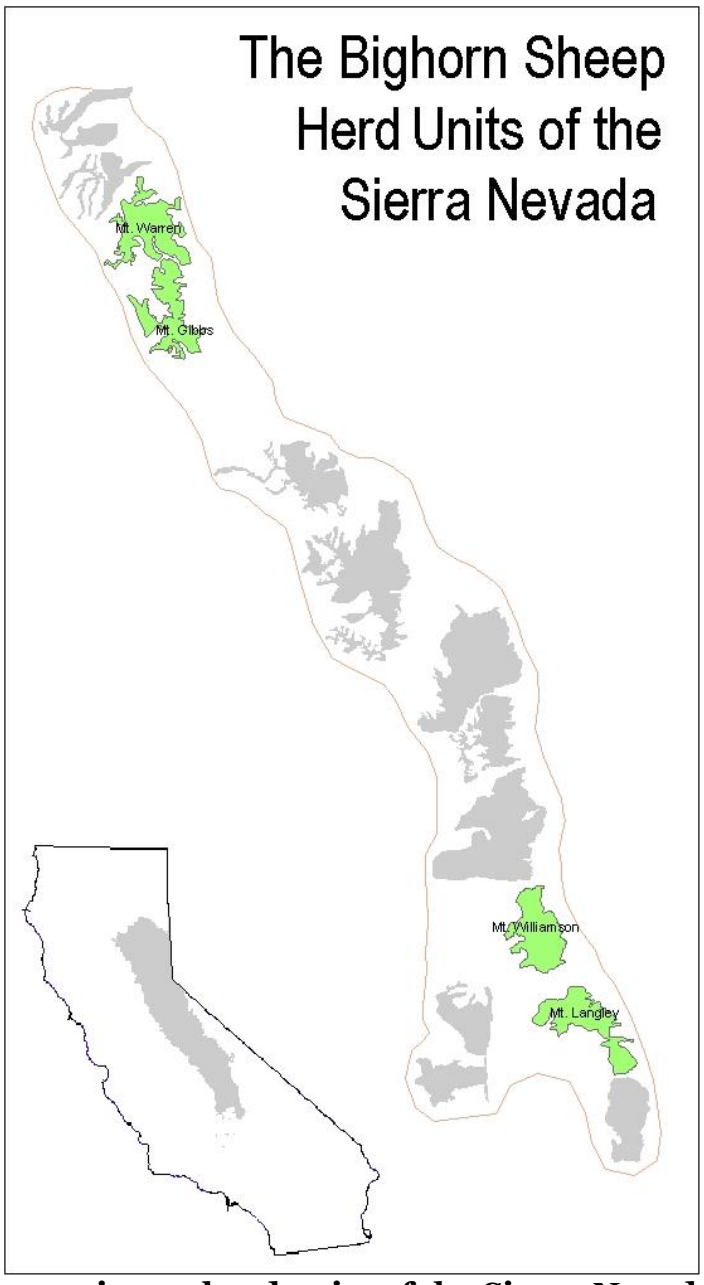

Figure 1. The four primary herd units of the Sierra Nevada include, from north to south, Warren, Gibbs, Williamson and Langley.

Results

Change was less than +4% on average for each of the herd units. One of the north herd units, Mt. Gibbs, had the most amount of change, and Mt. Langley in the south had the least. The results of the mixed model analysis indicated that the herd units were not significantly different from each other. Positive change was associated most with north aspects, low elevations, and steep slopes. More change rather than less change was also associated with low elevations and north aspects.

Our study indicates that tree encroachment in bighorn sheep range of the Sierra Nevada is not prevalent, but that local change may still be impacting the individual herd units in their winter and summer ranges.

Conclusions

Tree encroachment in the bighorn sheep herd units of the Sierra Nevada was found to be <+4%. The increase in tree cover may be attributed to external variables not explored in this analysis. The recovery of bighorn sheep however has benefited from viewing the historical landscape prior to major eras of settlement and anthropogenic change during the late 1800s and early 1900s. The methods employed for the interpretation of historical imagery were found to be robust to the shortcomings of the data, and further studies should seek to incorporate and extend the historical reach in time by using such methods.

References

65 FR 20. (2000) Endangered and Threatened Wildlife and Plants; Final Rule to List the Sierra Nevada Distinct Population Segment of the California Bighorn Sheep as Endangered. ed. F. a. W. S. Department of the Interior, 20-30. Ventura.

Burwell, T., A. (1999) Environmental history of the lower montane piñon (*Pinus monophylla*) treeline, eastern California. 270. Madison: University of Wisconsin.

Gruell, G. E. (2001) *Fire in Sierra Nevada forests: a photographic interpretation of ecological change since 1849*. Missoula: Mountain Press.

Miller, R. F. & J. A. Rose (1999) Fire History and Western Juniper Encroachment in Sagebrush Steppe. *Journal of Range Management,* 52**,** 550-559.

Romme, W. H., C. D. Allen, J. D. Bailey, W. L. Baker, B. T. Bestelmeyer, P. M. Brown, K. S. Eisenhart, M. L. Floyd, D. W. Huffman, B. F. Jacobs, R. F. Miller, E. H.

Wehausen, J. D. (1996) Effects of Mountain Lion Predation on Bighorn Sheep in the Sierra Nevada and Granite Mountains of California. *Wildlife Society Bulletin,* 24**,** 471-479.

Wehausen, J. D. & M. Hansen, D. (1988) Plant communities as the nutrient base of mountain sheep populations. In *Plant biology of eastern California,* eds. C. A.