Head to Head

Flawed model has serious conservation implications: Response to Turner et al.

By Stacey D. Ostermann-Kelm, Esther S.Rubin, Jeremiah D. Groom, James R. DeForge, Guy Wagner, Pete Sorensen, Steven G. Torres, Mark C. Jorgensen, Aimee J. Byard, and Oliver Ryder

Abstract Turner et al. (2004) developed a habitat selection model for a population of desert bighorn sheep (*Ovis canadensis*) in the Peninsular Ranges of southern California that is listed as a threatened and endangered population by the state of California and the federal government, respectively. We are concerned that the recent publication of an article by Turner et al. (2004) could be detrimental to the management and recovery of bighorn sheep in the Peninsular Ranges because it lends credibility to a flawed analysis of bighorn sheep habitat-use patterns. The model attempts to extrapolate conclusions from a limited subset of bighorn sheep data that is not representative of the study area and was not gathered in a manner conducive to the analysis methods used by the authors. The authors classified habitat pixels as "active" or "inactive" based on the presence–absence of bighorn sheep observations without considering monitoring intensity. Turner et al. (2004) also failed to consider the implications of basing their model almost entirely on a bighorn sheep subpopulation known to have atypical habitat selection patterns. This subpopulation in the northwestern Santa Rosa Mountains frequently used food and water sources within hillside urban areas. Because the Turner et al. (2004) model was developed using data primarily from this atypical subpopulation, the model has low external validity and is unlikely to accurately predict habitat selection by other bighorn sheep subpopulations in the Peninsular Ranges. Furthermore, with the NW subpopulation used in model development now excluded from urban areas, the Turner et al. (2004) model is unlikely to accurately predict habitat selection patterns of even this subpopulation. We suggest the Turner et al. (2004) model is at best only applicable to this subpopulation between the years 1994–1998.

Key words bighorn sheep, habitat modeling, habitat selection, mountain sheep, *Ovis canadensis*, Peninsular bighorn sheep, Peninsular Ranges, urbanization

Recently, Turner et al. (2004) developed a habitat selection model for a population of desert bighorn sheep (*Ovis canadensis*) in the Peninsular Ranges of southern California that is listed as a threatened and endangered population by the state of California and the federal government, respectively. Turner et al. (2004:429) stated, "Our objective was to quantify Nelson's bighorn sheep habitat in the northern Santa Rosa Mountains, identify those parcels of land having the greatest potential and probability for occupancy, and compare this to the USFWS (2001) critical-habitat designation." They developed a habitat model using bighorn sheep location data obtained through a Freedom of Information Act (FOIA) request to the USFWS field office in Carlsbad, California.

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Publication of the article by Turner et al. (2004) lends credibility to a flawed model that we are concerned may be detrimental to the management and recovery of bighorn sheep in the Peninsular ranges. The Turner et al. (2004) habitat model already has been used by development and building interests. Specifically, the model was used in a site-specific habitat analysis that concluded 487 hectares (1,204-acres) of undeveloped, mountainous terrain within designated Peninsular bighorn sheep critical habitat were either "non-habitat" or unoccupied, low-quality habitat unimportant for bighorn sheep ("Application of the Logistic PBS Habitat Model in Land Planning", unpublished manuscript and presentation submitted 26 May 2004 by J. Turner to the Palm Springs Planning Commission, Palm Springs, California, Case #5-0826-PD-258). Building proponents used the study results to argue in favor of building an 18-hole golf course, 351-room resort hotel, and >120 homes within designated Peninsular bighorn sheep critical habitat.

While development of a quantitative habitat model for bighorn sheep in the Peninsular Ranges is desirable, a model that is deficient in design or that inappropriately uses data for extrapolation may misdirect recovery actions for this endangered population. Here we discuss errors and biases of the model developed by Turner et al (2004). We offer this critique to help ensure that management of endangered Peninsular bighorn sheep is based upon the best available data and accurate interpretation of that data.

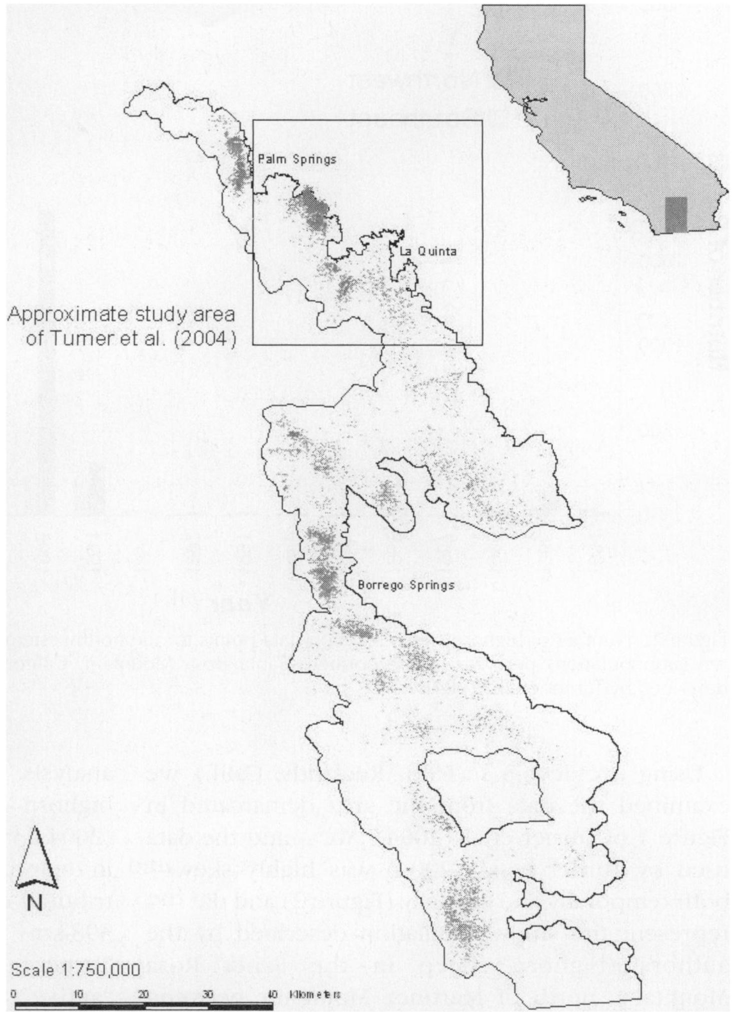

Figure 1. Map displaying data points (and the bighorn sheep essential habitat line) that were provided to Turner et al. by the U.S. Fish and Wildlife Service and the study area in the Santa Rosa Mountains, California, chosen by Turner et al. (2004).

Data misrepresentation and inferential limitations

We began our review of the Turner et al. (2004) habitat model by examining data used to develop the model. The USFWS provided Turner et al. with a dataset containing approximately 22,000 locations of bighorn sheep and representing 8 subpopulations within the United States Peninsular Ranges (Figure 1). These data were provided in the same format as they were used in the Recovery Plan (United States Fish and Wildlife Service [USFWS] 2000). The data were collected by multiple independent researchers having diverse study objectives and using a variety of monitoring methods and intensities (USFWS 2000). Turner et al. (2004) reportedly used 12,411 of these data points, including data from the current range of the bighorn sheep subpopulation northwest of State Route 74 in the Santa Rosa Mountains ("NW subpopulation" hereafter), and approximately half the current range of the subpopulation southeast of State Route 74 in the Santa Rosa Mountains ("SE subpopulation" hereafter; Rubin et al. 1998).

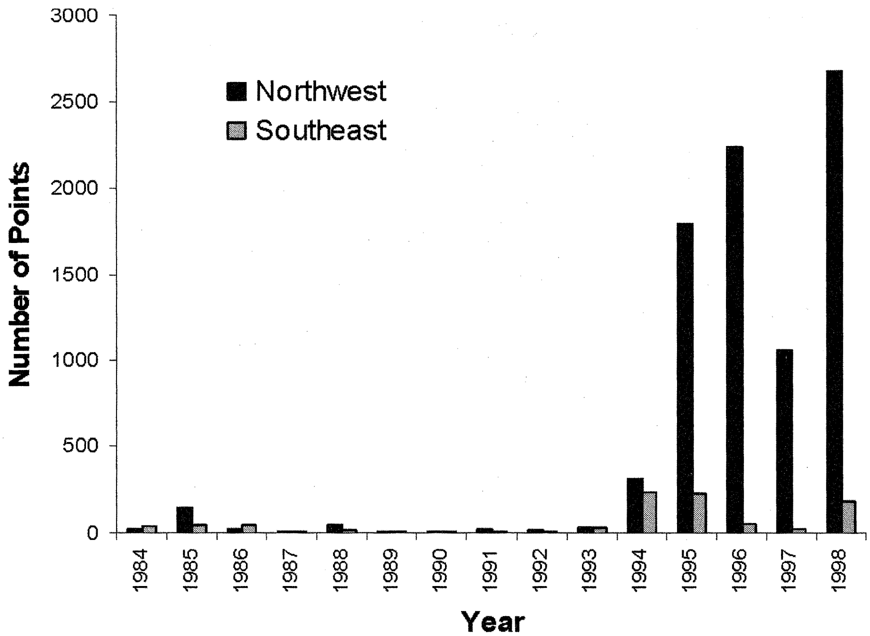

Figure 2. Number of bighorn sheep location data points for the northwestern and southeastern subpopulations per year in the northern Santa Rosa Mountain, California, study area described by Turner et al. (2004).

Using ArcView 3.3 (ESRI, Redlands, Calif.) we examined the data from the area demarcated in Figure 1 of Turner et al. (2004). We found the data used by Turner et al. (2004) was highly skewed both temporally and spatially (Figure 2) and did not represent the study population described by the authors (bighorn sheep in the Santa Rosa Mountains north of Martinez Mountain, between the years of 1984-1998).

To draw inferences from a sample to a population, the sample should be representative of the target population and be selected randomly or nearly randomly (White and Garrott 1990, Quinn and Keough 2002). The dataset chosen by Turner et al. (2004) fails both standards; it suffers from selection bias (Thompson et al. 1998), which causes misleading results because the samples do not truly represent the population. Turner et al. (2004) would have had to review the literature (DeForge and Scott 1982; Rubin et al. 2000, 2002; Ostermann 2001; Ostermann et al. 2001) or consult with various researchers who originally collected the data to understand the sampling biases inherent to the pooled dataset they chose. Bighorn sheep in the NW subpopulation occurred closer to urban areas and were monitored more intensively than bighorn sheep in the SE subpopulation during 1981-1998 (DeForge and Scott 1982, Ostermann 2001, Rubin et al. 2002). Furthermore, the ease of locating bighorn sheep when they were in urban areas resulted in a preponderance of bighorn sheep locations in or adjacent to urban areas in the NW subpopulation (Ostermann 2001). Ideally, Turner et al. (2004) would have subsampled the data prior to their analyses or used another technique to help compensate for variation in monitoring intensity within their chosen study area.

Another fundamental error in the Turner et al. (2004) model is also related to the authors' assumption regarding bighorn sheep monitoring. In both their regression analysis and in their metric "observations of bighorn sheep per km^2 per year," Turner et al. (2004:435) incorrectly assumed that the data used in their model was a result of monitoring effort distributed evenly across a 14-year study period and 398-km^2 study area. In developing their model, Turner et al. (2004) classified habitat pixels as "active" or "inactive" based on the presence-absence of bighorn sheep observations, without considering monitoring intensity or duration, and then used the model results to make generalized classifications of landscape areas ranging from nonhabitat to critical habitat (Turner et al. 2004). Given the low intensity and duration of monitoring in portions of the study area and the preponderance of data collected near the urban interface, it is likely that the Turner et al. (2004:442) model incorrectly classified important habitat as "unoccupied," "poor-quality," or "deficient."

A graphical display of the Turner et al. (2004) dataset (Figure 2) suggests unequal monitoring intensities that should have been investigated. Because these monitoring differences were not addressed, the non-representative and nonrandom sampling in the Turner et al. dataset violates basic statistical sampling principles and negates inferences regarding the population sampled, as well as inferences extrapolated to other populations

(White and Garrott 1990, Sokal and Rohlf 1995, Thompson et al. 1998, Quinn and Keough 2002).

A model representing the NW bighorn sheep subpopulation 1994–1998

Within the approximate Turner et al. (2004) study area, we identified 12,407 data points collected between 1981 and 2000. Although Turner et al. (2004) reportedly used 12,411 data points for the years 1984-1998 in their analysis, we could identify only 9,306 data points from the study area collected during that timeframe. For the 1984-1998 data set, approximately 90% of the data were from the NW bighorn sheep subpopulation and over 86% were from the NW subpopulation for the years 1994-1998. We also analyzed the data points in the 1981-2000 data set and found similar results: approximately 90% of the data points were from the NW bighorn sheep subpopulation and 79% were from the NW subpopulation over a 7-year interval (1994-2000). To maintain consistency with Turner et al. (2004), our discussion is based on the data set Turner et al. claimed to have used (9,306 data points from the years 1984-1998, Figure 2). Regardless of the ambiguity surrounding precisely which data Turner et al. (2004) analyzed, their habitat model was driven by data from the NW bighorn sheep subpopulation collected over a limited time interval.

While using data from primarily one subpopulation may not be problematic, it is unclear to us why Turner et al. (2004) limited their study area to only half the documented range of the SE subpopulation (Rubin et al. 1998, USFWS 2000) and chose not to use substantial amounts of data available from the SE subpopulation or other subpopulations in the Peninsular Ranges. More importantly, Turner et al. (2004) failed to discuss the implications of developing their model using data almost entirely from the NW subpopulation. The NW subpopulation is known to have atypical habitat selection patterns (Figure 3) and unusually high mortality rates relative to other bighorn sheep in the Peninsular Ranges (DeForge and Scott 1982, DeForge and Ostermann 1998, Rubin et al. 2000, USFWS 2000, Ostermann 2001, Ostermann et al. 2001). Because of their atypical habitat selection characteristics, the NW subpopulation was the least suitable of the 8 subpopulations in the United States Peninsular Ranges upon which to base an evaluation of critical habitat for Peninsular bighorn sheep.

Figure 3. Ewes and lambs of the NW bighorn sheep subpopulation browsing in an urban area within the northern Santa Rosa Mountains, California. Bighorn sheep in this subpopulation frequently used artificial sources of food and water available within hillside developments until a fence was constructed in 2002 to exclude bighorn from urban areas. Photo: S. Ostermann-Kelm.

Bighorn sheep in the NW subpopulation were first documented using artificial sources of food and water in urban areas within historical bighorn sheep habitat during the mid-1950s (DeForge and Scott 1982). A comparison of habitat selection by bighorn sheep in the NW subpopulation over time showed a 5-fold increase in bighorn sheep use of urban areas between 1981-1982 and 1995-1998 (Ostermann 2001). Female bighorn sheep monitored in 1995-1998 had significantly smaller home ranges and used habitat both within and closer to urban environments more frequently than bighorn sheep monitored during 1981-1982 (Ostermann 2001). In the 1990s the NW subpopulation also used habitat differently than the SE subpopulation, with NW animals exhibiting smaller home ranges and using lower elevations and gentler slopes (Rubin et al. 2002).

In addition, during 1994 to 1998, the NW subpopulation was at a record low number and consisted of only 21-24 adult animals (DeForge et al. 1995, USFWS 2000, Ostermann et al. 2001). In response to the high number of urban-related bighorn sheep mortalities (e.g., automobile collisions, strangulation in fencing, and poisoning from non-native vegetation; DeForge and Ostermann 1998, Ostermann et al. 2001) within the NW subpopulation, a fence was constructed in 2002 along the urban interface of the city of Rancho Mirage that was designed to exclude bighorn sheep from urban areas. Since completion of the fence, no bighorn sheep mortalities have been attributed to urbanization and as of 2004 the NW subpopulation had increased to 57 adult bighorn sheep (Bighorn Institute 2004).

Because the Turner et al. (2004) model was developed using data primarily from the atypical NW subpopulation, the model has low external validity (Lehner 1996) and is unlikely to accurately predict habitat selection by other subpopulations in the Peninsular Ranges. Furthermore, with the NW subpopulation now excluded from urban areas, the Turner et al. (2004) model is unlikely to accurately predict habitat selection patterns of even this subpopulation. We suggest the Turner et al. (2004) model is at best only applicable to the NW subpopulation between the years 1994-1998.

Data interpretation errors and omissions

For several reasons, the Turner et al. (2004) habitat model is flawed even when results are inferred to only the NW subpopulation during a 5-year time period. First, Turner et al. (2004) pooled data across 14 years and 2 distinct subpopulations without first testing for significant differences. Pooling data without testing for differences can produce misleading inferences (Schooley 1994). Indeed, within the Turner et al. (2004) study area, habitat selection had been shown to significantly differ by both subpopulation (Rubin et al. 2002) and time period (Ostermann 2001). This is problematic because, "[e]ven when sample sizes are relatively equal among years, combining data does not provide an average or typical pattern of habitat selection if use varies among years." (Schooley 1994:371).

A second problem is that by referring to their metric "bighorn observations/ km^2/year" to support various habitat classifications, Turner et al. (2004:435) erroneously assumed that the density of bighorn sheep locations in a given area was an indication of habitat quality. This metric is misleading because research objectives and associated monitoring intensities varied considerably among years, and it incorrectly implies that density of locations is an indication of habitat quality. The density of an organism's locations does not always accurately reflect habitat quality or importance (Van Horne 1983). When quantifying habitat use, particularly in an area adjacent to urban areas (such as the NW subpopulation), it is important to account for sampling biases caused by variation in visibility or monitoring effort (Manly et al. 1993).

Lastly, the model presented by Turner et al. (2004) neglected to address the issue of connectivity among bighorn sheep subpopulations. A central premise of conservation biology is the need to maintain connectivity among populations to preserve long-term genetic variability and demographic exchange (Gilpin and Soulé 1986). Habitat connectivity has been deemed particularly important for the conservation of bighorn sheep (Schwartz et al. 1986, Bleich et al. 1990). Bighorn sheep within the Peninsular Ranges comprise a metapopulation (Torres et al. 1994, Bleich et al. 1996, Boyce et al. 1997) or group of subpopulations connected by the movement of males and occasionally females (DeForge et al. 1997, Rubin et al. 1998, Boyce et al. 1999). Even if their model correctly represented habitat selection of the NW subpopulation, its application may isolate subpopulations. This could expose far-ranging animals to additional mortality risks and place isolated subpopulations at increased risk of extinction due to genetic drift and demographic and environmental stochasticity (Gilpin and Soulé 1986).

Problematic water source data

Turner et al. (2004) reported that water availability from perennial sources was the most decisive predictor of bighorn sheep habitat use in the Santa Rosa Mountains, which makes the accuracy of their water source data crucial. Turner et al. (2004) identified only 4 perennial water sources within their study area. Based on published documents (Bureau of Land Management 1980) and fieldwork (A. Byard, S. Ostermann, and E. Rubin), we identified 10 perennial water sources within the same area (Figure 4). In addition, bighorn sheep in the NW population frequently drank from the many water sources available in urban areas (e.g., fountains, sprinklers, swimming pools), so they were not restricted to perennial water sources prior to 2002 when the sheep exclusion fence was completed. Including all known perennial water sources in the study area may significantly alter the results of the Turner et al. (2004) model.

Results from Turner et al.'s (2004) habitat model also may have been confounded by the effects of urbanization on bighorn sheep habitat selection in

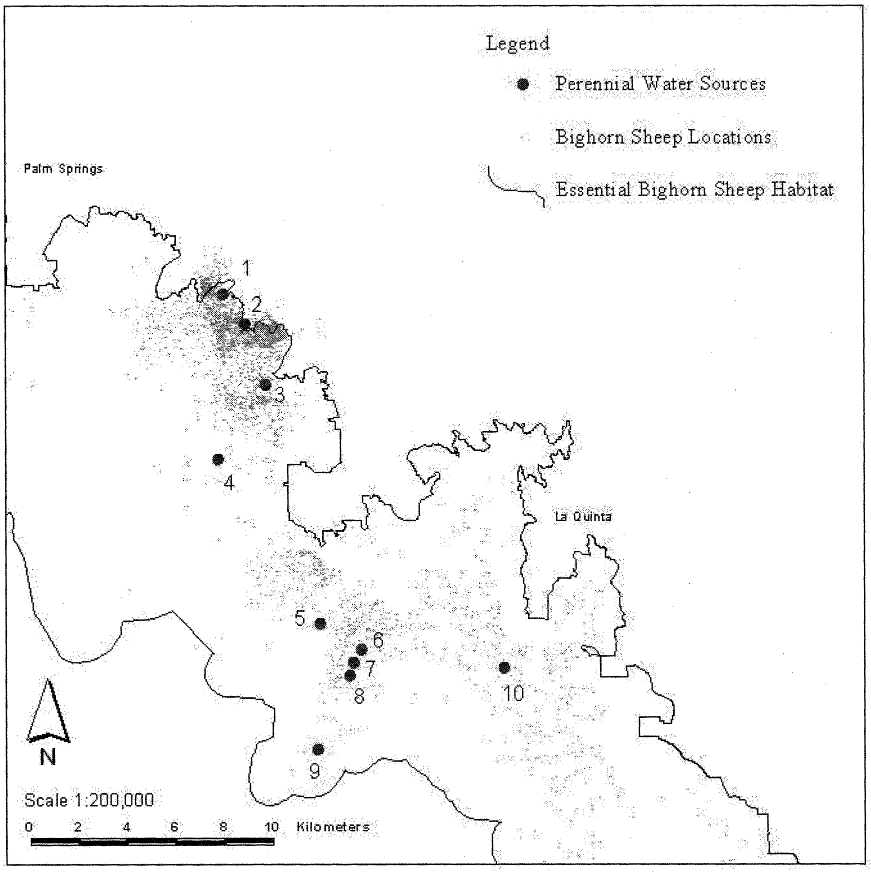

Figure 4. Perennial water sources within the northern Santa Rosa Mountains study area, as of 2004. Water sources were identified based on published documents (Bureau of Land Management 1980) and fieldwork (A. Byard, S. Ostermann, and E. Rubin). Water sources are identified as follows: (1) Rancho Mirage Bighorn Sheep Preserve*, (2) Bradley Spring*, (3) Magnesia Canyon Adit*, (4) Cat Canyon, (5) Carrizo Canyon, (6) Deep Canyon pool 1, (7) Deep Canyon pool 2, (8) Deep Canyon pool 3, (9) Deep Canyon pool 4, (10) Bear Creek Spring (asterisk indicates a manmade or altered water source).

the NW subpopulation. Using ArcView 3.3 to generate successive 1-km buffers centered on Bradley Spring (Figure 4), we found that 80% of all data points used by Turner et al. (based on our estimate of the data they selected) were within 3 km of this single water source. Bradley Spring is a man-made water source ("drinker") constructed within 25 m of a private housing community. Given the close proximity of this location to areas where bighorn sheep congregated in urban habitat, distance to water may not be the primary variable influencing sheep habitat selection. Instead, other factors, such as lush vegetation and water sources in urban areas (Figures 5) may have driven habitat selection for this subpopulation (Ostermann 2001, Rubin et al. 2002). Turner et al. (2004:436) stated that "...97% percent of all northern Santa Rosa Mountain bighorn sheep observations occurred within 3 km of a perennial water source" but they failed to report that most of these observations were near a single water source located along the urban-wildland interface.

While water sources appear to be important determinants of bighorn sheep distribution (Cunningham and Ohmart 1986, Andrew and Bleich 1999), standing water is not a year-round requirement for all bighorn sheep populations. Krausman et al. (1995) reported bighorn sheep existing in areas without water, and we have observed bighorn sheep in the Peninsular Ranges using habitat with no known water for months at a time (USFWS 2000). Therefore, areas far removed from perennial water also may represent important habitat for desert bighorn sheep. Seasonal water sources also are valuable to bighorn sheep and may influence habitat selection patterns. Defining essential habitat for bighorn sheep in the Peninsular Ranges as only those areas in close proximity to perennial water sources would result in the exclusion of many high-use areas that are important to bighorn sheep.

Conclusion

The Turner et al. (2004) model is at best valid for only the NW subpopulation for the years 1994-1998, before a fence was built along the urban-wildland interface. Because of the nature of the data used to build the model and changes in available habitat subsequent to data collection, results from the Turner et al. (2004) model cannot be extrapolated to other time periods or populations. As evident in Figure 2B in Turner et al. (2004), bighorn sheep in the northern Santa Rosa

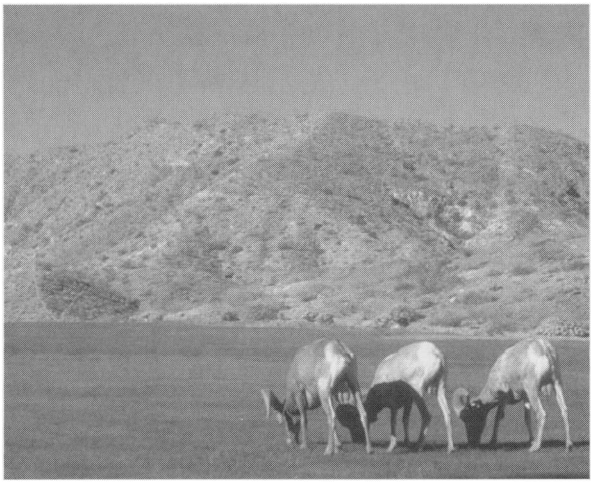

Figure 5. Bighorn sheep of the NW subpopulation browsing on an urban lawn in the northern Santa Rosa Mountains, California. The stark contrast in forage and water availability between natural and urban habitats suggests that resources within urban areas may have been an important determinant of habitat selection for this bighorn subpopulation prior to 2002. Photo: S. Ostermann-Kelm.

Mountains have used and continue to use many areas the habitat model suggests are nonhabitat.

A flawed habitat model may have serious consequences for the recovery of bighorn sheep in the Peninsular Ranges because it may misdirect recovery efforts. As stated by one of the Turner et al. authors (Krausman et al. 2000), avoiding extinction and eventually achieving recovery of bighorn sheep in the northern Santa Rosa Mountains will require careful management of bighorn sheep habitat. For this reason, it is important that the model developed by Turner et al. (2004) not be used for evaluating bighorn sheep habitat in the Peninsular Ranges.

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Saudi Arabia. He is an active member of the USFWS Peninsular Bighorn Sheep Recovery Team. ***Aimee J. Byard*** is a biologist and Associate Director of the Bighorn Institute, a nonprofit research and conservation organization located in Palm Desert, California. She has been involved in the Institute's captive breeding and field research programs for the recovery of Peninsular bighorn sheep since 2000. ***Oliver A. Ryder*** is head of the Genetics Division at Conservation and Research for Endangered Species (CRES), part of the Zoological Society of San Diego. His research interests and significant publications are in the fields of conservation biology, chromosomal and molecular evolution, and population genetics of endangered species. His efforts currently focus on the areas of genetic resource banking and conservation genomics. He is an active member of the USFWS Peninsular Bighorn Sheep Recovery Team.