IMPACT OF THE BULLOCK AND ASPEN FIRES ON DESERT BIGHORN SHEEP HABITAT IN THE SANTA CATALINA MOUNTAINS, ARIZONA

Final Report

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INTRODUCTION

The desert bighorn sheep *(Ovis canadensis mexicana)* population in Pusch Ridge Wilderness (PRW), Santa Catalina Mountains, Arizona has declined since the 1930s and was virtually extirpated in the late 1990s (Krausman et al. 1979, Krausman et al. 2000). Although there are still occasional reports of individual bighorn sheep being observed in PRW, the herd has essentially been extirpated, is not considered a viable population, and will not persist in the long term without active management (Krausman et al. 2000).

Multiple factors have been associated with the decline of desert bighorn sheep in PRW including urban development (i.e., housing development, road construction), human recreation (i.e., hikers, hikers with dogs, trail development), and changes in habitat conditions (Etchberger et al. 1989, Czech and Krausman 1997, Krausman et al. 1996, 2000, Papouchis et al. 2001). Habitat changes in PRW have been associated with the suppression of wildfires in the Santa Catalina Mountains (Etchberger et al. 1989, Krausman et al. 2000). Desert bighorn sheep prefer areas with high visibility over areas with less visibility (Wakelyn 1987, Etchberger et al. 1989). Fire suppression in the Santa Catalina Mountains over the last three decades has resulted in a 0.5%/year decrease in visibility in desert bighorn sheep habitat (Krausman et al. 1996). The Bullock fire in 2002 burned approximately 12,378 ha and the Aspen fire in 2003 burned over 34,323 ha in the Santa Catalina Mountains, including areas previously inhabited by desert bighorn sheep, however the affect of these fires on historic bighorn sheep habitat is unknown.

Our objectives were to estimate the amount of potential and historic bighorn sheep habitat in the Santa Catalina Mountains and to determine the affect of the Bullock and Aspen wildfires on these areas.

METHODS

To investigate the amount of potential and historic bighorn sheep habitat remaining in the Santa Catalina Mountains and the impact of recent wildfires on this habitat, we created a spatial model using Arclnfo and Arc View (Environmental System Research Institute, Inc. 2000) in a Geographic Information System (GIS). The model was based on United States Geological Survey (USGS) 1:24,000 digital elevation models (DEM) that evaluated 30 x 30 m cells. Digital data were acquired from the United States Geological Survey, U.S. Census Bureau, and the United States Forest Service (USFS).

Habitat suitability was based on important habitat characteristics common to viable desert bighorn sheep populations (Table 1). We first estimated the amount of potential and historic habitat available for bighorn sheep, and used these areas as the basis for future calculations. Habitat was defined as escape terrain (>60% slope) buffered by 500 m that was within 4 km of a water source, less than 1,830 m elevation, and within the Sonoran Desert Scrub and Chaparral vegetation associations. The DEM was used to select all cells with an elevation ≤ 1,830 m. The DEM was then converted into a slope coverage, where the maximum rate of change in slope was calculated from each cell to its neighbors. All cells with >60% slope were identified, and then buffered by 500 m. Water sources were identified using USGS digital line graphs (DLG), and updated with information from the land managers and state wildlife agencies. All cells >4 km from a 4water source were eliminated from further analysis. Within the available habitat (potential and historic), we delineated all areas that had been impacted by urban development.

We used Urbanized Area (VA) and road coverages provided by the U.S. Census Bureau to identify urban development. Data from the U.S. Census Bureau was used because it provided the most current information on urban development. Urbanized Areas are defined as having a minimum of residential development where the population density is ≥1,000 people/m^2. All UA and paved roads were buffered by 100 m, a minimum distance that bighorn sheep are displaced during human-bighorn interactions (Light 1971, Smith et al. 1991).

To evaluate the impact of recreation, we identified all major trails, campgrounds, ski areas, and unpaved roads that were located within the bighorn sheep habitat of each population. Recreation areas were identified from DLG, and updated with maps provided by the land managers. Recreation areas were buffered by 100 m, a minimum distance sheep are displaced during bighorn-human encounters (Light 1971, Smith et al. 1991).

We used a binary exclusion model to determine the amount of bighorn sheep habitat in the Santa Catalina Mountains. From the habitat historically available to bighorn sheep, we excluded all areas impacted by urban development and recreation independently, and in combination. Areas remaining after the urban and recreation features had been excluded were used to calculate the size of the largest habitat patch, and the size of the average habitat patch. Desert bighorn sheep are consistently located within these parameters (Cunningham 1989, McCarty and Bailey 1994, Wakeling and Miller 1990). Because bighorn sheep are not known to have historically occurred in the eastern portion of the range, this area was excluded from the GIS model for the historic habitat. Historic habitat calculations for the Santa Catalina Mountains were based only on areas known to have been used by bighorn sheep (Etchberger et al. 1989, Krausman et al. 1979).

To evaluate the impact of the Bullock and Aspen fires on potential and historic bighorn sheep habitat in the Santa Catalina Mountain we used a GIS coverage of the Burn Severity maps and the Normalized Difference Vegetation Index (NDVI) for the time periods immediately prior to and after the fire.

The USFS derived fire perimeters and burn severity index coverages using LANDSAT images by the Burned Area Emergency Rehabilitation (BAER) team. The perimeter of each fire was delineated using ARCVIEW GIS; areas within the fire perimeter were then classified into burn severity classes. Burn severity classes were unburned, low burn, moderate burn, and high burn. Low burn severity was defined as ground vegetation burned with > 1 0% needle scorch on trees, moderate burn severity was defined as ground vegetation burned with 10 - 70% needle scorch on trees; high burn severity was defined as needles and small branches consumed and some large branches consumed.

The NDVI was derived from remote sensing data and can be used to monitor spatial and temporal changes in vegetation. Changes in photosynthetic activity and biomass of vegetation result in changes in the reflectance in the near infrared and red range; these reflectance values can be used to generate the NDVI that functions as an index of the greenness of vegetation and can be used to compare the condition of vegetation of large spatial scales and allows for comparisons through time (Huete and Jackson 1987). The NDVI images consist of a series of pixels, each corresponding to an area on the earth's surface of 250 m X 250 m. Pixel values over a 16-day period are composited into 1 NDVI image; 23 NDVI images are produced each year. We used data collected by the Moderate Imaging Spectroradiometer (MODIS) carried by polar-orbiting satellites to calculate the NDVI to assess the greenness of vegetation immediately prior to the start of the wildfires and immediately after fires were extinguished. First we overlaid the

bighorn sheep habitat coverages with the NDVI images, we then extracted the NDVI values for all areas affected by the Aspen and Bullock fires. Because NDVI greenness values would be expected to decline during the summer prior to the start of the monsoon season, we also extracted all the NDVI values for all (burned and unburned) the areas within the potential and historic habitat coverages.

To determine the impact of the Bullock and Aspen fires on potential bighorn sheep habitat we overlaid the fire perimeter and burn severity index coverages with the potential and historic bighorn sheep habitat coverages. We then calculated the area (ha) of bighorn sheep habitat that was affected by fire and the area (ha) of habitat by each burn severity class.

RESULTS

Using our GIS model we calculated 39,201 ha of potential habitat (Fig. 1) in the entire Santa Catalina Mountains and 9,017 ha of historic desert bighorn sheep habitat (Fig 2) in the western portion of the range. Approximately 21 % (8,137 ha--Table 2) of the potential bighorn sheep habitat was burned during the Bullock and Aspen fires. Six percent of the area of the potential habitat experienced low burn severity, 13% was moderately burned, and 2% had a high burn severity index.

Approximately 24% (2,116 ha--Table 2) of the historic bighorn sheep habitat was affected by the Bullock and Aspen fires. Of the area in the historic habitat that was burned, approximately 22% experienced low burn severity, 2% had a moderate burn severity index, and > 1 % of the area had a high burn severity index.

The mean NDVI index for the burned area of the potential habitat was 32% lower after the Aspen fire than immediately prior to the start of the fire (t_{1020} = 43.93, $P \leq 0.001$ -- Fig. 3; Table 3). During this same time period, the area of the potential habitat that was not burned only

declined by 10% ($t_{3,022}$ = 42.63, $P \leq 0.001$). The mean NDVI index for the burned area of the historic habitat declined by 30% during the Aspen fire (t_{387} = 33.1, $P \leq 0.001$--Table 2) whereas the mean NDVI index for the unburned area of the historic habitat only declined by 15% ($t_{1,293}$ = 38.8, $P \leq 0.001$).

DISCUSSION

We found that historic bighorn sheep habitat in the western Santa Catalina Mountains has declined by approximately 64% from the 25,000 ha calculated by Etchberger et al. (1989) to 9,017 ha. This decline is likely the result of large areas previously considered bighorn sheep habitat that have become unsuitable primarily due to urban development and recreation. However, based on our habitat model there may be more potential bighorn sheep habitat in the Santa Catalina Mountains if the area in the eastern Santa Catalina Mountains. Any consideration of reintroductions of desert bighorn sheep in an attempt to reestablish bighorn sheep to the Santa Catalina Mountains should further assess the suitability of the areas identified as potential habitat by our model. Much of the potential habitat for bighorn sheep in the eastern Santa Catalina Mountains is not known to have been occupied historically by bighorn sheep and attempts should be made to determine the reason this area was not used by bighorn sheep. If there are factors not incorporated in our model that contributed to this area not being occupied, and therefore, make this area unsuitable for reintroductions these factors need to be determined.

One of the major factors involved in the decline of desert bighorn sheep in the Santa Catalina Mountains is fire suppression (Krausman et al. 1996). Changes in habitat conditions that have negatively affected bighorn sheep in the PRW have been associated fire suppression (Etchberger et al. 1989, Krausman et al. 2000). The lack of a natural fire regime has encouraged vegetation that reduces visibility thereby reducing habitat quality and may have caused bighorn

sheep to abandon areas of previously suitable habitat (Wakelyn 1987, Etchberger et al. 1989, Krausman et al. 1996).

The Bullock fire of 2002 and the Aspen fires in 2003 in the Santa Catalina Mountains burned areas of potential and historic bighorn sheep habitat. However, the extent of these fires in bighorn sheep habitat was limited to <25% in both the potential and historic habitat. Furthermore, the majority of habitat areas that burned experienced burn severity that may not have been high enough to remove vegetation that deceases visibility and habitat quality for desert bighorn sheep. While the NDVI greenness values we found prior to and after the Aspen fire declined 50-60% more in burned areas than in similar unburned areas over the same time period, the greenness values we observed in the burned area after the Aspen-fire were similar to greenness values regularly observed in unburned areas occupied by healthy bighorn sheep populations on the Cabeza Prieta National Wildlife Refuge, Arizona (J. W. Cain and P. R. Krausman, unpublished data). Therefore, the NDVI greenness values for the burned areas immediately after the Aspen fire indicate that a large portion of the vegetation remains. The use of satellite imagery to derive NDVI greenness indices supports the results from the use of the burn severity maps produced by the Burned Area Emergency Response team.

The use of natural and prescribed fires to create the habitat conditions preferred by bighorn sheep has been recommended (Etchberger et al. 1989, Krausman et al. 1996) and will likely be a necessary component of habitat restoration. Other factors (i.e., urban development and recreation) associated with the decline in desert bighorn sheep in the Santa Catalina Mountains also need to be addressed in any plan to reintroduce desert bighorn sheep to PRW. If bighorn sheep are to be translocated and are to persist in the Santa Catalina Mountains, an aggressive

management plan that reduces the conflicts between bighorn sheep, urban development, fire suppression, and human recreation will be required.

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Table 1. Suitability criteria used to evaluate desert bighorn sheep habitat.

Habitat Calculation	Criteria
1) Potential habitat area	Escape terrain that has slopes between 27-85 degrees (Smith et al. 1991). Buffer of 500 m around all escape terrain areas Permanent water source within 4 Ian (Bristow et al. 1996, Krausman and Leopold 1986). No natural barriers, such as large bodies of water, or swift-moving rivers (Smith et al. 1991).
2) Urban-caused habitat loss	Include all core suitable habitat criteria. Exclude man-made barriers, such as major highways, human developments, reservoirs, and impassable fencing (Smith et al. 1991). Exclude a 100m buffer around all high-use developed areas. High-use equals> 2,000 people/vehicles per year (Cunningham 1989).
3) Recreation-caused habitat loss	Include all core suitable habitat criteria. Exclude recreational trails (hiking, horseback riding, off-road vehicle, biking), roads, or rock-climbing areas. Exclude a 100 m buffer around all trails/roads that receive > 2,000 people/vehicles per year.
4) Potential habitat area currently available	Include all core suitable habitat criteria. Exclude all habitat lost to urbanization and recreation

Table 2. Area (ha) and burn severity of potential and historic bighorn sheep habitat burned during the Bullock fire in 2002 and the Aspen fire in 2003, Santa Catalina Mountains, Arizona

	Potential bighorn sheep habitat burned (ha)				Historic bighorn sheep habitat burned (ha)			
	Burn severity				Burn severity			
Wildfire	Low	Moderate	High	Total	Low	Moderate	High	Total
Aspen	520	4,581	347	5,448	1,905	158	3	2,066
Bullock	2,158	398	133	2,689	50	0	0	50

Table 3. Mean NDVI index for burned and unburned areas in historic and potential bighorn sheep habitat in the Santa Catalina Mountains, Arizona observed for prior to and after the 2003 Aspen fire.

	Unburned habitat					Burned habitat				
	Pre-fire		Post-fire			Pre- fire		Post-fire		
	NDVI index					NDVI index				
	Mean (SE)	n	Mean (SE)	n	*P*	Mean (SE)	n	Mean (SE)	n	*P*
Potential habitat	0.283 (0.0008)	3,023	0.253 (0.0007)	3,023	<0.001	0.356 (0.0012)	1,021	0.242 (0.0010))	1,021	<0.001
Historic habitat	0.291 (0.0012)	1,293	0.247 (0.0010)	1,293	<0.001	0.303 (0.0039)	388	0.214 (0.0018)	388	<0.001

List of Figures