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Bighorn Sheep Selection of Landscape Features in an Active Copper Mine

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Abstract

*Bighorn sheep (*Ovis canadensis*) and Dall's sheep (*O. dalli*) use mining areas despite high human activity. We studied bighorn sheep selection of landscape features within a mine in a desert environment to determine those important for bighorn sheep and to enhance reclamation efforts of mines in desert environments. We collared and observed 8 male and 6 female bighorn sheep from December 2003 to January 2005 in the Silver Bell Mountains, Arizona, USA. We classified 13 unique features within a mine landscape based on topography, hydrology, and vegetation. Subadult male, adult male, and female bighorn sheep used desert islands (54, 76, and 54%, respectively) followed by highwalls (14, <10, and 11%, respectively). Subadult male, adult male, and female bighorn sheep selected for desert islands, and subadult males and females also selected for highwalls, whereas adult males did not. We did not observe bighorn sheep using leach ponds, pit bottoms, or tailings dumps. Bighorn sheep behavior while on desert islands was similar to behavior recorded when outside the mine perimeter. Subadult male and female bighorn sheep fed and were alert less and socially interacted more on highwalls than they did while outside the mine perimeter. Bighorn sheep in mines select areas similar to conspecifics outside of mined areas. In areas where mining and bighorn sheep are in proximity, mining engineers and wildlife biologists should work together to design reclamation plans that benefit bighorn sheep. In places where revegetation is difficult (i.e., deserts), mine engineers should design infrastructure (i.e., roadways, waste dumps, buildings) to minimize the unnecessary destruction of native slopes and vegetation.* (WILDLIFE SOCIETY BULLETIN 34(4):1121–1126; 2006)

Key words

Arizona, bighorn sheep, desert, habitat, mining, Ovis canadensis*, reclamation.*

Wild sheep (*Ovis canadensis*, *O. dalli*) in North America use landscapes that offer areas of forage in proximity to steep rugged slopes necessary for security cover (Valdez and Krausman 1999). They rarely use areas with dense vegetation above eye level, presumably because those areas provide ambush cover for most predators of wild sheep (Valdez and Krausman 1999). Modern (open-pit) mining can transform the landscape in positive and negative ways. Modern mining can change areas of low topographic relief and dense and tall vegetation (>1 m) to steep, rugged slopes and cliffs with low vegetation (<1 m). In essence, modern mining techniques can alter the landscape in ways that promote occupancy and use by wild sheep (e.g., Elliott and McKendrick 1984, MacCullum and Geist 1992, Heffelfinger et al. 1995, Bristow et al. 1996, Oehler et al. 2005). Despite the opportunity to alter areas for some species (e.g., wild sheep), mining activities can result in habitat loss for many other species. Little research has been conducted on the impacts of mining activity on other ungulates (Kuck et al. 1985, Merrill et al. 1994), and we found no research assessing impacts on other species.

Wild sheep have been studied in and around active, closed, and reclaimed mines throughout western North America (Elliott and McKendrick 1984, MacCullum and Geist 1992, Heffelfinger et al. 1995, Bristow et al. 1996, Oehler et al. 2005). However, few studies have investigated how wild sheep use landscape features within a mine. Wild sheep used areas of mines that offered foraging opportunity (i.e., revegetated grasslands) while remaining near the steep, rocky slopes created by mining activity (Elliott and McKendrick 1984, MacCullum and Geist 1992). Although wild sheep used the revegetated grasslands in northern areas, revegetation is difficult in arid environments. However, bighorn sheep have been documented to use mines in deserts (Bristow et al. 1996, Oehler et al. 2005). Our objective was to study the selection of landscape features within an active mine in a desert to determine which features were most used by bighorn sheep and which features were selected for (i.e., used more than expected by chance) or against (i.e., used less than expected by chance). We predicted that bighorn sheep would select features of the mine that offered forage and escape terrain and avoid areas of low topographic relief without forage and features with high use by humans.

Study Area

The bighorn sheep population in the Silver Bell Mountains occupied a complex of peaks and ridges (i.e., Silver Bell Mountains, Ragged Top, and Waterman Mountains) in south-central Arizona, USA (111°30′W, 32°24′N). Elevations ranged from 580 m in the northwest to 1,290 m at Silver Bell Peak. Vegetation was composed of the Upland Sonoran Desert community and included palo verde (*Cercidium microphyllum*), saguaro (*Carnegiea gigantea*), prickly pear (*Opuntia* spp.), pincushion *(Mammillaria*

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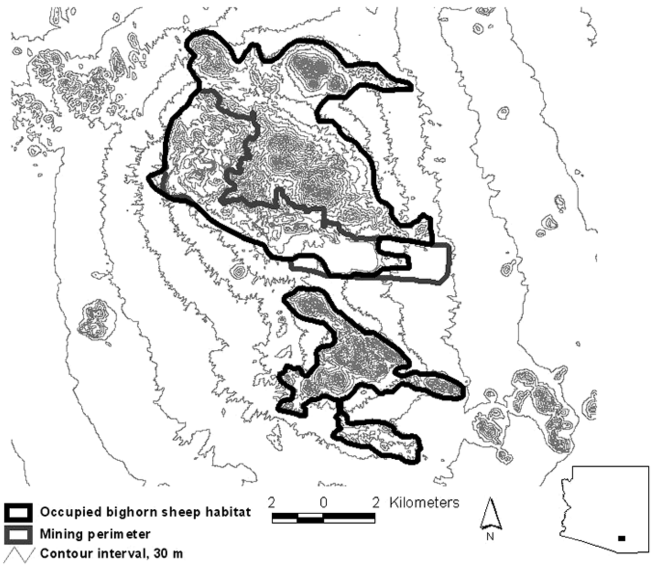

Figure 1. Bighorn sheep habitat and the Silver Bell Mine, Silver Bell Mountains, south-central Arizona, USA, 2003–2005.

spp.), creosotebush (*Larrea tridentata*), triangle-leaf bursage (*Ambrosia deltoidea*), and jojoba (*Simmondsia chinensis*; Turner and Brown 1994).

Climate in the Silver Bell Mountains was semiarid. Average annual precipitation was 312 mm, with more than half falling from July to October. Average maximum and minimum monthly temperatures ranged from 38°C in July to 6°C in December, 1983–2003 (Silver Bell Mine, unpublished data).

Large herbivores in the study area included mule deer (*Odocoileus hemionus*), collared peccary (*Pecari tajacu*), and domestic cattle. Predators of bighorn sheep in the study area included mountain lion (*Puma concolor*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), and golden eagle (*Aquila chrysaetos*).

The Silver Bell Mine was operated by Asarco and encompassed approximately 26 km^2 of the 73 km^2 of habitat currently occupied by bighorn sheep, as determined through radiotelemetry and aerial surveys (Fig. 1). There were 4 open and active pits with $\geq$2 ore dumps associated with each pit. The Silver Bell Mine uses a dump and leach process. Ore is pulverized by explosives and removed, forming pits in ore removal areas. Dumped ore is sprayed with an acidic solution to dissolve the copper, which is recovered through electrolysis.

Methods

We captured and radiocollared male and female bighorn sheep using a helicopter and a handheld net gun (Krausman et al. 1985). We classified radiocollared bighorn sheep as subadult male ($\leq$5 yr), adult male ($\geq$6 yr), and female (Geist 1971). We used very high frequency transmitters (Telonics, Mesa, Arizona) to aide in visually locating bighorn sheep. We systematically located each radiocollared bighorn sheep to obtain equal observations for each animal throughout the daylight period. We observed each animal only once per day. We divided the day into 3 periods: morning (sunrise–1000 hours), midday (1000–1500 hours), and evening (1500 hours–sunset). We determined use of each mine feature with focal animal sampling (Altmann 1974) and recorded the mine feature occupied once every minute, while observing animals from >200 m with spotting scopes. We defined 13 unique features of the mine landscape that were based on topographic, hydrologic, and vegetation characteristics (Table 1). All mine features, except 3 of 6 leach ponds, were available for use by bighorn sheep. We excluded the 3 leach ponds that were unavailable to bighorn sheep from our analyses.

Because animals were accustomed to vehicular traffic and we observed animals from a vehicle parked >200 m away, our observations did not appear to distract animals from their normal activities. We observed each animal for 30 minutes or until that animal left our field of view. We calculated the proportion of observed use (minutes) for each mine feature by individual animal. Because individuals spent varying amounts of time inside the mine perimeter, we used the percent proportions as counts of resource use to standardize the contribution of each animal to total use. For example, suppose we observed an animal for 125 minutes on a highwall out of 1,000 total minutes (12.5%), and another animal for 200 out of 700 total min (28.6%) on a highwall. We used 12.5 and 28.6 as a count of use of that feature, respectively.

We traversed the perimeter of the mine on foot with a handheld Global Positioning System (GPS; Garmin Internationale, Olathe, Kansas) to outline the area of the mine (not including patented lands not yet mined). We randomly selected point locations within the mine perimeter with the Random Point Generator extension (Jenness 2005) in a geographic information system (Arcview 3.2; Environmental Systems Research Institute, Redlands, California). We visited each point by locating that point with a handheld GPS unit and assumed that systematic error associated with the unit would be similar at each point by using the same unit. We classified each point location according to the mine feature where each point occurred. We calculated proportional availability of each feature and its standard error (Manly et al. 2002) for all mine features.

We asked 2 sequential questions about each group of bighorn sheep data. First, did individual animals select mine features differently? Second, despite differences in individual selection, were features selected in differing proportion to their availability? To analyze use and availability data, we used a design II analysis with sampling protocol A and an estimate of resource availability at the population level (Manly et al. 2002). To answer questions 1 and 2 by group, we calculated a chi-square statistic according to Manly et al. (2002). We then calculated population selection ratios for each feature used by bighorn sheep by group to determine which features were selected for, neutral, or against (Manly et al. 2002).

To determine what bighorn sheep were doing in each mine feature, we recorded behavior of bighorn sheep in each mine feature. We classified 5 observable behaviors: feeding,

Table 1. Landscape features and definitions in the Silver Bell Mine, Arizona, USA, 2003–2005.

Feature	Definition
Administration	Area that encompassed buildings, parking lots, and other infrastructure that were used in the maintenance and operation of the mine. Trees and herbaceous plants were along road edges, unused areas, and buildings.
Waste area	Areas of the mine that were cleaned of native vegetation. Vegetation commonly occurred in these areas and was herbaceous with some woody shrubs.
Desert island	Areas within the mine perimeter where the topography and vegetation had not been altered. They consist of similar species, density, and composition as similar areas outside of the mine perimeter.
Leach dump	Places where material was dumped and subsequently leached with an acidic solution. Leach dumps did not have vegetation and had a level surface.
Waste dump	Waste dumps were similar to leach dumps, except the material was not leached. Waste dumps commonly had some herbaceous plants and an occasional woody shrub or tree.
Tailings dump	The level surface of a tailings dump. The surface had a low density of trees, but few small shrubs and no herbaceous plants.
Haul road	Roadways that contain high volumes of traffic.
Light road	Roadways that were vegetated with herbaceous and low woody shrubs.
Highwall	Cliffs formed as a by-product of mining activity. Highwalls often contained benches of level slope, depending on height. Highwalls normally rim pits where ore extraction had occurred and did not normally have vegetation growing on them.
Leach pond	Ponds of liquid where acidic leach solution collected and was pumped to the leach dumps or processing plant. Most ponds were fenced with 2.4-m-high cyclone fencing.
Pit bottom	The area enclosed by highwalls. Pit bottoms did not have vegetation and had level slope.
Dump slope	Area of ore dumps that form a slope along the angle of repose. Dump slopes were not vegetated.
Tailings dump slope	Benched slopes that are made of milled tailings along the angle of repose. These slopes contain woody shrubs and small trees.

bedding, standing, alert, and interact. Alert behavior included alarm or attention postures (Geist 1971), and interacting behaviors were recorded when an animal was directing an action at another bighorn sheep (e.g., chase, butt, copulating). During each observation period ($\leq$30 min), we recorded behavior at 1-minute intervals using focal animal sampling with each radiocollared animal being the subject. We did not record data when the radiocollared animal or members of the group fled or exhibited alert behavior in the direction of the observer for $\geq$5 minutes. We calculated the proportion of time spent in each behavior on mine features, by group (i.e., subadult male [sub-M], adult male [ad-M], and female [F]). We used a paired *t*-test to determine if behavior of individual animals differed while they were in particular mine features inside the mine or outside the mine perimeter. This study was approved by the University of Arizona Institutional Animal Care and Use Committee (Protocol No. 03-104).

Results

We captured and radiocollared 3 sub-M, 5 ad-M, and 6 F bighorn sheep and observed their use of the mine from December 2003 to January 2005. We recorded 2,450, 1,912, and 7,066 minutes of mine use by sub-M, ad-M, and F bighorn sheep, respectively. We randomly selected and classified 486 point locations inside the mine perimeter. Bighorn sheep were mostly observed on desert islands (sub-M = 54%, ad-M= 76%, F = 54%) and highwalls (sub-M = 14%, ad-M <10%, F = 11%) during observations (Table 2). All other features were used <10% of the observations by feature. Desert islands (30%) and dump slopes (11%) were the most abundant features in the mine, with all other features nearly equally abundant (<10% each; Table 2).

We found individual differences in feature selection within all groups of bighorn sheep (sub-M: $x^2_{24} = 59.05$, 2-sided $P < 0.001$; ad-M: $x^2_{36} = 215.13$, 2-sided $P < 0.001$; F: $x^2_{60} = 269.53$, 2-sided $P < 0.001$). Despite individual differences within groups, we found groups of bighorn sheep using mine features disproportionately to their availability (sub-M: $x^2_{12} = 264.07$, 2-sided $P < 0.001$; ad-M: $x^2_{12} = 695.63$, 2-sided $P < 0.001$; F: $x^2_{12} = 520.72$, 2-sided $P < 0.001$).

No bighorn sheep used leach ponds, pit bottoms, tailings dump, or tailings dump slopes (Table 2). Subadult male bighorn sheep selected desert islands (95% CI for feature selection ratio = 1.51–2.24) and highwalls (95% CI for feature selection ratio = 2.38–2.84) and were neutral to the administration area, waste areas, waste dumps, haul roads, light roads, and dump slopes. We recorded no use of leach dumps by sub-M bighorn sheep. Adult male bighorn sheep selected desert islands (95% CI for feature selection ratio = 2.40–2.76) and were neutral to the administration area, waste areas, leach and waste dumps, haul and light roads, highwalls, and dump slopes. Female bighorn sheep selected desert islands (95% CI for feature selection ratio = 1.32–2.35) and highwalls (95% CI for feature selection ratio = 1.03–3.19) and were neutral to the administration area, waste areas, leach and waste dumps, haul and light roads, and dump slopes.

All groups of bighorn sheep selected desert islands, so we compared the behavior of bighorn sheep while on desert islands and outside the mine perimeter. We found no differences in the proportion of observations in each behavior by location (Table 3; feed: paired $t_{11} = 0.96$, 2-sided $P = 0.356$; bed: paired $t_{11} = -0.36$, 2-sided $P = 0.725$; stand: paired $t_{11} = -1.16$, 2-sided $P = 0.272$; alert: paired $t_{11} = 0.72$, 2-sided $P = 0.486$; interact: paired $t_{11} = 1.17$, 2-sided

Table 2. Availability of mine features and use by subadult male (sub-M), adult male (ad-M), and female (F) bighorn sheep in the Silver Bell Mine, Silver Bell Mountains, Arizona, USA, 2003–2005.

	Sub-M		Ad-M		F		Feature availability	
Mine feature	$\bar{x}$%	SE	$\bar{x}$%	SE	$\bar{x}$%	SE	$\bar{x}$%	SE
Administration	1.5	1.5	5.7	4.0	8.4	4.0	3.3	0.01
Waste area	6.3	1.9	3.3	2.5	3.1	1.1	8.4	0.01
Desert island	54.0	7.4	76.3	9.0	54.3	11.3	29.6	0.02
Leach dump	0.0		0.2	0.1	0.6	0.4	8.7	0.01
Waste dump	8.2	2.0	7.6	3.4	7.1	2.5	5.2	0.01
Haul road	2.2	2.2	0.6	0.4	4.6	1.7	7.6	0.01
Light road	7.2	3.0	1.6	0.7	6.9	1.2	4.4	0.01
Highwall	14.0	2.0	4.4	3.4	11.3	2.5	5.4	0.01
Dump slope	6.7	3.6	0.3	0.3	3.7	1.7	11.2	0.01
Leach pond	0.0		0.0		0.0		0.2	<0.01
Pit bottom	0.0		0.0		0.0		3.9	0.01
Tailings dump slope	0.0		0.0		0.0		1.2	0.01
Tailings	0.0		0.0		0.0		10.9	0.01

$P = 0.265$). We compared the behavior of sub-M and F bighorn sheep while on highwalls because those groups also selected for the highwall feature. We found no statistical differences in behavior of sub-M and F bighorn sheep between locations. We found sub-M and F bighorn sheep fed >2 times less, were alert >2 times less, and interacted 69% more while on highwalls than they did while outside the mine perimeter.

Discussion

There is a fundamental difference between mining techniques for coal and metals, which translates to differences in success of reclamation efforts to revegetate mined soils. Coal mining removes overburden (i.e., soil, rock) to access the coal deposit. The overburden is stored and later used to recontour the area (i.e., reclamation). Because this overburden is not treated, organic matter remains within the material, which subsequently provides nutrients for plant growth. However, metals are found within the parent material in varying concentrations. Depending on the process of mineral recovery (i.e., milling or electrolysis), parent material is either crushed into fine particles or sprayed with an acidic solution. Either process results in the absence of organic matter, which complicates revegetation. Lack of organic matter, coupled with low precipitation in desert areas, effectively thwarts most revegetation efforts on mines in desert regions.

Wild sheep used revegetated coal mines where grassland restoration was effective (Elliott and McKendrick 1984, MacCullum and Geist 1992). Bighorn sheep also used highwalls and other steep, rocky slopes (Elliott and McKendrick 1984, MacCullum and Geist 1992). We found similar use of a metal mine in a desert area, despite the lack of revegetated areas. The difference between the coal mines described by MacCullum and Geist (1992) and Elliott (1984) and the Silver Bell Mine was that the slopes with forage on the Silver Bell Mine were natural slopes unaffected by mining that occurred within the mining area, while foraging areas on the coal mines were reclaimed grasslands. The presence of forage in proximity to steep slopes apparently is an important requisite to bighorn sheep use of those areas. Desert islands in the Silver Bell Mine were the only mine feature that offered forage in similar quantity and diversity for bighorn sheep as available outside the mine.

Bighorn sheep in coal mines used the reclaimed grasslands near escape terrain for foraging and other daily activities (Elliott and McKendrick 1984, MacCullum and Geist 1992). Highwalls and other steep, rocky slopes were used for resting, interacting, and travel between areas (Elliott and McKendrick 1984, MacCullum and Geist 1992). We observed similar uses for desert islands and highwalls by bighorn sheep in our study.

Bighorn sheep do not use landscapes on and off mines differently (Oehler et al. 2005). Bighorn sheep habitat in non-mining areas has been characterized as areas with steep, rugged terrain in proximity to areas with low plant stature or density (i.e., high visibility) that provides adequate forage. Rugged terrain is used by bighorn sheep for security from predators and foraging areas for other daily activities (Valdez and Krausman 1999). These characters are present in mined areas where vegetated slopes are near steeply mined slopes.

Bighorn sheep exhibited similar behavior whether they were on desert islands in the mine or outside the mine, which would be expected given their increased use of the mine (Jansen 2005). However, some groups of bighorn sheep were less alert and interacted more while on highwalls. This may be explained by the lack of vegetation near highwalls simultaneously increasing visibility and decreasing potential ambush cover for predators. Oehler et al. (2005) found female bighorn sheep foraging less while on the mine than off. In general, bighorn sheep in our study behaved similarly in the presence of vehicles and blasting with explosives while on other mine features to those animals described by MacCullum and Geist (1992), with the exception that desert islands in our study area substituted for reclaimed grasslands of MacCullum and Geist (1992).

Table 3. Behavior of subadult male (sub-M), adult male (ad-M), and female (F) bighorn sheep on desert islands (DI) in the Silver Bell Mine and outside of the mine perimeter (NM) in the Silver Bell Mountains, Arizona, USA, 2003–2005.

			Feed		Bed		Stand		Alert		Interact	
	n	Location	$\bar{x}$%	SE	$\bar{x}$%	SE	$\bar{x}$%	SE	$\bar{x}$%	SE	$\bar{x}$%	SE
Sub-M	3	DI	24.6	7.1	41.1	7.7	27.3	2.5	1.0	0.8	3.6	0.4
Sub-M	3	NM	39.0	1.2	27.7	5.9	19.8	4.3	1.9	1.5	6.0	2.5
Ad-M	5	DI	17.1	3.6	39.3	10.2	36.8	6.7	2.1	1.6	1.7	0.3
Ad-M	4	NM	20.8	3.6	40.3	5.5	28.3	4.4	3.0	1.2	2.5	1.4
F	6	DI	28.3	2.5	37.1	4.8	28.4	4.4	1.8	0.4	0.5	0.1
F	5	NM	23.9	1.9	41.7	7.4	27.7	6.0	2.5	0.8	0.4	0.1

Management Implications

Our data supported our prediction that bighorn sheep would use features that offered similar characteristics to areas outside the mine. Bighorn sheep are capable of utilizing mining areas during all phases (i.e., operation, temporary closure, reclamation), if certain features exist. Features that provide forage (i.e., islands of native vegetation, reclaimed grasslands) must be present in proximity to escape terrain (i.e., highwalls, steep slopes). Thus, mining engineers should attempt to minimize destruction of those areas that provide forage, and reclamation plans should include maintenance of highwalls. We caution managers that specific or regional reclamation plans should not be generally applied across the distribution of wild sheep. For example, some deserts (e.g., Sonoran Desert) do not naturally have an abundant grass component (Turner and Brown 1994), which is reflected in the diets of bighorn sheep from those areas (Miller and Gaud 1989, Tarango et al. 2002). Therefore, reclaiming mined areas with grasses would not be as beneficial to bighorn sheep as reclaiming the area with native shrubs and trees in a similar quantity to areas not disturbed by mining. Likewise, reclaiming areas of the Rocky Mountains with shrubs and trees may not benefit bighorn sheep as much as designing native grasslands (Risenhoover and Bailey 1985, MacCullum and Geist 1992). Based on work by MacCullum and Geist (1992), Oehler et al. (2005), and this study, bighorn sheep can habituate to mining activity as long as areas of adequate forage near steep and rugged terrain exist. Although bighorn sheep habitat within a mine is disturbed, important habitat components still exist and human activity is likely predictable to bighorn sheep.

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Brian D. Jansen (left) earned his B.S. (2002) and M.S. (2005) degrees at the University of Arizona. His thesis research dealt with surface mining and desert bighorn sheep ecology. He also studied how a disease, infectious keratoconjunctivitis affected his study population of bighorn sheep. His wildlife research interests include the inter- and intraspecific relationships among large ungulates and large predators. He will be continuing his education by pursuing a doctorate at South Dakota State University in fall 2006, where he will be examining hunting mortality in a mountain lion population. ***Paul R. Krausman*** (center) is a professor of wildlife conservation and management at the University of Arizona, Tucson. His research and teaching interests include conservation and management of large mammals in arid environments. He is currently involved with the development of an M.S. course in wildlife and genetics at the University of Trás-os-Montes and Alto Douro, Vila Real, Portugal. He is the editor of Wildlife Monographs, former associate editor for the Wildlife Society Bulletin, and editor for the European Journal of Wildlife Research. He is also a Certified Wildlife Biologist. ***James R. Heffelfinger*** (right) is a Certified Wildlife Biologist with degrees from the University of Wisconsin-Stevens Point (B.S. 1986) and Texas A&M University-Kingsville (M.S. 1989). He has worked as a biologist for the federal government, state wildlife agencies, universities, and in the private sector in Texas, New Mexico, Mississippi, Wisconsin, North Dakota, and Arizona. He has authored or coauthored more than 100 scientific papers, book chapters, and popular articles in national and regional publications. He is the Secretary/Treasurer of the Southwest Section of The Wildlife Society and currently works as a Regional Game Specialist for the Arizona Game and Fish Department. ***James C. deVos Jr.*** (not pictured) is recently retired as Chief of Research at the Arizona Game and Fish Department and has been involved in research and management of wildlife in the Southwest for 31 years. His current conservation interests include methods to restore ecological function on coniferous forests and grasslands, developing methods to minimize impacts of highways on diverse wildlife species, and management of small and isolated wildlife populations.

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