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INFLUENCE OF MINING ON BEHAVIOR OF BIGHORN SHEEP

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ABSTRACT—Mining has been cited as detrimental to bighorn sheep (*Ovis canadensis*), but little research exists that has demonstrated those effects. We compared behavior of bighorn sheep while individuals were inside and outside of an active copper mine to determine if individual animals were altering their behavior relative to the active mine. We conducted this study in the Silver Bell Mountains, Arizona, from December 2003 to January 2005. We observed 3 radiocollared subadult males, 4 adult males, and 5 females, and recorded behavior throughout the daylight period. After accounting for differences by sex-age class (i.e., subadult male, adult male, female) and season (i.e., breeding, non-breeding), bighorn sheep fed less (6%) while inside the mine perimeter. Other behaviors (e.g., bedding, standing, alert, and interacting) were observed for similar amounts of time while within and outside the mine perimeter. Within sex-age classes, there were few differences in behavior. Subadult males fed less (mean $_{\text{difference}} = -18.6\%$, 95% C.I. = −43.1–6.0) and bedded more (mean $_{\text{difference}} = 14.3\%$, 95% C.I. = −40.9–69.4) while inside the mine. During the breeding season, adult males were alert less and interacted less (alert, mean $_{\text{difference}} = 4.1\%$, 95% C.I. = −1.63–9.9; interacting, mean $_{\text{difference}} = 3.1\%$, 95% C.I. = −5.7–11.9) while inside the mine. Females interacted more (mean $_{\text{difference}} = 0.37\%$; 95% C.I. = −0.01–0.8) while inside the mine area. Elements of modern mining activity (e.g., vehicular traffic, humans afoot near vehicles, sounds) might be predictable to bighorn sheep allowing them to habituate to those human activities.

RESUMEN—La explotación minera se ha considerado como perjudicial para los borregos cimarrón (*Ovis canadensis*), pero hay poca investigaciones que demuestren estos efectos. Comparamos el comportamiento de los borregos cimarrón mientras los individuos estaban dentro y fuera de una mina de cobre activa, para determinar si el comportamiento de animales individuales era alterado relativamente por la actividad de la mina. Conducimos este estudio en las montañas Silver Bell, Arizona, de Diciembre de 2003 a Enero de 2005. Observamos 3 machos sub-adultos, 4 machos adultos, y 5 hembras con radio-collares y registramos datos del comportamiento usando muestras de un animal central durante el período de luz en el día. Después de clasificar por sexo y edad (i.e., macho sub-adulto, macho adulto, hembra) y temporada (i.e., apareamiento, no-apareamiento), el borrego cimarron se alimento menos (6%) mientras estaba dentro de el perímetro de la mina. Otros comportamientos (e.g., acostado, parado, alerta, interactuando fueron observados por periodos similares dentro y fuera del perímetro de la mina. Entre el grupo de sexo y edad, hubieron pocas diferencias en el comportamiento de los borregos cimarrones dentro y fuera de la mina. Los sub-adultos machos se alimentaron menos (mean $_{\text{difference}} = -18.6\%$, el 95% C.I. = −43.1–6.0) y descansaron acostados más (mean $_{\text{difference}} = 14.3\%$, el 95% C.I. = −40.9–69.4) cuando estuvieron dentro de la mina. Durante la estación de apareamiento, los machos adultos estuvieron alerta e interactuaron menos (alerta, (mean $_{\text{difference}} = 4.1\%$, el 95% C.I. = −1.63–9.9; interacciones, (mean $_{\text{difference}} = 3.1\%$, el 95% C.I. = −5.7–11.9) durante el tiempo que estuvieron dentro de la mina. Las hembras interactuaron más (mean $_{\text{difference}} = 0.37\%$; el 95% C.I. = −0.01–0.8) durante el tiempo que estuvieron dentro del área de la mina. La actividad de la mina moderna (e.g., trafico vehicular, humanos a pie cerca de vehículos, ruidos) puede ser predecible para los borregos cimarrones, los cuales pueden habituarse a esas actividades humanas.

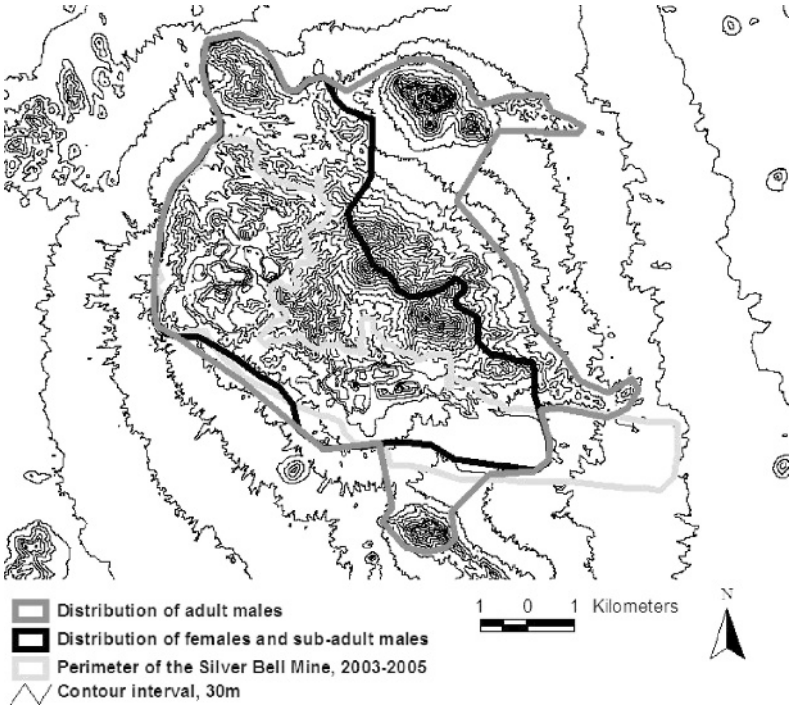

FIG. 1—Distribution of bighorn sheep (*Ovis Canadensis*) and the Silver Bell Mine in the Silver Bell Mountains, Arizona.

Resource extraction is a broad category of human activity that can have negative consequences for some species (Kuck et al., 1985; Hook, 1986; Dyer et al., 2001), but might benefit others (Elliot, 1984; MacCullum and Geist, 1992). Bighorn sheep (*Ovis canadensis*) are believed to be sensitive to human activity (Duncan, 1960; McCutcheon, 1981; MacArthur et al., 1982; Bleich et al., 1990; Krausman et al., 2001). However, several researchers have demonstrated that bighorn sheep can habituate to predictable and benign encounters with humans (Geist, 1971; Miller and Smith, 1985; Stanger et al., 1986; Papouchis et al., 2001). In some cases, bighorn sheep shift activity patterns in response to humans (Leslie and Douglas, 1979; Campbell and Remington, 1981), presumably to minimize encounters with humans.

We studied behavior of bighorn sheep that spent part of their time within an active mine. Our objective was to compare behavior of individuals while within an active mine and while outside the mine. Because we observed bighorn sheep spending more time within the mine when it was active than while it was closed (Jansen, 2005), we expected bighorn sheep would exhibit similar behaviors regardless of their location on or off the mine area.

METHODS—*Study Area*—The Silver Bell Mountains are a complex of peaks and ridges located in southern Arizona (111°30′W, 32°24′N; Fig. 1). Elevations range from 670 m in the northwest to 1,290 m at Silver Bell Peak. Vegetation was composed of the Arizona Upland subdivision of the Sonoran Desertscrub community and dominant plants included palo verde (*Cercidium microphyllum*), saguaro (*Carnegiea gigantea*), prickly pear (*Opuntia*), pincushion (*Mammillaria*), creosotebush (*Larrea tridentata*), triangle-leaf bursage (*Ambrosia deltoidea*), and jojoba (*Simmondsia chinensis*–Turner and Brown, 1994).

Climate in the Silver Bell Mountains was semi-arid. Average annual precipitation was 312 mm, with >50% falling July–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).

The Silver Bell Mine, operated by Asarco, was the dominant human activity within the area. Mining in the Silver Bell Mountains began in the 1890s and in 1904, >3,000 people were living within the range (Sherman and Sherman, 1969). Modern mining techniques (e.g., open-pits, milling, dump, and leach) began in the 1940s. The Silver Bell Mine was active continually until

it temporarily closed in 1984. Operation was resumed in 1996 and expanded from 19 km² to 26 km².

Bighorn sheep used 58 km² (including the 26 km² mine) of the Silver Bell Mountains during this study. Habitat occupied by bighorn sheep outside the mine perimeter had little human activity, which was limited to occasional hiking and hunting of bighorn sheep. We did not see any hikers during our extensive fieldwork outside the mine perimeter, but an informal sign-in can was found on top of Silver Bell Peak, indicating that some recreational hiking had occurred. Two hunters were permitted to harvest one bighorn sheep each during December 2003. Low levels of cattle grazing (e.g., 234 cattle were grazed each year over 2,442 ha, despite the stocking limit of 437 head) occurred along the lower limits of habitat occupied by bighorn sheep and activities related to law enforcement and illegal trafficking occurred in areas away from occupied habitat.

The population of bighorn sheep in the Silver Bell Mountains was estimated at 65–84 animals during the study. Large herbivores in the study area included mule deer (*Odocoileus hemionus*), collared peccary (*Pecari tajacu*), and domestic cattle. Potential predators of bighorn sheep were cougars (*Puma concolor*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and golden eagles (*Aquila chrysaetos*).

Data Collection—We studied behavior of bighorn sheep from December 2003 to January 2005. We captured and radiocollared males and females with a net-gun fired from a helicopter (Krausman et al., 1985). All radiocollared bighorn sheep were classified as subadult male (>6 mo–4 y), adult male (≥5 y), and female (≥2 y–Geist, 1971). We divided daylight into 3 periods (i.e., sunrise–1,000 h, 1,001–1,500 h, and 1,501 h–sunset) and systematically located each radiocollared animal to obtain an even distribution of sampling across the daylight period. We divided the annum into 2 seasons, breeding and non-breeding. The breeding season began on the mean date radiocollared animals were observed in mixed groups. Mixed groups contained adult males and females. The non-breeding season began on the mean date of the first observation of each radiocollared individual following the last observation of that individual in a mixed group.

We used focal-animal sampling (Altmann, 1974) to quantify behavior and recorded whether or not the individual was within the mine perimeter. We classified behaviors into 5 categories; feeding, bedding, standing, alert, and interacting. Alert behavior included alarm or attention postures (Geist, 1971) and interacting behaviors were recorded when an animal was directing an action at another individual (e.g., chase, copulating, or head-butting). We instantaneously sampled each radiocollared animal once every minute for 30 min or until they moved out of view. 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 ≥5 min.

Data Analysis—We summed the recorded counts for each behavior by individual and calculated the proportion of total observations for each behavior by individual. We examined behavior of bighorn sheep after accounting for any differences between sex-age classes and season. We also examined differences in behavior between inside and outside of mining areas by sex-age classes and among sex-age classes by season. We used a 3-factor ANOVA to determine the influence of the mine on behavior, in light of any sex-age class and seasonal differences in behavior. Because all radiocollared sheep spent time inside and outside the mine perimeter (Jansen, 2005), we used a paired *t*-test to test for differences in time spent in each behavior category by mine occupancy.

RESULTS—We recorded behavior of 3 subadult males, 4 adult males, and 5 female bighorn sheep, from December 2003 to January 2005. The non-breeding season was 12 January–11 July 2004, and the breeding season occurred 11 July–25 November 2004. Mean times of total observation for subadult males, adult males, and adult females inside the mine perimeter were 669 (*SE* = 312), 413 (*SE* = 233), and 1,068 min (*SE* = 194), respectively. Mean minutes of total observation for subadult males, adult males, and adult females outside the mine perimeter were 456 (*SE* = 81), 632 (*SE* = 200), and 478 min (*SE* = 145), respectively. Observation periods were terminated prematurely due to departure of focal animals from our field of view an average 25.2% (*SE* = 1.49) and 26.3% (*SE* = 2.86) while inside and outside the mine, respectively. Premature termination of observations did not differ by location (paired $t_{11} = 0.315$, 2-sided $P = 0.759$).

Behavioral Differences Despite Sex-Age Class or Season—After accounting for sex-age class and season, we observed bighorn sheep feeding during 20.4 (*SE* = 1.82) and 26.0% (*SE* = 1.82) of observations inside and outside the mine perimeter, respectively. Bighorn sheep were bedding during 40.2 (*SE* = 3.10) and 37.0% (*SE* = 3.10) of the observations inside and outside the mine perimeter, respectively, and standing during 30.3 (*SE* = 2.47) and 26.4% (*SE* = 2.47) of observations inside and outside the mine perimeter, respectively. Bighorn sheep were alert during 1.80 (*SE* = 0.55) and 2.65% (*SE* = 0.55) of observations inside and outside the mine perimeter, respectively. These sheep interacted during 2.77 (*SE* = 0.94) and 3.09% (*SE* = 0.94) of observations inside and outside the mine perimeter, respectively.

After accounting for sex-age class and season, bighorn sheep fed less while within the mine ($F_1 = 4.73$, 2-sided $P = 0.070$). Bighorn sheep were observed bedding ($F_1 = 0.533$, 2-sided $P = 0.938$), standing ($F_1 = 1.25$, 2-sided $P = 0.540$), alert ($F_1 = 1.10$, 2-sided $P = 0.558$), and

TABLE 1—Behavior of subadult male, adult male, and adult female bighorn sheep (*Ovis canadensis*) during the breeding and non-breeding seasons in the Silver Bell Mountains, Arizona, December 2003–January 2005; paired *t*-test (2-sided *P*).

	n	Season	Mean % feeding	Mean % bedding	Mean % standing	Mean % alert	Mean % interacting
Subadult males	3	Breeding	28.35	34.77	23.83	2.08	7.24
	3	Non-breeding	27.00	36.92	24.78	1.31	4.78
Paired *t*-test			−0.54 (0.63)	0.29 (0.79)	0.13 (0.90)	−0.54 (0.63)	−0.58 (0.60)
Adult males	4	Breeding	18.00	29.92*	37.06	4.00	4.83*
	4	Non-breeding	19.43	45.99*	27.31	2.50	0.51*
Paired *t*-test			0.54 (0.63)	2.92 (0.06)	−1.64 (0.20)	−0.68 (0.55)	−1.54 (0.22)
Adult females	5	Breeding	19.75	44.48	31.60	1.92	0.47
	5	Non-breeding	24.29	38.69	26.98	2.69	0.70
Paired *t*-test			1.08 (0.34)	−1.01 (0.37)	−1.01 (0.37)	0.68 (0.54)	1.72 (0.16)

* Indicates differences of ≥10% or ≥2 ×.

interacting (F_1 = 0.057, 2-sided P = 0.374) similarly while inside and outside of the mine perimeter.

Subadult Males—We detected no difference by season in time spent in each behavior by subadult males (Table 1); thus, we combined seasonal behavior data and tested for differences when they were inside or outside the mine area. Subadult males spent less time feeding while inside the mine than outside (mean $_{\text{difference}}$ = −18.55%, 95% C.I. = −43.11–6.00, paired t_2 = −3.25, 2-sided P = 0.083). Males fed 19% less and bedded 15% more on average while inside the mine when compared to outside of the mine throughout the year (Table 2). We did not find a difference in amount of time allocated to other behaviors on or off the mine (Table 2).

Adult Males—We detected suggestive evidence that some behaviors of adult males differed between seasons; we saw them bedding 16% less and interacting 9 times more on average during the breeding season than in the non-breeding season (Table 1). Because of these differences in seasonal behavior, we compared mine occupancy of adult males seasonally.

During the breeding season, we detected no difference in time spent feeding, bedding, standing, and interacting while inside or outside the mine perimeter (Table 3, 2-sided $P > 0.300$). However, we have some evidence that adult males were nearly 4 times more alert while outside the mine than inside the mine (paired t_3 = 2.28, 2-sided P = 0.107). Although statistical evidence was weak, adult males interacted 2

TABLE 2—Behavior of sub-adult male, adult male, and female bighorn sheep (*Ovis canadensis*) while inside and outside an active mine in the Silver Bell Mountains, Arizona, between December 2003 and January 2005. Paired *t*-test (2-sided *P*).

	n	Mine status	Mean % feed	Mean % bed	Mean % stand	Mean % alert	Mean % interact
Sub-adult male	3	Inside	20.49*	41.95*	19.77	0.89	5.56
	3	Outside	39.04*	27.66*	26.72	1.92	6.00
Paired *t*-test			−3.25 (0.08)	1.12 (0.38)	0.98 (0.43)	−0.57 (0.63)	−0.17 (0.88)
Adult male	4	Inside	15.00	41.95	35.79	2.15	1.26*
	4	Outside	20.83	40.33	28.34	2.98	2.49*
Paired *t*-test			−3.10 (0.05)	0.14 (0.90)	0.96 (0.41)	−0.46 (0.68)	−1.01 (0.39)
Female	5	Inside	24.19	38.57	28.33	2.24	0.74*
	5	Outside	23.85	41.72	27.70	2.51	0.37*
Paired *t*-test			0.06 (0.95)	−0.77 (0.48)	0.24 (0.82)	−0.26 (0.81)	2.71 (0.05)

* Indicates differences of ≥10% or ≥2 ×.

TABLE 3—Seasonal behavior adult male bighorn sheep (*Ovis canadensis*) while inside and outside an active mine in the Silver Bell Mountains, Arizona, between December 2003 and January 2005. Paired *t*-test (2-sided *P*).

Season	Mine status	Mean % feed	Mean % bed	Mean % stand	Mean % alert	Mean % interact
Breeding	Inside	15.70	34.43	39.62	1.41*	2.62*
	Outside	19.02	26.59	36.13	5.54*	5.71*
Paired *t*-test		0.65 (0.56)	−0.79 (0.49)	−0.75 (0.51)	2.28 (0.11)	1.13 (0.34)
Non-breeding	Inside	16.16	43.12	34.50*	2.70	0.55
	Outside	21.58	48.12	22.82*	2.22	0.46
Paired *t*-test		1.17 (0.33)	0.35 (0.75)	−1.20 (0.32)	−2.20 (0.85)	−0.46 (0.67)

* Indicates differences of ≥10 percentage points or ≥2 ×.

times more while outside the mine than inside (Table 3).

During the non-breeding season, we detected no difference in time spent in each behavior category while inside or outside the mine perimeter (Table 3, 2-sided $P > 0.300$), but we noted adult males standing 12% more while inside the mine than outside the mine.

Adult Females—We detected no seasonal difference in behavior of females (Table 1), so we combined seasonal behavioral data and tested for differences when they were inside and outside the mine. We found no difference in time spent feeding, bedding, standing, and alert between locations (Table 2, 2-sided $P > 0.480$). However, females interacted twice as often while inside the mine area (mean $_{\text{inside}} = 0.74\%$, mean $_{\text{outside}} = 0.37\%$, paired $t_4 = 2.71$, 2-sided $P = 0.054$).

DISCUSSION—Overall, behavior of bighorn sheep was similar in and outside the mining area. Bighorn sheep fed 6% less inside the mine than outside.

Females in a gold mine in California foraged less in the mine area than off during summer and autumn, but more during spring (Oehler et al., 2005). Oehler et al. (2005) suggested that females were spending more time being vigilant because of mine-caused disturbances, but we noted no difference in alertness of females associated with location.

Differences in behavior recorded by Oehler et al. (2005) and our study might be related to history of the mines. Bighorn sheep in California were studied during the first 3 y of mine operation within the mountain range, whereas the Silver Bell Mine has been operating at varying levels since the 1890s. Oehler et al. (2005) examined the first generations of bighorn sheep subjected to mining and we examined our population after many generations being subjected to mining activity. The general lack of behavioral differences could be expected because we documented that bighorn sheep increased their use of mining areas when mining activity resumed (Jansen, 2005).

Bighorn sheep can be sensitive to human activity (Hamilton et al., 1982; Krausman et al., 2001). However, bighorn sheep might not be affected by predictable human activities for which they have had time to adjust (Hicks and Elder, 1979; Miller and Smith, 1985; Stanger et al., 1986; Papouchis et al., 2001). There are few publications relating human activity and changes in behavioral patterns of bighorn sheep (Leslie and Douglas, 1979; Campbell and Remington, 1981; Stockwell et al., 1991; Oehler et al., 2005). In this study area, mining at the current levels does not seem to be detrimental to use of habitat or behavior by bighorn sheep (Jansen 2005).

The Arizona Game and Fish Department captured and handled all bighorn sheep according to protocol. T. W. Smith, D. M. Conrad, J. R. Heffelfinger, and C. R. Anderson assisted with captures. This study was approved by the University of Arizona Institutional Animal Care and Use Committee (Protocol 03-104). We thank D. Duncan, K. Arnold, and B. Stonehouse of the Silver Bell Mine who granted and facilitated access to the mine property. R. J. Steidl reviewed earlier drafts of the manuscript. Funding was provided by the Arizona Game and Fish Department Federal Aid in Wildlife Restoration W-78-R and Wildlife Conservation funds, Foundation of North American Wild Sheep, Desert Bighorn Council, Asarco Limited Liability Corporation, Pima County, Arizona Desert Bighorn Sheep Society, Coalition for Desert Protection, Bureau of Land Management, and the University of Arizona.

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