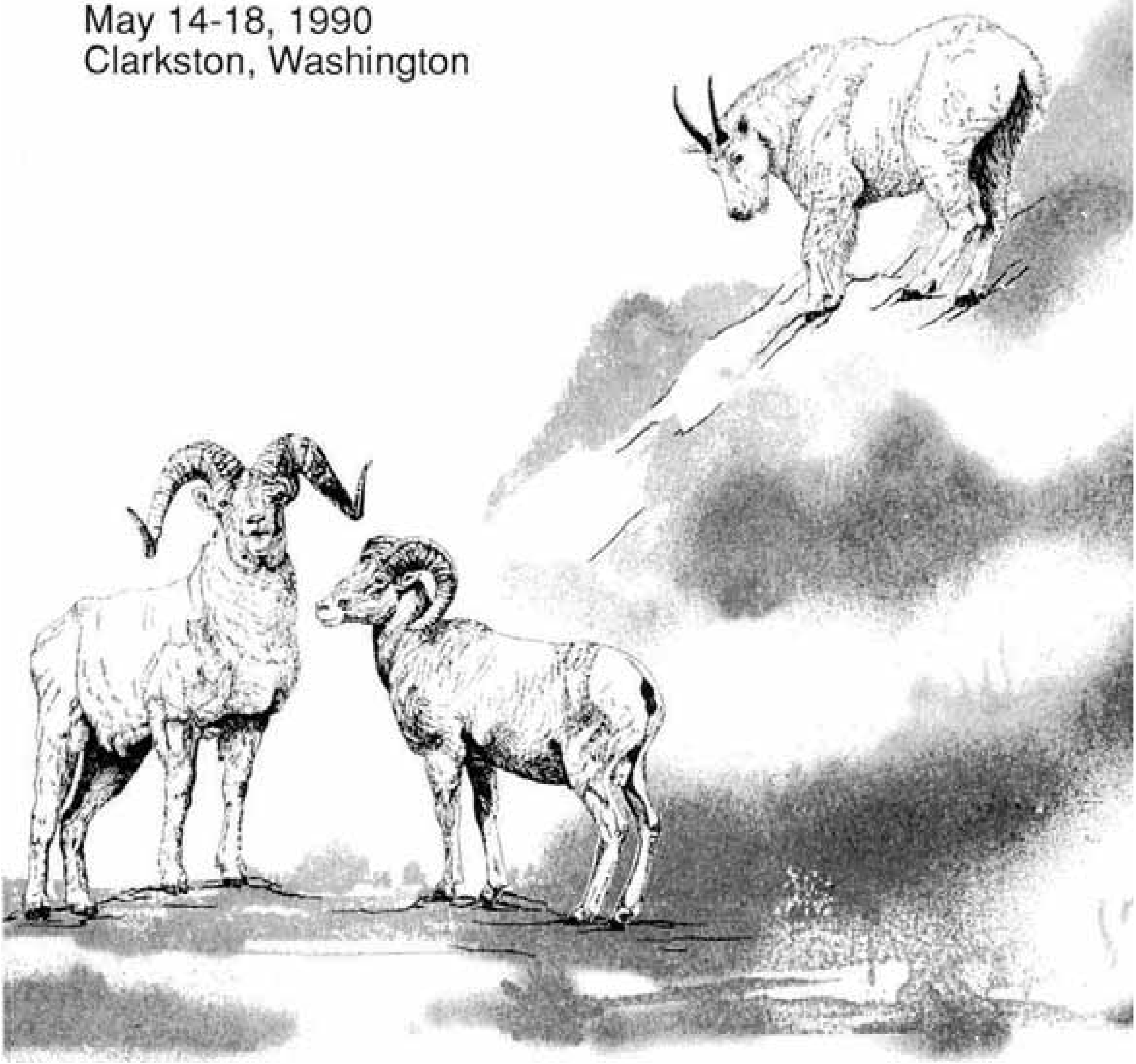
Northern Wild Sheep and Goat Council

Proceedings of the Seventh Biennial Symposium

May 14-18, 1990
Clarkston, Washington



FOREWORD

Papers in these proceedings were presented during the Seventh Biennial Symposium of the Northern Wild Sheep and Goat Council held May 14-18, 1990 at Clarkston, Washington. The Symposium was sponsored by the Idaho Department of Fish and Game, the Oregon Department of Fish and Wildlife, the Washington Department of Wildlife, and the Wallowa - Whitman National Forest. The Foundation for North American Wild Sheep, Cody, Wyoming, provided needed financial support.

These papers have been reviewed, but not refereed. Each manuscript was read critically by one or two peer biologists, and suggestions were submitted to each author. No papers were rejected based on peer review and final versions of all papers reflect the responses of the authors. This review process is designed to enhance the timely dissemination of useful information. However, the reader is responsible for critically evaluating the information she or he chooses to accept. This is always the responsibility of a professional biologist.

Thanks are extended to the following for reviewing manuscripts: L. Adams, W. Boyce, A. Cooperrider, M. Cunningham, D. Douglas, M. Dunbar, W. Foreyt, W. Heimer, K. Hurley, K. Keating, J. Lemos, M. Masteller, J. McCarthy, D. Onderka, J. Peek, D. Reed, W. Samuel, G. Schoonveld, K. Smith, T. Spraker, T. Thorne, E. Williams, W. Wishart and G. White. The Council thanks Wendy Haas, Encampment, Wyoming, for use of her sketches on the cover of this and previous proceedings and Nike' Goodson Stevens and L. Friis for illustrations in this proceedings.

NORTHERN WILD SHEEP AND GOAT COUNCIL

PROCEEDINGS OF THE SEVENTH BIENNIAL SYMPOSIUM

MAY 14 - 18, 1990

CLARKSTON, WASHINGTON

Edited by James A. Bailey

Northern Wild Sheep and Goat Council

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Northern Wild Sheep and Goat Council

The Northern Wild Sheep and Goat Council is a nonprofit professional organization, developed in 1978 from the parent organization - The Northern Wild Sheep Council.

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Bienn. Symp. North. Wild
Sheep and Goat Counc. 7:1-2.

RECOMMENDATIONS OF THE NORTHERN WILD SHEEP AND GOAT COUNCIL REGARDING PRIVATIZATION/OWNERSHIP OF WILD SHEEP AND GOATS IN NORTH AMERICA

The Northern Wild Sheep and Goat Council is one of two associations of professional biologists involved in wild sheep and goat management in North America. It consists of approximately 100 professional sheep and goat biologists as well as university faculty members and students of wild sheep and goats from Alaska, Alberta, British Columbia, Colorado, Idaho, Montana, North Dakota, the Northwest Territories, Oregon, South Dakota, Utah, Washington, Wyoming, and the Yukon Territory. Consequently, it represents the pooled expertise of northern wild sheep and goat managers and researchers throughout North America. The Council has assumed, as one of its functions, an advisory role on issues involving wild sheep and goat conservation and management.

In recent years, the sale of surplus wild sheep and goats by zoos and wild animal parks has provided increasing opportunity for individuals to purchase wild sheep and goats. Use of these animals on private preserves and game ranches brought this issue to the attention of the Council. After review and discussion of the available data, the following resolution was adopted by the Council at its 1990 meeting in Clarkston, Washington.

WHEREAS wildlife in North America has traditionally belonged to the public, and;

WHEREAS private ownership of wildlife has frequently lead to inappropriate and adverse public perceptions of hunting, unfair chase taking, inhumane treatment of wildlife, and trade in wildlife, and;

WHEREAS private ownership of wildlife provides opportunity for illegal commerce in wildlife parts, and;

WHEREAS commerce in wildlife without a uniform system of disease inspection has been shown to facilitate movement of non-native diseases and parasites, and;

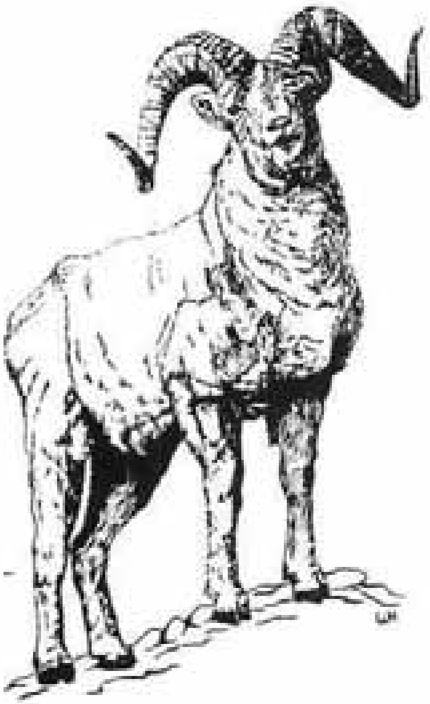
WHEREAS privately owned wildlife occasionally escape and therefore pose the threat of interbreeding and disruption of genetic integrity to native wildlife, and;

WHEREAS skillful, professional management of wildlife is required to assure its future in modern North America;

BE IT HERETOFORE RESOLVED that the Northern Wild Sheep and Goat Council strongly disapproves of private ownership of wild mountain sheep and goats, except by zoos certified by the American Association of Zoological Parks and Aquariums for the purposes of display and public education, protection and propagation of endangered species, and scientific study.

BE IT FURTHER RESOLVED THAT the Northern Wild Sheep and Goat Council strongly disapproves of exotic sheep and goat importation into States, Provinces, and Territories of North America which support native wild sheep and goat populations.

POPULATIONS AND MANAGEMENT



Bienn. Symp. North. Wild Sheep
and Goat Counc. 7:3-11.

POPULATION STATUS AND TRANSPLANTING HISTORY OF CALIFORNIA BIGHORN SHEEP IN OREGON

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Abstract: California bighorn sheep (Ovis canadensis californiana) were native to southeastern Oregon. The last original sheep was reported about 1915. In 1954, California bighorn sheep were reintroduced from British Columbia to Hart Mountain. Trapping of that herd for release in other native habitat has led to over 20 newly established herds with over 1,800 animals currently in Oregon. From 1960 to 1990, 444 sheep have been captured and transplanted to new locations. Hunting permits have been offered for 570 rams since 1965, with 411 being taken. Funds received from one bighorn sheep tag auctioned each year have helped finance transplant operations since 1987.

The California bighorn sheep are one of Oregon's premier big game species along with Rocky Mountain bighorns (Ovis canadensis canadensis). They are generally considered to be morphologically intermediate between the Rocky Mountain bighorn and the desert bighorn (Ovis canadensis nelsoni). Habitat occupied by the California subspecies is also intermediate to the Rocky Mountains and the Sonoran Desert.

The High Desert of southeast Oregon is prime habitat for the California bighorn sheep because of the prevalence of fault-block mountains and high lava plains. High elevation rimrock areas interspersed with shrub/bunchgrass benches provide both escape cover and forage.

This paper describes the history of the California bighorn sheep populations in Oregon and provides a record of transplanting during 1960-90 aimed at filling as many of the native habitats as possible.

ORIGINAL DISTRIBUTION

Most historic reports place the California bighorn's range throughout central and southeast Oregon from the Deschutes River Canyon near The Dalles, southward along the east side of the Cascade Mountains within the high desert land types to the California and Nevada borders (Fig. 1). The range extended east to the Idaho border and north to the Burnt River drainage south of Baker City. Some early accounts suggest that Burnt River and the Strawberry Mountains near John Day were inhabited by the Rocky Mountain bighorn. The Oregon Department of Fish and Wildlife has agreed with reports favoring California bighorns as the most likely subspecies for these 2 areas (Mace 1969).

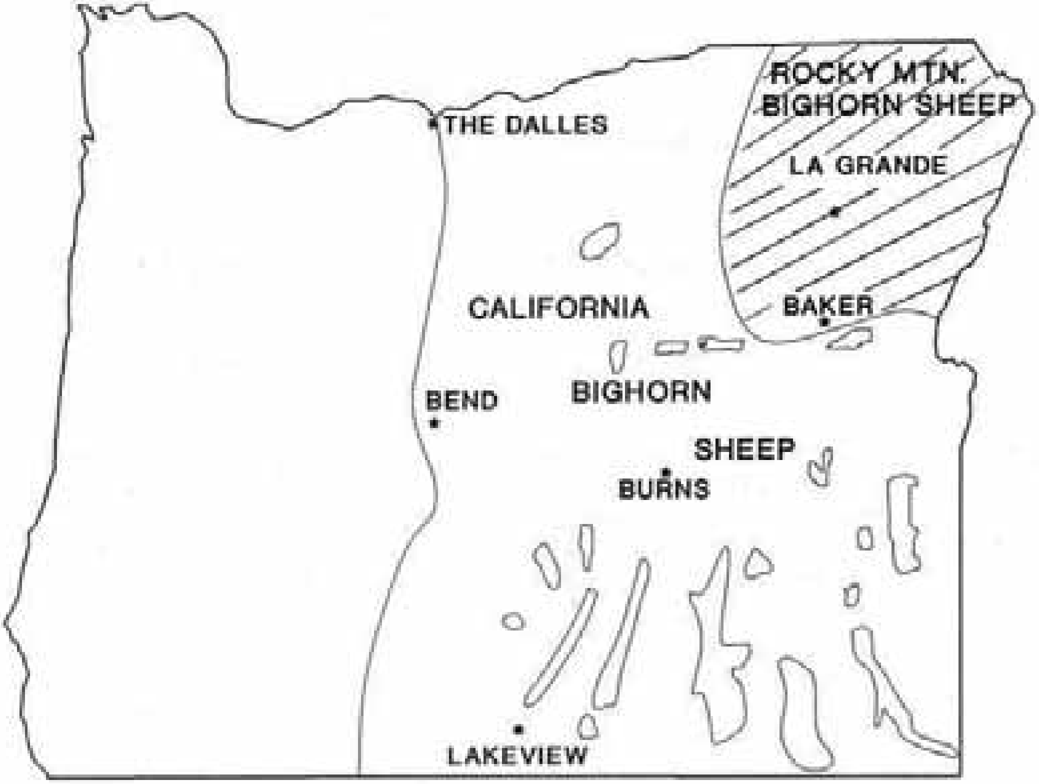

Fig. 1. Distribution of California bighorn sheep in Oregon

The Blue Mountains of Northeast Oregon are believed to have historically contained Rocky Mountain bighorns, so that subspecies has been reintroduced to native habitats in that region.

POPULATION HISTORY

The most reliable records of native bighorn sheep in Oregon indicate the last sheep disappeared about 1915 from the Steens Mountain. The last record for Hart Mountain was about 1912 (Mace 1969).

Several theories have been advanced to account for the extirpation of this subspecies from Oregon. Diseases from the huge flocks of domestic sheep that grazed the high desert at that time have been given credit for most of the decline. Winter loss due to livestock overgrazing of winter range and severe weather hastened the decline. Scabies mites supposedly caused loss of hair and increased mortality due to exposure during severe winters in the late 1800's. Certainly the unrestricted taking of bighorn sheep for meat and hides during this period aided the population decline that eventually led to complete loss of the subspecies from Oregon.

REINTRODUCTION

The idea of reintroducing bighorns to Oregon was originally presented to the U.S. Bureau of Biological Survey in 1936 by a supervisor of the Fremont National Forest, W. O. Harriman. With the aid of Stanley Jewett and Ira Gabrielson, 23 Rocky Mountain bighorns from the National Bison Range in Montana were released on Hart Mountain in 1939. Records show the introduction failed due to poor condition of the animals and habitat suspected unsuitable for the subspecies (Mace 1969).

Restoration of bighorn sheep to Oregon was still on the minds of some people, and in 1950 the Oregon State Game Commission negotiated with the British Columbia Game Department to obtain California bighorns. Release sites in Oregon were selected and the agreement finalized by 1954. The U.S. Fish and Wildlife Service offered Hart Mountain National Antelope Refuge as a release site where an enclosure could be built for protection of the herd.

On 4 November 1954 a successful trapping effort resulted in capture of 20 sheep near Williams Lake, B.C. The herd consisted of 1 ram, 12 ewes, and 7 lambs. They were released from a double-decked truck on 6 November 1954 within a 35-acre portion of the planned enclosure on Hart Mountain. The fence around the 600-acre enclosure was completed in July 1955 and the herd flourished within. In June 1957, 18 sheep from the enclosure were released on the west face of Hart Mountain as the first attempt to establish a free-ranging population in Oregon.

The Hart Mountain enclosure herd of California bighorn sheep was used as the source of animals for release to other native habitats in southeast Oregon through the 1960's. The fence was eventually removed during the early 1970's and further capture efforts for transplanting utilized free-ranging sheep.

TRANSPLANT HISTORY

During December 1960 through January 1990 444 California bighorn sheep have been captured in Oregon and released into other sites in Nevada, Washington, and Oregon. The largest number (375) was reintroduced to selected sites in Oregon. These sites were prioritized on the basis of native range characteristics believed to be most important to California bighorns. All sites are within the original range of the subspecies. Four California bighorn herds have served as capture sources for all sheep transplanted from Oregon (Table 1). Most sheep (364) have been trapped on Hart Mountain. Thirty-nine came from Leslie Gulch, 27 from Steens Mountain, and 14 from Aldrich Mountain.

Releases into 22 locations in Oregon have led to establishment of what is hoped will become 12-15 populations. Convergence of herds from individual transplant sites is beginning to form contiguous herd ranges covering larger areas of suitable habitat.

CAPTURE METHODOLOGY

Throughout the 30 years of bighorn transplanting, 4 capture methods have been used. Original attempts within the Hart Mountain enclosure utilized a corral trap into which sheep were herded by people on foot. The method was somewhat successful, so early attempts to capture free-ranging bighorns on Hart Mountain centered around the use of permanent corral traps. Subsequent efforts utilized a helicopter to haze the sheep into trap wings made of woven wire fencing. Some of these wings were several hundred yards long. Many attempts captured so few sheep that complete releases were not possible. However, periodic successes such as occurred in 1971 and 1983 (Table 1) kept this procedure high on the list of capture techniques.

Two events changed the direction and the success of bighorn sheep trapping in Oregon. These were: (1) cooperative capture projects with Nevada and California wildlife agencies; and (2) designation of a Governor's sheep tag to be auctioned annually to raise bighorn sheep management funds.

The direct effects of the cooperative projects were the introduction of Oregon personnel to 2 new techniques, and the realization that if funds were available, success was nearly always achieved. In January 1984, crews from Nevada, California, and Oregon first utilized the linear drive netting technique on bighorn sheep at Hart Mountain. A total of 21 sheep was captured and released at new locations in Nevada and Oregon. Close relationships were developed among personnel of each state and led to more extensive cooperative projects in 1987. In February 1987, 2 cooperative projects (Leslie Gulch and Hart Mountain) between Nevada and Oregon resulted in the successful release of 73 bighorns in the 2 states (Table 1). Linear drive netting was the original method of choice, but it was augmented by use of a Coda Netgun. Most equipment and funding was provided by Nevada in exchange for half the captured sheep. Oregon lacked the necessary equipment as well as funds, but had herds to use as sources of transplant stock.

The Oregon Legislature solved the monetary problems for the bighorn sheep program in 1987 when they approved a "Governor's Sheep Tag" to be auctioned annually. Proceeds of this auction went directly to the Oregon Department of Fish and Wildlife to be used for bighorn sheep management. Funds were used to purchase linear drive nets, netguns and accessories, and helicopter time for capture operations.

Oregon's trapping and transplanting success took a major leap forward. First, every sheep could go to a new site in Oregon, resulting in a 100% increase in bighorn sheep released in Oregon compared to prior cooperative ventures. Second, methods were available that virtually guaranteed success whenever a capture operation was attempted.

Linear drive netting and netgunning have emerged as the 2 dominant methods utilized by the Department for California bighorn sheep capture. Since first utilizing drive nets in 1984, 296 sheep have been transplanted using these 2 methods (Table 2). One hundred thirty-eight have been captured using drive nets and 153 with the netgun. During these capture efforts, 5 sheep were caught by hand as opportunities occurred.

In 1989 and 1990, the emphasis shifted to netgun capture. Some factors causing this shift were: (1) less manpower required; (2) long set-up time for drive nets; (3) netguns select specific individuals; and (4) more experience with the netgun made it more efficient.

Table 1. Summary of trapping and transplanting California bighorn sheep in Oregon.

Date	Capture Site	Release Site	Sheep No.
12/60	Hart Mtn.	Steens Mtn.	4
1/61	" "	" "	7
11/65	" "	Leslie Gulch	17
8/68	" "	Sheldon NWR (NV)	8
7&8/71	" "	Canyon Mtn.	21
11/75	" "	Abert Rim	3
12/76	" "	" "	2
12/76	" "	Pueblo Mtn.	16
1/77	" "	Abert Rim	5
2&3/78	" "	Aldrich Mtn.	14
11/80	" "	Pueblo Mtn.	7
11/80	" "	Fish Cr. Rim	2
12/81	" "	Aldrich Mtn.	4
10/83	" "	Pueblo Mtn.	17
10/83	" "	Iron Point	21
10/83	" "	Deary Pasture	14
1/84	" "	Hadley Cr.	8
1/84	" "	Jackson Mtn. (NV)	13
2/87	Leslie Gulch	Burnt River	15
2/87	" "	Jackson Mtn. (NV)	15
2/87	Hart Mtn.	Painted Canyon	15
2/87	" "	Riverside WMA	8
2/87	" "	Nevada (2 sites)	20
10/87	" "	Oregon Canyon	27
10/87	" "	Red Butte	16
1/88	Steens Mtn.	McClellan Mtn.	15
1/88	" "	Fish Cr. Rim	12
2/88	Leslie Gulch	Riverside WMA	9
2/89	Hart Mtn.	Thirty-Mile Cr.	14
2/89	" "	Coglin Buttes	16
2/89	" "	Home Cr.	17
1/90	Aldrich Mtn.	Washington (4 sites)	13
1/90	" "	Sheepshead Mtn.	1
1/90	Hart Mtn.	" "	15
1/90	" "	Cottonwood Cr.	14
1/90	" "	Whitehorse Cr.	19

Time spent in pursuit was higher with drivenetting than with netgunning. Stress levels and body temperatures were higher with the increased pursuit time inherent in drivenetting. Average sheep mortality has been 4.4% since 1984 when a majority of Oregon's bighorns have been captured (Table 3). Mortality by each method is within acceptable limits, but is under close scrutiny on all operations. Over the last 3 capture operations, close attention to monitoring stress, and better procedures for reducing it, have reduced losses to capture myopathy. Oregon's goal is to reduce capture-related mortalities to only those few "unavoidable accidents" that occur anytime big game animals are being restrained and handled by man.

Table 2. Number of California bighorn sheep captured by various methods in Oregon, 1984-1990.

Year	Capture technique			Total
	Drivenet	Netgun	Other	
1984	19	-	2	21
1987	88	32	-	120
1988	21	18	1	40
1989	10	37	2	49
1990	-	66	-	66
Total	138	153	5	296

Table 3. Comparison of capture-related mortalities occurring from 1984-1990.

Method	No. Captured	Mortality	
		No.	%
Drivenets	138	8	5.8
Netguns	153	6	3.9
Other	5	0	0.0
Total	296	14	4.4

CURRENT POPULATION STATUS

Field biologists estimate that the California bighorn herds in Oregon total 1,805 animals at the end of March 1990 (Table 4). The largest contiguous herd (425) is found on Hart Mountain. There are also 425 bighorns in the Owyhee River Canyon, but these 5 transplants have not yet merged into 1 population. The Steens Mountain herd of 250 sheep has been stable for almost 10 years. Some range expansion is being noted, but the core habitat maintains a stable population.

Of the more recently established herds, Aldrich Mountain and the Pueblo Mountain/Alvord Peaks populations have shown the greatest increases. The Pueblo/Alvord herd has established a migration pattern to a major winter range, and uses several widely separated summer ranges. The Abert/Alkali Rims herd appears to be more stable after a large initial increase. Dispersion to other locations may be occurring, however.

Considering the rate of increase of established herds, Oregon could easily have 3,000 California bighorn sheep by the year 2000. When all the native range is occupied a much higher population is expected.

HUNTING OPPORTUNITY

One original objective of reintroducing California bighorn sheep to Oregon was the potential for a few of the state's sportsmen to harvest a ram. The sportsmen were paying the bill through license fees for other species, so they should be allowed to benefit if sheep numbers reached the point where surplus rams were available. This dream became reality

Table 4. Estimated numbers of California bighorn sheep in Oregon, March 1990.

Herd	Pop. size
Hart Mtn.	425
Steens Mtn.	250
Owyhee	425
Strawberry Mtns.	15
Abert/Alkali Rims	135
Pueblos/Alvord	175
Aldrich Mtn.	150
Fish Cr. Rim	30
Hadley Cr.	30
Burnt River	30
Coglin Butte	20
Riverside	20
Lower John Day R.	20
E. Trout Cr. Mtns.	60
Sheepshead Mtns.	20
Total	1,805

in a relatively short time. In 1965, 11 years after the return of these sheep to Oregon, a hunt was authorized on Hart Mountain. There have been permits allocated for Hart Mountain in 23 of 25 years since 1965. In 1968, the first hunt was authorized for Steens Mountain. Hunts have occurred for 22 years in that area. The Leslie Gulch herd on the Owyhee River has had 17 hunts since 1973.

Five hundred seventy permits have been authorized in Oregon for California bighorn sheep and 411 rams have been harvested (Table 5). The herds on Hart Mountain, Steens Mountain, and Leslie Gulch have provided the bulk of the recreational opportunity, but newly established herds with great growth potential are currently entering the hunting picture as older rams become available. Hunting opportunity for 45 rams was offered on a permit basis in 1989.

Table 5. Harvest of California bighorn sheep in Oregon, 1965-1989.

Herd range	Ram harvest
Hart Mtn.	180
Steens Mtn.	125
Lower Owyhee	70
Warner	13
Aldrich Mtn	10
Pueblo/Alvord	5
Juniper	4
Upper Owyhee	2
Middle Owyhee	1
Strawberry	1
Total	411

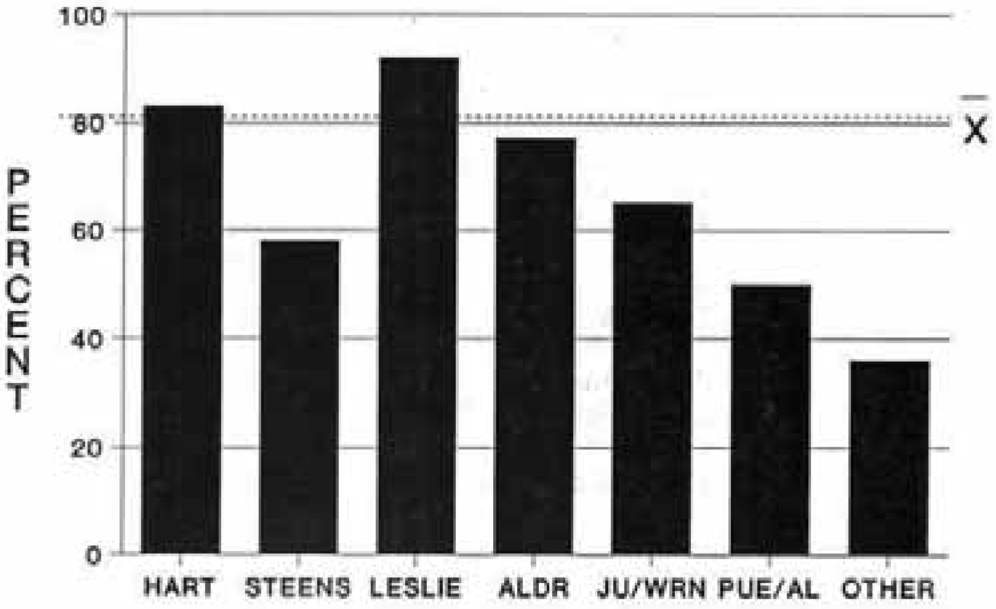

Fig. 2. Hunter success in Oregon for major California bighorn sheep herds, 1965-89.

Hunter success on the various hunt areas since 1965 has averaged 72% (Fig. 2). Leslie Gulch leads the list with 92%, Hart Mountain is second with 83%, and Aldrich Mountain is third at 77% hunter success. The ruggedness of terrain on Steens Mountain affects the ability of hunters to harvest rams on that escarpment. Only 58% success has been achieved for the 217 permits authorized to date. Success on the remaining hunts has generally been lower, evidently influenced by lower numbers of legal rams available in those hunt areas.

The size of California bighorn rams harvested in Oregon has been good for the subspecies. The largest Boone and Crocket score recorded to date (green horns) has been 175 5/8. All hunt areas have shown similar patterns of age classes and scores. The 125 rams taken on Steens Mountain averaged 150 3/8 points in size with ages ranging from 2 to 12 years (Fig. 3). Two of the smaller rams were taken as 1/2 curls during 1974 and 1975 when the minimum regulation was lowered to 1/2 curl or larger.

The best average Boone and Crocket scores were achieved on Steens Mountain when rams reached 10 years of age, an age class with little representation in harvest and in census. Only 9 rams have been taken over 9 years of age (Table 6). Under the current 3/4 curl harvest regulation, few 2-3 year old rams are taken, with the majority of the harvest comprised of 4-7 year old animals. It may be ill-advised for management to expect or attempt to produce large numbers of rams over 8 years of age.

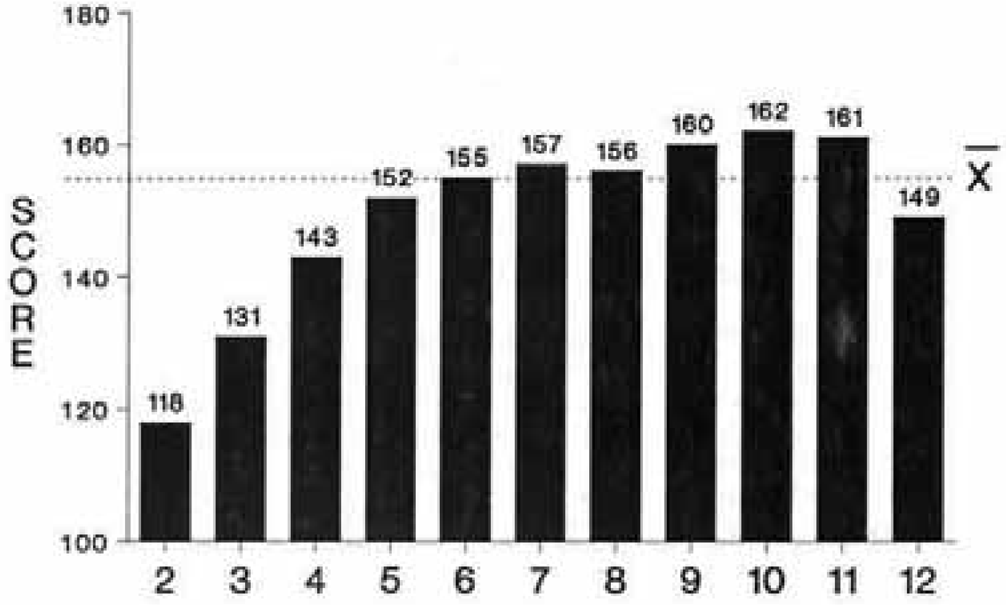

Fig. 3. Boone and Crocket scores in relation to age of 125 California bighorn rams from Steens Mountain, Oregon.

Table 6. Estimated age and Boone and Crocket scores for 125 California bighorn rams harvested on Steens Mountain, 1968-1989.

	Estimated age	No. harvested	Average B. & C. score
	2	3	118.0
	3	12	130.5
	4	21	143.1
	5	18	152.0
	6	22	155.3
	7	20	157.0
	8	13	155.8
	9	8	160.4
	10	5	162.3
	11	2	160.6
	12	2	149.2
Total		125	150.4

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Bienn. Symp. North. Wild Sheep
and Goat Counc. 7: 12-18.

STATUS AND DISTRIBUTION OF CALIFORNIA BIGHORN SHEEP IN IDAHO

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Abstract: Helicopter surveys and ground observations were used to estimate the distribution, population size and age and sex ratios of 4 reintroduced California bighorn sheep (*Ovis canadensis californiana*) populations in southwest Idaho. Between 1963 and 1966, 38 bighorns were translocated from the Chilcotin River area of British Columbia, Canada to the East Fork of the Owyhee River drainage. An additional 12 were moved to the Little Jacks Creek drainage in 1967. In 1989, the minimum population of California bighorns in Idaho was at least 1027 and the average population increase has been 12.5% per year. We estimate that bighorns are occupying 58% (681 km^2) of the available bighorn habitat. Bighorns from these herds have been used to establish 4 additional herds in Idaho, 3 in Nevada and 1 in Oregon. Variability of herd composition data is discussed.

Historically, California bighorn sheep were numerous throughout the mountains and canyon lands of southwest Idaho. Bailey (1936) stated that bighorn sheep occupied "every canyon, cliff, and lava butte in eastern Oregon". Because these habitats are contiguous with habitats in southwest Idaho, we assume sheep were equally numerous in Idaho south of the Snake River.

Historical and archeological evidence supports this conclusion (Hanna and Rath 1976). Bighorn populations were heavily exploited as food for miners, prospectors and homesteaders (Bailey 1936). Large numbers of cattle and domestic sheep grazed on and adjacent to bighorn habitats during a period of unrestricted livestock grazing between the 1860's and the 1930's, resulting in the elimination of California bighorn populations in Idaho. The last reported sighting of a California bighorn sheep occurred during the 1920's in the Owyhee River drainage (Hanna and Rath 1976).

Reduced livestock numbers and the resulting improved range conditions by the 1960's encouraged wildlife biologists and land managers to consider reintroducing California bighorns onto historic habitats in Owyhee County. Between 1963 and 1967, California bighorns were translocated from Chilcotin, British Columbia: 38 to the East Fork of the Owyhee River drainage and 12 to the Little Jacks Creek drainage.

In 1980, the Idaho Department of Fish and Game initiated an aggressive trapping and transplanting program designed to reintroduce bighorns into all suitable habitats. Between 1980 and 1990, 37 sheep were moved to 3 sites in Nevada and 111 to 4 sites in Idaho (Table 1). Sheep from Idaho herds were reintroduced into the Bruneau/Jarbidge, South Fork of the Owyhee, and Big Jacks Creek drainages in Owyhee County and the Cottonwood Creek drainage of Twin Falls County. Twenty-six bighorns were relocated from the Chilcotin area of British Columbia to 2 sites in Idaho during this period, 12 to the Bruneau/Jarbidge and 14 to Big Jacks Creek.

Table 1. Transplants of California bighorn sheep from Idaho by trapping site, release site and composition, 1980-1989.

Date	Trap Site	Release site	(N) Rams	Ewes	Total
03/80	Little Jacks	Granite Mtns. NV	1	4	5
02/81	Little Jacks	Jarbidge River, NV	3	9	12
12/82	East Fork Owyhee	Bruneau-Jarbidge	2	10	12
12/84	East Fork Owyhee	Bruneau-Jarbidge	2	9	11
01/85	Little Jacks	Bruneau-Jarbidge	1	0	1
01/85	Little Jacks	South Fork Owyhee	2	7	9
12/86	East Fork Owyhee	Snowcloud Mtns. NV	1	6	7
12/86	East Fork Owyhee	Cottonwood Cr.	4	11	15
12/87	Little Jacks	Cottonwood Cr.	3	8	11
03/88	East Fork Owyhee	Big Jacks Cr.	2	0	2
11/88	Little Jacks	Cottonwood Cr.	5	9	14
11/88	Little Jacks	Snowcloud Mtns. NV	2	11	13
11/88	East Fork Owyhee	Big Jacks Cr.	9	15	24
11/89	Little Jacks	Bruneau-Jarbidge	2	10	12

Hunting was initiated in 1969 and 133 rams have been harvested from the Little Jacks and East Fork of the Owyhee populations.

STUDY AREA

The study area is located in Owyhee County in southwest Idaho. Most of this area is a rolling plateau averaging 1,700 - 1,900 m in elevation. This plateau is sharply divided by several major drainages including

Little Jacks Creek, the Bruneau/Jarbidge River, East Fork of the Owyhee River and Big Jacks Creek (Fig. 1). Canyon walls along these drainages are composed of recent rhyolitic and basaltic materials and average 300 m high. These walls are typically step-like, with tiers of cliffs separated by small "benches" with shallow soils.

Vegetation typically consists of a variety of sagebrush (Artemisia spp.) communities. The few trees are primarily western juniper (Juniperus occidentalis) and mountain mahogany (Cercocarpus ledifolius) and usually occur singly and widely scattered . Willows (Salix spp.) occur in riparian areas. On the high plateau, Wyoming big sagebrush (Artemisia tridentata wyomingensis) dominates areas having moderately deep soils while low sagebrush (Artemisia arbuscula) dominates areas of shallow stony soils. Rabbitbrush (Chrysothamnus spp.) and plains pricklypear (Opuntia sp.) occur on disturbed sites. Common grasses include: cheatgrass brome (Bromus tectorum), bluebunch wheatgrass (Agropyron spicatum), Sandberg bluegrass (Poa sandbergii), and bottlebrush squirreltail (Sitanion hystrix).

METHODS

Helicopter surveys were conducted over all areas of known bighorn use during 1983, 1985, 1987 and 1990; additional surveys were conducted on the Little Jacks Creek population in 1988 and 1989. A Bell 206 III Jet Ranger or Hiller 12-E helicopter with 2 observers was flown on 65 m contours over all known, suspected or contiguous bighorn habitats. Survey methods were standardized for these flights, except that a stratified random sample survey (Scheaffer et al. 1979) was conducted in 1987 on the East Fork of the Owyhee herd, and the number of sheep in the units not flown was estimated. The areas surveyed increased as populations expanded or new populations were established. The recently introduced population in Cottonwood Creek was not surveyed.

Data recorded included location, total numbers and herd composition. All aerial observations of sheep were plotted on topographic maps. Use areas were determined by including all canyon areas where sheep were observed and the flats within 1 Km of these canyons. The amount of potential habitat was estimated by mapping canyon lands and adjacent flats within 1 Km that had topographic and vegetative characteristics similar to areas currently used by sheep.

RESULTS AND DISCUSSION

East Fork of the Owyhee Population

In 27 years since the initial transplant, the Owyhee River herd has increased steadily. During the 1990 survey, 607 sheep were observed (Table 2). The growth rate averaged approximately 11% per year.

Recent lamb:ewe ratios have been relatively high (0.50 to 0.57, Table 3). These ratios are comparable to the 0.50 lambs:ewe reported for the same population in 1975 (Hanna and Rath 1976). Ram:ewe ratios have been highly variable (0.37-0.90) The percentage of the population that was rams 3/4 curl or larger ranged from 6.3 to 13.5 and averaged 9.7. The average percentage of rams 3/4 curl or larger is comparable to that observed for a lightly hunted dall sheep population in Alaska (Heimer and Smith 1976).

The distribution of this population has increased from the initial transplant site in Battle Creek. Bighorns now occupy all the available habitat in the East Fork and South Fork drainages except for the upper portions of the South Fork and it's tributary, the Little Owyhee River north of the Nevada border (Fig.1). Bighorns are currently using 211 km^2 (89%) of the 238 km^2 of available habitat with an estimated density of 2.9 sheep per km^2. The currently used range extends along 56 km of the East Fork of the Owyhee River from the Duck Valley Indian Reservation to the Oregon border. The Oregon Department of Fish and Wildlife estimates that this population has expanded another 55 km down the East Fork and number about 75 animals in Oregon (Bill Olson pers. comm.).

Hanna and Rath (1976) reported that by 1975, the Owyhee River herd had stabilized at a population of 275 animals and that the population was slow in expanding it's range. Our information shows that the herd has continued to increase and has rapidly expanded it's range.

Little Jacks Creek

The Little Jacks Creek herd has increased from the initial transplant of 12 animals to an observed minimum population of 208 sheep (Table 3). The average yearly growth rate (14.3%) was higher than that observed for the Owyhee River population.

Observed lamb:ewe ratios have been more variable than those observed for the Owyhee River herd and ranged from 0.34 to 0.58 (Table 3). Ram:ewe ratios were highly variable ranging from 0.26 to 1.3 (Table 3). Three-quarter curl and larger rams made up an average of 12.2% of the population and approached the 15% reported by Heimer and Smith (1976) for unhunted dall sheep herds in Alaska.

Table 2. Helicopter census results for the Owyhee River Herd, Idaho, 1983-1990 and herd composition.

Date	(N)	Rams:100 Ewes:Lambs[a]	%≥ 3/4 Curl
8/83	334	90:100:56	37
11/85	273	63:100:57	22
8/87	329 (397)[b]	85:100:50	32
6/90	607	37:100:55	39

a. Males and females ≥ than 1 year of age included as adults.
b. Estimate based on random stratified sampling procedure.

Table 3. Helicopter census results for the Little Jacks Creek Herd, Idaho, 1983-1990.

Date	(N)	Rams:100 Ewes:Lambs[a]	%>3/4 Curl
9/83	115	74:100:53	3
8/85	85	130:100:53	33
11/85	96	95:100:45	42
6/87	184	61:100:58	49
8/87	164	26:100:34	30
6/88	184	112:100:34	32
6/89	205	50:100:43	40
6/90	208	111:100:50	38

a. Males and females ≥ 1 year of age included as adults.

This population has not expanded it's range at the same rate as the Owyhee River herd. The observed distribution was similar between the 1983 and 1990 surveys but the density increased from 0.68 to 1.2 sheep per km^2 (Table 4). Although a large amount of suitable habitat was located in the adjacent Big Jacks Creek drainage no expansion of use was documented. In 2 locations these habitat areas are within 1.6 km of each other. In 1988 bighorns were reintroduced into Big Jacks Creek and within 4 months movements of radio collared sheep were documented between the 2 populations. Bighorns currently occupy 169 km^2 of habitat at a density of 1.2 sheep per km^2. The adjacent areas of Big Jacks Creek to the east and Castle Creek to the west provide approximately 400 km^2 of additional habitat for expansion.

Recent Introductions

The recently introduced Bruneau/Jarbidge (1980) and Big Jacks Creek herds (1988) were added to the survey schedule in 1990. Eighty-four bighorns were observed in the Bruneau/Jarbidge drainage and 38 in Big Jacks Creek. The Bruneau/Jarbidge herd currently uses 135 km^2 of the 278 km^2 of available habitat. The Big Jacks Creek herd has a potential habitat area of 166 km^2 but observations have been insufficient to estimate the current use area.

Table 4. Minimum population and density estimates for California bighorn sheep in Idaho, 1990.

Population	Minimum # Observed (N)	Occupied Habitat (km^2)	Minimum Density/km^2
East Fork of Owyhee	607	211	2.90
Little Jacks Creek	208	169	1.20
Bruneau/ Jarbidge	84	135	0.62
Big Jacks Creek	38	166	0.23
Total	1027[a]	681	1.36

a. Includes an estimate of 50 sheep in the Cottonwood Creek herd and 50 sheep transient in Owyhee County.

The Cottonwood Creek population in Twin Falls County is estimated at 50 animals (Craig Kvale pers. comm.) but has not been added to the survey schedule. The status of this herd has not been determined.

Idaho Department of Fish and Game Region III personnel estimate that an additional 50 sheep are transient animals in the mountainous portion of Owyhee County (Charles Harris pers. comm.).

Herd Composition

The wide ranges of observed ram:ewe and lamb:ewe ratios probably resulted from sampling biases rather than actual changes in herd composition. Rams were more visible when on the flats than when in the canyon lands. Ram use of the flat areas above the canyons was highest during the spring green up period (Bodie et al. 1989). Rams were the least visible when using the highly dissected cliffs. The high variability in ram:ewe ratios and the percentage of rams 3/4 curl or larger limits the usefulness of these data in assessing the effects of hunting on these populations.

Ewes and lambs were more difficult to observe during the spring period than at other times of the year due to pre- and post- natal behavior. Ewes selected the highly dissected cliffs for lambing and for a period of 4 - 5 weeks after parturition until the lambs were of sufficient size to keep up with the ewes. If surveys are conducted during this period +-some lambs will be missed. During some years the previous year's ram lambs were at a stage of horn growth that made them difficult to distinguish from ewes. These factors tended to overestimate ram:ewe ratios and underestimate lamb:ewe ratios.

The average number of rams observed on surveys was highest during the spring but was still highly variable and short term trends in ram numbers were difficult to document. A more accurate and precise methodology for estimating population trends and herd composition is needed.

The Idaho California bighorn sheep reintroduction program has been extremely successful with populations increasing at an minimum average yearly rate of 11%. It appears that there is sufficient habitat available to allow the Owyhee County herds to expand their range and increase their populations.

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POPULATION DYNAMICS OF TWO TRANSPLANTED BIGHORN SHEEP HERDS IN SOUTHCENTRAL WYOMING

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Abstract: Success of transplanting Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) herds in Wyoming has been limited. A goal of this study was to identify reproductive and mortality patterns contributing to poor population performance in 2 transplanted herds in Wyoming. After release in the 1970s, both herds rapidly increased during the first 6-10 years, subsequently declined, and currently appear to be stable, but at levels potentially predisposing to long-term losses in genetic heterozygosity. During this study (1986-88), high mortality of lambs restricted population growth. Approximately 55% of lambs died each year, resulting in 22 lambs/100 adult ewes after winter. Most lamb mortality (75%) occurred during late summer and fall, with relatively little occurring during winter. Diseases were proximate causes for most lamb deaths. Mortality of adult ewes was low; only 2 of 18 radio-marked ewes died. Birth rates and lamb survival declined substantially after the initial phase of population growth in the 1970s, and these changes appear responsible for population declines and current herd stagnation. Population trends are consistent with classical density-dependent population regulation via limited food resources for ungulates that are released into largely unexploited and restricted habitats.

Transplanting frequently has been used to establish new herds of bighorn sheep in the central and northcentral Rocky Mountains. Sufficient time (15-30 years) has elapsed to assess many transplanting efforts, and results are not particularly encouraging (Bailey 1988, Smith and Butler 1988, Risenhoover et al. 1988). In Wyoming, most transplanted populations remain

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small and have poor reproductive success, potentially predisposing to reductions in genetic heterozygosity and inbreeding depression (Cook 1990).

We began studies in 1986 to identify factors that contributed to the poor population performance of 2 transplanted herds in southcentral Wyoming. Population history for each is typical of other herds introduced throughout the state. One herd is considered to be relatively successful, whereas the other suffered severe declines, requiring a supplemental release of 19 sheep in 1989. In this paper, we describe population dynamics of these 2 herds during 1986-88, and describe long-term population dynamics from herd establishment through 1988.

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DESCRIPTION OF STUDY AREAS

The 2 herds in this study were established by transplanting on ranges that historically supported bighorns (Haas 1979). Transplant stock for both releases came from the Whiskey Mountain herd near Dubois, Wyoming. Forty-one sheep were released in the North Platte River Canyon in 1971. This herd subsequently separated into 3 subherds, 1 at Bennett Peak (BP), a second near the A Bar A Ranch, and a third at Douglas Creek (DC). The second herd resulted from a release of 69 sheep in the Encampment River Canyon (ENC) in 1976 (Haas 1979, Cook 1990).

Sheep occurred on ranges that primarily supported big sagebrush/antelope bitterbrush (Artemisia tridentata/Purshia tridentata) communities. Important, but less common communities included juniper (Juniperus spp.) on xeric, rocky sites; aspen (Populus tremuloides), Douglas-fir (Pseudotsuga menziesii), or lodgepole pine (Pinus contorta) forests on more mesic sites; and grass-dominated communities on windblown ridges. Sheep occupied steep, V-shaped canyons along the North Platte and Encampment Rivers. Elevations ranged from 2230 m to 2800 m. Annual precipitation averaged about 30 cm at lower elevations but exceeded 40 cm at higher elevations. Temperatures ranged from over 26 C in summer to below -30 C in winter, with an average annual temperature of 3 C (Haas 1979, Cook 1990).

METHODS

Population dynamics were evaluated by repetitive sampling to estimate numbers of sheep in sex and age classes and to identify changes in sex/age composition through time. Sex/age composition was determined for all groups of sheep encountered while searching for 20 radio-marked adult sheep. During most of the study, we located each marked sheep at least 10 times monthly. This approach resulted in visual observations of 1/2 to 3/4 of the sheep within a subherd each sampling day, and approximated a complete census over a season.

Sheep were classified based on the following sex/age categories: (1) adult males and females, at least 2 years-old; (2) yearling males and females, ranging from 13-24 months; and (3) lambs, less than 13 months old. We classified adult rams based on horn size as described by Geist (1971). Because rams occupied ranges away from ewes in most seasons, we estimated numbers of rams and ram:adult ewe ratios from data collected in December only, when ram numbers peaked on ranges occupied by ewes.

We estimated the number of animals in each sex and age class based on single-day counts of sheep when confident that no groups of sheep were double-counted. The highest counts during a season provided the best estimate of total sheep in each sex/age category for the season. Summing these categories provided a minimum estimate of total population size. Estimates of annual juvenile mortality were calculated by dividing the number of lambs dying at the end of their first spring by number of lambs born. A conservative estimate of birth rates was derived from mid-June through mid-July lamb:adult ewe ratios. Birth, death, and lamb:adult ewe estimates were multiplied by 100 and presented as percentages.

Population data prior to this study were obtained from the Wyoming Game and Fish Department's (WGFD) annual job completion reports and from Haas (1979). Annual juvenile mortality was estimated by dividing post-season lamb:adult ewe ratios by pre-season lamb:adult ewe ratios. The WGFD generally collected pre-season data during summer and post-season data in early winter to early spring (B. Rudd, pers. commun.). Linear regression analyses were used to detect significant trends in population characteristics.

RESULTS

Pre-study Population Dynamics

The North Platte herd was established with 17 ewes, 3 rams, and 21 lambs in winter, 1970-71. WGFD estimated 200 sheep were present by 1976, suggesting an annual rate of increase of about 30%. However, Muchmore (1975) reported an annual rate of increase of 13% during the first 4 years after release. By 1979, WGFD indicated 300-350 sheep were present. But this estimate was reduced to 160 sheep with development of a ONEPOP simulation model in the early 1980s. Although these records are inconsistent, WGFD personnel who have monitored this herd since the late 1970s believe there were 50-100 more sheep present in 1979-1981 than today (J. Bohne, pers. commun.). Thus, the herd apparently increased from 41 to about 200 sheep in 1980 and declined to about 130-140 sheep by 1986. This suggests an increase of about 20% per year during the 1970s, and a decline of 5% per year between 1980 and 1986.

The Encampment herd was established with 30 ewes, 8 rams, and 31 lambs in 1976-77. This herd increased to 85 the first 2.5 years (Haas 1979) and apparently peaked at 120 in 1983 based on WGFD ONEPOP simulation modeling, an increase of 10-15% per year. The herd decreased to about 45 sheep by 1986. This suggests a rate of decline averaging 30% per year, but the decline may have been precipitous based on sketchy information.

Initiation of declines in both herds apparently coincided with severe winters. Moderate mortality was suspected during the severe winter of 1978-79 in the North Platte herd, with reduced recruitment of lambs since then. Possibly substantial mortality occurred in the Encampment herd during the severe winter of 1983-84, and lamb recruitment also was reduced in subsequent years (J. Bohne, pers. commun.).

Lamb:ewe ratios for both herds suggest substantial changes in birth and mortality rates since 1972 (Fig. 1). Percentages of ewes with lambs in early to mid-summer declined from about 80 to 46% in the North Platte herd, and declined from 70 to 42% in the Encampment herd. Lamb mortality increased from about 20% [including 1976 mortality estimates from Haas (1979)] to 53%. Mortality could not be estimated during the first 10 years of the North Platte herd, but estimates of mortality were high (50%) and roughly constant during the last 9 years (Fig. 1).

Current Population Characteristics

Numbers of adult ewes ranged between 20 and 30 in each subherd during most years of the study (Table 1). Numbers of yearlings ranged between 5 and 10 at DC and 2 to 9 in the other subherds. We estimated 8 adult rams each at DC and A Bar A, 5 at BP, and 7 at ENC, with data pooled among years. About 14, 48, 20, and 18% of adult rams were class I, II, III, and IV, respectively.

We estimated the average minimum population at about 105 yearling and adult sheep in the North Platte herd and 38 yearling and adult sheep in the Encampment herd during 1986-88. Although 3 years' population data may be insufficient to determine population trends, data suggest numbers of adult ewes declined at A Bar A and BP and increased at DC and ENC (Table 1). There was a net loss of about 5 adult ewes and a net gain of 2 adult ewes in the North Platte herd and Encampment herds, respectively. This evidence suggests the herds were either declining slightly or approximately stable.

Lamb production and mortality varied among years and subherds (Table 2). Birth rates averaged 50%, but ranged from 32% at A Bar A, about 47% at BP and ENC, to 75% at DC. Lamb mortality averaged 55% during 1986-88, ranging from 26% at DC to 80% at BP. Lamb:adult ewe ratios averaged nearly 50% just after lambing, but declined to 22% by the following spring.

Four periods of rapid mortality were documented, with the majority of this mortality occurring from mid-July through November. In addition, most lambs born at ENC in 1986 died by the following spring, but no data were collected between August and the next spring, so timing of mortality was not determined. During the 3 years of study, 61 of 141 lambs born died before their first winter (43% pre-winter mortality). Significant lamb mortality also occurred during several winters, particularly at A Bar A and BP. Of 80 lambs alive before winter, approximately 16 died during winter (11% of all lambs born).

Mortality of adult ewes was low. Two of 18 radio-collared adult ewes died. Radio-marked ewes were monitored an average of 2.1 years, suggesting that about 5% of adult ewes, or 5 ewes in both herds combined, died each year. However, there were 10-12 yearling ewes produced each year (Table 1).

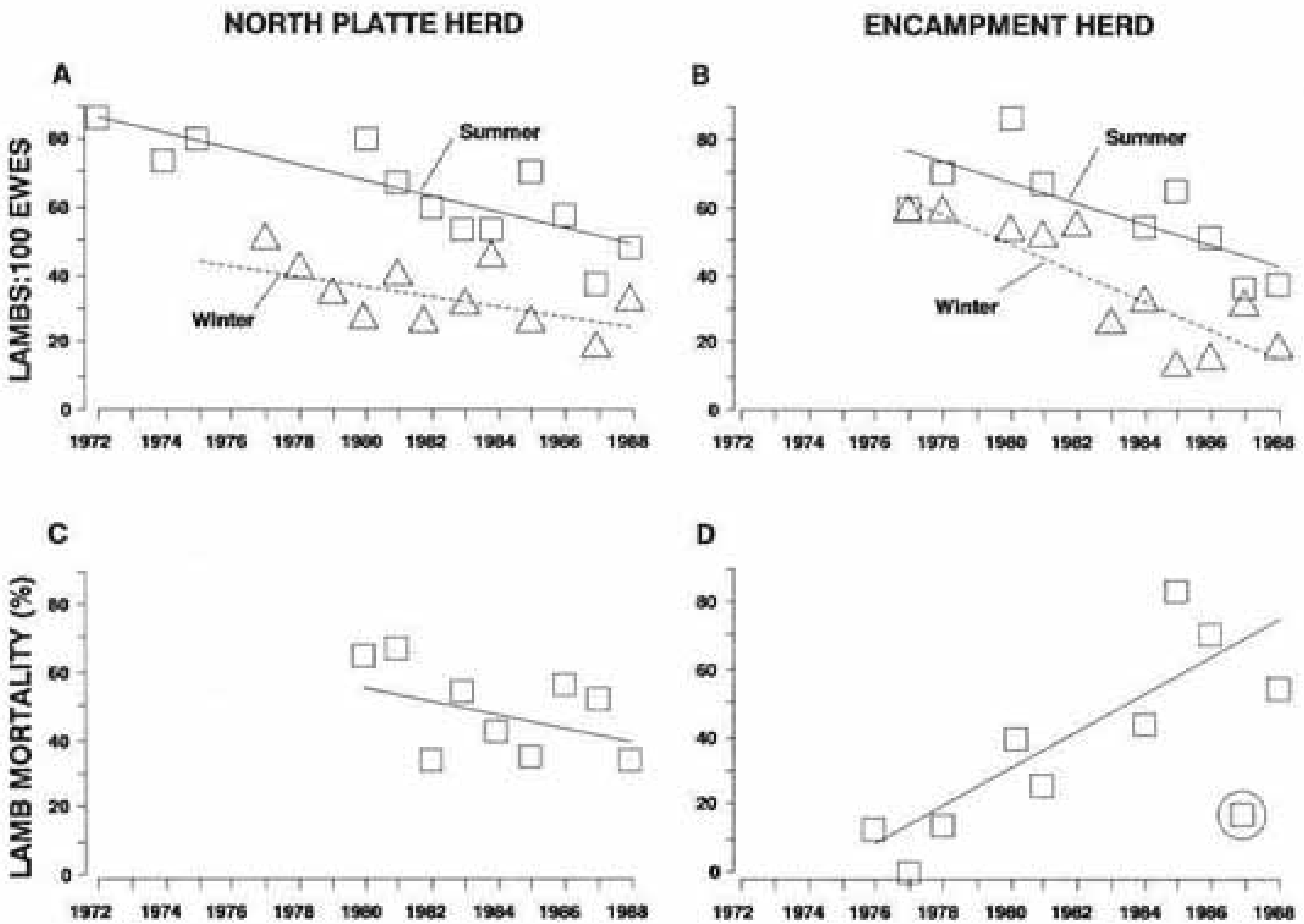

Figure 1. Summer and winter lamb:ewe ratios for the North Platte (A) and Encampment herds (B), and lamb mortality rates (winter lamb ratios/summer lamb ratios x 100) for the North Platte (C) and Encampment herds (D). Summer and winter lamb:ewe ratios in both herds were significantly ($P < 0.05$), inversely correlated to year. Lamb mortality rates were significantly correlated to year at Encampment (with or without the circled outlier), but were uncorrelated ($P > 0.05$) to year in the North Platte herd.

Table 1. Minimum, non-repetitive estimates of sheep in each sex and age class (except adult rams) at Douglas Creek, A Bar A, Bennett Peak, and Encampment, 1986-88.

Year	Adult ewes	Yearling ewes	Yearling rams	Summer lambs	Spring[a] lambs
			Douglas Creek		
1986	19	6	2	12	11
1987	23	6	4	19	6
1988	21	4	1	13	12
			A Bar A		
1986	25	2	4	15	4
1987	28	0	1	2	1
1988	23	1	1	8	5
			Bennett Peak		
1986	27	2	6[b]	15	1
1987	26	1	1	10	5
1988	22	2	0	12	2
			Encampment		
1986	26	0	2	13	4
1987	26	2	1	10	9
1988	28	5	4	11	5

[a] Spring lambs are those that survived their first winter.

[b] These 6 yearling rams were probably not born at Bennett Peak. This group of 6 was observed together in late winter 1986-87 at Bennett Peak and most were observed several weeks later at A Bar A.

Table 2. Minimum, non-repetitive estimates of lamb numbers just after lambing (post-lambing), pre-winter, and post-winter (April), 1986-88.

Year	Season	Douglas Creek	A Bar A	Bennett Peak	Encampment
1986	Post-winter	10	7	5	-
1986	Post-lambing	13	15	15	13
1986	Pre-winter	11	7	3	7
1987	Post-winter	11	4	1	4
1987	Post-lambing	19	2	10	10
1987	Pre-winter	7	1	9	9
1988	Post-winter	6	1	5	9
1988	Post-lambing	13	8	12	11
1988	Pre-winter	13	7	2	5
1989	Post-winter	12	5	2	5[a]

[a] One of these 5 lambs died in April due to a broken leg.

This suggests actual adult ewe mortality averaged about 10% per year, assuming high survival of yearling ewes and a stable population.

DISCUSSION

The Encampment and North Platte herds have been typical of populations that were introduced into largely unexploited habitats (Caughley 1970, 1976). After a single eruptive oscillation, both herds stabilized at levels apparently in equilibrium with forage resources. The North Platte herd increased about 5-fold and the Encampment herd increased about 2-fold before declining.

Marginal production and high mortality of lambs are the most important proximate mechanisms currently restricting both herds. Lamb mortality averaging 55% resulted in 22 lambs per 100 adult ewes after winter. Thorne et al. (1979) indicated 8-36 lambs per 100 ewes may result in declining populations. Festa-Bianchet (1987) reported an Alberta population increased when lamb survival to weaning varied from 51-87% and October-May lamb survival averaged between 80-100%. Geist (1971) identified lamb mortality of 55% in a declining population in Alberta. Moreover, our estimates of lamb:ewe ratios are low compared to other herds in Wyoming (Oldemeyer et al. 1971, Thorne et al. 1979, Hurley 1985, Smith 1988), Colorado (Streeter 1969, Baumann 1978), and Montana (Erickson 1972, Brown 1974, Pallister 1974); their winter/spring estimates of lamb:ewe ratios ranged from 34 to 77%.

Declines in birth rates and lamb survival (Fig. 1) after introduction are consistent with classical density-dependent population theory (Caughley 1979, Caughley and Krebs 1983). As herbivore density increases, intraspecific competition would reduce forage availability per sheep. Density-dependent theory of Caughley (1976, 1979) also predicts that relatively intense use of preferred forages at high herbivore density would reduce carrying capacity of ranges, by reducing abundance and productivity of selected forages. Thus, sheep populations would be less productive after declines then before declines, even though sheep densities before and after declines might be roughly equal (Cook 1990).

In our study, nutrient quality of food during summer, rather than forage abundance, was correlated to lamb survival (Cook 1990). Alpine ranges were unavailable, precluding access to high quality forage during summer (Hebert 1973, Thilenius 1975), when nutrient requirements for lactation and lamb development are high (National Research Council 1985). This indicates the amount of food meeting nutritional requirements for reproduction, rather than standing crop of all forages, most influenced population dynamics. In addition, the limiting effects of food were exacerbated by poor habitat conditions (Risenhoover and Bailey 1985, Wakelyn 1987). Gentle slopes (< 25%), sparse escape terrain, and dense forests around occupied ranges restricted sheep to small portions of total potential range (Arnett 1990, Cook 1990).

However, the sensitivity of bighorns to disease confounds simplistic food-limitation mechanisms. Frequent, and often spectacular declines in populations due to disease (Spraker 1979, Goodson 1982, Hibler et al. 1982, Coggins 1988, Festa-Bianchet 1988) suggest parasites and pathogens may limit populations below forage-determined carrying capacities. Nearly all lamb mortalities documented in our study (13) resulted from disease. We also observed sick lambs that were never recovered for necropsy. Most mortality occurred during brief die-offs in summer and early fall, a mortality pattern not likely stemming from predation.

Disease offers an alternative hypothesis of population regulation. As sheep populations increase, densities of parasites (Hibler et al. 1982) and pathogens in hosts and habitats may increase, thereby increasing infection and transmission rates in sheep. However, 3 lines of evidence in our study refute this hypothesis: (1) lungworm (Protostrongylus spp.) and gastrointestinal parasite levels were low in these herds (as low as any reported in the bighorn literature, in the case of lungworms) (Arnett et al. 1989, Cook 1990); (2) declining birth rates, which generally should be unaffected by the diseases that affected lambs (Cook 1990), accounted for much of the declines in lamb recruitment; and (3) one subherd (DC) in the North Platte herd maintained high birth and survival rates, even though this subherd occupied its range as long as the other subherds.

Our data suggest disease in lambs was a proximate mechanism through which food limited survival and thus regulated population size. Festa-Bianchet (1987) believed susceptibility of bighorns to disease precluded the occurrence of visibly emaciated animals, but forage conditions nevertheless ultimately determined population size by influencing susceptibility to disease. The relationship between summer nutrition and summer lamb survival has long been recognized (Streeter 1969, Horesji 1972, Douglas and Leslie

1987, Festa-Bianchet 1987), and the relationships among nutrition, disease, and survival of sheep are receiving greater recognition (Schwantje 1986, Festa-Bianchet 1987, Cook 1990).

MANAGEMENT IMPLICATIONS

This study and the mediocre or poor success of transplanting bighorns in the central Rocky Mountains indicate: (1) managers should adopt transplanting techniques to compensate for the poor dispersal and colonizing tendencies of bighorns (Geist 1983); and (2) intensive management will be required to produce populations of adequate size to preclude inbreeding depression over the long-term.

Transplanting in Wyoming has usually been conducted in winter, restricting opportunities (due to accumulation of snow) to spread sheep throughout all portions of suitable ranges. After 20 years, sheep in southcentral Wyoming have failed to colonize suitable or superior areas that are close (< 7 km) to occupied ranges. Potential exists to double or triple population sizes by releasing sheep into these unoccupied areas. Use of helicopters to place groups of sheep throughout potential range would have increased initial release costs, but may have resulted in larger populations with a higher probability of long-term persistence.

Habitat management that would permit expansion of occupied ranges or facilitate establishment of migratory routes between seasonal ranges should be beneficial. Treatments that would improve the quality of habitats (Wakelyn 1987, Risenhoover et al. 1988) or quality/quantity of forage in occupied ranges may increase the probability of long-term success with transplanting. Prescribed fire is useful for improving forage conditions for bighorns during all seasons in southcentral Wyoming (Cook et al. 1989, Arnett et al. 1989, Cook et al. 1990). In conclusion, we concur with Bailey (1986, 1988) and Risenhoover et al. (1988) that management problems with bighorns present particularly difficult challenges; expecting long-term success after transplanting without subsequent management has proven to be unrealistic in most cases in the central Rocky Mountains.

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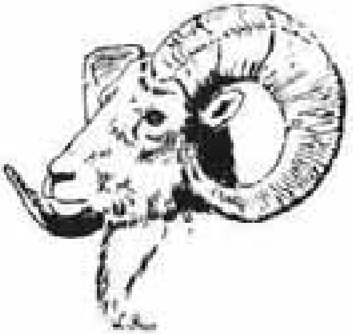

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DALL SHEEP MOVEMENTS NEAR FORT GREELY, ALASKA: PRELIMINARY FINDINGS

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Abstract: Movements and seasonal ecology of 8 ewe and 7 ram radio-collared Dall sheep (Ovis dalli dalli) on and adjacent to Fort Greely, Alaska (FGA) were studied to allow mitigation of potential disturbance due to military training exercises. Relocations indicated 5 different subpopulations, 4 of which used a centrally located mineral lick in early summer. Older rams traveled greater distances than ewes and young rams. No rams died during the 2-year study, but 4 of 8 ewes died. Recommendations are offered to protect these populations and their habitat with respect to military exercises.

FGA is 1 of 2 military bases in the world with Dall sheep and the only one open to sheep hunting. In the study area (Fig. 1), 24 hunters took 14 full-curl rams in 1988. The Army has rarely used sheep habitat for training, but increasing troop strength and resistance to Army use of off-post lands could alter the situation.

The Army began research in cooperation with the Alaska Department of Fish and Game (ADF&G) to identify seasonal use patterns of alpine terrain within the study area and to recommend mitigation in the event of Army/sheep conflicts.

Objectives of this study were: to delineate summer and winter ranges, migration routes, lambing area, rutting areas, and mineral licks; and to estimate population size, sex-age composition, and adult mortality. In this paper we report preliminary findings and offer insights into the suitability of our methods.

We thank R. Duckworth, U.S. Army Forces Command (retired), for efforts in funding this project. Without funds from the Army Agricultural/Grazing Outlease Program, the study would not have begun. Majors R. Aaron and T. Roberts, Aviation Detachment Commanders at Fort Greely, and their officers and men are especially recognized for preparing and flying the many relocation missions. All helicopter costs were borne by their budget. Many ADF&G personnel assisted: C. Smith helped define the project; E. Crain, R. Beasley, and M. McNay assisted in the net capture; R. Nowlin darted sheep; and P. Valkenburg and S. DuBois relocated collared sheep. L. Laravee and R. Warbelow expertly piloted capture helicopters under less than ideal conditions. The efforts of all are gratefully acknowledged.

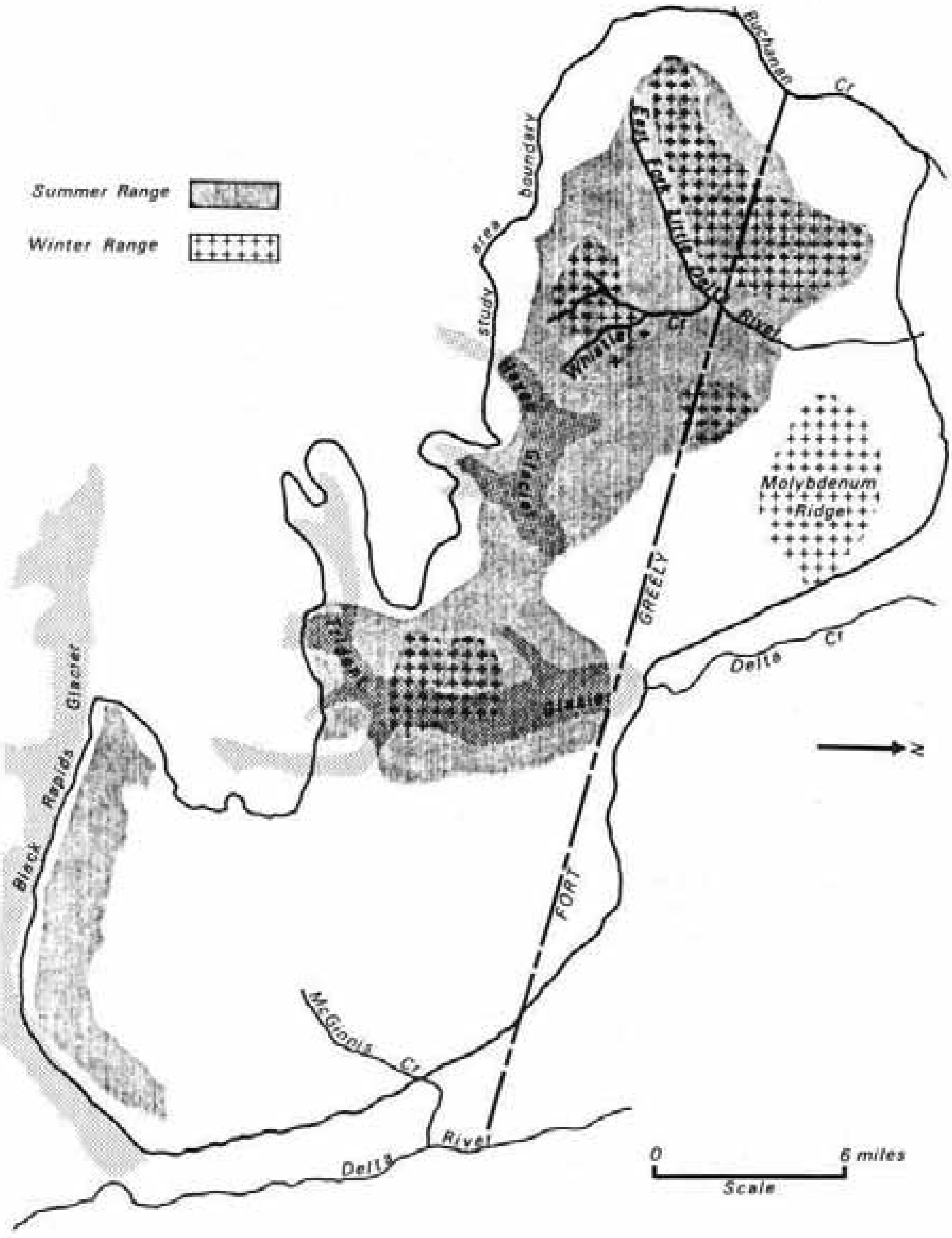

Fig. 1. Winter and summer ranges of Dall sheep, Fort Greely, Alaska study area.

STUDY AREA AND METHODS

The study area, about 1150 km^2, is on the north face of the eastern Alaska Range in interior Alaska. Most of the military reservation lies on the Tanana Flats at about 800 m elevation, but some alpine terrain (850-2,150 m) supports Dall sheep. Peaks up to 4,250 m lie immediately south with 4 major glaciers occupying heads of the drainages. Lower elevations are shrub-dominated by alder (Alnus spp.), dwarf birch (Betula nana), and willow (Salix spp.). The alpine zone is dominated by forbs and grasses of typical Dall sheep habitat with many rock falls and talus slopes almost devoid of vascular plants. Temperatures range from 32C to -48C. North-bound air flowing over the Alaska Range produces prevailing catabatic winds that remove snow from exposed slopes, creating stable habitat for sheep. Moose (Alces alces), caribou (Rangifer tarandus), grizzly bear (Ursus arctos), and wolves (Canis lupus) are common in the area.

To determine seasonal movements we captured and radio-collared 15 sheep and aged each by counting horn annuli (Table 1). Six ewes and 4 rams were captured using a helicopter skid-mounted projectile net (Heimer and Mauer 1990) and fitted with mortality-sensing (11-hr delay) radio collars (Telonics, Mesa, AZ) on April 21, 1988. On July 18, 3 rams and 2 ewes were fitted with similar collars after being captured using conventional darting techniques (Heimer and Mauer 1990).

Table 1. Dall sheep captured in 1988 at Fort Greely, Alaska.

Collar ID	Sex	Capture method	Date of capture	Age[a] (years)	Date of death[b]	Age at death (years)	Cause of death
8	F	net	4/21/88	3.9	12/02/89	5.5	unknown
3	F	net	4/21/88	5.9	10/22/88	6.5	unknown
1	F	net	4/21/88	"old"	1/28/89	?	unknown
0	F	net	4/21/88	7.9	4/26/89	8.9	fall
7	F	net	4/21/88	7.9			
2	F	net	4/21/88	3.9			
17	F	dart	7/18/88	3.1			
6	F	dart	7/18/88	7.1			
X	M	net	4/21/88	1.9			
F	M	net	4/21/88	1.9			
V	M	net	4/21/88	4.9			
T	M	net	4/21/88	1.9			
4	M	dart	7/18/88	5.1			
Z	M	dart	7/18/88	5.1			
11	M	dart	7/18/88	2.1			

[a] Birth date assumed to be the last week of May.

[b] Date of death assumed to be the midpoint between the last live mode signal and the first mortality mode signal.

Beginning on May 25, 1988, marked sheep were located 6 times from a Piper PA-18 Super Cub and 14 times from an Army Bell UH-1 helicopter. We never located all 15 sheep in 1 flight. Once, 2 sheep were located when we visited a mineral lick. Tracking flights ended April 10, 1990. Each location was plotted on a 1:250,000 USGS map. Heimer's (1973) definitions were used to classify Dall sheep range as summer range (territory occupied after peak mineral lick use in early July until migration to winter range in early October), or winter range (occupied from November until movement toward a mineral lick in early May).

Sheep were assumed dead when the collar broadcasted in mortality mode. Collars were retrieved as soon as practical. When possible, cause of death was determined from evidence at the site. However, this was difficult because landing clearance and snow conditions dictated that 2-4 months passed before death sites could be investigated on the ground.

A high-intensity survey of the study area was attempted using standard techniques (Geist 1968, Heimer 1985, Heimer and Watson 1986). However, high winds and logistic problems resulted in early termination of the survey. The area between Trident and Black Rapids Glaciers was covered.

RESULTS

One hundred fifty-four observations ($\overline{x}$ = 10.3/sheep) suggest 5 separate subpopulations (Fig. 2). Except on Molybdenum Ridge, where about 50 ewes and lambs wintered, winter ranges appear to lie within summer ranges. Separate winter ranges are uncommon in the Alaska Range (Heimer 1973, Heimer and Watson 1986). Molybdenum Ridge and the northern extension of sheep distribution along the west side of the East Fork, Little Delta River (EFLDR) lie on FGA. We sometimes observed about 100 sheep in the latter area. Migration routes were not observed. However, we inferred the approximate migration routes of 1 subpopulation (Fig. 2). Also, we could not find rutting or lambing locations, but these areas are typically small areas within winter ranges (Heimer 1973, Heimer and Watson 1986).

Of the 15 sheep collared, 13 used the headwaters of Whistler Creek (Fig. 2) in late June. We identified a mineral lick where about 80 sheep were seen at 1 time. Lick use was consistent with reported patterns of mineral lick use in Alaska (Heimer 1988). Two sheep captured near Trident Glacier were not seen during the period of lick use. We do not know if they use this lick.

Four collared ewes died (Table 1). At least 1 was over 8 years old and "at risk" (Watson and Heimer 1984). Cause of death - a fall - was apparent in 1 case. Other causes were uncertain, but the locations of these deaths suggested predation was involved. These sites were typical of areas where predation has been documented (Murie 1944, Heimer 1973). No rams died during the study. Rams in these age classes (2-7 yrs) usually have low mortality rates (Heimer and Watson 1986).

Between Trident and Black Rapids Glaciers (Fig. 1), 161 sheep were counted. Of these, 58% were classed as ewes, 14.2% as lambs, and 27.7% as Class II, III, and IV rams. Class II, III, and IV rams comprised 7.4%,

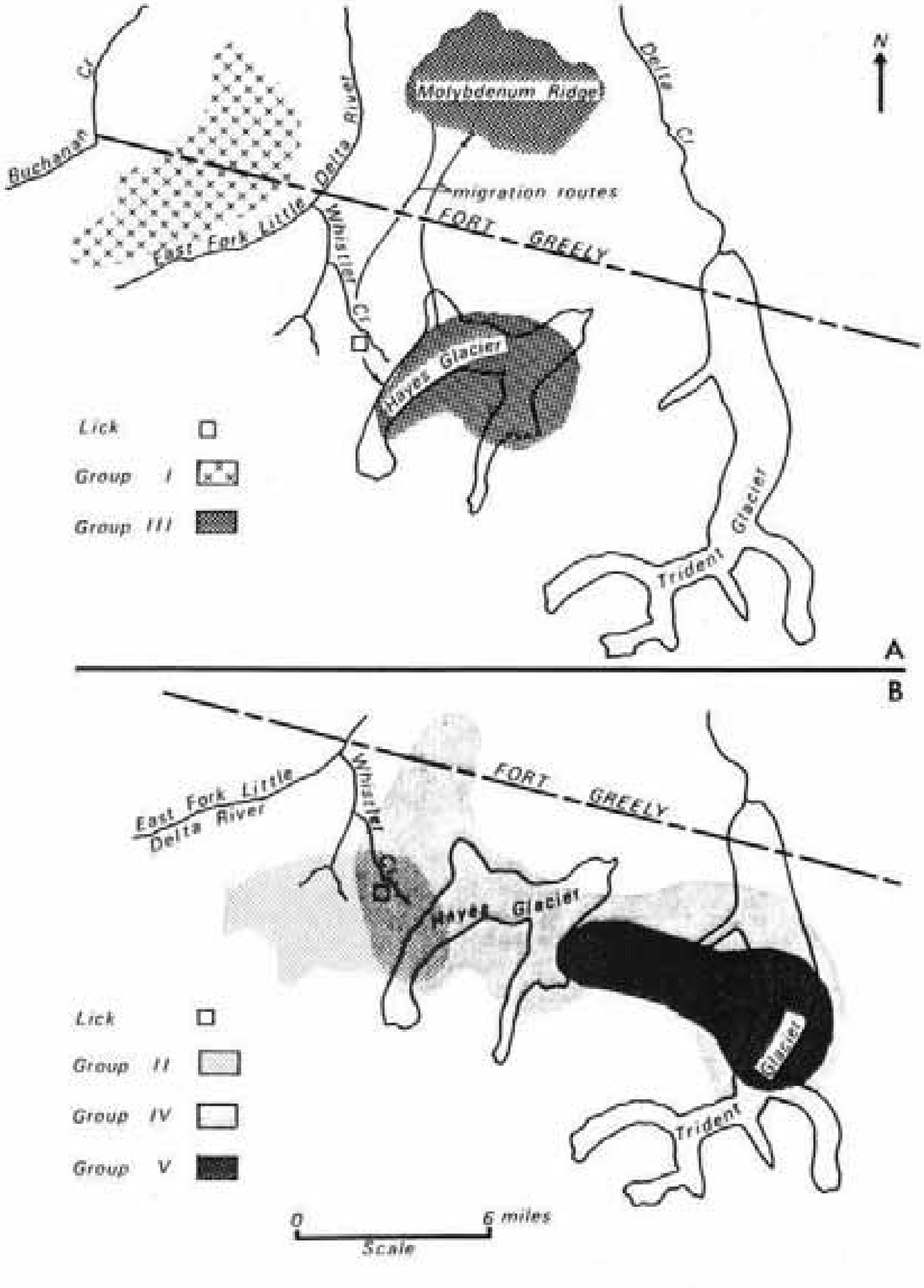

Fig. 2. Ranges of subpopulations in western half of study area, Fort Greely, Alaska, 1988–1989.

15.4%, and 4.9%, respectively, of the population sampled. This sample indicated poor lamb production (24 lambs:100 ewes). We observed no sheep between Trident Glacier and McGinnis Creek (Fig. 1).

DISCUSSION

Each of the 5 subgroups of Dall sheep in the western part of the study area (Fig. 2) contains marked individuals. Group I, with 6 marked sheep, consists of ewes and young rams that winter and summer in the mountains west of the EFLDR and cross the EFLDR only to use the Whistler Creek mineral lick. Group II, with 3 marked sheep, also consists of ewes and young rams. It winters and summers in the Whistler Creek/Hayes Glacier area. Group III (2 marked sheep) is mainly ewes. It winters on Molybdenum Ridge, moves to Whistler Creek to use the mineral lick, and then summers in the Hayes Glacier vicinity. Group IV is a ram band containing 2 marked rams and moves between Whistler Creek and Trident Glacier (19 km), the greatest distance traveled by any group. Seasonal ranges have yet to be determined for these rams. Group V, with 2 marked sheep, is a ewe and young ram band that winters and summers between Hayes Glacier and Trident Glacier. We found no evidence that Group V uses the Whistler Creek mineral lick.

There was no evidence that any of these groups moves outside the study area. Sheep were collared on the margins of the area but were never found outside it. Their main seasonal movements were toward the Whistler Creek drainage in the center of the study area, and then to their individual seasonal ranges.

We observed about 150 sheep on FGA in winter and 100 in summer (Group III wintered south of FGA). All sheep habitat on the installation warrants protection, and Molybdenum Ridge, Group III's winter range, may be essential habitat.

We recommend the Army take the following protective measures. First, vehicular traffic should be excluded from elevations above 1070 m (3500 ft) in the mountains between Buchanan Creek and Delta Creek. This will preclude destruction of alpine habitat. Second, large ground exercises spread over a large area should not occur on sheep range. Small numbers of troops may deploy in sheep habitat as if they remain within 1 m^2 at any given time. This should provide ample escape territory for any sheep frightened by men and equipment.

Anticipated annual mortality for prime age ewes is 3-6% (Watson and Heimer 1984), but our sample was too small to make a meaningful comparison. The high annual mortality of collared ewes in this study (25%) may have been due to sheep avoiding our large, low flying tracking helicopter. There is frequent helicopter activity in this area, but Army pilots normally stay at least 500 ft above ground. One mortality was due to a fall, but the cause of the fall was unknown. Still, sheep in this area are less likely to run when approached by small helicopters such as those used in capture operations (Heimer and Mauer 1990) than are sheep in other areas.

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ALTERNATE RUTTING STRATEGIES IN MOUNTAIN SHEEP: MANAGEMENT APPLICATIONS

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Abstract: A 10-year closure to ram hunting in the Wrangell-St. Elias National Park, which formerly produced the largest Dall rams in the world, failed to produce more rams that rank among the leaders in Boone and Crockett listings. Based on recollections of sheep hunters who frequented the Wrangell Mountains when record sheep were taken, it was common to find 1 outstanding ram in each geographically distinct area frequented by several ram groups in the fall. These observations are consistent with reports from unhunted bighorn sheep and may be considered supportive evidence for at least 2 alternate rutting strategies among mountain sheep: the "normal" and the "alpha ram" strategies. Experience in Alaska has identified a third rutting strategy, the "immature ram" strategy, which is manifested in populations of Dall sheep where mature, dominant rams are scarce or absent. It appears that sheep managers can select among these rutting strategies by varying harvest management to favor relative frequencies of behavior patterns during rut. This possibility should be recognized because predominant rutting strategies will influence achievement of management goals.

Boone and Crockett (B&C) Club records (1989) indicate more of the unusually large Dall sheep (_Ovis dalli dalli_) recorded have been harvested from the northern Chugach and southeast Wrangell Mountains of Alaska than from any other area. Most of these rams were harvested between 1955 and the late 1960s. Heimer and Smith (1975) demonstrated that this area has the highest horn growth potential in Alaska, hence its high frequency of larger rams. However, the relatively short time period during which the collection of the unusually large rams occurred requires further explanation.

I suggest these rams were taken due to unique circumstances. Prior to 1955, these sheep habitats had never been hunted intensively for trophy rams. From the mid-1950s to the late 1960s, the human population of Alaska increased as did the number of Dall sheep hunters. This hunter population included a group of highly motivated and competent trophy hunters. Finally, there was concurrent use of high-performance, light aircraft for access into and scouting of sheep habitats. These circumstances resulted in recording 73% of the top 25 Dall rams in the B&C records during this relatively brief period. During the last 20 years, only 2 rams with horns large enough to rank among the top 25 recorded Dall rams have been taken. Many hunters and some biologists have speculated high harvest rates have resulted in few rams old enough to attain maximum growth (Kay 1988).

Based on this speculation, sheep hunters who received congressionally mandated subsistence hunting privileges in the Wrangell-St. Elias National Park (Heimer 1978, 1980, 1985) expected a bonanza of new "book" rams to be available following passage of the Alaska National Interest Lands Conservation Act. They reasoned that because these ranges had been essentially closed to hunting for 10 years, old and unusually large rams should be abundant. However, extensive scouting and high-effort hunting by these extremely selective, "hard-core" trophy hunters have failed to produce a single "high book" ram from the National Park. This raises the question: "Why are rams in these areas living long enough, but not growing big enough to place high in the Boone and Crockett book?"

The purposes of this paper are to propose an answer to this question, to emphasize that harvest management can influence rutting strategy, and to suggest that once managers have defined management objectives, selection of the appropriate harvest plan can increase the likelihood of management success.

METHODS

Literature on rutting strategies among mountain sheep was reviewed. Experience with changes in rutting strategy, inferred from results of varying ram age structures among Alaskan Dall sheep, was evaluated. Two of the more experienced sheep hunters, who participated in harvest of the top 20 B&C Dall rams, were interviewed.

RESULTS

Literature Review

Geist (1968, 1971) described rutting behavior in bighorn (Ovis canadensis), Stone (O. d. stonei), and Dall sheep. The typical pattern in these populations was for several mature dominant rams to limit rutting participation by immature rams. Mature rams circulated among groups of ewes, identified and courted estrous ewes, guarded them from the advances of subordinate rams, and eventually copulated with them. This pattern is typically considered the "normal" rutting strategy.

Hogg (1984, 1987) described a rutting system in which use of a central rutting area by estrous bighorn females enhanced their opportunities for mate selection. This system distinctly favored the largest horned, or alpha ram. This ram was sought by ewes, and due to his status he was able to engage in sperm competition with subordinate rams that obtained opportunistic copulations from ewes they intercepted, blocked, and tended as these ewes traveled toward the alpha ram on the rutting area (Hogg 1988). Dispersion of ewes from the geographic center of the tending area varied coincident with the presence of super-dominant rams (Hogg 1987). Greater mating success by rams of lower rank attended greater dispersion of ewes from the center of tending. Because of the apparent advantages in reproductive fitness which accrue to the dominant ram, I call this the "alpha-ram" strategy.

Ram Age Structure in Alaskan Dall sheep

A third rutting strategy has been identified among heavily hunted populations of Dall rams. I call this the "immature ram" strategy. In some Alaska populations, virtually all rams above 3/4-curl development were removed under hunting regulations in effect before 1979 (Heimer 1980). In these populations, Class II rams, having less then 3/4-curl horns (Geist 1968), became active breeders (Nichols 1972). These young rams behaved differently than mature rams, and their behavior was part of a maladaptive syndrome involving decreased ewe fecundity and unusually high mortality among young rams (Heimer et al. 1984, Heimer and Watson 1986a,b).

Interviews With Sheep Hunters

Anecdotes from 2 experienced sheep hunters who were active in the Wrangell/Chugach Mountains during the heyday of trophy sheep harvest suggested it was typical to find 1 unusually large ram in a discrete mountain block which contained several ram bands in the fall. One hunter (F. Cook, #2 B&C ram, 1956, pers. commun.) covered the Chugach Mountains extensively on foot. The other (J. Harrower, #16 B&C ram, 1961, pers. commun.) flew in, guided in, and hunted the Wrangell Mountains extensively. The unusually large rams, colloquially called "herd rams" were often clearly larger than the accompanying rams which were also uncommonly large by today's standards.

DISCUSSION

Past harvest of virtually all "high book" Dall rams from the Wrangell and Chugach Mountains coupled with the failure of these sheep ranges to produce rams of similar size in recent years suggest that "180-point" rams are scarce there today. Closure of this area to open hunting more than 10 years ago has certainly allowed time for several cohorts of rams to realize their maximum horn growth potentials. Still, the few dedicated sheep hunters who have expended their efforts in search of new records have been disappointed.

In any study, definition of ram rutting strategy is determined by the preponderance of a recorded behavior pattern. The spectrum of normal but differing behaviors ranges from those exhibited by the highest to the lowest ranking rams in any ram band. If the age structure of a ram band changes, the frequency distribution of observable behaviors will reflect the change in age structure.

If the "alpha-ram" strategy, as I interpret it from Hogg (1984, 1987), represents a predictable result of social ascendancy to alpha status by an unusually large ram, it should occur among unhunted Dall sheep. Furthermore, if it selects for larger males, it should favor an overall increase in horn size. However, the "alpha-ram" strategy is unlikely to occur in hunted populations. If trophy hunting removes individuals with alpha-ram potential before it is fully expressed (because hunters shoot the larger rams), the "alpha-ram" strategy cannot develop. Hence, I suggest the "alpha-ram" strategy was not unusual in the Wrangell/Chugach Mountains (and across Alaska) before the alpha rams were removed by trophy hunters. Once this rutting system was disrupted by removing alpha rams and the "normal" rutting strategy prevailed (along with open hunting for rams of a minimum legal horn size), reestablishment of the "alpha-ram" strategy became improbable.

Reestablishment of the "alpha-ram" strategy requires several sequential events. The first requisite is production of an unusually superior male through chance recombination of genetic material. The chance occurrence of an occasional "super ram" in populations where very large rams are not typical is demonstrated by the Summar (B&C #8) and the Johnson-Brennan (B&C #21) rams. These rams are the only Alaska Range rams in the top 100 B&C records, yet they rank highly. Another demonstration of this chance occurrence was the recent harvest of 2 rams which will rank among the top 10 B&C list from the Brooks Range.

Once a "super ram" is produced, he must survive to realize his potential. When his physical potential is realized, this ram must either attract ewes to a tending area (if one was not maintained through traditional ewe movements), or so dominate subordinates on the tending area that his reproductive fitness greatly exceeds theirs. Following this sequence, mate selection for this ram by ewes should occur with increased frequency.

I suggest the probability that these events will occur in the required sequence is small. However, once an alpha ram system develops, it should accelerate selection for large horns and be self sustaining so long as a succession of alpha rams dominate the geographic center of reproductive activity. Any mortality removing the alpha ram or his immediate successors would select forcefully for the "normal" rutting strategy. It should be emphasized that mortality other than trophy hunting could easily disrupt the "alpha-ram" strategy. Such mortality includes uncommonly difficult weather (Watson and Heimer 1984) and surplus killing of entire ram bands by wolves (R. Tobey, ADF&G, pers. commun.). Harvest by humans is the single mortality factor managers can easily control.

Hence, managers choosing to favor selection for or maintenance of the "alpha-ram" strategy must be prepared to eliminate or strictly regulate harvest of the alpha ram by humans and predators. Conversely, aggressive selection for this rutting strategy to attain nonconsumptive use goals may require culling of subdominant rams with low horn growth potential. If hunting is to be maintained along with the "alpha-ram" strategy, harvest must be strictly controlled and limited, perhaps to the sustained culling of designated individuals from the subdominant ram pool, although harvest of the largest ram could be allowed once he was nearing the end of his probable life expectancy and a successor was present.

Selection for the "normal" rutting strategy requires the effective presence of mature (Class IV) rams. These mature rams limit social and reproductive behavior by immature rams (Geist 1971, Nichols 1972, Heimer and Watson 1986a,c, 1990). Managers can produce this effect by ensuring a suitable age structure through eliminating hunting for rams, or by managing harvest to protect mature rams. Protecting mature rams can be accomplished by carefully controlling harvest from all ram age/size categories or, paradoxically, by limiting harvest to the Class IV (full-curl) segment of the ram population. In Alaska, where vast areas with large populations of sheep are used by hunters who prefer to take mature males, the latter strategy has proven effective (Heimer and Watson 1990).

Results of 6 years of full-curl ram hunting in a heavily hunted portion of interior Alaska indicate that selection for the "normal" rutting strategy has raised the abundance of Class IV rams to the point that, even with comparatively low sheep per hunter ratios, hunters appear incapable of harvesting all the Class IV rams recruited annually. During the 6 years of full-curl management, the total number of sheep per hunter in these populations has averaged 15. Still, there has been no decrease in sustainable harvests using a full-curl regulation to cultivate the "normal" rutting strategy in Alaska. In fact, harvests have increased (Heimer and Watson 1990) as predicted by Heimer and Watson (1986a). Hence, I suggest that selecting for the "normal" strategy is the most appropriate and practical means of maximizing ram harvests.

The Alaskan experience suggests that a third rutting strategy results from the social disruption accompanying nearly complete removal of Class III and Class IV rams from populations which previously evidenced the "normal" rutting strategy. In populations where the "immature ram" strategy became operative, rut was prolonged and was characterized by excessive courting and chasing behaviors on the part of immature rams (Nichols 1972, 1978). These rams would otherwise have been inactive.

The results of this rutting strategy in the Alaska Range were maladaptive. Low ewe fecundity and increased mortality among young rams were implicated as results of the "immature ram" strategy (Nichols 1978; Heimer and Watson 1982, 1986a,b,c; Heimer et al. 1984). Reestablishing an abundance of Class III and IV rams through progressively more restrictive hunting regulations was associated with selection for the "normal" rutting strategy, restoration of typically high ewe fecundity, and increased ram survival. Alaskan experience suggests the maladaptive symptoms associated with the "immature ram" strategy will become apparent when Class II-IV rams:100 "ewes" (as classified from aircraft when yearlings cannot be distinguished from ewes) ratios fall below 30:100 (Heimer and Watson 1986b).

The population survey and hunter-control effort required to select for establishing the "alpha-ram" strategy may render it an impractical management alternative except in aggressive attempts to increase ram horn size or pursuit of management goals which are primarily nonconsumptive. The "normal" strategy currently appears to be the most cost-effective strategy managers can select to maximize ram harvests. Selection for the "immature ram" strategy should be limited to situations where population reductions are desired. Sheep managers may find progress is more readily attainable if they shift their thinking toward conscious selection of rutting strategies designed to achieve management goals rather than selecting rutting strategies "by default" as unconsidered results of traditional consumptive or nonconsumptive management programs.

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THE EFFECTS OF PROGRESSIVELY MORE RESTRICTIVE REGULATIONS ON RAM HARVESTS IN THE EASTERN ALASKA RANGE

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Abstract: Behavioral and energetic theory, as well as empirical observations, suggest that young ram survival will be compromised in Dall sheep populations when few dominant rams are present, and that maximum sustainable harvests of Dall rams will be greater if full-curl rather than 3/4- or 7/8-curl rams are harvested. Consequently, an experimental full-curl regulation was established in a heavily hunted portion of the Alaska Range as a field test of this hypothesis. Results after 6 years of full-curl ram harvest regulations show a significant increase of 49% in mean ram harvest over previously sustained levels. Increased survival of young rams is the most viable explanation.

The purposes of this paper are to present an analysis of the full-curl Dall sheep (Ovis dalli dalli) harvest reported from a heavily harvested portion of the Alaska Range, and to relate it to the specific predictions of Heimer and Watson's (1986a,b) hypotheses regarding intensively harvested populations under full-curl regulation.

Ram harvest from the Alaska Range has been restricted under 3 regulatory schemes defining the minimum age/size limit for legal rams. From 1951 through 1978, minimal legal size was 3/4-curl. The 3/4-curl regulation was adapted to Dall rams from bighorn sheep (Ovis candensis) management (Dimarchi 1978). From 1979 through 1983, harvest was limited to 7/8-curl or greater rams. The 7/8-curl regulation was a response to economic, aesthetic, and biological concerns raised by the specter of a harvest consisting predominantly of 3/4-curl rams after approximately 40% of Dall sheep habitat in Alaska was closed to sheep hunting pending passage of the Alaska National Interest Lands Conservation Act (Heimer 1980). Since 1984, harvest has been limited to rams with at least full-curl horns or with both horns broken. The full-curl regulation was experimentally established in the Alaska Range east of Mt. McKinley to assess its effect on harvests in an area managed for the maximum opportunity to participate in Dall ram hunting (Heimer 1985).

If mortality resulting from ram hunting is limited exclusively to those rams which are shot, it follows that ram harvests should decline as the minimum age at harvest increases (such as with regulatory changes in legal bag limit from 3/4- to 7/8- and eventually full-curl). However, several studies suggest this is not what happens. Using behavioral observations and energetic theory, Geist (1971) postulated that involvement of young rams in breeding would increase their mortality rate. Heimer (1980) related Geist's postulation of the costs of social dominance specifically to intense harvest of 3/4-curl rams and lowered sustainable harvest rates. Later, Heimer et al. (1984) documented compromised survival among young, marked rams in populations which were heavily cropped at 3/4-curl age/size.

When compared with survival of like-aged Dall rams from the unhunted sample reported by Murie (1944) and Deevey (1947), the hunted populations showed notably higher mortality among immature rams. This high mortality was interpreted as suggestive of an age-independent mortality cost associated with social dominance because dominant behaviors are exhibited by young rams when mature rams are scarce or absent (Nichols 1972). The low survivorship of immature marked rams (Heimer et al. 1984) was consistent with Geist's (1971) prediction. Similar patterns of increased immature ram mortality have been identified in other heavily exploited bighorn sheep populations (Stewart 1980, Festa-Bianchet 1986, Jorgensen and Wishart 1986, Barichello et al., 1987).

Finally, Heimer and Watson (1986a) hypothesized that restoring ram abundance in populations where few old rams were present would result in increased maximum sustainable ram harvests. They suggested this would result from a combination of increased survival of young rams and increased ewe fecundity (Heimer and Watson 1986b). Heimer and Watson (1986a) also suggested the most practical management approach to increasing ram abundance in heavily cropped areas was establishment of a full-curl regulation for ram hunting.

On the basis of this body of work, the Alaska Department of Fish and Game established regulation of legal horn size at full-curl (or with both horns broken) in the Alaska Range east of Mt. McKinley beginning in 1984. The intent was to test the prediction of Heimer and Watson (1986a) that a greater ram harvest could be sustained under full-curl regulation than under 3/4- or 7/8-curl regulations. Sheep populations of the Alaska Range east of Mt. McKinley were selected because their population history was well known and intense harvest pressure had been documented there for many years.

METHODS

Ram harvest data reported from the Nenana River to the eastern limit of Delta Creek (Fig. 1) were summarized for the periods with each regulation (3/4-curl, 7/8-curl, and full-curl) in effect (Table 1). This portion of the eastern Alaska Range was selected for harvest comparisons because it receives intense pressure by ram hunters and is free of complications attending emigration and immigration. The marshy lowlands to the north, the glacial continental divide to the south, and the Nenana River to the west are barriers to sheep movement. Additionally, sheep are absent between Delta Creek and McGinnis Creek on the eastern border. This gap in distribution was first noted in 1973 (Alaska Department of Fish and Game, unpubl. data) and later confirmed using radio-marked sheep (Spiers and Heimer 1990).

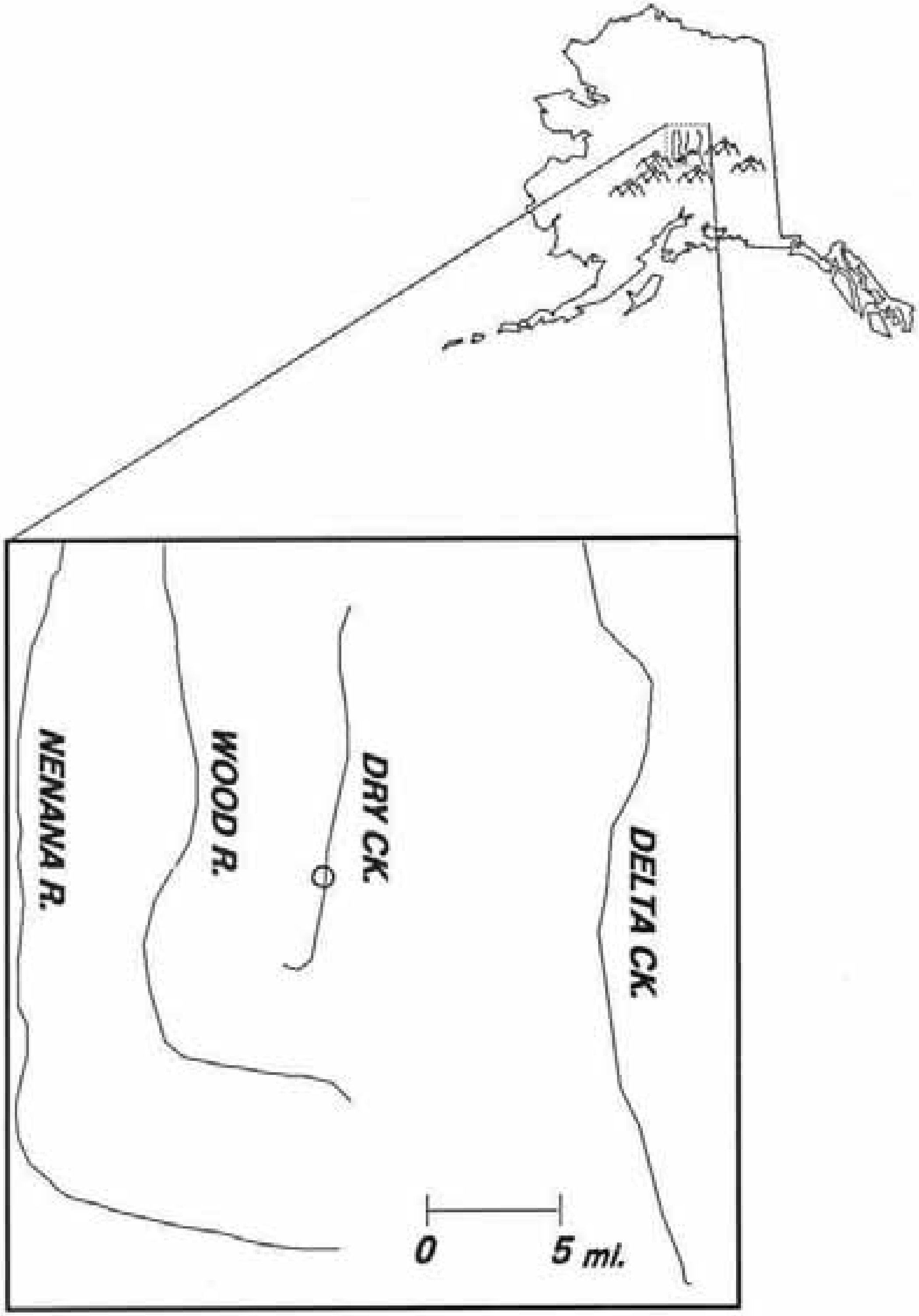

FIG 1. HARVEST COMPARISON AREA, EASTERN ALASKA RANGE

Table 1. Legal horn size, harvest, hunter numbers, percent success, relative cohort size, ewe population size, and horn size by year for the eastern Alaska Range, 1968-90.

Legal horn size/ year	Harvest	Hunter numbers	Percent success	Yearling: 100 ewe ratio (year recruited)	Ewe population size in production year	Ram horn size (in)
<u>3/4-curl</u>						
1968	107	224	48	--	--[a]	33.1
1969	82	217	38	--	--[a]	32.9
1970	97	228	43	--	--[a]	33.6
1971	121	309	39	--	--[a]	33.8
1972	104	302	34	--	--	32.5
1973	74	224	33	13 (1968)	--	31.3
1974	95	199	48	31 (1969)	--	31.8
1975	97	217	45	31 (1970)	734[b]	32.3
1976	114	250	46	51 (1971)	724[d]	32.3
1977[c]	103	244	42	16 (1972)	714[d]	32.3
1978	98	248	40	11 (1973)	704[d]	31.8
<u>7/8-curl</u>						
1979	86	226	38	11 (1973)	704[d]	33.4
1980	88	220	40	25 (1974)	694[d]	34.9
1981	117	253	46	23 (1975)	685[b]	34.9
1982	112	216	52	16 (1976)	690[d]	34.0
1983	100	206	49	17 (1977)	695[d]	33.7
<u>Full-curl</u>						
1984	108	300	36	17 (1977)	695[d]	34.0
1985	102	293	35	25 (1978)	700[d]	34.0
1986	138	362	38	19 (1979)	705[d]	34.2
1987	142	354	40	36 (1980)	707[b]	35.0
1988	151	415	36	43 (1981)	810[d]	35.2
1989	161	405	40	25 (1982)	787[d]	34.3
1990[e]	119	--	--	7 (1983)	743[d]	--

[a] No population estimate, however other ungulate populations in immediate area were high.

[b] Estimated from aerial censuses.

[c] Minimum harvest estimate.

[d] Linear interpolation between aerial censuses.

[e] Preliminary minimum harvest, hunter numbers, and horn size not known; this year not included in statistical tests.

This portion of the eastern Alaska Range includes the Dry Creek study area populations described by Heimer (1974), Smith (1978), and Heimer and Watson (1986a,b). The Dry Creek study area contains 20-25% of the 5,000 sheep in the eastern Alaska Range study area. Ewe population sizes from the Dry Creek area were used as indices of population size and trend in the eastern Alaska Range from 1968 to 1989. Ewe population sizes (Tables 1 and 2) were estimated using resightings of marked sheep on comparable high effort fixed-wing aircraft censuses (Heimer and Watson 1986b). Horn size (Table 1) was calculated from hunter reports.

Ratios of yearlings:100 ewes observed at the mineral lick on Dry Creek each year (Heimer and Watson 1986b) were used as indices of relative cohort sizes within the study area (Table 1). On-ground classifications of sheep throughout the eastern Alaska Range from 1972 through 1978 showed production and recruitment ratios gathered at the Dry Creek mineral lick accurately reflected those of sheep populations from other portions of the study area (Smith 1978).

Mean harvest, hunter numbers, and hunting success were compared among the 3 regulatory periods. Means for hunter numbers and hunting success from the periods of differing regulations were compared using a 2-tailed Student's $\underline{t}$-test ($\underline{P} < 0.05$). The 2-tailed test was selected because the directions of change were not specified in the hypothesis. Student's 1-tailed test was used to test for significance ($\underline{P} < 0.05$) of change in mean harvest because it was predicted to increase. Linear regression analysis was used to test the relationship between harvest and hunter effort plotting harvest as a function of hunter effort.

RESULTS

Harvest

Mean harvest (Table 1) under the full-curl regulation (harvest = 134 rams/year, S = 24, N = 6 years) was significantly greater ($\underline{t} = 2.7249$, $P < 0.05$) than under 3/4- (harvest = 99 rams/year, S = 13, N = 11 years) or 7/8-curl (mean = 101 rams/year, S = 14, N = 5 years) regulations ($\underline{t} = 4.4035$, $\underline{P} < 0.001$). There was no significant difference ($\underline{t} = 0.2783$, $\underline{P} > 0.05$) in mean harvest between the 3/4-curl regulation period and the 7/8-curl regulation period. When data from the 3/4- and 7/8-curl harvest periods were pooled, their mean (100 rams/year, S = 13, N = 16 years) was significantly less ($\underline{t} = 4.3149$, $\underline{P} < 0.001$) than the mean full-curl harvest.

Hunter Numbers

There was no significant difference ($\underline{t} = 1.0612$, $\underline{P} > 0.05$) between the mean number of hunters using the area under the 3/4-curl (mean = 242 hunters, S = 35, N = 11 years) and 7/8-curl regulations (mean = 224 hunters, S = 18, N = 5 years). However, testing the mean for these periods pooled (mean = 236 hunters, S = 31, N = 16 years) revealed a significant ($\underline{t} = 2.9925$, $\underline{P} < 0.01$) increase in hunter numbers during the full-curl regulation period (mean = 309 hunters, S = 91, N = 6 years).

Hunter Success

Percent hunter success was variable between regulatory periods. There was no significant difference ($\underline{t} = 0.3075$, $\underline{P} > 0.05$) between the mean percent success during the 3/4-curl (mean = 41%, S = 5, N = 11 years) and the 7/8-curl periods (mean = 45%, S = 6, N = 5 years). When these periods were pooled (mean = 42%, S = 5, N = 16 years) and compared with hunter success during the full-curl period (mean = 38%, S = 2, N = 6 years), a statistically significant decrease was identified ($\underline{t} = 2.148$, $\underline{P} < 0.05$).

Effect of Hunter Numbers on Harvest

Harvest was not closely linked to the number of hunters participating when harvest was tested as an independent variable. Regression of harvest as a function of hunter numbers (Table 1) during the 16 years of 3/4- and 7/8-curl regulations, when there was no significant difference in harvest or success, but a large variation in the number of hunters, (range = 199-309 hunters, mean = 236 hunters) did not suggest a strong, linear relationship (harvest = 0.22 hunters + 47, r = 0.53).

Horn Size

Horn size decreased significantly ($\underline{t} = 3.742$, $\underline{P} < 0.01$) from a mean of 33.2 inches (S = 0.5263, N = 5 years) before 1973 to a mean of 31.9 inches (S = 0.4761, N = 6 years) from 1973 through the end of the 3/4-curl regulation period. Subsequently, horn sizes increased with the 7/8- and full-curl regulations.

Ram harvests from 1971 and 1972 were produced by 309 and 302 hunters, respectively. These levels of participation by hunters were higher than in the years between 1968 and 1983 (all of which had 253 or fewer hunters afield). The mean number of hunters for 1971 and 1972 was 306 hunters, 37% above the mean of the previous 3 years and 44% above the mean of the following 3 years. Changes in horn size, harvest, and the transiently high hunter numbers of 1971 and 1972 (Table 2) indicate standing stocks of rams were depleted during those years.

Table 2. Mean indicator ewe population size, harvest, hunter numbers, and percent success for the eastern Alaska Range, 1968-89.

Regulation (years)	Mean indicator ewe population in Dry Creek	Mean annual harvest	Mean number hunters	Mean harvest success
3/4-curl (1968-78)	724 ewes	99 rams	242	41%
7/8-curl (1979-83)	700 ewes	101 rams	224	45%
Full-curl (1984-89)	713 ewes	134 rams	354	38%

Ram Survival

Yearling cohort sizes, as indicated by yearlings:100 ewes ratios, and their relationship to harvests when these cohorts reached legal age/size suggest increased survival of sublegal rams. Yearlings:100 ewes ratios produced in 1968-71 (before ram depletion by heavy hunting and the winter of 1971-72) averaged 31 yearlings:100 ewes ($N = 4$, $S = 15.5$). These cohorts eventually produced mean harvests of 99 3/4-curl rams per year. The mean yearlings:100 ewes ratio for cohorts which produced rams harvested during the 7/8-curl period (1973-77) was significantly less ($\underline{t} = 3.4758$, $\underline{P} < 0.02$), averaging only 18 yearlings:100 ewes ($N = 5$, $S = 5.6$). However, harvests from these smaller cohorts still produced a mean of 101 7/8-curl rams per year which is almost identical to the 99 rams per year harvested from the significantly larger cohorts. These data suggest that survival to harvestable age was greater for these smaller cohorts.

DISCUSSION

The significant increase in mean ram harvest under full-curl regulation is consistent with Heimer and Watson's (1986a,b) prediction that increased ewe fecundity, natality, and young ram survival expected to result from minimally distorted ram age structures would lead to increased ram harvests where maximum hunting participation is allowed. The credibility of this result should be enhanced because use of all harvest data following the full-curl regulation minimizes the negative effect of including the harvests from the first 2 years following the period of maximal 7/8-curl ram harvest. Results suggest harvest did not respond to regulatory change until the third year following implementation of the regulatory change (Table 1). During 1986-1989, the third through sixth years of full-curl regulations, mean ram harvests (149 rams/year) exceeded harvests during 3/4-curl hunting (99 rams/year) by 50%.

The statistically significant 58% increase in hunter participation during the full-curl regulation period suggests the increased harvest could have been due to increased numbers of hunters aside from any effects of ram social structure on production or survival of young rams. We do not think the data support this explanation.

For this hypothesis to be acceptable, it must follow that harvest of rams was low enough under 3/4- and 7/8-curl regulations that standing stocks of full-curl rams were accumulating to be harvested later. There are no data which suggest this occurred. Aerial survey data from 1974 and 1975 (Heimer and Watson 1986b) showed rams greater than 3/4-curl were scarce, amounting to only 3% of the total population, while Heimer and Smith (1975) reported other hunted populations in Alaska were averaging 15% rams greater than 3/4-curl.

Furthermore, the decrease to significantly smaller mean horn sizes after 1972, the unusually severe winter of 1971-72 (Watson and Heimer 1984), the transiently high hunter numbers of 1971 and 1972, and the weak regression coefficient of harvest as a function of hunter numbers during the 3/4- and 7/8-curl regulatory periods argue against this hypothesis. The eastern Alaska Range has been heavily hunted since the early 1970s. All these findings consistently argue against the possibility that the primary cause of increased ram harvests was increased hunting pressure.

If the increasing harvest of full-curl rams did not result from increased hunter effort, alternate explanations must be considered. One population response associated with increased ram abundance in the Dry Creek study area was increased ewe fecundity and resulting lamb production (Heimer and Watson 1986c). Another possibility, also postulated by Geist (1971) and Heimer and Watson (1986a,b), is lowered mortality among young rams.

The sustained harvest of about 100 rams under the 7/8-curl regulation, even though this harvest came from smaller yearling recruitments, suggests increased survival. Class III and IV rams were scarce during the aerial survey of 1975. Still, the unusually large cohort of 51 yearlings:100 ewes recruited in 1971 (Heimer and Watson 1986b) would have been 3 years old (Class II) when the yearling cohort of 1973 was recruited. Surviving members of the large 1971 cohort would have been in Classes III and IV when the 1977 cohort was recruited. It is possible that the rams from the 1971 cohort could have limited social activity by the ram cohorts harvested during the 7/8-curl period by dominating these younger rams even though these dominating rams were not fully mature themselves. The 49% higher harvests recorded under the full-curl regulation suggest survival increased further with the increasing presence of Class III and IV rams. V. Geist (pers. commun.) predicted further increase in harvest would follow change from 7/8- to full-curl based on the radical increase in rutting activity he reported among rams of approximately 7/8-curl size (Geist 1971).

Before concluding increased production and increased ram survival are the primary causes of increased harvest, other possibilities must be considered. Wolf numbers were reduced in 1976 and 1977. This may have decreased ram mortality during 1976-78. Before 1976, sheep were presumably being used by wolves in the absence of abundant preferred prey (moose and caribou) (Heimer and Stephenson 1982). However, wolf numbers were reestablished at their previous abundance by the beginning of the 7/8-curl regulatory period. They currently persist at densities which are equal to or exceed those documented during 1968-75 (McNay 1986). Still, moose and caribou populations adjacent to sheep ranges have increased, and wolves may now be killing fewer sheep than before. However, yearling recruitment and survival rates of marked ewes in the Dry Creek population showed no changes in relation to wolf abundance from 1970 through 1986 (Heimer and Watson 1990).

Weather may also affect lamb production and young ram survival. To test this possibility, Heimer and Watson (1986c) investigated snow accumulation as an indicator of weather severity during gestation, assessed the severity of weather at lambing, and correlated growing conditions for food plants in summer with subsequent lamb production and yearling recruitment. Weather conditions likely to affect production and survival were not statistically different ($\underline{P} > 0.05$) during periods with 3/4-, 7/8-, and full-curl hunting (Heimer and Watson 1986c).

Furthermore, documented ewe survival has shown no significant variability ($P > 0.05$) (Heimer and Watson 1990) throughout the 3/4-, 7/8-, and full-curl periods. We think weather conditions should affect young rams and ewes equally. Consequently, we do not think the increased ram harvests can be attributed to unusually favorable weather conditions.

Lastly, increased harvests could have been due to ewe population growth in the study area. This did not occur. Evidence suggests the Dry Creek study population accurately represents the population trend for sheep throughout the study area (Smith 1978). The ewe population in the Dry Creek area has not increased sufficiently to account for the increases in harvest (Tables 1 and 2). The Dry Creek ewe population declined slightly but steadily from 1970 through 1975, and then slowly increased beginning in 1977 (Table 1). It is currently thought to be about as large as it was in 1970. Still, there is no significant difference ($P > 0.50$) between the average Dry Creek ewe population size (719 ewes) associated with the mean harvest of 99 rams per year at 3/4-curl and the mean ewe population size (734 ewes) linked to the mean harvest of 134 full-curl rams from 1984 to 1989. The 2% increase in the trend-indicating ewe population could not be responsible for the 32% to 49% increase in ram harvest.

In conclusion, we think the most likely causes of the observed increase in harvest were increased lamb production and increased ram survival. Both of these causes were probable and predictable results of a more ordered social environment. It is possible that decreased predation associated with wolf reductions and a subsequent shift away from sheep as a major prey item for wolves contributed somewhat to the increased ram survival. The other possible causes including increased hunter effort, increased population size, and favorable weather conditions appear to offer little in the way of explanation.

We emphasize the only consistently management-alterable variable among this list of possibilities is ram population composition. Managers may or may not be able to limit predation, and they certainly cannot control weather. Hunter numbers can be controlled by restrictive permit systems, but this method carries the risk of decreased public interest and is not typically a means for maximizing public benefits. This leaves control of the age structure of rams through hunting regulations as the manager's most promising tool for increasing public benefits associated with maximum-use management objectives involving hunting.

We have empirically demonstrated that full-curl regulations did not result in a reduced harvest. In contrast, harvest increased following full-curl regulations. The causes of this increase are not ambiguous. Hence there appears to be little risk and measurable gain associated with full-curl regulations or other means of assuring a minimally compromised ram age structure in populations managed to provide maximum hunting and harvest opportunities. In Alaska, hunters clearly favor an assured opportunity to take larger rams and have vocally supported increased full-curl ram regulations.

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INDUSTRIAL DEVELOPMENT ON PRIME BIGHORN SHEEP RANGE IN SOUTH-WEST ALBERTA

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Abstract: During 1987-1989, Shell Canada Limited completed construction of a new road and the drilling of 2 gas wells on a mountain ridge in south-west Alberta. Construction occurred between May 1 and November 30. The area is a winter range and lambing ground for 40-60 bighorn sheep. The area is also used during the fall. Animal distribution and behavior were monitored before and during construction activities. Industrial development *per se* did not cause bighorn sheep to abandon their traditional ranges or to alter their movement patterns. However, the attraction of the animals to wellsites, chemicals, fresh concrete, and other materials, and the animals mingling among industrial equipment was a significant concern.

In early 1986, as part of the on-going development of the Waterton Gas Field, Shell Canada Limited proposed drilling 2 wells (Wat 51 and Wat 52) on the Prairie Bluff Ridge, 18 km north of Waterton National Park. At that time, little was known of the spatial and temporal use of the area by bighorn sheep. In October 1986, Shell initiated an intensive monitoring study to provide baseline data on animal distribution and movements and to assess the impact of industrial development. Specific objectives included: 1) determine the timing and amount of bighorn sheep use of Prairie Bluff Ridge; 2) identify important feeding areas; and 3) monitor and assess reactions to construction, drilling and production activities. The study is continuing to assess the distribution of bighorn sheep and their use of Prairie Bluff 1 year after the end of construction activities.

The objective of this paper is to detail distribution before and during the development phase and the animal's response to industrial activities. We acknowledge G. Hoffman and T. Ross for their valuable field assistance throughout the study.

STUDY AREA

The Prairie Bluff complex consists of a series of high ridges and minor peaks south-west of Pincher Creek, in south-west Alberta. Elevation ranges 1,500-2,100 m. The area presents a high degree of physiographic and vegetational heterogeneity within 2 distinct ecoregions. Above 1,800 m, the alpine region features rounded peaks and gently sloping ridges of stonefields and red argillites. On the east and south, vertical walls of limestone extend into the lower elevation subalpine region which is largely represented by the cliffs and scree and talus slopes below them. The alpine region supports widely dispersed grass-*Dryas* communities. In the subalpine, fescue (*Festuca scabrella*) communities are dominant, but vary in density and species composition depending on aspect, slope and underlying material.

When this study was initiated, in 1986, the regional bighorn population was recovering from a major pneumonia-related die-off. Prairie Bluff was believed to be used as winter range by about 30 bighorn sheep. However, the level of utilization and animal presence during other seasons were uncertain. The herd is hunted in the fall (rams only). Prior to Shell gas development, vehicular access to the Prairie Bluff ridges was limited to motorcycles and other all-terrain vehicles along an old trail.

METHODS

Timing of Construction Activities

To minimize the potential impact of industrial activities on bighorn sheep on Prairie Bluff, construction was limited to May-November and extended over 3 years, 1987-1989. On November 2, 1987, Shell begun construction of the access road and the preparation of the wellsites. Construction activities were suspended November 30, and resumed May 1, 1988. During the summer of 1988, after road construction was finished, Shell proceeded with gas well drilling. All activities were suspended again on November 30, 1988 and resumed May 1, 1989. In the summer of 1989, Shell constructed an underground pipeline along the access road. During this period, production buildings and equipment were erected on the wellsites, and a powerline was built following the access road. Vehicular access along the road was limited to Shell and construction personnel and government staff. The old trail was reclaimed, ending public vehicular access onto the ridges.

Animal Observations

The study began in October 1986, before the beginning of industrial activities (November 1987). Distribution and movement of sheep were studied with extensive ground surveys conducted at least 1 or 2 days a week. During the months of industrial activity (November 1987, May-November 1988, and May-June 1989), movements and distribution were monitored daily. The objective of daily monitoring was to determine the immediate impact of construction activities on the animals and, if needed, to advise and assist Shell Canada in minimizing it.

All wildlife observations and animal movements were recorded and marked on 1:20,000 vertical aerial photographs. Attempts were made to observe and video-document the responses of animals to identifiable activities such as rock blasting and helicopter flying.

RESULTS AND DISCUSSION

From October 1986 to October 1989, 449 days were spent in the field. Bighorn sheep were observed on 1,290 occasions, totaling 8,838 animals, including duplicate observations. Data from a separate radio-telemetry study (ewes and yearlings) indicated that the bighorn sheep of Prairie Bluff are part of a local population which does not travel to Waterton National Park (Morgantini unpubl. data).

Population Status and Lamb Production

During the winter of 1986-87, prior to Shell industrial development, Prairie Bluff wintered 18 ewes-yearlings, 10 lambs and 8 young rams. Two winters later, in 1988-89, at the end of construction activities, the herd had increased to 33 ewes-yearlings, 14 lambs and 9 young rams.

During the study, most lambing was found to occur on winter range, within 1,400 m of a wellsite. Shell activities on Prairie Bluff did not disrupt lambing or affect lambing habitats. At the end of May 1988, and in early June, after 1 month of wellsite construction, 11 lambs were born in the area, 50 % of the 1988 lamb production by the Prairie Bluff herd. The following year, 13 lambs were born on Prairie Bluff, 81 % of the 1989 lamb production. The lower production from the previous year is believed to be due to heavy snowfall and blizzard conditions that affected the area in late May-early June 1988.

Animal Distribution

Between 1987 and 1989, the industrial development of Prairie Bluff did not cause bighorn sheep to abandon their range and did not appear to permanently affect animal distribution. Figures 1-4 show the distribution of animals over the study area in winter, spring, summer, and fall, 1988 and 1989. Differences in numbers of observations between years reflect different numbers of field days.

A direct, significant impact on distribution was detected in only 2 instances. The first, in November 1987, when Shell began construction in the area, was caused by heavy helicopter activity. During that month, sheep reduced their use of Prairie Bluff, but re-established their traditional distribution in December, when construction was suspended. The second impact was noted in spring 1988, when bighorn sheep were heavily attracted to a wellsite by the presence of substances (drilling muds, oils, solvents, etc.) used during drilling operations (Figure 2). Due to that attraction, both wellsites were later fenced.

Behavioral Responses to Construction Activities.

Shell's operations were categorized as: helicopter support; caterpillar work, grading and vehicular traffic along the road and on wellsites; drilling for rock blasting and blasting; drilling rig operations; pipeline construction and wellsite activities.

Helicopter support.-- During November 1987, a helicopter was used to ferry fuel, people and equipment to the top of Prairie Bluff. A total of 247 flights with a Bell 212 (61.8 hrs) and 16 flights with a Bell 206 (4.7 hrs) were conducted, averaging 9 flights/day. Responses of sheep to helicopter flying were observed on 20 occasions (a total of 115 animals). In most cases (N=15, 76 animals) a significant behavioral response was detected. This consisted of increased level of alertness which was apparent before the observer could hear the helicopter. Reactions ranged from interrupted feeding and slow escape to panic fleeing. In 6 instances (42 animals), total disruption of activity and herd structure was detected. In 5 observations (39 animals) there was no apparent reaction. Nonetheless, it was evident that helicopter activity had an impact on bighorn sheep behavior and distribution in November. Subsequent to these observations, Shell abandoned the use of helicopters.

Caterpillar work, grading, and vehicular traffic.-- Disturbance associated with caterpillar operation and grading was minor because it was localized and with minimal noise. Further, to minimize any potential impact, Shell personnel had been instructed not to step off the road or approach any animal.

In general, bighorn sheep took little overt notice of activities along the road and were frequently seen grazing within 20 m of the road in spite of its construction, grading or passing vehicles (Figure 2). In many instances (N=19, 137 animals), sheep were observed on the road as a vehicle approached. Some of these encounters occurred when an animal crossed the road as a vehicle approached. But frequently, sheep appeared to be attracted to the road by previously spilled fluids (diesel, oil, concrete, etc.). In most cases, sheep moved off only to return onto the road after the vehicle had passed. On other occasions, however, the animals had to be herded off the road by the driver of the vehicle.

Rock drilling and blasting.-- Activities associated with rock drilling and site preparation for blasting did not appear to cause overt behavioral responses from bighorn sheep. On several occasions, animals grazed close to the site of activities (25 m) and had to be moved away before blasting could proceed. Blasting occurred along the road and on wellsites, in November 1987 and May 1988, and along the lower reaches of the road for pipeline construction, in June 1989.

Most blasting occurred in November 1987. During 19 days, approximately 42,899 kg of explosive were used in 22 blasts. Charges along the road were relatively small: 15 blasts averaging 53 kg/blast. Charges on wellsites were significantly larger: 7 blasts averaging 6,015 kg of explosive. Even though bighorn sheep were avoiding the area due to helicopter disturbance, their responses to blasting were observed in 8 instances (63 animals). In most cases (N=5, 52 animals), their reaction consisted of looking toward the blast followed by continued feeding. However, in all but 1 of these observations, the animals were more than 2 km distant and upwind (average wind speed: 10-15 km/hr). In 1 instance, 2 ewes and 1 lamb were grazing within 500 m from a road blast site. As the blast occurred, the animals jumped and run for approximately 50 m. Then after watching for 120 seconds, they resumed feeding. In another observation, 4 ewes and 1 lamb, 2 km distant, fled as the blast occurred. A major impact was detected when 2 ewes and 1 lamb were 1.4 km distant, at the same elevation and in direct view, of a large blast (9,256 kg of explosive) on a wellsite. The animals fled over a ridge and remained restless, milling and looking around for 20 minutes.

In spring 1988 and 1989, rock blasting consisted only of small charges and was restricted to the lower section of the road. Responses of the animals ranged from an apparent total indifference to a startled reaction that consisted of either looking toward the source of the noise, or getting up and/or running for 5-10 m, then resuming their previous activity.

Pipeline construction.-- The underground pipeline from the Prairie Bluff wellsites to the Waterton Field gathering system was constructed during June-July, 1989. Due to the nature of pipeline construction (trenching, welding and backfilling) and its timing (during the lambing season), there were reasons for concern. An open trench, 1 m wide and 1 m deep, with pipe sections laying beside the trench on wooden blocks for welding, and an opposite dirt berm, could have been a hazard and a barrier for ewes and new-born lambs moving from lambing grounds onto summer ranges. Shell addressed these concerns by adopting an unusual construction schedule. No trench was left open overnight on the Prairie Bluff Ridge. In this area, every day, while a section of the trench was excavated, sections of pipe were welded together in another location. When the trench was completed, the welded sections were moved and laid in it. The trench was then backfilled. Further, movements of bighorn sheep were constantly monitored to detect when the animals were heading toward the area with the open trench and to warn construction personnel. This pipeline construction approach resulted in a slower schedule, but was effective in minimizing negative impacts. Ewes and new-born lambs were able to move through the construction area toward their summer range with minimal or no impediment.

Drilling rig operations and wellsite activities.-- Throughout the period of construction activities on Prairie Bluff, bighorn sheep were frequently observed grazing near wellsites. However, these results may be misleading. Direct responses of bighorn sheep to wellsite operations (drilling, servicing, etc.) cannot be assessed due to the attraction of the animals to materials on site. It is impossible to determine how the animals would have responded to the presence of a large drilling rig, and associated level of activities, had not they been attracted to the wellsites. During the winters of 1987-88 and 1988-89, with no construction activity in the area, the presence of wellsites and equipment did not affect bighorn sheep distribution, as they were frequently observed grazing near them (Figure 1).

Attraction to Materials on Wellsites and Along the Road

During summer 1988, when gas well drilling was underway, bighorn sheep ranged mostly on summer ranges, away from Prairie Bluff. In October, however, with increased use of the Prairie Bluff region, the animals detected materials on the wellsites and along the new road. These consisted of small amounts of fluids (drilling muds, oil, fuel, etc.) spilled off vehicles or during drilling operations. At that time, sheep were frequently observed licking along the road and milling around equipment on 1 wellsite. The attraction of the wellsite was solved by erecting a temporary fence.

Through winter 1988-89, bighorn sheep were occasionally observed eating dirt and licking the ground along the road and on the other wellsite. This attraction, however, did not significantly affect their distribution (Figure 1).

During April-June 1989, and to some extent over the summer, the attraction of bighorn sheep to industrial materials was a concern, and had a major impact on distribution (Figure 2). Prior to fencing the second wellsite, the animals had to be moved off frequently because they were interfering with construction activities. The attraction overrode any natural avoidance that the animals may have had about people or equipment. Bighorn sheep were seen eating fresh concrete, pipe insulation, paper, cardboard, twine, mulch, licking at powerpole insulators, at equipment, at various chemicals and fluids spilled on roads or on wellsites, etc. Animals were observed crawling under gates, crawling under fences, leaning with their front legs against fences, standing in the middle of the road licking contaminated soil irrespective of approaching vehicles, etc. This behavior is remarkable considering that 1) the Prairie Bluff herd is separate from the Waterton National Park herds; 2) animals were not habituated to human activities; and 3) rams are hunted in the fall.

Shell addressed the problem by effectively and permanently fencing the wellsites and all the disturbed soil around them with 2.5 m high chain-link. Shell also instructed personnel and contractors to maintain a clean site and to clean up spills immediately. It is expected that the attractive chemicals in the small areas of contamination along the road will be leached away by rain and snow.

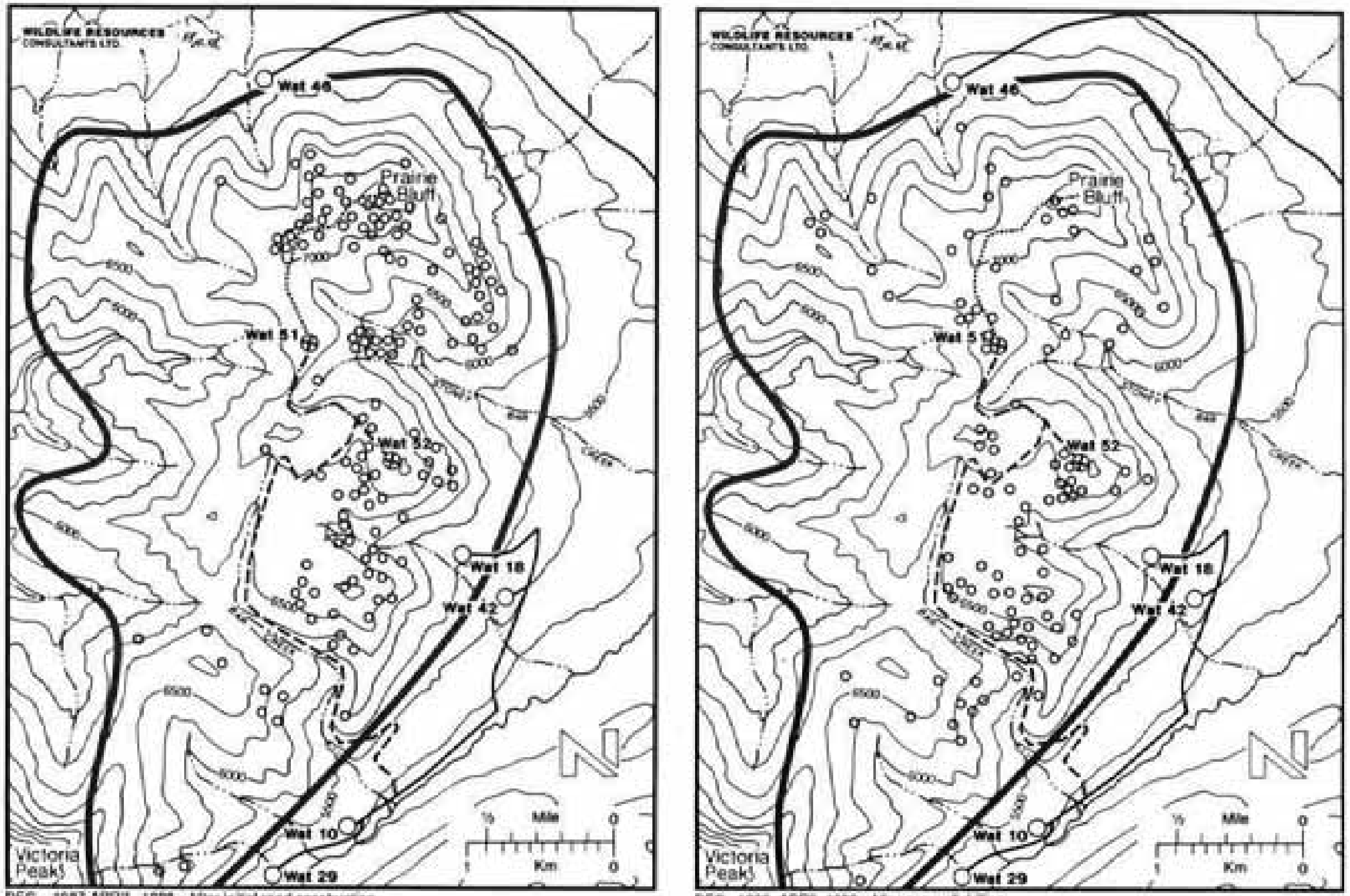
The substance or substances that attract the animals are not known. Samples of contaminated soil and materials have been collected and are being analyzed.

CONCLUSIONS

On a short term basis, the industrial development of Prairie Bluff, a prime winter range for bighorn sheep in southern Alberta, does not appear to have significantly impacted animal movements or distribution. How the herd will respond over the years is uncertain. At present, the 2 fenced wellsites are in production and servicing traffic along the new road is limited to an average of 1 vehicle/day. No public motorized access is allowed.

The limited impact of construction activities is largely due to the mitigative measures adopted by Shell. The commitments to limit activities within the less critical period May-November, to restrict vehicular access along the new road, and to fence the 2 wellsites, in addition to a willingness to address potential wildlife conflicts as they occurred, significantly contributed to minimize impacts.

The attraction of bighorn sheep to materials used during industrial operations is a potential problem that should be considered whenever industrial activity on prime range is proposed. The attraction could affect animal distribution and lead to uneven range utilization. But, more important, it can lead bighorn sheep to display most unusual and unexpected behaviors. These can result in property damage or could harm the animals by exposing them to potentially toxic chemicals and industrial hazards.

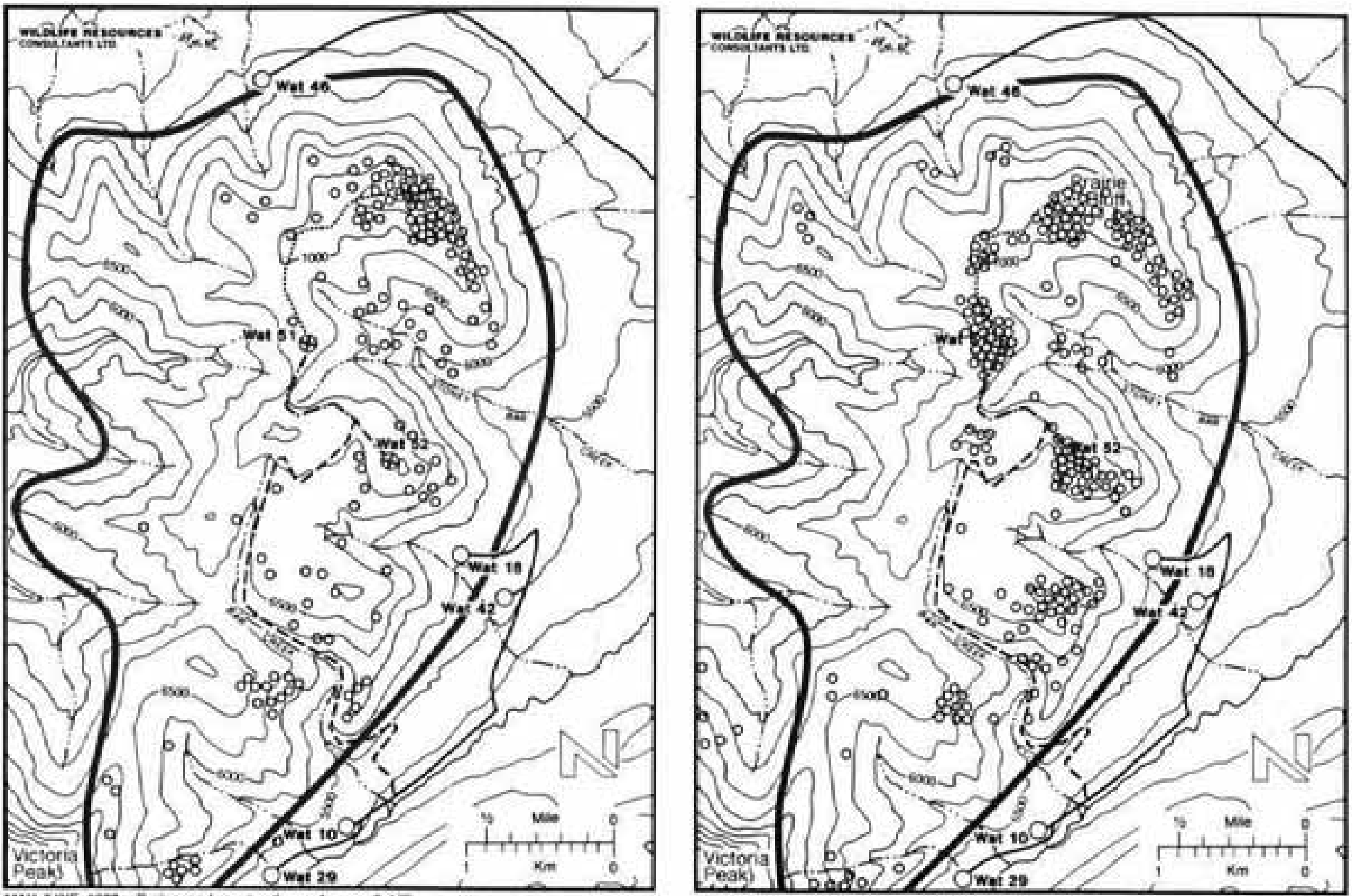


DEC., 1987-APRIL, 1988 - After initial road construction.
Based on observations made during 48 field days.

DEC., 1988- APRIL 1989 - After gas well drilling.
Based on observations made during 32 field days.

——— Service Road — — — New service Road —·—— Upgraded Trail ·········Trail ▬ Study Area Boundary

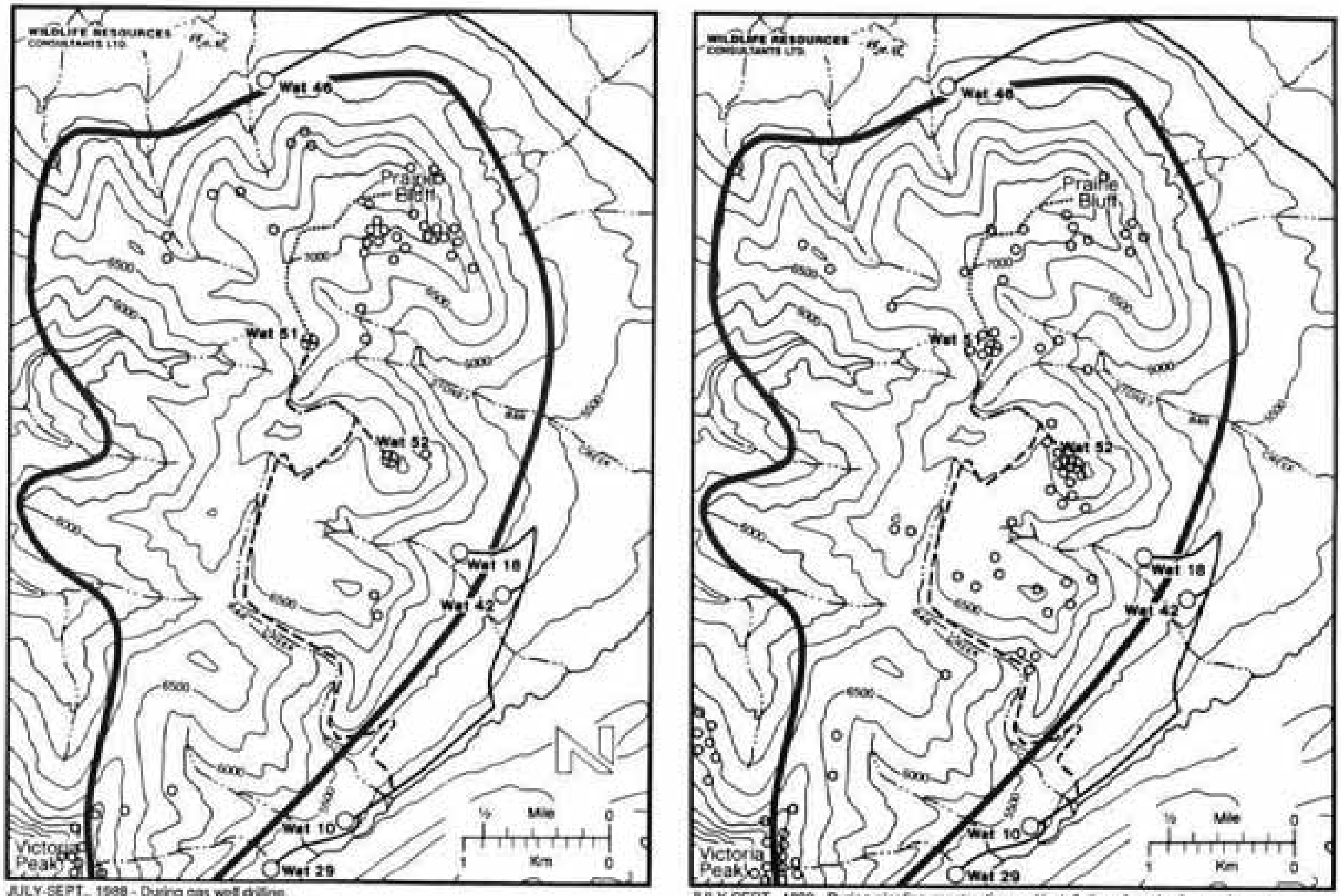
FIGURE 1 BIGHORN SHEEP SIGHTINGS, WINTER , 1987-88 AND 1988-89.



MAY-JUNE, 1988 - During road construction and gas well drilling.
Based on observations made during 61 field days.

MAY-JUNE, 1989 - During well testing and pipeline construction.
Based on observations made during 58 field days.

FIGURE 2 BIGHORN SHEEP SIGHTINGS, SPRING, 1988 AND 1989.

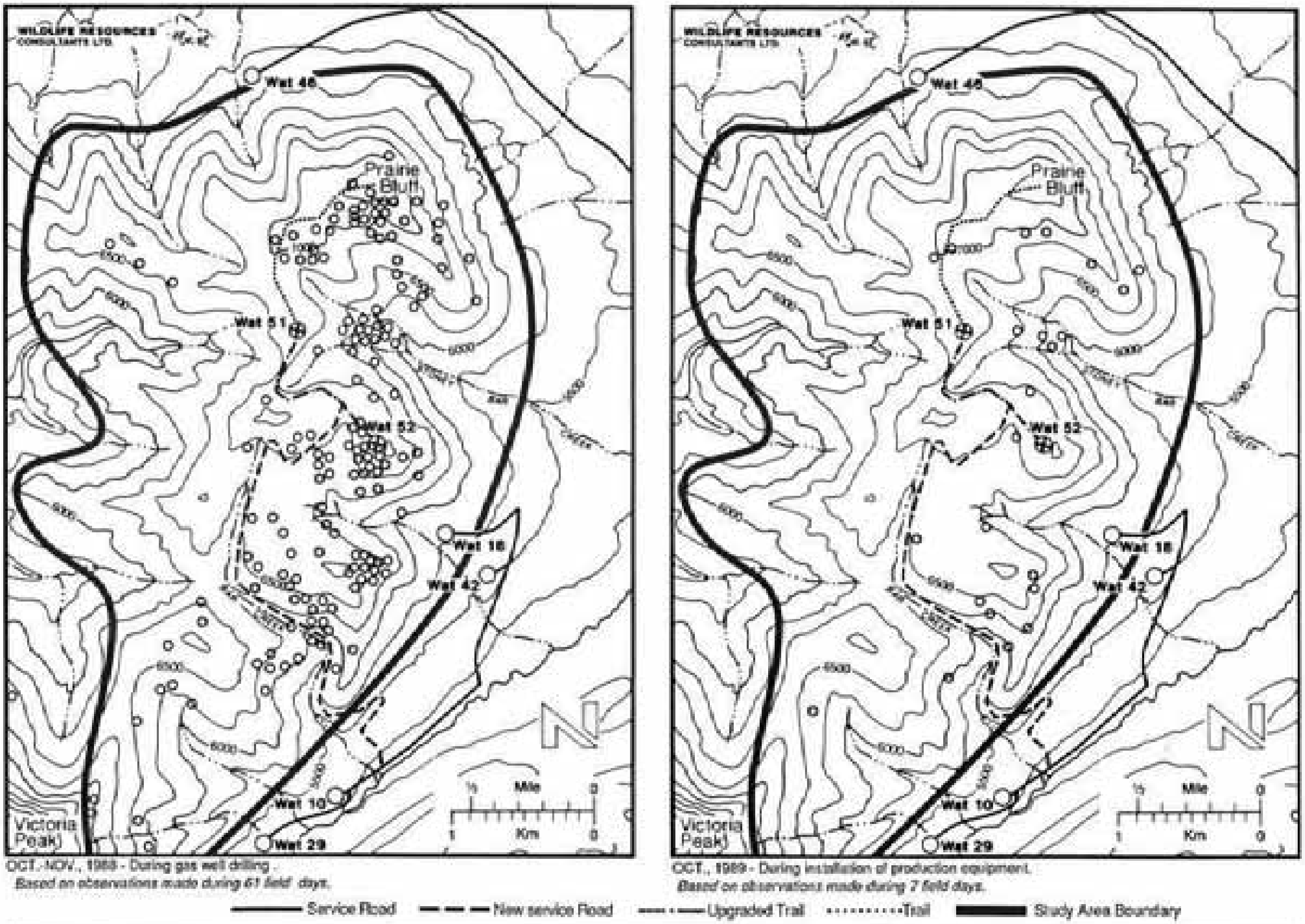


JULY-SEPT., 1988 - During gas well drilling.
Based on observations made during 27 field days.

JULY-SEPT., 1989 - During pipeline construction and installation of production equipment.
Based on observations made during 27 field days.

——— Service Road — — — New service Road —·—— Upgraded Trail ·········Trail ▬▬ Study Area Boundary

FIGURE 3 BIGHORN SHEEP SIGHTINGS, SUMMER, 1988 AND 1989.



OCT.-NOV., 1988 - During gas well drilling.
Based on observations made during 61 field days.

OCT., 1989 - During installation of production equipment.
Based on observations made during 7 field days.

FIGURE 4 BIGHORN SHEEP SIGHTINGS, OCT.-NOV., 1988 AND OCT. 1989.

BIGHORN

DISEASES

Bienn. Symp. North.Wild Sheep
and Goat Counc.7:67-75.

PROBLEMS WITH "MULTIPLE LAND USE" DEALING WITH BIGHORN SHEEP AND DOMESTIC LIVESTOCK

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Abstract: Under the multiple land-use concept, the interaction of bighorn sheep (*Ovis canadensis*) with domestic livestock has produced 4 problems. These problems are utilization of range resources by domestic livestock, displacement of sheep from valuable range, interbreeding, and disease. These 4 problems with emphasis on the transmission of diseases are discussed. Viral, chlamydial, rickettsial, mycoplasmal, bacterial and parasitic diseases that are potential hazards to bighorn sheep are described.

The first documented problem associated with intermixing of domestic animals with bighorns was the transmission of infectious diseases. These diseases including anthrax, *Pasteurella* sp. and scabies were devastating to bighorn sheep populations in the late 1800s and early 1900s (Buechner 1960). In recent years there has been increased awareness of the problem of domestic animal and bighorn sheep interactions. The concept that has been promoted for years, "Multiple Land Use," in regard to grazing different species of ruminants on the same range needs reevaluation. Grazing and/or intermixing of domestic sheep, cattle and exotic ruminants with bighorn sheep may not be an acceptable management strategy.

Four problems affecting bighorn sheep that share range with domestic sheep and cattle have been observed. The first is utilization of forage by cattle, domestic sheep and exotic ruminants. Some ranges used by cattle and domestic sheep, referred to as "high summer ranges" are critical winter ranges for bighorn sheep. When bighorn sheep arrive on these critical winter ranges, they may find them overgrazed by domestic animals. This can significantly reduce winter nutrition for bighorn sheep.

Another problem is displacement of bighorns. When domestic sheep and cattle occupy a bighorn range, bighorn sheep may abandon that part of their original range occupied by the domestic animals. If this occurs over an extended period of time these bighorn sheep may permanently lose some of their range. This problem with range occupancy can also be secondary to utilization by other wildlife such as elk and deer, and human activity. McCollough (1982) found that only 4-5% of the perferred range of the Trickle Mountain herd of bighorn sheep was used by cattle, but in my opinion this is a real problem that needing further investigation.

A third problem is interbreeding. Occasionally, bighorn rams, especially young rams, will leave their herds and travel long distances. These rams will occassional intermix with domestic sheep and breed receptive ewes. These rams can easily contract diseases and bring these diseases back to their original herds or to other bighorn herds. These young rams may also transmit endemic diseases between bighorn sheep herds. On the other hand, stray bands of domestic sheep may run with bighorns and not only introduce diseases but introduce their genes into the bighorns.

Lastly, there is the generic problem of transmission of diseases from domestic and exotic ruminants to bighorn sheep. Viral, chlamydial, rickettsial, bacterial and parasitic diseases that potentially can be transmitted between domestic sheep and cattle and bighorns will be described. The following is not a complete list, but includes the more common diseases found in domestic sheep and cattle.

Viral diseases of domestic sheep and cattle that may be transmitted to bighorn sheep include bluetongue (BT), contagious ecthyma (CE), bovine respiratory syncytial virus (BRSV), parainfluenza type-3 (PI-3), ovine progressive pneumonia (OPP), caprine arthritis/encephalitis (CAE), scrapie, bovine virus diarrhea (BVD), and ulcerative dermatosis (UD). Of these BT, CE, BRSV, and PI-3 have been diagnosed in bighorn sheep.

Bluetongue is a noncontagious, infectious, orbivirus of ruminants that is spread by Culicoides. BT is primarily a disease of domestic sheep. Cattle appear to be the reservoir host but rarely suffer illness from the virus. Four serotypes of BT are present in the United States (Barker and Van Dreumel 1985). It is not certain which serotypes infect bighorn sheep. BT appears to be pathogenic in desert bighorn lambs and is believed to predispose lambs to pneumonia (Jessup and DeForge, pers. commun.). BT has been seen on 2 occasions in captive bighorn sheep that were penned within 1 to 2 miles of domestic sheep in Colorado. The disease caused an acute hemorrhagic enterocolitis in these 2 Rocky Mountain bighorn sheep (Spraker unpubl. data). BT has not been diagnosed as a cause of mortality in free-ranging Rocky Mountain bighorn sheep in Colorado.

Contagious Ecthyma is an important disease in bighorn sheep. CE is common in domestic sheep and goats and is caused by a parapoxvirus. CE is characterized by proliferative lesions around the margins of the lips, muzzle and teats (Yager and Scott, 1985). Domestic sheep are routinely vaccinated for CE. CE has been diagnosed in desert and Rocky Mountain bighorn sheep (Samuel 1975). CE causes a severe proliferation dermatitis around the nose, lips and teats in bighorns. CE may be severe in young lambs and can result in mortality. Although CE can cause lesions in adults, it usually does not result in mortality. However, if animals are on poor range or if CE affects them during the winter, apprehension of food can be difficult. As a result, adult animals could starve. CE is transmitted among animals by direct contact, especially from dam to neonate via nursing, by contamination of the environment and by contact with dogs. The virus that is shed from scabs of infected animals can persist on the ground up to 10 years.

Bovine Respiratory Syncytial Virus is a common disease of cattle (Dungworth 1985) and has been found in desert and Rocky Mountain bighorn sheep throughout the western United States (Dunbar et al. 1985). A respiratory syncytial virus (BHS-RSV) has been isolated in a bighorn lamb with pneumonia from a herd suffering from a all-age die-off in Ouray, Colorado. Pasteurella haemolytica biotype T was also isolated from this lamb (Spraker et al. 1986). The virulence of this virus is not known and the role it plays in all-age die-offs is not understood. However, BRS-RSV and Pasteurella haemolytica bioptype T were isolated from bighorn sheep lungs in 2 herds suffering from a respiratory disease in Colorado during the winter of 1989-1990. In one herd (Estes Park), the sheep only manifested mild clinical signs characterized by coughing and serous nasal discharge. Mortality was not observed in this herd. On the other hand, the Powderhorn Canyon herd suffered extensive mortality. One major difference between these two herds is that the Estes Park herd is treated for Protostrongylus and has a extremely low lungworm burden, whereas, the Powderhorn Canyon herd has a relative high lungworm load. The importance of Protostrongylus in the mortality suffered by the Powderhorn Canyon herd is not known, but in the authors opinion probably plays an important role (Spraker unpubl. data).

Parainfluenza type-3 is an important virus in cattle and domestic sheep (Dungworth 1985). PI-3 titers have been found in numerous Rocky Mountain and desert bighorn herds throughout the western United States (Howe 1966). PI-3 may be an important viral agent predisposing bighorns to bacterial pneumonias. Viral infection leading to bacterial pneumonia has been documented in domestic sheep, cattle and pigs (Dungworth 1985). Therefore, this pathogenesis may occur in bighorn sheep.

Ovine progressive pneumonia is a lentivirus disease that causing chronic interstitial pneumonia in domestic sheep (Dungworth 1985). This disease is transmitted amoung domestic sheep by close contact, to lambs during the first days of life, and is transplacentally transmitted. Animals affected with OPP usually do not manifest clinical signs until they are 3 to 4 years old. In Colorado, approximately 225 free-ranging bighorn sheep from the Estes Park and Georgetown herds have been tested for OPP, but antibodies have not been found (Spraker unpubl. data).

Caprine arthritis encephalitis is a retroviral infection (similar to OPP) characterized by neurological, respiratory and arthritic lesions in domestic goats. CAE is transmitted via carrier animals and milk and is common in domestic goats (Jubb et al. 1985). Titers to CAE have not been found in free-ranging bighorn sheep. However, 2 desert bighorn lambs that were seronegative to OPP/CAE were fed goat colostrum and both converted to seropositive. These 2 animals were released in the wild, but died due to encephalitis at approximately 18 months of age (D. Jessup pers. commun.).

Scrapie is a chronic infectious disease affecting the central nervous system of domestic sheep and is present throughout the western United States (Sullivan 1985). Six cases of scrapie were diagnosed in Colorado in 1989. A scrapie-like disease has also been found in 3 free-ranging mule deer and a free-ranging elk in Colorado (Spraker unpubl. data). This disease usually is transmitted to the newborn lamb. Clinical signs in affected animals do not appear until the animal is 2 to 4 years old. Free-ranging bighorns are probably susceptible to scrapie, although none have been diagnosed.

Bovine Virus Diarrhea is primarily a disease of cattle. A virus similar to BVD causes border disease or "hairy shakers" in domestic sheep (Barker and Van Dreumel 1985). Titers to BVD have occasionally been found in free-ranging bighorns in Colorado. The importance of BVD in bighorn sheep is unknown.

Ulcerative dermatosis is an uncommon disease of domestic sheep characterized by ulcerative lesions of the lips, face, legs, feet, vulva, prepuce and penis. UD is caused by an unclassified poxvirus. Transmission is by direct contact and coitus. This disease is potentially transmissible to free-ranging bighorns especially at common water holes and by interbreeding with domestic sheep (Yager and Scott 1985).

Chlamydia is a common infectious agent of domestic sheep and cattle. Chlamydia can cause upper respiratory disease, keratoconjunctivitis, arthritis, and abortion in these animals (Dungworth 1985, Jubb et al. 1985). It is a common cause of abortion in domestic sheep in Colorado. Chlamydia have been isolated from bighorn sheep (Pearson and England 1979) and appear to be able to cause an upper respiratory infection, keratoconjunctivitis, and arthritis in these animals. Abortion associated with chlamydia in bighorn sheep has not been documented. Since chlamydia is common in domestic sheep and cattle, it should be monitored in bighorn sheep populations. Chlamydia has been isolated from 3 bighorn sheep herds in Colorado, including Almont Triangle, Trickle Mountain and Grant. Ocular lesions and upper respiratory signs were associated with this chlamydial infection in 1 herd (Grant) after it was placed in captivity (Spraker unpubl. data).

Anaplasma ovis is a tick-transmitted rickettsial organism occurring in domestic sheep. The organism affects erythrocytes and causes anemia (Valli 1985). Anaplasmosis has been diagnosed in desert bighorns in Mexico. It is not known if this disease can be transmitted from domestic sheep to bighorn sheep, or if the organism of domestic sheep is the same agent described in Mexican bighorns. Caution should be taken if Mexican bighorns are transplanted into the United States. Titer to _A. ovis_ has been detected in desert bighorn sheep in southern California (D. Jessup pers.commun.).

A mycoplasma agent (_Mycoplasma arginini_) has been isolated from bighorn lambs with pneumonia in 1970 from Pike's Peak, Colorado (Spraker 1979). The organism has also been isolated from captive bighorns (Al-Aubaidi et al. 1972). Mycoplasma pneumonia caused by _Mycoplasma ovipneumoniae_ is present in domestic sheep (Dungworth 1985). Mycoplasma pneumonia may be transmitted from domestic sheep to bighorn sheep, but there has been no evidence to directly implicate domestic sheep for transmitting this disease.

Numerous bacterial diseases affect both domestic and bighorn sheep. Anthrax transmitted from domestic sheep was believed to have killed numerous bighorn sheep in the late 1800's (Buechner 1960). Anthrax is an acute bacteremia caused by _Bacillus anthracis_ that produces postmortem lesions similar to those observed in acute septicemic pasteurellosis (Valli 1985).

Pasteurellosis is a common disease causing septicemia/bronchopneumia in bighorn and domestic sheep. Pasteurellosis was blamed for the death of bighorn sheep in the early 1900's. It was believed to have been transmitted from domestic sheep (Buechner 1960). Several types of _Pasteurella_, including _Pasteurella multocida_ and _Pasteurella haemolytica_ biotypes A and T, have been found within the nasal cavity, tonsil and lung of domestic and bighorn sheep. These organisms have been isolated from both sick and healthy bighorns. Species of _Pasteurella_ isolated from domestic sheep can potentially cause an acute fulminating pneumonia in bighorn sheep (Foreyt and Jessup 1982, Onderka and Wishart 1988, Foreyt 1989). Circumstantial evidence suggest that some of the _Pasteurella_ spp. of domestic sheep are highly pathogenic to bighorn sheep; conversely _Pasteurella_ spp. of bighorn sheep are probably not pathogenic to domestic sheep (Onderka and Wishart 1988). _Pasteurella_ play a major role in the pathogenesis of all-age die-offs and lamb mortality of bighorn sheep. Of all the bacterial species that affect bighorn sheep, Pasteurella is probably the most important.

Johne's disease or paratuberculosis is an important bacterial disease caused by Mycobacterium paratuberculosis and occurs in domestic sheep, cattle, goats, bighorns, Rocky Mountain goats and most exotic ruminants (Williams and Hibler 1982, Barker and Van Dreumel 1985). Bighorn sheep and Rocky Mountain goats in the Mount Evans/Grant herds west of Denver, Colorado are infected with paratuberculosis. This disease causes a chronic granulomatous enteritis. Clinical signs include intermittent diarrhea and emaciation. Animals contract the disease in the first 3 to 4 months of life and usually do not manifest clinical signs until 2 to 4 years of age. Johne's disease can be transmitted transplacentally. In an infected domestic bovine, ovine, or caprine herd the disease kills approximately 5-10% of the animals in the herd each year (Barker and Van Dreumel 1985). Paratuberculosis is an extremely important disease that should be guarded against to avoid transmission to other bighorn herds. If Johne's disease is diagnosed, the infected herd is not a suitable source for transplants.

Brucellosis, both Brucella abortus and B. ovis, occur in the western United States and affect both domestic sheep and cattle. B. abortus causes abortion in cattle and has a potential of being transmitted to bighorns in areas where cattle and bighorn ranges overlap. Approximately 350 bighorn sheep sera from 4 herds (Estes Park, Georgetown, Sugarloaf/Terryalls, and Cottonwood Canyon) in Colorado have been tested for B. abortus and all were negative (Spraker unpubl. data). B. ovis is common in domestic rams in Colorado. This disease is spread primarily through breeding. A bighorn ram entering into a domestic sheep herd and breeding with estrus ewes could acquire this organism and transmit it to other wild sheep. This organism causes little to no harm to ewes but causes an chronic suppurative epididymitis in rams and reduces fertility. Titers to B. ovis have been found in free-ranging bighorn sheep throughout Colorado (Severin unpubl. data).

Bacterial diseases of domestic sheep and cattle that have not been diagnosed in bighorn sheep include Campylobacter intestinalis, leptospirosis, and Foot Rot. C. intestinalis is a common cause of abortion in domestic sheep in the western United States. Leptospirosis is a disease of cattle and sheep and has the potential of being transmitted to bighorn sheep. The primary agent of foot rot is Bacteroides nodosa. This is a chronic infection of the interdigital area and hoof and leads to lameness. This disease has not been found in bighorn sheep. Caseous lymphadenitis, Corynebacterium ovis, is an important disease of domestic sheep in the western United States. This disease is caused by Corynebacterium ovis. This bacteria is a wound contaminant and probably not a significant disease that would be transmitted to bighorn sheep.

Numerous parasitic diseases may be transmitted to bighorn sheep. Probably most important is scabies. Older literature suggests that scabies of domestic sheep is transmissible to bighorn sheep. However, documentation has not been made. Recent work suggests a difference between the scabies mite from domestic sheep compared to the mite of bighorn sheep and cattle. Until it is determined if the scabies of domestic cattle or sheep is transmissible to bighorns, precautionary measures should be taken to avoid contact between infected animals.

Oestrus ovis is a

parasitic larva of a fly that lives in the frontal sinuses of domestic sheep. This parasite has been found in desert and Rocky Mountain bighorn sheep (Capelle 1966). This organism appears to be more of a problem in desert bighorns than in Rocky Mountain bighorns. O. ovis maybe responsible for, or at least associated with, a condition called chronic frontal sinusitis which can be fatal to desert bighorn sheep.

Demodex is a mite found in domestic sheep and cattle. A case of demodectic mange in Rocky Mountain bighorn sheep has recently been found (Spraker unpubl. data). The Rocky Mountain sheep with Demodex sp. did not have clinical signs of dermatitis. The significance of this finding and the possibility of transmission between domestic sheep and cattle to bighorn sheep has not been determined.

Bighorn sheep are susceptible to at least 2 species of lungworms, Protostrongylus and Muellerius. Muellerius is transmissible between domestic sheep and bighorn sheep; Protostrongylus is not. Muellerius occurs in a few domestic sheep populations in the western United States. Muellerius capillaris was involved in a die-off of captive bighorn sheep (DeMartini and Davis 1977). Muellerius has only been found in free-rangeing bighorns from South Dakota (Spraker unpubl. data).

The lungworm, Protostrongylus, of bighorn sheep is not transmissible to domestic sheep. There are 2 species of Protostrongylus, P. stilesi and P. rushi. P. rushi lives in the bronchi and bronchioles of the lung, whereas P. stilesi lives in the alveolar spaces. Experimental transmission of these parasites to domestic sheep have failed (R. Lange pers.commun.). Protostrongylus appears to be associated with Pasteurella in causing all-age die-offs and lamb mortality in bighorns (Marsh 1938).

Elaeophora schneideri is a filarial nematode that inhabits the carotid arteries of mule deer. It is transmitted by horseflies (Hybomitra and Tabanus). Horsefly activity is primarily in June/July. Domestic sheep, goats, elk, and moose are susceptible and infection may be fatal (Hibler and Adcock 1971). There is no reason why bighorn sheep should have a natural resistance. Under normal conditions, bighorns are not in ideal horsefly/mule deer habitat in June/July; but with some recent bighorn sheep transplants, this natural protection may be eliminated. This indiscrete transplanting of bighorns may place them on ranges of endemic diseases of other wildlife. Bighorns should not be transplanted into areas of known endemic elaeophorosis.

The above list of disease is not complete. Many known and unknown diseases pose a threat to bighorn sheep populations. If bighorn sheep, domestic sheep, cattle, and exotic ruminants are allowed close contact due to multiple land use, many diseases may be transmitted to the bighorn sheep.

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EFFECT OF CHRONIC STRESS ON IMMUNE SYSTEM FUNCTION OF ROCKY MOUNTAIN BIGHORN SHEEP

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Abstract: Decreased immunocompetence due to stress has been implicated in the susceptibility of bighorn sheep (*Ovis canadensis canadensis*) to bronchopneumonia induced by a variety of pathogens. In a 34-day preliminary study, features of the immune system of domestic sheep (*O. aries*) stressed by confinement and noise were studied. During a 150-day experiment, we investigated the effect of chronic stress on immune system function of (1) wild-caught bighorn ewes, which we assumed to be stressed by recent capture, a novel environment, and repeated handling, and (2) tame bighorn ewes, which we assumed experienced minimal stress due to handling. Plasma cortisol was also measured. Lymphocyte blastogenesis was depressed below baseline and plasma cortisol increased during the trial in domestic sheep. In the bighorn sheep study, lymphocyte blastogenesis was depressed during the first 35 days but then returned to baseline. During most of the study, lymphocyte blastogenesis and leukocyte numbers of wild and tame bighorns were similar even though plasma cortisol was significantly higher in the wild animals. Alterations of lymphocyte blastogenesis and leukocyte numbers were associated with lambing, adrenocorticotropic hormone treatment, and acute confinement. Results suggest that approximately the first month of protracted exposure to stressors is the most detrimental to immune system function and that portions of this system can adapt to chronic stress even with elevated levels of plasma cortisol.

Stress, defined as the need for an individual to make abnormal or extreme adjustments in physiology or behavior to cope with adverse aspects of its environment (Fraser et al. 1975), is thought to be an important co-factor in precipitating bronchopneumonia, and perhaps other diseases, in bighorn sheep (Forrester 1971, Thorne 1971, Hudson 1973, Thorne 1982, Spraker 1984, Bailey 1986). The paradigm is "shipping fever" of cattle which involves transport stresses and, often, contact with viral or bacterial pathogens (Hoerlein and Marsh 1957, Hambdy et al. 1963, Kelley 1988). The proposed mechanism for this interaction is through stress induced elevated circulating glucocorticoids which inhibit the immune system, predisposing an individual to infectious disease (Munch et al. 1984, Roth 1985, Kelley 1988, Griffin 1989). The physiologic effects of stress have been measured by elevations of plasma, serum, urine or fecal glucocorticoids, in a variety of animals, including domestic and bighorn sheep (Fulkerson and Jamieson 1982, Harlow et al. 1987b, Spraker et al. 1984, Miller et al. 1990, Spraker and Adrian 1990). Effects of stress on immune system function have not been studied extensively in ruminants, though recently there has been increased interest in stress in these animals (Moberg 1985, Roth 1985, Kelley 1988). Observations of stress-related epizootics of bronchopneumonia in wild bighorns and occurrences of similar disease in recently captured, presumably highly stressed, bighorn sheep (Hudson 1973, Thorne 1982) prompted us to study immune system function in chronically stressed domestic and bighorn sheep.

Lymphocyte blastogenesis tests are commonly used in many species to assess function of portions of the immune system (Outteridge 1985). Briefly, these tests measure the nonspecific responsiveness of T and B lymphocytes. These cells play a central role in animal immune systems. T lymphocytes (T cells) are particularly important in cell-mediated immunity and in regulating of other portions of the immune system. B lymphocytes (B cells) are the primary cells involved in humoral immunity or antibody production. Though lymphocyte blastogenesis tests do not measure all functions of the immune system they provide valuable information about the function of major segments of this system.

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MATERIALS AND METHODS

This study was conducted concurrently with investigations of the effects of acute and chronic stress on adrenal responsiveness and cardiac frequency in domestic and bighorn sheep (Harlow et al. 1987a,b).

Animals

Five adult mixed-breed domestic sheep were used during preliminary studies (Harlow et al. 1987a). They were acclimated to halter restraint and confined separately in adjoining 1.5 x 3 m stalls. Indwelling jugular catheters were surgically implanted, threaded through tubing secured at the halter rope and passed through a concrete block wall into an adjoining room where blood was collected. The sheep were stressed for 34 days by exposure to short bursts of loud noise occurring at random intervals (between 15 and 160 sec) during day and night.

A group of chronically stressed bighorn sheep was established by bringing 5 pregnant ewes from Whiskey Basin near DuBois, Wyoming into captivity at the Sybille Wildlife Research and Conservation Education Unit near Laramie, Wyoming in late April. Only 4 animals were sampled after day 35 of captivity. Four pregnant bighorn ewes, hand-raised at Sybille, were used as unstressed control animals.

During the study, all bighorns had lambs; lambs were removed from the wild ewes for hand-raising, those from the tame ewes were allowed to remain with their dams. Birth dates were 4, 5, 11 June and 2 July for the wild bighorns and 12 June (2 lambs), 9 and 16 July for the tame bighorns. One tame ewe developed mild clinical signs of pneumonia during late May and again in early July and was treated with antibiotics. The other tame and wild bighorns remained clinically healthy. As part of the study of heart rate and stress (Harlow et al. 1987b), the bighorns were subjected to adrenocorticotropic hormone (ACTH) treatment once each during June and July and to acute confinement stress within a handling crate for 3 hrs with repeated blood sampling during August.

Hematology and Lymphocyte Blastogenesis

Blood from domestic sheep was periodically collected through catheters during the noise stress study. Blood was collected during late April-September from manually restrained bighorns by venipuncture within 15 min; the order of bleeding was variable. Samples were obtained from 9:00 - 11:00 AM when cortisol levels are lowest during the circadian cycle in desert bighorn sheep (_O. canadensis cremnobates_) (Turner 1984). Blood was collected directly into syringes containing 40 U/ml sodium heparin (Elkins-Sinn, Inc., Cherry Hill, NJ 08034) and processed within 8 hr. Blood was diluted 1:2 in Hank's balanced salt solution (HBSS), layered on ficoll/hypaque type 400 (Sigma Chemical Co., P.O. Box 14508, St. Louis, MO 63178), centrifuged 30 min at 1200 x g, and the mononuclear cell layer harvested. Mononuclear cells were rinsed 3 times in HBSS and diluted in RPMI 1640 plus 5% fetal bovine serum to contain 4 x 10^6 viable cells/ml. Mitogen assays were performed in 96 well microtiter plates with triplicate wells set for each of 3 mitogens and a triplicate without mitogens serving as an unstimulated control. Each well contained 100 ul of cell suspension plus 100 ul of mitogen diluted in culture medium, or, in control wells, 100 ul of additional culture medium. The T lymphocyte mitogens phytohemagglutinin (PHA-M, Difco Laboratories, P.O. Box 1058, Detroit, MI 48232) and concanavalin A (con A, Pharmacia Fine Chemicals, Box 175, 575104, Uppsala, Sweden) were used at a 1:80 dilution and at 5 ug/ml respectively. Bacterial lipopolysaccharide (LPS, _E. coli_ 0127:B8, Sigma Chemical Co.) was used at 100 ug/ml as a B lymphocyte mitogen.

Plates were incubated at 37 C in a humidified, 5% CO_2 atmosphere. At 48 hr of incubation, 0.5 uCi tritiated thymidine (specific activity 2.0 Ci/mmole; DuPont Co., NEN Products BRML-Chandler Mill, Wilmington, DE 19898) was added to each well. After an additional 18 hr incubation, cells were harvested onto glass fiber filters with a multisample cell harvester. Filters were dried and placed in scintillation vials with 3 ml scintillation fluid. Each vial was counted in a scintillation counter 3 times for 1 min and average counts per minute recorded for each triplicate. Results were expressed as mitogen stimulated average counts per minute minus unstimulated background counts per minute.

Plasma cortisol levels were determined by radioimmunoassay (Harlow 1987a,b). Routine complete blood counts and differential counts were conducted on heparinized blood samples (Jain 1986). Results are reported as absolute cell numbers.

Differences between means were tested using paired t tests of samples at day 0 and at various poststress sampling intervals. P values < 0.05 were considered significant.

RESULTS

Domestic Sheep

Mean plasma cortisol values increased significantly during confinement and noise stress (Fig. 1) except when the noise generator failed (Harlow et al. 1987a). Mean total leukocyte counts remained fairly stable during the trial, but mean lymphocyte and eosinophil numbers declined, though not significantly (Fig. 2). Lymphocyte blastogenesis responses (Fig. 3) to con A and PHA were similar and significantly depressed below prestress values by day 5. By the end of the 34-day trial, mean responses were reduced approximately 45 % below baseline; these differences were not statistically significant due to considerable individual variation. By 34 days, however, mean responses to LPS were depressed approximately 90 % below baseline.

Bighorn Sheep

Mean plasma cortisol was significantly elevated in captive wild bighorn sheep as compared to tame bighorns (Fig. 4) during most of the 150-day trial (Harlow et al. 1987b). Peak mean cortisol values occurred around the time of lambing in both groups of bighorns.

Mean total leukocyte counts in the 2 groups of bighorns were similar over time, ranging from about 6,000-12,000/ul (Fig. 5). Counts varied greatly near the end of the trial in wild bighorns, associated with confinement stress trials. Mean total lymphocyte counts in the 2 groups of bighorns were also similar over time with significant increases in the mean count for each group occurring during 1 sampling near the time of lambing (Fig. 6). Again, considerable fluctuation in mean lymphocyte numbers occurred in the wild bighorns near the end of the study, in association with confinement stress. Mean absolute numbers of circulating eosinophils increased during June and July following lambing in both groups and then declined back to baseline near the end of the study. However, the increase was not statistically significant due to considerable individual variation (Fig. 7).

Lymphocyte blastogenesis varied considerably over time (Fig. 8), with much of the fluctuation occurring around the time of lambing. Mean responses to T cell mitogens were significantly depressed in wild-caught bighorns during the first month of captivity (Fig. 9), and then rebounded to starting values or higher during the second month. Mean responses to LPS were slightly depressed, but not significantly, in the wild bighorns during the first month. Mean response to PHA, but not to con A, was significantly depressed near the end of the study in the wild bighorns. During the study, there was declining responsiveness of lymphocytes from both groups of bighorns to LPS (Fig. 10).

Increases in mean B cell responses, but not mean T cell responses, occurred about 1 mo prior to lambing in both groups of bighorns. This was followed by a decline in B cell responses immediately prior to lambing and a return to near normal values after lambing (Fig. 11).

DISCUSSION

Increased plasma cortisol values in the noise stressed domestic sheep were associated with decreases in absolute numbers of circulating lymphocytes and eosinophils and little alteration in the total leukocyte count. This combination of hematologic changes characterizes a "stress leukogram" (Duncan and Prasse 1977, Jain 1986) that has been described in a variety of species. Significant depression of both T and B lymphocyte responses during the 34 days suggests that these animals were immunosuppressed during this period. The functional significance of the apparent immunosuppression is not clear because the animals were not challenged with exogenous infectious agents; however, this model of chronic stress may be useful in future controlled studies of immunocompetence.

Increased mean plasma cortisol of wild bighorn sheep as compared to tame bighorn sheep indicated that the wild animals were stressed by captivity and handling. Changes in lymphocyte blastogenesis and hematologic parameters in the wild bighorns during the first month of captivity were very similar to the responses of the stressed domestic sheep (Figs. 3,9). Mean absolute numbers of lymphocytes was depressed and responses of T lymphocytes declined. This suggests there may have been immunosuppression during this month, possibly predisposing these animals to disease. Although all our wild bighorns remained clinically normal, out-breaks of disease have been reported in recently captured bighorns (Parks et al. 1972, Hudson 1973, Thorne 1982) suggesting this apparent immunosuppression is functionally significant. Immunosuppression during the first month of captivity has been investigated in bighorns using PHA stimulated mononuclear cell cultures (Hudson 1973), and in red deer (Cervus elaphus) using con A, PHA and pokeweed mitogen, a B and T cell mitogen (Griffin 1989). In both of these cases, lymphocyte responses were significantly depressed during 2-4 weeks following capture.

Decreased resistance to disease associated with chronic stress is most often associated with infections and disease due to opportunistic pathogens rather than to more virulent primary pathogens (Griffin 1989). The predisposition to disease caused by these less virulent agents in animals compromised by stress has been suggested in the "shipping fever" example in domestic animals related to infection by Pasteurella spp. (Hoerlein and Marsh 1957). Pasteurellosis is one of the most important diseases of bighorn sheep (Thorne 1982). We know that many bighorns carry Pasteurella spp. in tonsil and upper respiratory tract (Thorne 1982, Dunbar 1990). The effects of chronic stress, with elevated circulating cortisol levels and declining responsiveness of lymphocytes could be important in the pathogenesis of some forms of pasteurellosis in bighorn sheep.

Our study in wild bighorns extends previous observations (Hudson 1973) by showing a rebound in T lymphocyte responsiveness during the second month of captivity. Surprisingly, this rebound occurred in the face of elevated plasma cortisol levels. Presumably this rebound is a reflection of adaptation of portions of the immune system to chronic stress. The ability of the immune system to adjust to chronic stress has been documented in rats conditioned to stressors. In these animals, there was an initial depression of lymphocyte response to con A followed by a rebound in the presence of elevated corticosteroids (Croiset et al. 1987). These findings provide evidence that factors other than corticosteroids effect regulation of the immune system under stress. In addition, Keller et al. (1983) showed that immunosuppression associated with stress may occur in the absence of elevated corticosteroids in adrenalectomized rats, again suggesting a multiplicity of factors affecting regulation of the immune system (Moberg 1985, Griffin 1989).

It is reassuring to document that portions of the immune system of bighorns can adjust to chronic stress, at least under controlled conditions. We do not know how the responses of bighorns compare to other species. There is abundant evidence for individual and species variation in response to stress (Moberg 1985).

Mechanisms of adaptation to chronic stress are not known; however, recent studies suggest the effects of cortisol on lymphocytes may be modified. Lymphocytes and monocytes have receptors for corticosteroids on cell membranes (Kelley 1985, Golub and Gershwin 1985). A possible mechanism for immune system adaptation to prolonged elevated levels of cortisol is a T cell derived lymphokine (glucosteriod response-modifying factor) that blocks the suppressive effects of corticosteroids on T cell helper activity for antibody synthesis (Fairchild et al. 1984). Prolonged elevated levels of circulating corticosteroids could affect receptor densities and sensitivities of these cells.

The trend of declining responses of lymphocytes to LPS is more problematic. B cells are central to the humoral arm of the immune system which is known to be very important in defense against bacterial pathogens (Bellanti 1978), including Pasteurella spp. (Confer et al. 1989). This decline in responsiveness occurred in both the tame and wild bighorns in association with increases of plasma cortisol in both groups. Increased cortisol in the tame bighorns could have been due to the stress of repeated handling and blood collection. The decline in B lymphocyte responses could have been due elevated cortisol levels, however, it is also possible that changes in unmeasured factors were affecting responses of these cells. The hormonal changes associated with parturition and lactation could influence function of these cells. A similar pattern of fairly stable T cell function and declining B cell function during chronic stress simulated with repeated ACTH injections for 41 days has been described in captive bighorns (Miller 1988).

There was considerable fluctuation in lymphocyte blastogenesis and hematologic responses around the time of lambing in both groups of bighorns. The trend of increasing eosinophil numbers during this time may have reflected visceral migration of larvae of Protostrongylus stilesi across the placenta in late pregnancy (Hibler et al. 1972, 1974). Visceral migration of nematode larvae is associated with peripheral eosinophilia (Duncan and Prasse 1977, Jain 1986). It is also of note that eosinophilia occurred when plasma cortisol values were high.

Fluctuations in B cell responses, but relatively stable T cell function, occurred around the time of lambing. These changes could be explained by the need to assure natural passive transfer of immunity to the lamb via antibodies in colostrum. The ewe must mount an adequate B cell response to infectious agents in the environment prior to lambing to provide those antibodies. However, this hyperreactivity of the humoral immune response would not be desirable at the time of lambing because of the increased likelihood of alloantigen response to paternal antigens at parturition. Hence, a decline in responsiveness just prior to lambing might be desirable. The stresses of late gestation and parturition may cause additional decrease in B cell responses with a rebound to full competency as these factors are removed.

We suggest researchers be very careful when interpreting the immune competence of individual bighorns from a single measure of plasma cortisol. Normal T cell blastogenesis may occur with elevated cortisol levels though B cell responses may be depressed. Conversely, suppressed lymphocyte function may occur at normal cortisol levels.

This study provides preliminary information on the function of the immune system of bighorn sheep exposed to stress. The immune system is extremely complex and variable among individuals. Many factors, including inputs from the endocrine and nervous systems determine an animal's response to stress. We only investigated only a few aspects of this system. Because of the apparent importance of stress and disease in bighorn sheep, and our need to understand these processes to effectively manage wild sheep populations, additional studies of the effects of stress on the immune system are needed.

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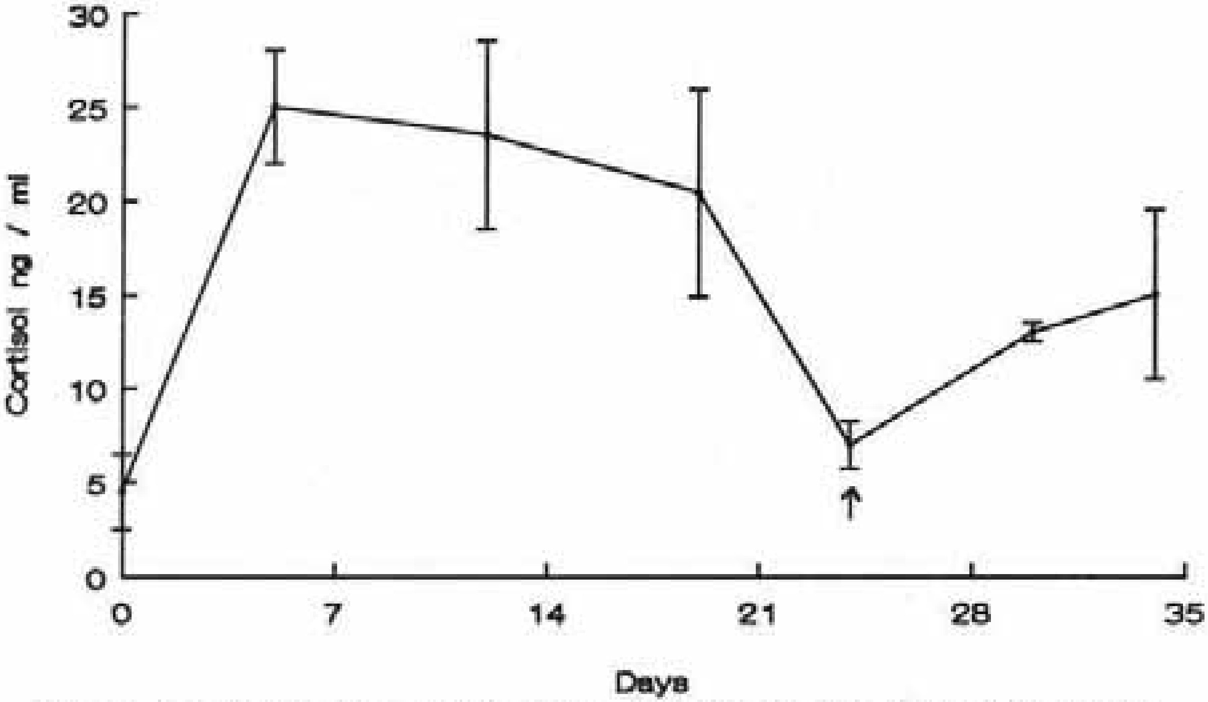

Fig. 1. Plasma cortisol values (mean, SE) of domestic sheep exposed to noise stress. The noise generator failed on days 23 and 24 (arrow).

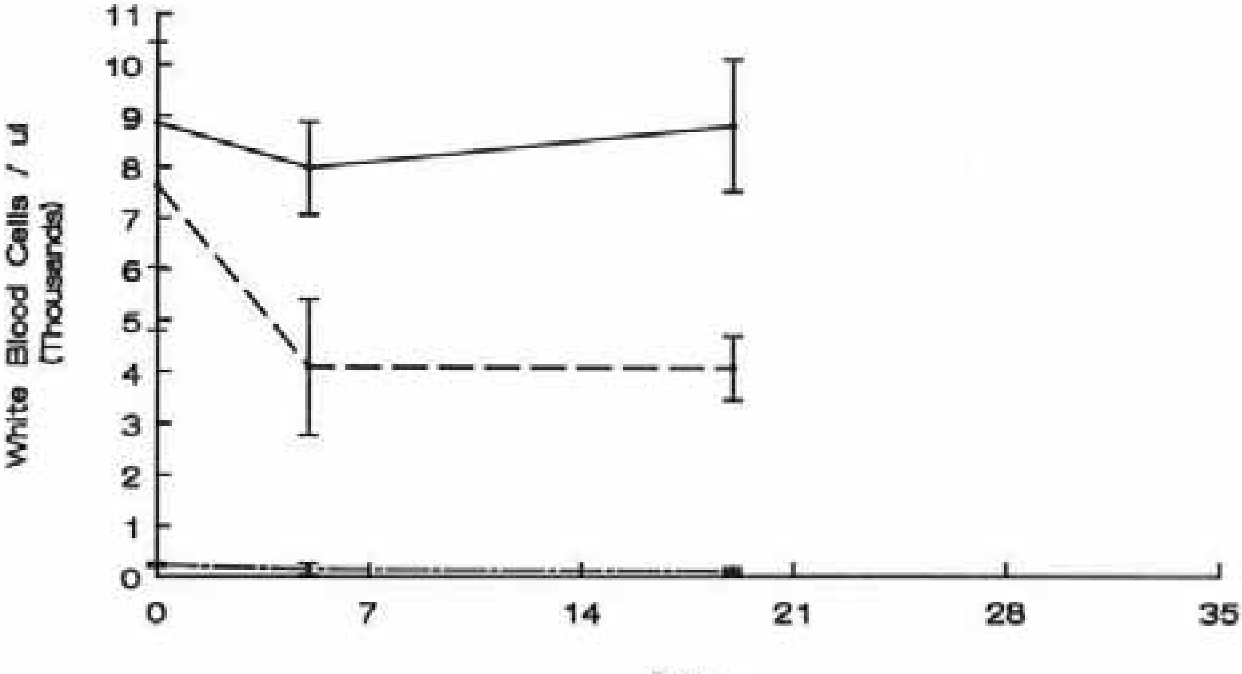

Fig. 2. Absolute white blood cell numbers (mean, SE) of domestic sheep exposed to noise stress. ——— = total leukocytes/ul; – – – = lymphocytes/ul; -·-·= eosinophils/ul.

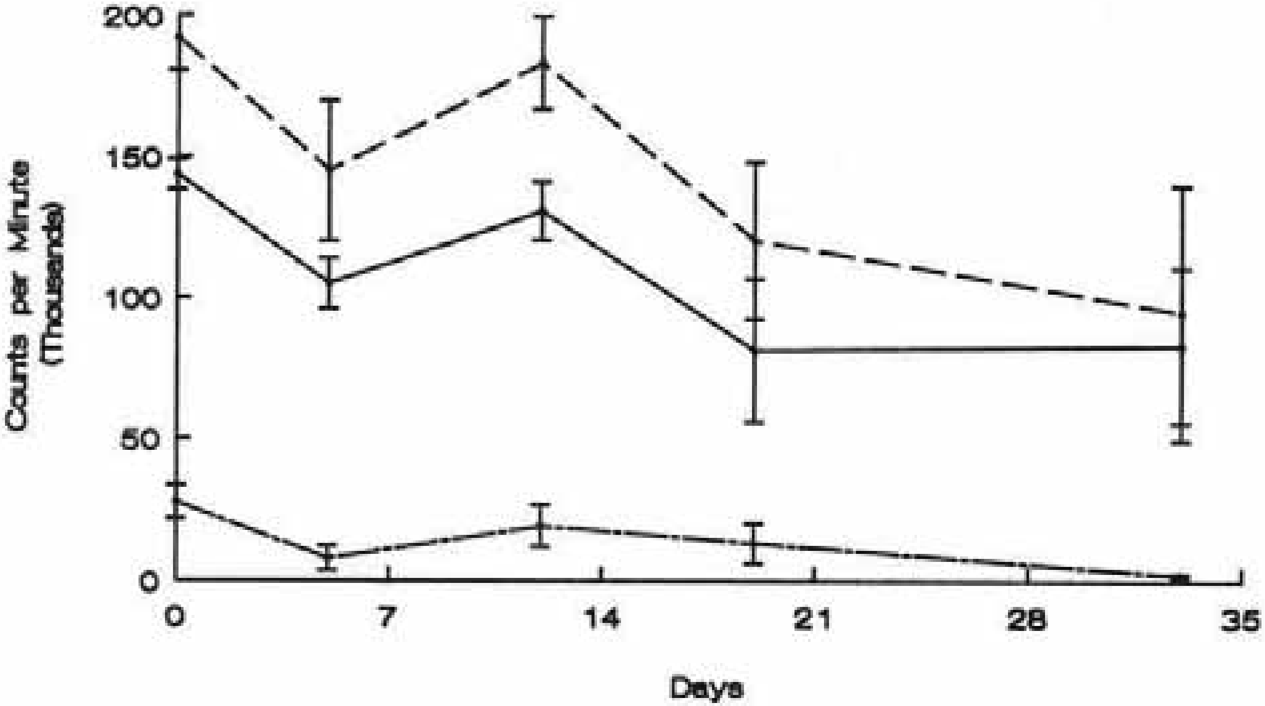

Fig.3. Results of lymphocyte blastogenesis tests (mean counts/minute, SE) from domestic sheep exposed to noise stress. ---- con A stimulation; —— = PHA stimulation; -·-·- = LPS stimulation.

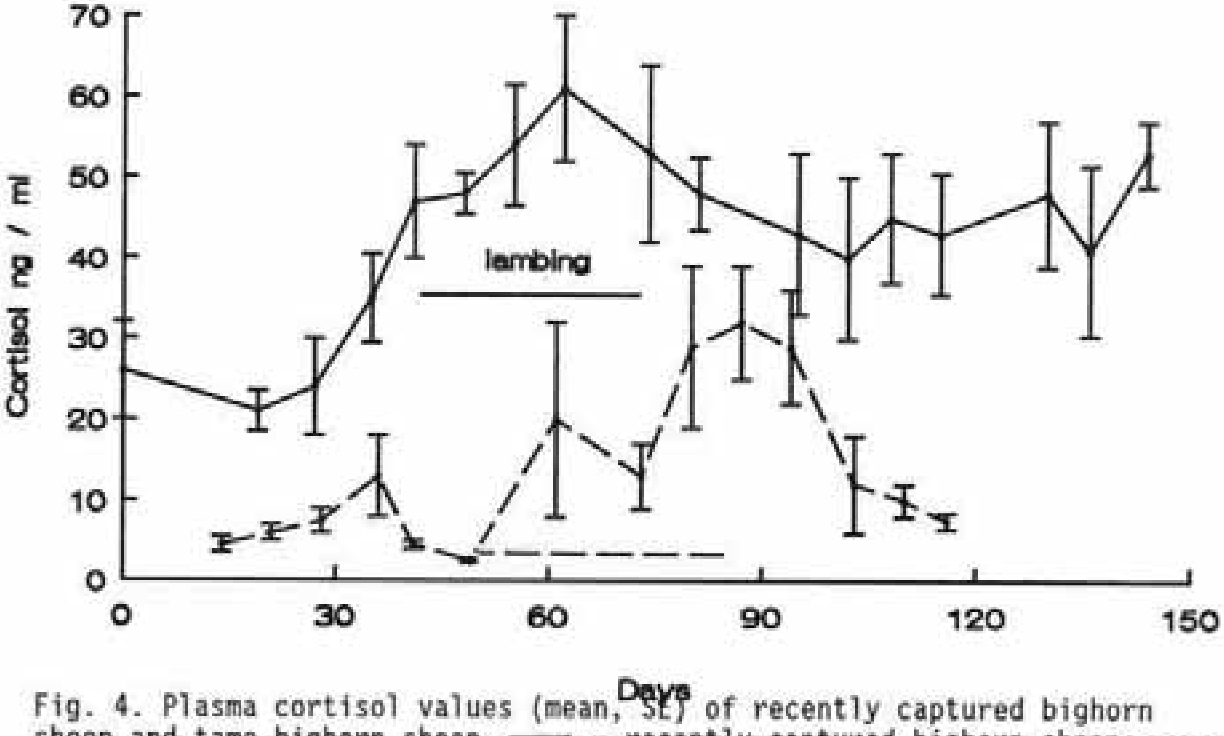

Fig. 4. Plasma cortisol values (mean, SE) of recently captured bighorn sheep and tame bighorn sheep. —— = recently captured bighorn sheep; ---- = tame bighorn sheep.

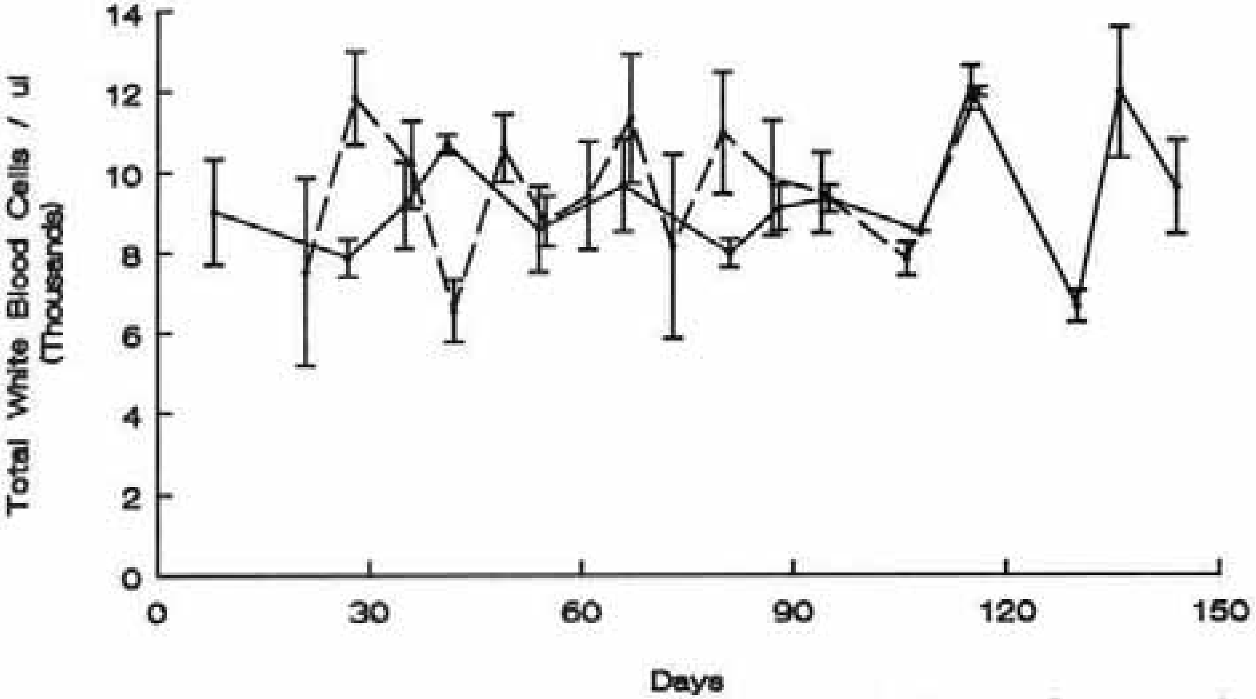

Fig. 5. Absolute white blood cell numbers (mean, SE) of recently captured bighorn sheep and tame bighorn sheep. —— = recently captured bighorn sheep; — — = tame bighorn sheep.

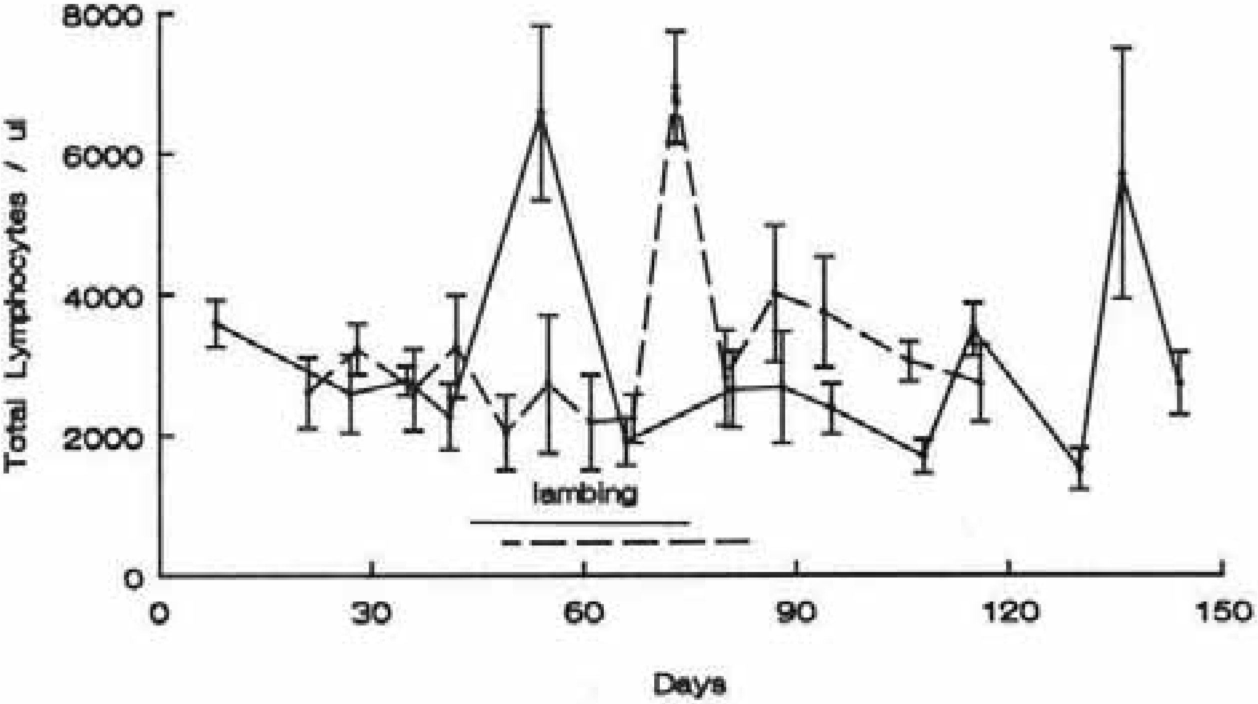

Fig. 6. Absolute lymphocyte numbers (mean, SE) of recently captured bighorn sheep and tame bighorn sheep. —— = recently captured bighorn sheep; — — = tame bighorn sheep.

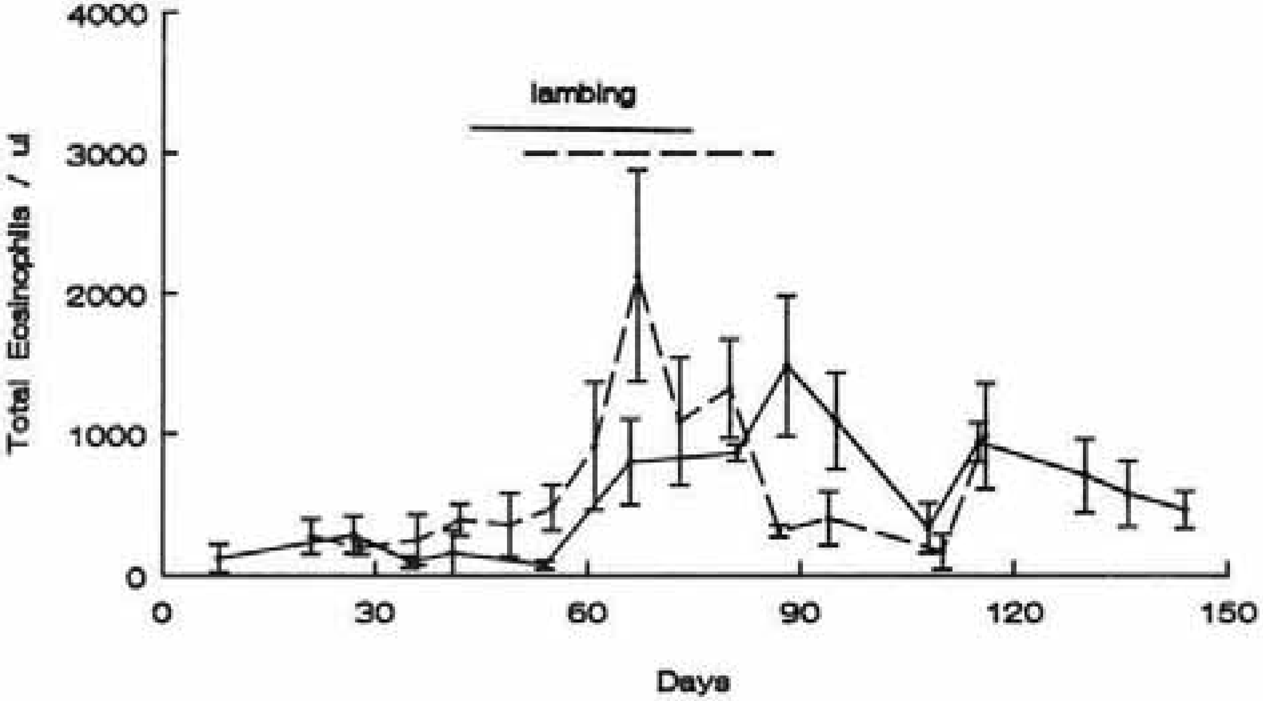

Fig. 7. Absolute eosinophil numbers (mean, SE) of recently captured bighorn sheep and tame bighorn sheep. ——— = recently captured bighorn sheep; – – – = tame bighorn sheep.

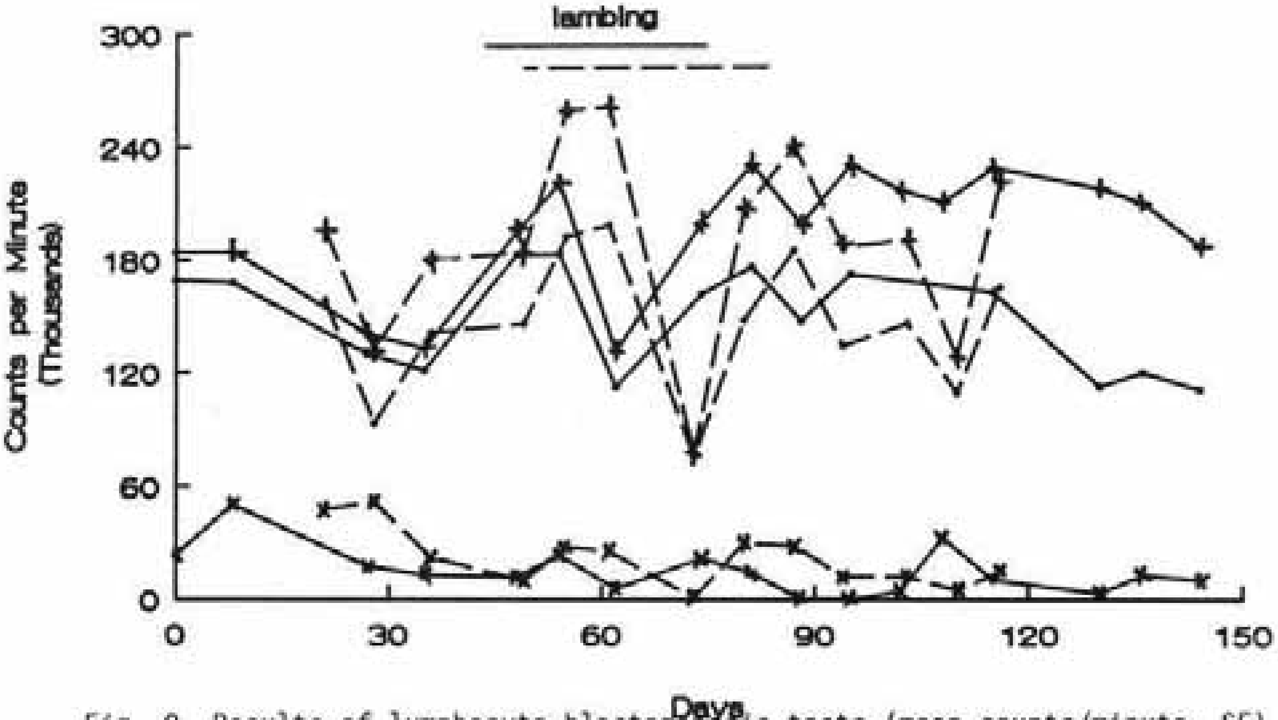

Fig. 8. Results of lymphocyte blastogenesis tests (mean counts/minute, SE) from recently captured bighorn sheep and tame bighorn sheep. ——— = recently captured bighorn sheep; – – – = tame bighorn sheep; + = con A stimulation; • = PHA stimulation; ✱ = LPS stimulation.

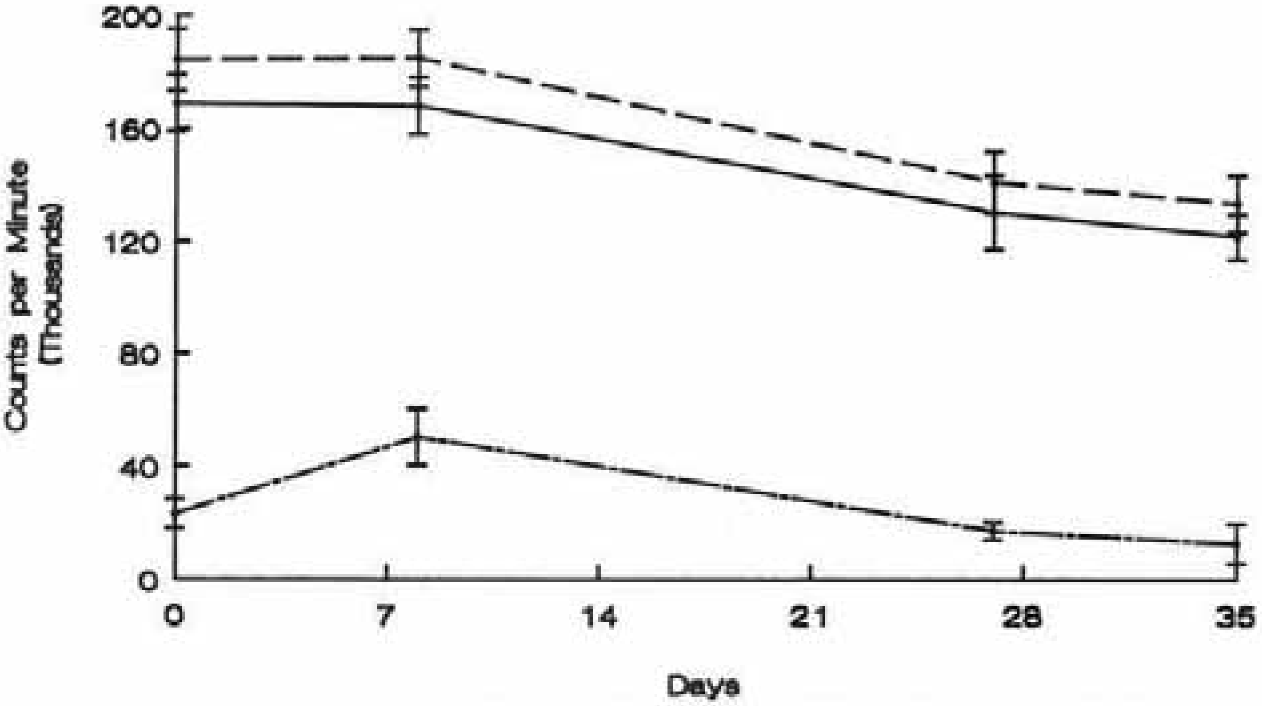

Fig. 9. Results of lymphocyte blastogenesis tests (mean counts/minute, SE) from recently captured bighorn sheep. — — — = con A stimulated; ——— = PHA stimulated; —·—·— = LPS stimulated.

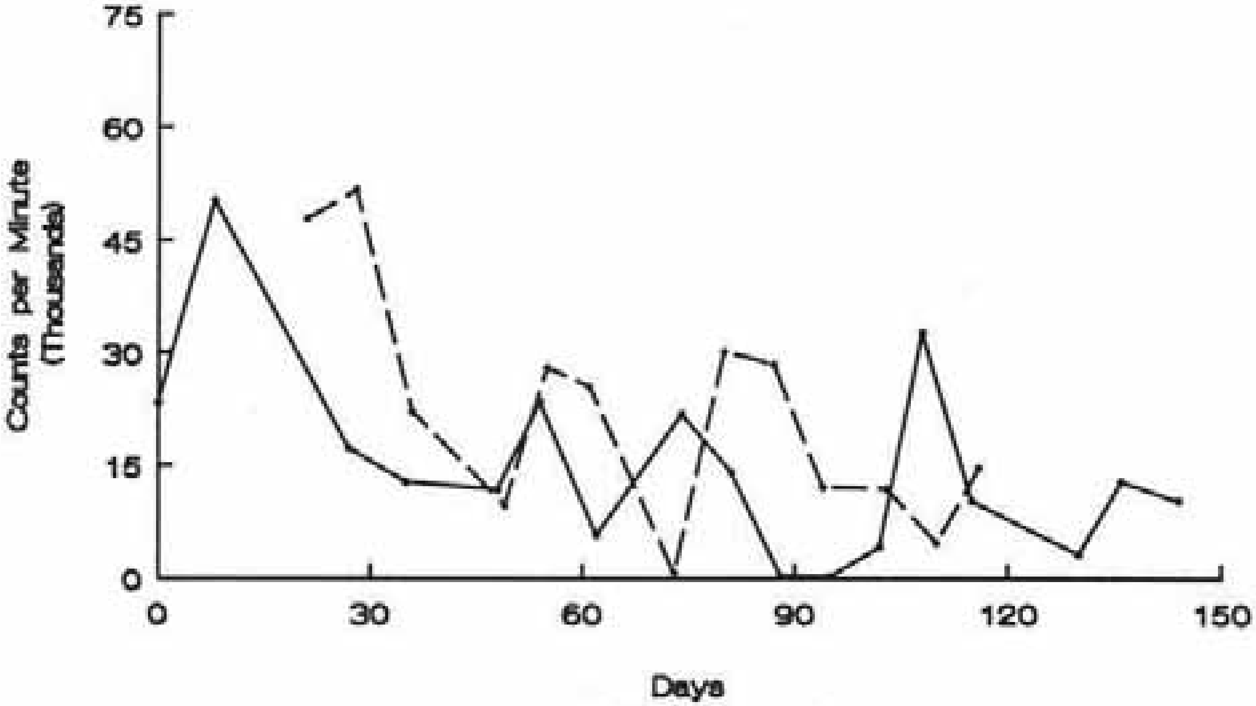

Fig. 10. Results of lymphocyte blastogenesis tests (mean counts/minute, SE) stimulated with LPS from recently captured bighorn sheep and tame bighorn sheep. ——— = recently captured bighorn sheep; — — — = tame bighorn sheep.

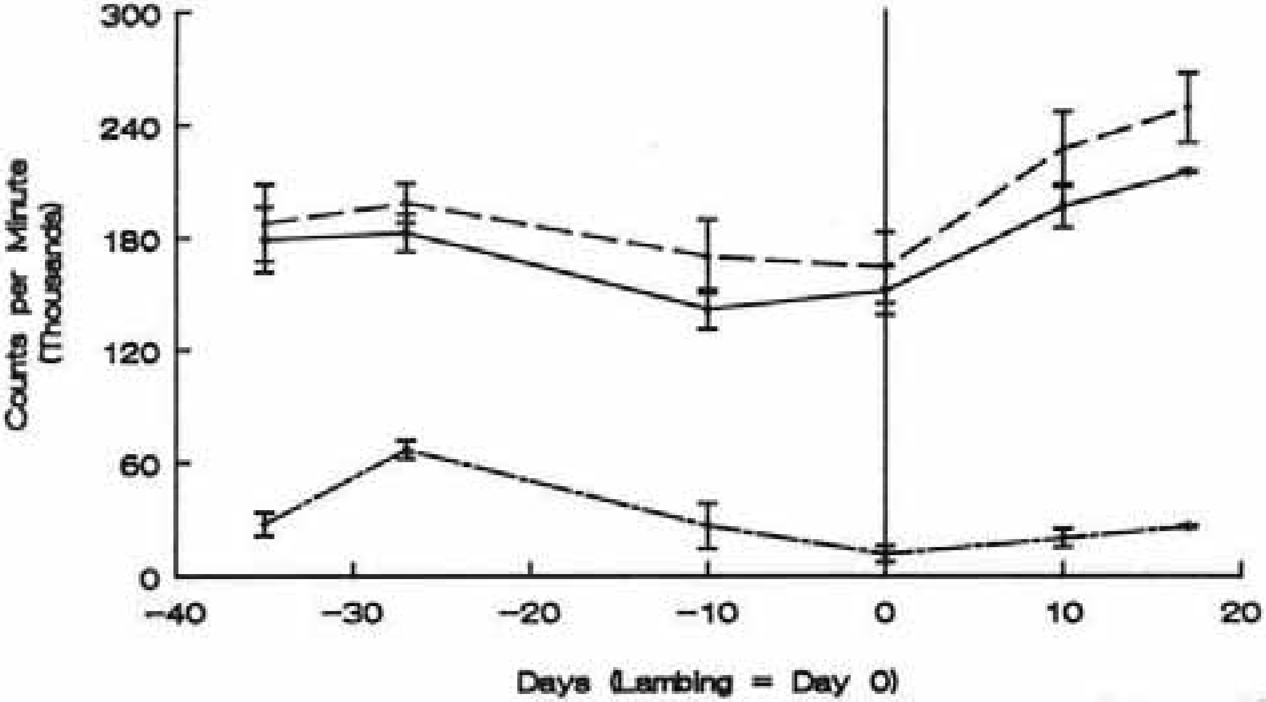

Fig. 11. Results of lymphocyte blastogenesis tests (mean counts/minute, SE) from bighorn sheep around the time of parturition. — — — = con A stimulated; —— = PHA stimulated; —·—·— = LPS stimulated.

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PNEUMONIA IN BIGHORN SHEEP: EFFECTS OF *Pasteurella haemolytica* FROM DOMESTIC SHEEP AND EFFECTS ON SURVIVAL AND LONG-TERM REPRODUCTION

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Abstract: Based on experiments and field observations, pneumonia caused by *Pasteurella haemolytica*, primarily serotypes A_2, T_3, T_4, T_{10}, can be devastating in bighorn sheep. Under controlled conditions, 2 Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) exposed to 2 domestic sheep developed pneumonia and died. Serotypes of *P. haemolytica* isolated from dead bighorns included A_2, $T_{3,4,10}$, and T_{10}. In a second experiment, *P. haemolytica* from domestic sheep was accidentally introduced into a captive herd of *O. c. canadensis* at Washington State University, and resulted in respiratory disease in the 10 sheep, and death in 3 sheep. *P. haemolytica* was isolated from most of these sheep after exposure; whereas, none had detectable *P. haemolytica* from nasal swabs before the accidental induction. Although lambs were born to clinically normal ewes that were shedding *P. haemolytica* in nasal secretions, all lambs died each year for 2 consecutive years after the pneumonia episode. Lambs were healthy until 6-11 weeks of age when they developed pneumonia and died. Lambs were apparently protected for several weeks after birth by passive immunity from colostrum. When this immunity waned, they were overwhelmed by *P. haemolytica* from nasal secretions of their ewes. Two adult bighorn ewes which had no detectable *P. haemolytica* from nasal swabs were added to the herd, and died from pneumonia within a year. A noninfected control herd of *O. c. canadensis* maintained in a different pen at the University had no detectable *P. haemolytica* from nasal swabs, experienced no mortality, and had 100% lamb survival.

Based on these studies, it is likely that recruitment into bighorn sheep herds that survive mortality due to pneumonia caused by *P. haemolytica* will be very low for several years after the initial pneumonia episode. Healthy bighorn sheep introduced into herds that are shedding pathogenic serotypes of *P. haemolytica* are also likely to die. Management recommendations include: 1) exclusion of domestic sheep from contact with bighorn sheep, 2) prohibition of moving healthy bighorns into populations of bighorns that have survived a pneumonia episode or are shedding *P. haemolytica* in nasal secretions, and 3) prohibition of moving survivors from pneumonia episodes, or bighorns shedding *P. haemolytica*, into healthy populations.

Pneumonia is the major mortality factor affecting bighorn sheep in North America. The pneumonia complex is a multi-factorial disease (Fig. 1), often involving several infectious agents incuding lungworms (*Protostrongylus*); viruses, primarily parainfluenza-3 virus, respiratory syncytial virus and infectious bovine rhinotracheitis virus; and bacteria, primarily *Pasteurella haemolytica*, *P. multocida* (Spraker and Hibler 1982, Spraker et al. 1984). Stress can also be important in the pneumonia complex, and can result from adverse environmental conditions, competition with other animals, handling and transportation methods, confinement, interaction with humans, and other factors (Spraker et al., 1984). Depending on circumstances, 1 or more of these factors may predispose to, or cause clinical pneumonia. Certain strains of *P. haemolytica* apparently are the most important causes of pneumonia in bighorn sheep, and much research has focused on the epidemiology and prevention of pneumonia caused by *P. haemolytica*.

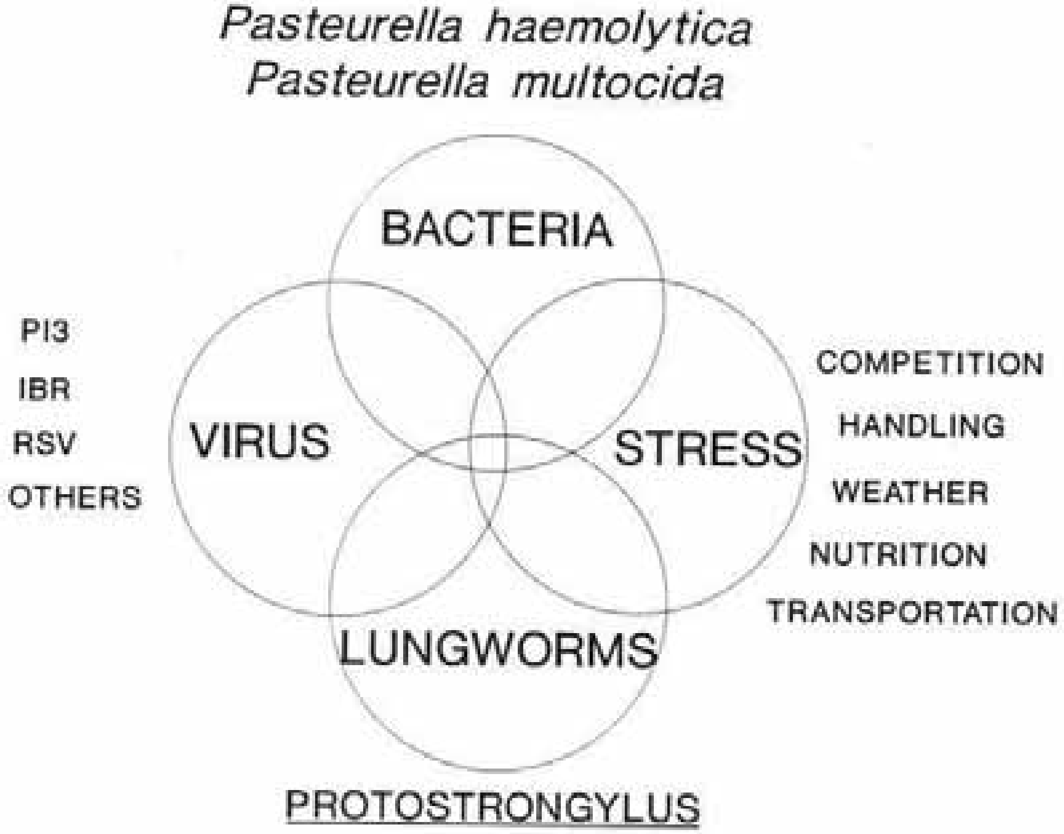

Fig. 1. Causes of the pneumonia complex in bighorn sheep.

Bighorn sheep are highly susceptible to bacterial pneumonia. Epizootics of bacterial pneumonia have decimated several bighorn populations in North America (Onderka and Wishart 1984, Coggins 1988). The domestic sheep-bighorn sheep interaction has become a focus of research because domestic sheep carry strains of P. haemolytica that do not usually affect domestic sheep adversely, but when transferred to bighorn sheep are usually lethal to bighorns (Foreyt and Jessup, 1982; Onderka and Wishart, 1988; Onderka et al., 1988; Foreyt, 1989). The objective of this research was to 1) evaluate the domestic sheep-bighorn sheep association 2) evaluate the short-term and long-term survival of bighorn sheep exposed to bacteria from domestic sheep, and 3) evaluate lamb survival from bighorn sheep ewes that survived a pneumonia episode.

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METHODS

Domestic Sheep - Bighorn Sheep (Experiment 1)

Two bighorn sheep, 1-1/2 year-old rams, were maintained in a 7 x 10m room with concrete walls and floor. Food consisted of alfalfa hay and hay pellets, and mineralized salt and water were provided at all times. The bighorns were born in captivity at Washington State University (WSU) and were well adjusted to captivity and humans. After 3 months of acclimating the bighorns, 2 yearling wether domestic Suffolk sheep, about 6 months old, were introduced into the room. On the day of introduction, nasal swabs were collected from all sheep and evaluated for bacteria by standard laboratory methods. Additional nasal swabs were collected and evaluated on days 13 and 14 after introducing the domestic sheep. When animals died, complete necropsies, including pathology, virology, serology, parasitology, and bacteriology were done by the Washington Animal Disease Diagnostic Laboratory (WADDL), Pullman, Washington. Standard laboratory methods were used.

Ewe and Lamb Survival (Experiment 2)

In November, 1987, laboratory personnel used a 145cm polyethylene tube, 6mm in diameter, to collect cells from the lungs of several live domestic sheep (Silflow et al. 1989) which had P. haemolytica in nasal secretions as determined from nasal swabs. The serotype was not determined. Following this lavaging procedure, the tube was flushed with saline and the outside of the tube was wiped with 70% alcohol. The same tube was then used within an hour to lavage 3 captive bighorn sheep which were maintained in a 2ha (5 acre) pen containing 7 mature and 3 immature bighorn ewes. Between 7-12 days following this procedure, all 10 bighorns developed respiratory disease consisting of coughing, increased respiratory rates, and nasal discharges. Sheep were lethargic and anorectic. Three sick sheep were captured and treated with gentamycin and oxytetracycline at 20 mg/kg of body weight, but it was decided that the stress of capture was too detrimental, and treatment was discontinued. In the 3 captured sheep, serum selenium levels were evaluated and considered marginal; therefore, selenium was increased in the mineralized salt from 20 to 90 parts per million. Sheep were observed daily. In December, 1987, an 8-year-old clinically healthy ram from Hall Mountain, Pend Oreille, County, Washington was introduced into the herd, and in January, 1989, 2 clinically healthy adult ewes from northwest Montana were introduced. Two additional bighorns, a ewe and lamb from the same herd in Montana, were introduced into a nonaffected control herd of bighorns (3 rams and 1 ewe) which were maintained on a 2.4ha (6 acre) pasture at WSU. Nasal swabs taken at the times of introduction did not indicate the presence of *P. haemolytica* in any introduced sheep or in the sheep in the unaffected control pen. Sheep were captured once or twice yearly to collect nasal swabs for bacteria isolations, blood serum for virus antibody analysis, feces for parasite analysis, and for hoof trimming and routine health care.

RESULTS

Domestic Sheep - Bighorn Sheep (Experiment 1)

The domestic sheep remained healthy throughout the experiment. At introduction, *P. haemolytica* A_1 was isolated from 1, and *P. haemolytica* T_4 was isolated from the other (Table 1). Both bighorn sheep developed respiratory disease including coughing and rapid respiration on day 13 of the experiment. On day 14, 1 bighorn (OR41) died, and the other (GR 39) was recumbent and moribund, and was euthanatized. Lesions at necropsy were similar in both bighorns and were consistent with an acute, fibrinohemorrhagic, severe, pleuropneumonia of bacterial orgin. Nonhemolytic and hemolytic serotypes of *P. haemolytica* were isolated from lungs, nasal swabs, thoracic fluid, lavage fluid, lymph nodes and tonsils (Table 1). Serotypes included A_2, $T_{3,4,10}$, and T_{10}. Viruses were not isolated from bighorns or domestic sheep and serology results were unremarkable. Lungworms were not present and other parasite numbers were negligible.

Table 1. Summary of domestic sheep - bighorn sheep experiment.

	DOMESTIC SHEEP	BIGHORN SHEEP
Day 0	Both Normal #1 *P. haemolytica* A_1 #2 *P. haemolytica* T_4	Both Normal #1 Negative #2 Negative
Day 13	Both Normal	Respiratory Signs (Both) #1 *P. haemolytica* (A_2, $T_{3,4,10}$) nasal *P. haemolytica* (A_2, T_{10}) lavage #2 *P. haemolytica* (A_2) nasal *P. haemolytica* (A_2, $T_{3,4,10}$) lavage
Day 14	Both Normal	Both Dead #1 *P. haemolytica* (A_2, $T_{3,4,10}$) lung *P. haemolytica* (A_2) thoracic fluid also *P. haemolytica* tonsil, lymph node #2 *P. haemolytica* (A_2, $T_{3,4,10}$) lung *P. haemolytica* ($T_{3,4,10}$) lymph node *P. haemolytica* (A_2) thoracic fluid also *P. haemolytica* tonsil

Ewe and Lamb Survival (Experiment 2)

In 1987 following onset of the pneumonia episode, 3 of 10 bighorn ewes, included 2 that had been treated with antibiotics died 6, 18, and 54 days, respectively, after the experimental accident. Lesions were similar and consistent with bronchopneumonia of bacterial origin. *Pasteurella haemolytica* T_4 was isolated from lung tissue of all 3, and *Corynebacterium* sp. was isolated from 1. Few lungworm larvae and parasite eggs were detected and other infectious agents were not isolated. The introduced ram developed respiratory disease approximately 30 days after introduction, but recovered after several months. During fall 1989, the ram became progressively thinner and lethargic, did not shed his summer pelage, and died in November. At necropsy, lesions were consistent with chronic pneumonia, and *P. haemolytica* was isolated from lungs. Other infectious agents were not isolated. The 2 adult ewes from Montana that were introduced into the herd in January, 1989, died in July and November, respectively, following 2-5 days of respiratory disease. Similar necropsy findings consistent with pneumonia were present, and *P. haemolytica* was isolated from both ewes, including serotypes A_2, T_4, and $T_{4,10}$. Other infectious agents were not isolated.

Isolates of *P. haemolytica* from the live adult bighorns are listed in Table 2. Based on analysis of nasal swabs, the *P. haemolytica* infection declined steadily, but persisted for 2 years in bighorn sheep in Pen 1. In contrast nasal swabs from bighorns in Pen 2 were negative throughout this period (Table 2).

Table 2. Prevalence of *Pasteurella haemolytica* (number sheep infected/number tested) isolated from nasal swabs from captive adult bighorns following pneumonia episode in November, 1987.

1987	1988	1989		1990
Nov-Dec	Aug-Nov	May-July	Oct-Nov	Apr
Infected Pen				
9/12 (75%)	7/15 (47%)	7/28 (25%)	3/16 (19%)	0/5 (0%)
Noninfected Pen				
0/5	0/12	0/7	0/12	0/5

Before the pneumonia episode, 16 lambs were born in 1986 and 1987 (Table 3). After the pneumonia episode in fall 1987, 11 lambs were born in 1988 and 1989. All these lambs died between 6-11 weeks after birth.

Table 3. Summary of bighorn sheep mortality in a captive herd which was affected by pneumonia in the fall of 1987.

1986	1987	1988	1989
6/7*	10/10	3/7	8/9
	3 ewes died "Pneumonia"	All lambs died "Pneumonia"	All lambs died "Pneumonia"
	Add adult ram December, 1987 Died November 1989		Add 2 adult ewes January 13, 1989. Both died - July, November, 1989

*First number indicates lambs, second number indicates ewes.

In 1989 the mean age of death was day 61 (Table 4). One late lamb in 1989 was born August 14, after the other 7 lambs had died. In almost all cases, lambs were clinically healthy until 1-2 days before death, developed respiratory disease characterized by open mouth breathing and rapid respirations, and died the next day. At necropsy lesions were similar in all lambs and were consistent with acute fibrinohemorrhagic pneumonia with fibrinous pleuritis. Usually the cranial and cardiac lung lobes were involved. *Pasteurella haemolytica* was isolated from all lambs. Serotypes from 4 of the lambs included T_4, from 3 lambs, $T_{3,4}$, from 1 lamb, and $T_{3,4,10}$ from 1 lamb.

Table 4. Summary of bighorn lamb deaths in captivity, 1989, and isolates of *Pasteurella haemolytica* from these lambs.

Lamb No.	Age at death (days)	Isolation
1	47	*P. haemolytica*
2	53	*P. haemolytica* $T_{3,4,10}$
3	78	*P. haemolytica* T_4
4	60	*P. haemolytica* T_4
5	56	*P. haemolytica* T_4, $T_{3,4}$
6	70	*P. haemolytica*
7	78	*P. haemolytica*
8	43	*P. haemolytica*
	$\bar{x} = 61$	

DISCUSSION

These studies support the importance of pneumonia in bighorn sheep and illustrate the short- and long-term effects of the disease. In experiment 1, the 2 bighorns exposed to domestic sheep developed respiratory diseases and died within 2 weeks of exposure to domestic sheep. Although the serotypes of *P. haemolytica* isolated from the domestic sheep and from the bighorns were different, it is likely that more serotypes were present in the domestic sheep than were isolated. Standard practice at Washington Animal Disease Diagnostic Laboratory is to isolate 1 or 2 morphologically similar bacterial colonies from each agar plate for characterization. If many serotypes are present, only 1 or 2 will be isolated. Tonsillar biopsies and tonsillar swabs from bighorn sheep yield a higher percentage of *P. haemolytica* isolates than do nasal swabs (Dunbar et al. 1990). Unfortunately, my data are from nasal swabs alone and represent active shedding of bacteria into the environment. Although stress may be important in predisposing bighorns to pneumonia, I feel that bacteria transfer from domestic sheep to bighorns with resultant pneumonia is an important management and biological concern. Previous experiments have demonstrated the adverse association between domestic sheep and bighorn sheep, indicating that serotypes A_2, T_3, T_4, and T_{10}, alone or in combination, are the most pathogenic known serotypes in bighorns (Onderka and Wishart 1988, Onderka et al. 1988, Foreyt 1989). Severe pneumonia in bighorns has also been reported to occur without the presence of domestic sheep (Onderka and Wishart 1984) and may be caused by similar serotypes of *P. haemolytica*.

In experiment 2, it is likely that *P. haemolytica* from domestic sheep initiated the pneumonia in the captive bighorn herd. Although the plastic tube used to lavage the domestic sheep was rinsed in saline and wiped with an alcohol swab, it is probable that some bacteria remained in the tube and infected the bighorns. All the bighorns developed chronic respiratory disease, and 3 died within 50 days. Under field conditions, a similar episode may have caused higher mortality because more energy would have been required for feeding and movement. Only 3 lambs were born to the 7 surviving ewes in 1988 due to their poor condition during the breeding season and early gestation. Seven ewes survived the pneumonia episode and became clinically normal, but many remained chronic shedders of *P. haemolytica* (Table 2) for over 2 years.

All lambs died of bronchopneumonia during 1988 and 1989 (Table 3). It is likely that lambs are protected against pneumonia resulting from *P. haemolytica* by colostral immunity. When the immunity wanes at 5-8 weeks after birth, *P. haemolytica* from their dams or other sheep overwhelm them, and cause the pneumonia and death observed in this experiment and probably in field outbreaks of pneumonia. Based on the reduced prevalence of ewes shedding *P. haemolytica* over time (Table 2), it is probable that lamb survival will increase in 1990.

The ram added to the affected herd of sheep in 1987, and the 2 ewes added in 1989 died of pneumonia between 7 months and 2 years later, indicating the long-term deleterious effects of P. haemolytica in adult, presumably noninfected bighorns.

Based on these and other studies (Onderka and Wishart 1984, Bailey 1986, Coggins 1988) it is probable that following a pneumonia episode in bighorn sheep, initial mortality will affect sheep of all ages, and subsequent mortality in future years will primarily affect lambs between 4-9 weeks old. Lamb survival may be correlated with prevalence of ewes that are shedding P. haemolytica in nasal secretions. Lamb mortality and mortality of healthy sheep introduced into affected populations are likely to be high for 2 or more years following a pneumonia outbreak. Breeding and lambing synchrony may be disrupted as indicated by late lambs and nonbreeding ewes. Based on these data, my recommendations for bighorn sheep management include: 1) exclusion of domestic sheep from contact with bighorn sheep by excluding domestic sheep from lands occupied by bighorns, and by preventing bighorn transplants into areas used by domestic sheep; 2) prohibition of moving healthy bighorns into populations of bighorns that have survived a pneumonia episode or are shedding P. haemolytica in nasal secretions; and 3) prohibition of moving survivors from pneumonia episodes, or bighorns shedding P. haemolytica in nasal secretions, into healthy populations. Considering the long-term recovery time of a population following a pneumonia die-off, a more drastic option is to kill all survivors, and then start a new population with healthy transplanted bighorns. However, a local gene pool would be lost. Until an effective vaccine is developed or a resistant strain of bighorn is discovered, preventive disease management is important to reduce the probability of pneumonia related mortality in bighorn sheep populations.

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SEROTYPES OF PASTEURELLA HAEMOLYTICA IN FREE RANGING ROCKY MOUNTAIN BIGHORN SHEEP

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Abstract: A total of 100 Rocky Mountain bighorn sheep (Ovis canadensis canadensis) from central Idaho, which had no known contact with domestic sheep, were monitored for causes of respiratory disease during Dec. 1988-Apr. 1989. Among 3 herds 2 were apparently free, or had a low incidence of respiratory disease, while the third herd had a high incidence of respiratory disease. Nasal and tonsillar samples from the sheep were cultured for Pasteurella haemolytica. Fifty-three isolates of P. haemolytica belonging to biotypes A (10), T (38) and 3 (5) were cultured from 38 animals. Six of the 10 biotype A isolates were untypable, 3 were identified as A_2 and 1 as A_{11}. Although some biotype T isolates agglutinated in individual antisera 3, 4 or 10 and were therefore identified as serotypes T_3 (5), T_4 (2) or T_{10} (5) respectively, most isolates were atypical in that they agglutinated in 2 or 3 of the antisera. Seventy-two percent of the isolates were hemolytic on blood agar compared to a low incidence of hemolytic isolates reported in other studies.

Pasteurella species have been incriminated as important pathogens of bighorn sheep, causing pneumonia and often death (Marsh 1938, Post 1962, Foreyt and Jessup 1982, Spraker et al. 1984). Naturally occurring outbreaks of pneumonia caused by Pasteurella haemolytica have been reported in free-ranging bighorns (Taylor 1976, Wishart et al. 1980, Spraker and Hibler 1982, Onderka and Wishart 1984). Some outbreaks of pneumonia have been suspected of being caused by contact with domestic sheep. Onderka and Wishart (1988) and Foreyt (1989) suggest that certain types of P. haemolytica may be common to domestic sheep and that some of these types may cause fatal pneumonia in bighorn sheep. A few investigators (Taylor 1976, Onderka et al. 1988, Onderka and Wishart 1988) have used serotyping of P. haemolytica to investigate pneumonia in bighorn sheep. However, little information exists concerning specific serotypes in healthy or diseased bighorn sheep.

Pasteurella haemolytica isolates are tested for biochemical reactions to establish biotypes and with antisera to detect specific antigens on the organisms for serotyping. Biotyping and serotyping of

P. haemolytica are commonly performed in investigating pneumonia in domestic livestock (Biberstein and Thompson 1966, Thompson et al. 1977, Gilmour 1980, Fraser et al. 1982, Confer et al. 1988). The *P. haemolytica* group currently has 3 recognized biotypes, A, T and 3 (Kilian and Frederiksen 1981). Serotypes 1, 2, 5, 6, 7, 8, 9, 11, 12, 13 and 14 can be distinguished in A biotype while the T biotype has 4 recognized serotypes; 3, 4, 10 and 15. Serologically untypable strains, with biochemical characteristics typical of biotypes A and T also occur. Serotype designations have not been developed for biotype 3 organisms. Although hemolysis is a cardinal characteristic of *P. haemolytica*, non-hemolytic strains have been reported. Isolates from domestic sheep are characteristically hemolytic, whereas a predominance of non-hemolytic strains has been reported in bighorn sheep (Onderka and Wishart 1988).

Serotyping increases precision in detecting organisms associated with disease, following the course of an epizootic, and detecting transmission among animal populations. In this study, serotyping of *P. haemolytica* from healthy and diseased bighorn sheep, having no known contact with domestic sheep, was conducted to establish whether particular serotypes were indigenous in a given bighorn sheep and which were associated with disease.

We acknowledge the assistance of the Idaho Department of Fish and Game, Idaho State Department of Agriculture, and The Wilderness Research Center of the University of Idaho.

STUDY AREA

The study was conducted in central Idaho along the main Salmon River and its tributaries. Major tributaries included Morgan Creek, near Challis; Panther Creek, near Shoup; Middle Fork of the Salmon River and Big Creek, both within the Frank Church River of No Return Wilderness.

The topography is characterized by high mountain peaks and ridges dissected by numerous deep, narrow valleys. Elevations range from 600-2800 m. The main study area was on sheep winter ranges at lower elevations. The Salmon River and Middle Fork canyons cut deep into the huge batholith, a vast granitic mass measuring 112 by 385 km. The Salmon River canyon is one of the most rugged in North America and is hot and dry in summer. Annual precipitation in the study areas ranges between 23-38 cm. During winter, southern exposures often are bare, while there are 45-65 cm of snow on north-facing slopes.

Ponderosa pine (*Pinus ponderosa*) occupies areas along lower river breaks. In other areas, grassy slopes reach to the river. The principal grass is bluebunch wheatgrass (*Agropyron spicatum*) and important shrubs are curlleaf mountain mahogany (*Cercocarpus ledifolius*), bitterbrush (*Purshia tridentata*) and big sagebrush (*Artemisia tridentata*).

METHODS

One hundred free-ranging Rocky Mountain bighorn sheep consisting of

71 adult females, 21 adult males, (1½-11 years of age), and 8 lambs (7-11 months), were either captured (87), killed (7), found dead (5) or died during capture (1) in the Salmon River drainage during Dec. 1988-Apr. 1989. Sheep were sampled from 3 populations within the drainage. Sixty were sampled from Morgan Creek near Challis. This herd consists of about 250 animals and has been increasing over the last 5-6 years. Thirty sheep were sampled from the main Salmon River herd, below the town of Shoup. This herd consists of about 485 animals and has been increasing recently, however not to the extent of the Morgan Creek herd. The Big Creek herd, in a tributary of the Middlefork of the Salmon River consists of about 200 animals, of which 10 were sampled. This herd has experienced low lamb production for the past 3-4 years but population is above 10-year average.

Most sheep were captured using a net gun (Coda Enterprises, Inc., Mesa, Arizona, 59 sheep) fired from a helicopter or using a projectile dart (Cap-Chur gun, Palmer Chemical and Equipment Co., Ltd., Douglesville, Georgia, 29 sheep) containing either etorpine hydrochloride (American Cyanamid Co., Princeton, New Jersey) or carfentanil citrate (Wildlife Laboratories, Inc., Fort Collins, Colorado). Diprenorphine (American Cyanamid Co.) was administered by hand-held syringe to reverse both drugs. Animals were aged by tooth eruption and horn development. All live-captured animals were examined by a veterinarian for signs of illmess and, except for 2 adult ewes, released after samples were collected.

Swab samples were taken from nasal passages of all sheep using rayon-tipped, 20 cm, swabs (Culturette, Marion Laboratories Inc., Kansas City, Missouri). Tonsil biopsies were obtained from bighorns as described by Dunbar et al. (1990), and were transported in modified Stuart's transport medium (Culturette, Marion Laboratories Inc.) to the laboratory. Two apparently healthy adult ewes were transported to the Caine Veterinary Teaching and Research Center, Caldwell, Idaho, where they were euthanized and necropsied. Eight necropsies were performed in the field.

Tissue samples from field necropsies were individually placed in sterile plastic bags (Whirl-Pac Bags, Nasco, Modesto, California), iced and transported by express mail to the University of Idaho, Caine Veterinary Teaching and Research Center, Caldwell, Idaho or the Washington Animal Disease Diagnostic Laboratory, Washington State University, Pullman, Washington. Samples were cultured within 48-72 hours from collection.

Surfaces of sufficiently large tissue samples were seared to destroy surface bacteria, prior to culture. Sterile instruments were used to obtain tissues for culture from beneath seared areas. Tonsillar tissues of ≥1g were placed in sterile plastic bags with sterile Brain-Heart-Infusion (Becton Dickinson Microbiology Systems, Cockeysville, Maryland) broth and macerated in a tissue homogenizer (Tekmar Co., Cincinnati, Ohio) to release bacteria from crypts. Smaller tonsil samples were rubbed on culture media to enhance bacterial release.

All samples were cultured on Columbia Agar (Becton Dickinson

Microbiology Systems) with 5% citrated sheep blood and on a selective Columbia Blood Agar with added vancomycin (6ug/ml) and nystatin (12.5ug/ml) (Sigma Chemical Co., St. Louis, Missouri), a medium which is selective for Pasteurellaceae. The inoculated culture media were incubated at 37C and examined daily for at least 3 days.

Bacterial isolates which were gram-negative, oxidase-positive and produced acid reactions when inoculated into triple-sugar-iron (Becton Dickinson Microbiology Systems) agar slants were evaluated by additional biochemical tests to determine if they were Pasteurella spp. Biotypes and serotypes were determined according to published procedures (Frank and Wessman 1978, Kilian and Frederiksen 1981).

RESULTS

Sixty sheep from the Morgan Creek herd had a high prevalance of mild to severe signs of respiratory disease with coughing, mucopurulent nasal discharge and abnormal lung sounds unon auscultation. Several animals in addition to those captured, were observed coughing and in poor health. Thirty sheep from the Salmon River herd included a moderate number with signs of respiratory disease, ie. coughing and clear nasal discharge. However, 1 adult ram had severe respiratory disease. Ten sheep from the Big Creek herd showed no signs of respiratory disease and others observed from the ground were all apparently healthy.

Pasteurella haemolytica was found in 32% of the sheep from Morgan Creek, 50% from Salmon River and 30% from Big Creek. Fifty-three isolates of P. haemolytica were cultured from 38 of 100 bighorn sheep and identified as biotypes, A (10), T (38) and 3 (5). Three of the 10 biotype A isolates reacted in A_2 antisera, 1 in A_{11} and the remaining 6 were untypable with available typing sera. Five of the 38 biotype T isolates were classified as T_3, 2 as T_4 and 5 as T_{10}. The remainder of the biotype T isolates reacted in more than 1 of the type sera in combinations of T_3, T_4, T_{10} (N=21), T_3, T_4 (N=1) and T_4, T_{10} (N=4).

Biotype A was isolated only from nasal passages, except for 1 isolate from the larynx of an adult ewe that was euthanized and necropsied. The A biotypes were isolated at a greater frequency from lambs (43%) than from adult bighorns (18%) from the Morgan Creek and Salmon River herds. No lambs were sampled from the Big Creek herd.

Pasteurella haemolytica biotype T was isolated from both tonsils and nasal passages of bighorn sheep but at a higher rate from nasal passages of sheep from herds showing signs of respiratory disease (Morgan Creek 68%, Salmon River 13%) than from the apparently healthy Big Creek herd (0%).

Three of the 5 isolates of biotype 3 were from tonsillar tissue and 2 from nasal passages. No correlation was observed between serotypes of P. haemolytica and either sex or age, except as previously mentioned for lambs.

Biotypes A, T and 3 were isolated at approximately the same frequency from the Salmon River and Morgan Creek herds. Neither biotype A nor 3 was isolated from the Big Creek herd. Pasteurella haemolytica was isolated from 3 tonsils but not from nasal swabs of sheep in the Big Creek herd. Serotypes T_{10} (hemolytic) and T_4, T_{10} (hemolytic) combination were the only isolates from the Big Creek herd.

Thirty-eight of the 53 isolates (72%) were hemolytic on blood agar. Twenty-eight of the 100 sheep had at least 1 isolate of P. haemolytica that was hemolytic. Eighty-four percent of the isolates from the Morgan Creek herd, 56% from the Salmon River herd, and 100% from the Big Creek herd, were hemolytic. Both hemolytic and non-hemolytic isolates of of biotypes A, T and 3 were found.

DISCUSSION

Biotyping and serotyping P. haemolytica has enhanced understanding of this organism and associated disease and development of control measures for preventing P. haemolytica pneumonia in domestic animals. However, biotyping and serotyping P. haemolytica in bighorn sheep have only recently occurred (Taylor 1976, Onderka et al. 1988, Foreyt 1989, Dunbar et al. 1990) and investigations have been limited. Study of suspected transfer of P. haemolytica from domestic sheep to bighorn sheep has been hampered by lack of knowledge about the carrier states of sheep for specific serotypes of P. haemolytica by domestic sheep and bighorn sheep before they commingled. The carrier states of animals in these studies were based on isolation of Pasteurella from nasal samples. However, we have found that tonsillar biopsy samples are more reliable than nasal samples for detecting Pasteurella carriage in bighorn sheep (Dunbar et al. 1990). The use of tonsil biopsies or tonsillar swabs and serotyping would identify carrier animals and possibly allow tracking the transfer of P. haemolytica between species or individuals.

Biotypes and serotypes of P. haemolytica found in this survey include several not previously described. Taylor (1976) found serotype T_3 in bighorns (O. c. nelsoni) from Nevada. Onderka et al. (1988) reported serotypes T_3, T_4 and T_{15} in wild bighorns from Alberta, Canada, and Foreyt (1989) reported serotypes T_3, A_2, A_9 and A_{11} in a captive bighorn sheep herd, in Washington state, after they commingled with domestic sheep. No isolations of P. haemolytica were found in nasal samples from the bighorn sheep prior to the introduction of domestic sheep in his study, and no tonsillar sampling was done prior to commingling. In our study, serotypes T_3, T_4, T_{10}, A_2, A_{11} and biotype 3 were isolated from both nasal and tonsil samples. We also found that the majority of the biotype T isolates of P. haemolytica agglutinated in 2 or 3 of the antisera. The finding of biotype T isolates which reacted >1 serotype is rare in domestic species. These may represent organisms unique to the bighorns.

Onderka and Wishart (1988) used hemolytic serotype T_{10} to trace the transfer of P. haemolytica from domestic sheep to captive bighorn sheep, since T_{10} was not isolated from nasal passages of bighorn sheep prior to commingling with domestic sheep infected with hemolytic T_{10}. However, in this study, hemolytic T_{10} was commonly carried in the palatine tonsils of free-ranging bighorn sheep having no known contact with domestic sheep. We observed that most (72%) isolates of P. haemolytica, from bighorn sheep were hemolytic, in contrast to 7% in Alberta bighorns (Onderka and Wishart 1988).

Onderka et al. (1984) observed hemolysis characterized most P. haemolytica isolates from domestic sheep and non-hemolysis characterized isolates from bighorn sheep in Alberta. Their study suggested that if bighorn sheep carried hemolytic P. haemolytica, these isolates may have been transferred from domestic sheep. The bighorns in our study carried mainly hemolytic isolates of P. haemolytica despite no known contact with domestic sheep. However, we cannot exclude that the hemolytic isolates of P. haemolytica in our bighorn sheep did not historically originate from domestic sheep.

In this study, no correlation was found between serotypes of P. haemolytica and signs or severity of respiratory disease. However in individual animals with signs of respiratory disease, as was the case in the Morgan Creek herd, the T biotypes were isolated at a higher frequency from nasal passages compared to sheep from the 2 herds with less or no signs of respiratory disease. Consequently, it appears that the T biotype, normally carried in the palatine tonsils of most apparently healthy sheep, proliferate as a sheep becomes stressed, and invade nasal passages, where biotype A is a more common commensal.

The roles of serotypes and of the characteristic of hemolysis of P. haemolytica in the bighorn sheep pneumonia-complex needs further investigation. Techniques such as fingerprinting based on bacterial proteins and DNA components, will help to characterize P. haemolytica strains that vary in frequency among animal species and may have greater virulence for some species. These techniques will help to detect the spread of bacterial pathogens among herds and species. However, until these new techniques are developed and tested, serotyping will continue to be an important tool.

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PASTEURELLACEAE FROM BIGHORN AND DOMESTIC SHEEP

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Abstract: Nasal, tonsil and lung samples from bighorn and domestic sheep (Ovis canadensis and Ovis aries) were cultured for members of the Pasteurellaceae family of bacteria. Pasteurella haemolytica was isolated from 38% of 120 bighorn sheep and 71% of 73 domestic sheep. Biotypes A, T and 3 were isolated from both bighorn and domestic sheep. Multiple biotypes were isolated from some animals. Biotype T organisms were isolated from 76% of the culture-positive bighorn sheep and 21% of the culture-positive domestic sheep. In contrast, biotype A was isolated from 30% and 75% of the culture positive bighorn and domestic sheep, respectively. Organisms identified as biotype 3 P. haemolytica were isolated from 13% and 11% of the 2 respective groups of animals. Only biotype T organisms were isolated from the lungs of bighorn sheep with respiratory disease. The outer membrane of each bighorn, domestic and American Type Culture Collection (ATCC) biotype T isolate was treated with sodium dodecyl sulfate and the proteins were separated by polyacrylamide gel electrophoresis (SDS-PAGE) to develop fingerprints for comparison. The bighorn isolates did not show patterns identical to those of either the domestic or ATCC strains.

The family Pasteurellaceae includes the closely related genera Pasteurella, Haemophilus and Actinobacillus. These organisms are Gram-negative, characteristically pleomorphic and non-motile. Most ferment glucose, produce oxidase and alkaline phosphatase and they vary in ability to produce catalase. Most grow aerobically although some are capnophilic and fail to grow without CO_2. All are obligate parasites of animals, with the majority being commensals of the upper respiratory tract (Mannheim 1984). Many species act as opportunistic pathogens in susceptible individuals. Susceptibility is increased by predisposing or concurrent infections with a variety of viruses or other bacteria and by stresses including fatigue, poor nutrition, temperature extremes and transportation. Pasteurallaceae, most notably, Pasteurella haemolytica and P. multocida are associated with respiratory disease in domestic sheep and cattle (Timoney et al. 1988). Haemophilus somnus is a common pathogen of young calves and feedlot age cattle.

Pasteurellaceae are believed to occur in animals in all climates and can be detected in the nasal passages and tonsils of a high percentage of clinically normal animals. A typical disease due to a Pasteurellaceae organism is the "shipping fever" syndrome in cattle, a respiratory disease characterized by dyspnea, anorexia and pyrexia following a combination of stress factors including shipping. Inclement weather, weaning, castrating, dipping and shipping appear to be stresses most commonly associated with predisposition of domestic sheep to respiratory disease (Gilmour 1980).

Three biotypes of P. haemolytica, A, T and 3, are differentiated based on biochemical reactions. Biotypes A and T are further differentiated into serotypes by antisera which detect specific antigens. Biotype A contains serotypes 1, 2, 5, 6, 7, 8, 9, 11, 12, 13 and 14. Four serotypes, 3, 4, 10 and 15, are recognized within biotype T (Timoney et al. 1988). Biotype 3 organisms have not been separated into serotypes.

Pasteurella haemolytica A2 is most commonly associated with pneumonia in domestic sheep but can be cultured from nasal secretions of normal sheep. Biotype T organisms have a tropism for the tonsils of sheep and are rarely found elsewhere in clinically healthy animals. Biotype T serotypes are associated with septicemia and pneumonia in domestic sheep particularly in the late fall and early spring (Gilmour et al. 1974).

Pasteurella haemolytica strains have also been incriminated as the cause of disease and devastating losses of bighorn sheep populations (Post 1962). In some instances domestic sheep were believed to be sources of Pasteurella that caused illness and death of bighorn sheep (Foreyt 1989, Foreyt and Jessup 1982). It was speculated that clinically healthy bighorn sheep were free of strains of Pasteurella common in domestic sheep, and that strains present in healthy domestic sheep were highly virulent for the bighorn. Several authors have recommended that bighorn and domestic sheep be separated by buffer zones, assuming that even chance encounters would result in transmission of Pasteurella from domestic to bighorn sheep resulting in disease and death of the bighorn sheep (Foreyt 1989, Foreyt and Jessup 1982).

We report information from an ongoing study in which P. haemolytica isolated from bighorn and domestic sheep are being evaluated. Evaluation includes biotyping, serotyping and use of sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) to separate proteins from the outer membranes of P. haemolytica isolates. These procedures are being used to detect similarities and variances of organisms and to monitor the incidence and distribution of particular bacterial strains in sheep populations. Support for this study has been provided by the Idaho sheep Commission, the Idaho Department of Fish and Game, and USDA Formula Funds.

MATERIALS AND METHODS

Samples were collected from 120 bighorn and 73 domestic sheep. The bighorn sheep included 110 live-captured and released after sampling, 3 collected for disease investigation, 3 which died due to trauma which occurred during capture, 2 hunter kills and 2 animals found dead. Animals were captured by use of a net gun or a projectile dart containing a chemical tranquilizer (Dunbar et al. 1990). Samples taken from live-captured animals included nasal swabs from 52, tonsil swabs from 4, and both tonsil and nasal samples from 54. Tonsillar biopsies were taken from some of the latter group as described by Dunbar et al. (1990). All dead sheep, except 1 hunter-killed animal, were necropsied. Tissues including tonsils, lung and liver were collected from all necropsied animals. All samples were transported on ice to the University of Idaho, Caine Veterinary Teaching and Research Center (CVTRC) and were processed for bacterial cultures within 72 hr of collection.

Samples from domestic sheep included nasal swabs from 32 clinically normal 4-8 week-old lambs in a flock maintained at CVTRC, and lung samples from 18 adult sheep with respiratory disease that were brought to CVTRC by various owners. In addition nasal and tonsillar swab samples were collected from 23 adult sheep which had grazed on land adjacent to an area near Challis, Idaho, where bighorn sheep are known to range. Samples from the latter group were transported to the laboratory and cultured for bacteria within 48 hr of collection.

Pasteurella haemolytica type strains 1-12 were obtained (National Veterinary Services Laboratory, Ames, IA 50010) and used as controls to monitor agglutination reactions and for comparisons in evaluating outer membrane proteins of isolates from other sources.

All samples were cultured on Columbia Blood Agar (Becton Dickinson Microbiology Systems, Cockeysville, Maryland 21030, USA) with 5% citrated sheep blood (CBA). In addition, tonsillar and nasal samples were cultured on a selective CBA with added Vancomycin (6 ug/ml) and Nystatin (12.5 ug/ml, Sigma Chemical Co., St. Louis, Missouri 63178, USA) to reduce growth of other bacteria and thus enhance the detection of Pasteurellaceae. The inoculated media were incubated in an atmosphere of air with 5% added CO_2 at 37 C and bacterial growth was evaluated at 24 hr intervals for at least 3 days. Bacterial isolates with colonial morphology suggestive of Pasteurellaceae were speciated and identified to biotype by standard procedures (Carter 1984, Kilian and Frederiksen 1981). Serotyping was conducted by slide agglutination (Frank and Wessman 1978).

The outer membrane proteins of Pasteurella isolates were prepared by the procedure of Carlone et al. (1986) prior to separation by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Briefly, all bacteria were propagated on CBA for 16-24 hr at 37 C to standardize the growths of the organisms and reduce possible phenotypic variances. The protein isolation procedure used sonication for bacterial disruption, differential centrifugation for isolation of the membranous fractions and sodium N-lauroyl sarcosinate for dissolution of the cytoplasmic membranes. Outer membrane proteins were concentrated by centrifugation and the protein concentration was determined by a modification of the Lowry procedure (Markwell et al. 1978). The outer membrane proteins (OMP) were solubilized in a buffer containing glycerol, 2-mercaptoethanol, SDS and 0.05% bromphenol blue. A 20 ul volume of the SDS treated OMP (2 ug/ul) was loaded per lane of the 12% polyacrylamide gels and electrophoresis was conducted using 35 MA/gel. The gels were fixed in a 7.5% Trichloroacetic acid aqueous solution for 2-8 hr, and stained in a 0.25% solution of Coomassie brilliant blue for 2-4 hr. Unbound stain was removed with an aqueous solution containing 25% methanol and 7.5% acetic acid.

The stained gels were photographed with translucent and oblique lighting using Technical Pan (Eastman Kodak Company, Rochester, NY, 14650). Each SDS-PAGE lane was scanned with a densitometer (Hoefer Scientific Instruments, San Francisco, CA 94107) connected to a desktop computer (IBM-XT) with a GS-365 Data System software (Hoefer Scientific Instruments, San Francisco, CA 94107). The computer was used to monitor tracings and record data for determining molecular weight and comparing patterns ("fingerprints") produced from the evaluations of different organisms. Primary emphasis was given to evaluating biotype T organisms, since T biotypes predominated in the samples from bighorn sheep.

RESULTS

Pasteurella haemolytica was isolated from 46 of the 120 (38.3%) bighorn and 52 of the 73 (71.2%) domestic sheep. Although biotype T P. haemolytica isolates predominated in bighorn and biotype A were most common in domestic sheep samples, all three biotypes, A, T and 3, were isolated from both species of sheep (Figs. 1, 2). More than one biotype was isolated from some animals. Biotype combinations, A and T, and A and 3, were each isolated from 4 bighorn sheep (Fig. 1). Biotypes A and T, A and 3, and T and 3 P. haemolytica were isolated from 1, 1, and 2 domestic sheep respectively (Fig. 2).

Biotype A P. haemolytica was much more common in nasal than in tonsil samples of both sheep species. Ten of 11 A isolates from bighorn were from nasal samples; one was from a tonsil sample. Biotype A isolates were cultured from nasal samples of 11 and tonsil samples of 2 adult domestic sheep. Young lambs had a higher incidence of P. haemolytica in nasal samples (21 of 32) than was detected in samples from adult sheep.

Biotype T P. haemolytica was isolated from nearly equal numbers of nasal (12), of tonsillar (13), and in both nasal and tonsillar samples (12) of bighorn sheep. The 6 biotype T isolates from domestic sheep were from tonsil swabs of adult animals (3) and from nasal samples (3) of young lambs.

Only biotype T was isolated from the lungs of bighorn sheep including 4 which died with pneumonia, 1 which was killed in the terminal stage of pneumonia, and 2 which were live-captured and judged to be clinically normal prior to euthanasia of 1 and apparent death due to trauma of the other. Biotypes A and T were isolated in pure cultures from the lungs of 5 and 4 domestic sheep respectively, which died due to pneumonia. Biotype 3 organisms were isolated from equal numbers of clinically normal bighorn and domestic sheep, (i.e. 6 [5%] and 6 [8%]) respectively.

The isolates of biotype T obtained from domestic sheep agglutinated rapidly in 1 of the antisera; 3, 4 or 10, with occasional weak reactions in 1 of the other 2 antisera. In contrast, most isolates from bighorn sheep agglutinated rapidly in more than 1 antisera, with the most frequent reaction being strong agglutination in all 3 antisera.

Biotype T and A isolates had marked differences in the number and placement of major OMP bands by which these biotypes could be readily differentiated (Fig. 3). All biotype T isolates from a single bighorn sheep gave the same agglutination pattern and identical SDS-PAGE profiles. Major differences were evident between biotype T isolates from different sheep (Fig. 4). These differences were most evident in comparison of the OMP bands in the 33-40 x 10^3 dalton range (Fig. 4). Minor bands of proteins with molecular weights less than 30 x 10^3 and more than 40 x 10^3 daltons were also present. However the concentrations of these proteins were too low for optimum detection.

DISCUSSION

The percentage of bighorn sheep that was culture positive for *Pasteurella* was approximately half of that detected for domestic sheep. While the prevalence of *Pasteurella* may be less in bighorn sheep, this difference may also reflect variation related to geographic location, or due to sampling or handling procedures. Many samples from bighorn sheep captured early in the test period did not reach the laboratory for 48-72 hours. Samples collected later in the study included tonsillar crypt biopsies and most of the later samples reached the laboratory within 48 hr. Both the type of sample, i.e., tonsillar biopsies, and the shorter period from collection to processing, increased the probability of *Pasteurella* isolation. Since, *Pasteurella* are fastidious organisms which do not survive in dry material and do not survive out of the host for more than a few hours unless present with blood, mucus or tissue, detection is optimized by culturing samples within 4-6 hr (Mannheim 1984). Therefore, the lower incidence of isolations from bighorn than from domestic sheep may have occurred because samples collected in remote areas could not be processed within an optimum time. Lost viability of *Pasteurella* in samples and the fact that these organisms are inhibited in culture by other bacteria which are common in the environment (Corbeil et al., 1985) may have contributed to the low incidence of isolation of *Pasteurella* in another study (Onderka and Wishart 1988).

The relatively low numbers of biotype T isolates in samples from domestic sheep compared to bighorn sheep was an unexpected finding since biotype T *P. haemolytica* are common in domestic sheep, particularly in the tonsils of feeder-age lambs (Gilmour et al., 1974, Al-Sulton and Aitken 1985). Few herds and individual domestic sheep were tested and therefore the data from our limited study would probably include a limited number of *P. haemolytica* T strains and cannot be interpreted to represent all domestic sheep.

Similarly, the low incidence of biotype A isolated from bighorn sheep is in contrast to a high incidence detected in domestic sheep in our study and by Al-Sulton and Aitken (1985).

Although all bighorn Pasteurella isolates were serotyped, the fact that most of the isolates agglutinated in more than 1 antisera did not correlate well with tests results on domestic sheep isolates (Thompson et al. 1977). Therefore, greater emphasis was placed on evaluating SDS-PAGE profiles for detecting variation and shared components among the P. haemolytica isolates. The OMP profiles of these organisms are sufficiently discriminative to identify 3 distinct fingerprints (Fig. 4). In similar studies of Acinetobacter strains isolated from humans, major proteins were common and nondiscriminatory in a number of strains which were subsequently distinguishable by variation in molecular weights of minor proteins (Dijkshoorn et al. 1987).

We have evaluated a limited number of P. haemolytica isolates from animals in Idaho during 18 months. Additional samples will be collected from both domestic and bighorn sheep in Idaho and samples from other areas are being requested. As isolates are grouped based on similarity of major proteins, additional profiles will be produced using greater OMP concentrations to enhance evaluation of minor protein bands. Bacteria which appear to have identical fingerprints will also be tested by Western-blot assays to detect antigenic variances which may be present in organisms with common molecular weights of proteins. In addition, analyses of the DNA of these organisms will be conducted to detect variances in restriction endonuclease susceptibilities. These procedures will make it possible to determine if P. haemolytica isolates from different sources are identical. It may also be used to monitor transmission of particular bacterial strains within a herd or between different populations of sheep.

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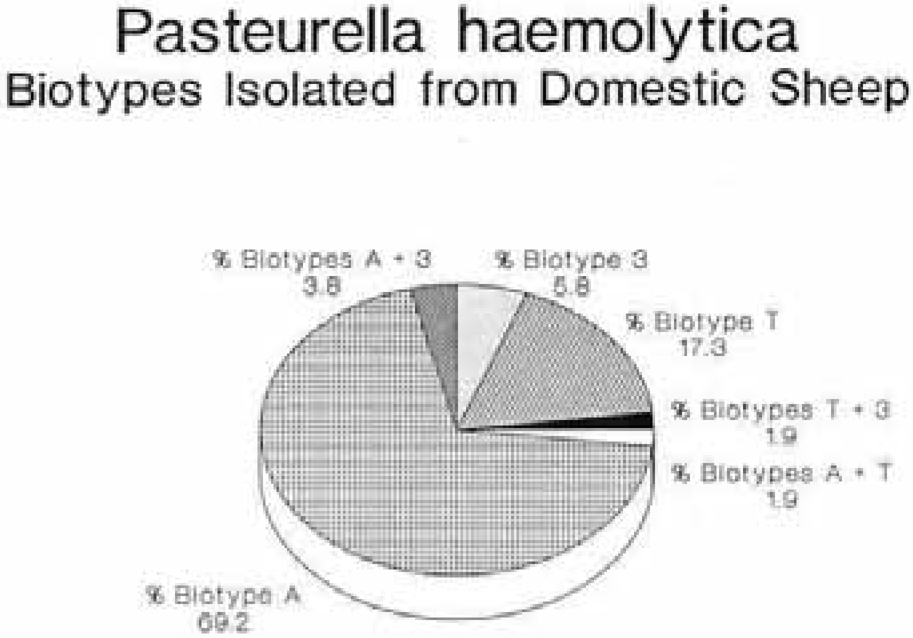

Fig. 1. Biotype distribution of *Pasteurella haemolytica*

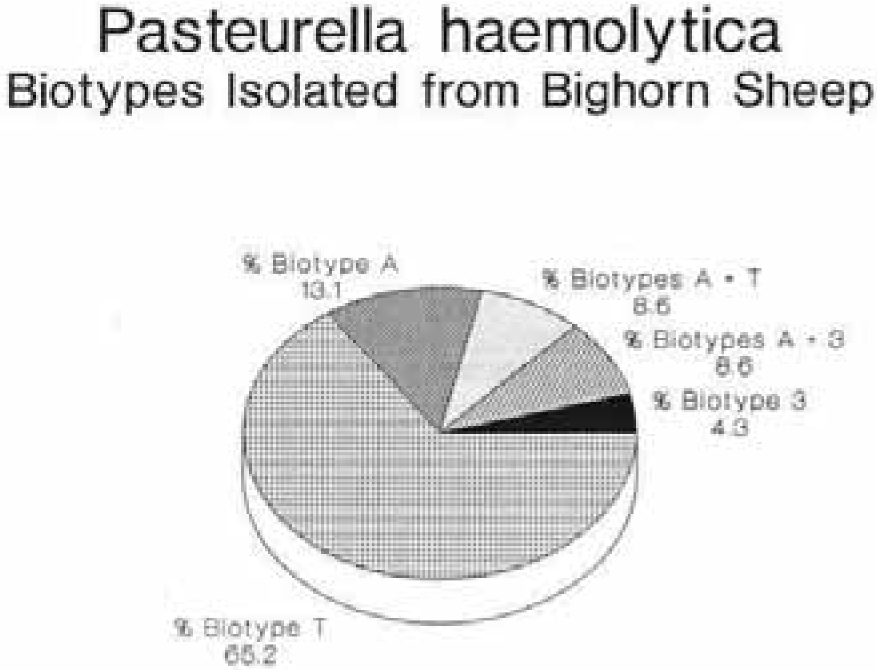

Fig. 2. Biotype distribution of *Pasteurella haemolytica*

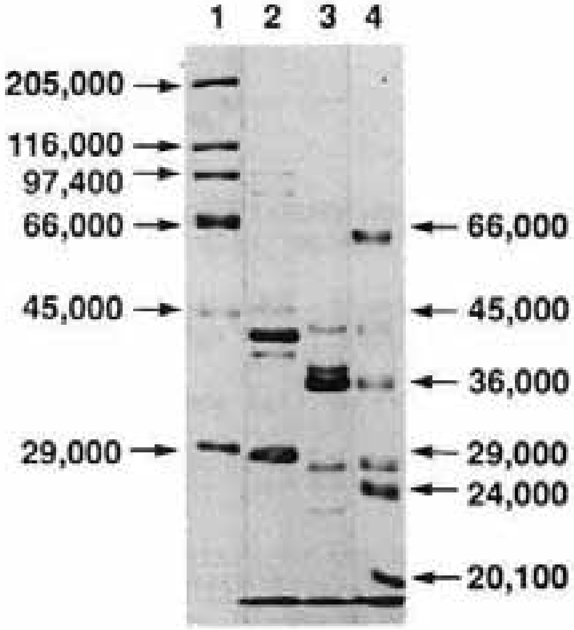

Fig. 3. Major outer membrane proteins present in Pasteurella haemolytica A1 (lane 2) and P. haemolytica T isolated from lung of bighorn sheep (lane 3). Proteins with indicated molecular weights are in lanes 1 and 4.

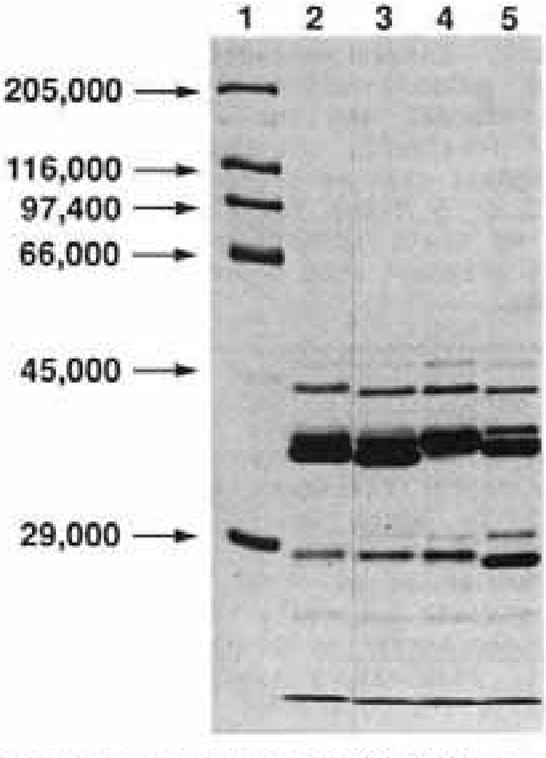

Fig. 4. Outer membrane protein SDS-PAGE profiles of 4 Pasteurella haemolytica isolates in lane 2, 4, and 5 (bighorn sheep isolates) and lane 3 (domestic sheep isolate). Proteins for molecular weight standards are separated in lane 1.

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SAFETY AND EFFICACY OF FENBENDAZOLE AGAINST PROTOSTRONGYLUS SPP. INFECTIONS IN ROCKY MOUNTAIN BIGHORN SHEEP (OVIS CANADENSIS CANADENSIS)

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Abstract: Fenbendazole, at a precalculated dosage of about 10 mg/kg of body weight, was fed in pelleted feed each day for 3 consecutive days to over 200 wild Rocky Mountain bighorn sheep in Washington (n=65), Idaho (n=75), and Oregon (n=75) during winter, 1985-1986. A second study in Washington (n=60 sheep) was conducted in 1986-1987. Before treatment, lungworm larvae were detected in feces from 84, 93, and 97% of the sheep from Washington, Idaho, and Oregon, respectively. Mean pretreatment numbers of *Protostrongylus* spp. larvae/g of feces (lpg) were 5.9 (WA), 13.2 (ID), and 24.4 (OR). Posttreatment samples had 0.1, 0, and 6.8 lpg, respectively, indicating high efficacy. Larvae were detected in 3% (WA), 0% (ID), and 67% (OR) of the animals after treatment. Numbers of other parasites were also reduced, and the reproductive rate (ewe:lamb ratios) improved after treatment. At Washington State University, 6 pregnant and 6 non-pregnant captive bighorns were fed fenbendazole at 30 or 50 mg/kg BW (3 or 5 times the field dosage) each day for 6 consecutive days and no toxic effects were observed. Six healthy lambs were born to the pregnant ewes indicating the safety of the drug in pregnant bighorn ewes.

Lungworms of the genus *Protostrongylus* are prevalent in bighorn sheep populations (Forrester and Senger 1964, Forrester 1971, Uhazy et al. 1973, Hibler et al. 1982). The lungworm-pneumonia complex is an important mortality factor for Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in North America (Buechner 1960, Forrester 1971). Mortality results from bacterial invasion of lungs damaged by lungworm infections (Hibler et al. 1982, Spraker and Hibler 1982). The pneumonia preceding death generally results from a combination of lungworms, bacteria (*Corynebacterium* or *Pasteurella* spp.), and viruses (parainfluenza 3 virus, respiratory syncytial virus). Mortality is frequent in lambs because transplacental infection by lungworm larvae occurs, and the maturing lungworms overwhelm the young lambs, predisposing them to pneumonia before they are 3 months old. In populations where lungworm infection produces high mortality, the loss of the breeding stock may exceed the recruitment of lambs, resulting in population extirpation (Forrester 1971, Hibler et al. 1982). By eliminating or significantly reducing numbers of lungworms in bighorn sheep, recruitment rates may be increased because mortality due to the lungworm complex may be reduced significantly.

This trial was to determine the safety and effectiveness of fenbendazole in feed against Protostrongylus spp. in naturally infected bighorn sheep. In the Pacific Northwest, bighorns can be fed the drug in feed primarily in winter when ewes are pregnant; therefore, determining safety of the drug in pregnant bighorn sheep was also a primary objective.

We thank personnel from the Idaho and Oregon Departments of Fish and Game, the Washington Department of Wildlife, and veterinary students from Washington State University for assisting with this project. S. Zender and J. Andrews made the safety study possible by allowing use of the sheep at Washington State University. Funding was provided by the Western Region USDA Interregional Project 4, Minor Use Animal Drug Clearance Program.

METHODS

Field Study

Wild Rocky Mountain bighorn sheep were studied in Washington, Idaho, and Oregon in winter 1985-1986, and in Washington in winter 1986-1987. The Hall Mountain herd of about 80 sheep was in northeast Washington (Pend Oreille County). These sheep had moderate lungworm infections, had been fed pelleted feed and hay in winter for several years, and were acclimated to people and feeding practices. I (WJF) had monitored lungworm numbers in these sheep for several years. They have never been hunted. Sheep were treated in winter 1985-1986 and 1986-1987. In Idaho, the Panther Creek herd in the Salmon River Drainage consisted of about 140 sheep, and historically had a moderately heavy infection of lungworms. Rams were hunted in fall. Sheep were treated after the hunting season (winter 1985-1986) to allow a 8-10 month drug withdrawal period. The Lostine herd of about 100 bighorns was in northeast Oregon (Wallowa County). These sheep were also given supplemental feed in winter for several years. I (WJF) had monitored lungworm levels in these sheep for about 5 years. Rams were hunted on a limited basis in fall. Sheep were treated after the hunting season (winter 1985-1986) to allow an 8-10 month drug withdrawal period. Treated sheep were observed daily throughout the experiment to determine any deleterious effects associated with treatment. Animals were not killed for tissue evaluation or drug residue analysis because of their value.

Feed And Drug Composition

Supplemental feed consisted of a pelleted ration (alfalfa 69%, barley 31%). Feeding began in December, 1985, and continued for about 30 days before drug administration. During the 30 days, average daily consumption was determined. Numbers of sheep eating the pellets were counted each day and the average feed consumed per head per day was calculated. The amount of drug (fenbendazole) mixed in feed and pelleted at the Washington State University Feed Plant, was calculated to approximate a daily intake of 10 mg/kg of body weight. The medicated feed was used for 3 consecutive days in January or early February. Traditionally, sheep ate the pellets within 1 hour. We observed the sheep as they ate to determine the number of sheep, the identity of as many sheep as possible, and the amount of feed consumed.

Sheep

I had monitored parasite levels of these populations for several years and determined that 85-100% of the sheep in all 3 herds were infected with lungworms (Protostrongylus spp.). Many sheep in 2 of the 3 populations (WA and OR) were ear-tagged over the last few years for identification. Other sheep had specific horn growths, color patterns, or physical deformities that identified them.

Twelve sheep used for the safety study were captured at Hall Mountain in a corral trap on December 19, 1985, and transported to Washington State University. Animals were marked with ear tags, and released into a 2-ha (5-acre) enclosure developed specifically for bighorn sheep. Treatment was accomplished in January 1986.

Parasitology

During the pretreatment feeding period, fresh fecal samples were collected from observed sheep and placed in whirl-pak bags that were numbered with sheep tag numbers. Samples from non-tagged sheep were collected randomly. About 30 pretreatment fecal samples were collected from each population on the day of treatment. Approximately 20 pellets were collected from each sheep and 10 g of feces were evaluated for lungworm larvae with the Baermann technique (Beane and Hobbs 1983). Numbers of Protostrongylus larvae per g of feces were recorded. Fecal flotation (sugar solution, sp. gr.=1.27) was used to determine the identities and numbers of other parasites.

About 4 weeks after treatment, 30 fecal samples were collected from tagged and untagged sheep in each population. Feces were analyzed to determine numbers of Protostrongylus larvae and other parasites per g.

Percent efficacy was measured by mean number of larvae in the pretreatment samples, minus mean numbers of larvae in the posttreatment samples, divided by mean number of larvae in the pretreatment samples, times 100.

Penned Sheep Safety Study

Twelve sheep (6 mature ewes, 3 immature ewes, 1 ram lamb and 2 ewe lambs) from the Hall Mountain population were maintained at Washington State University to determine the safety of fenbendazole. Six sheep (Group 1) were treated daily with fenbendazole in feed for 6 consecutive days at 30 mg/kg of body weight (BW) which was 3x the proposed field dose of 10 mg/kg. Six sheep (Group 2) were treated daily for 6 days with fenbendazole in feed at 50 mg/kg BW, 5x the proposed field dose. Sheep were assigned randomly to treatment groups with 1 lamb in Group 1 and 2 lambs in Group 2. Sheep were observed at least twice daily to determine if any adverse signs were associated with drug treatment. Since treatment was after the breeding season, mature ewes (2 1/2 years-old and older) were assumed to be pregnant. Sheep were maintained at WSU for 30 days before treatment and for 6 months after treatment. Observations on lambs born to treated ewes were recorded.

Feed Analysis

Replicate feed samples were analyzed for fenbendazole content by Scientific Associates, Inc., St. Louis, MO 63123.

RESULTS

Feed assay results were 111-115% of theoretical, indicating excellent mixing of drug. No toxicity of the drug was observed in any herd of sheep.

Parasitology

In all studies, sheep ate the medicated pellets readily, usually within one hour, indicating the palatability of fenbendazole. Based on pretreatment analysis of fecal samples, Protostrongylus larvae were detected in 84-100% of sheep in each population (Table 1). Mean numbers of larvae were 5.9-24.4 per gram of feces. After treatment, Protostrongylus larvae were detected in 0-67% of the sheep, with 0.68 larvae per gram of feces (Table 1), indicating a substantial reduction in larvae. Gastrointestinal parasites such as Nematodirus, Trichuris, and Moniezia, also were adversely affected by treatment (Table 1). Other parasites present in low numbers were trichostrongyles, Eimeria spp., and Skrjabinema sp.

Lamb-Ewe Ratios

In Washington, the lamb-ewe ratios for 5 years before treatment were 17-63:100. The year after initial treatment, the ratio was 73:100 (Table 2).

Table 2. Ewe-lamb ratios in The Hall Mountain, Washington, bighorn herd before and after treatment with fenbendazole in 1986.

Year	Lambs/100 ewes
1981-82	17
1982-83	36
1983-84	59
1984-85	63
1985-86 (Treatment)	41
1986-87	73

Safety Study in Captive Bighorn Sheep

During the 30-day acclimation period in the 2-ha pen, the sheep adjusted to the fences and to daily vehicle traffic nearby. No acclimation problems were apparent. Sheep in Group 1 that were fed fenbendazole at 30 mg/kg BW for 6 consecutive days, and sheep in Group 2 that were fed fenbendazole at 50 mg/kg BW for 6 consecutive days ate the feed readily. No adverse effects associated with treatment were observed. Between May 19, and June 3, 1985, 6 lambs were born to the 6 mature ewes and 5 of these were raised to weaning. The sixth lamb was removed from the ewe on the day of birth because of severe weather conditions, and it subsequently died of pneumonia at 5 days of age.

DISCUSSION

Based on the data, fenbendazole is safe when incorporated into feed and fed to wild bighorn sheep at approximately 10 mg/kg BW. Efficacy of fenbendazole against Protostrongylus spp. was excellent in 2 of the 4 studies, and moderate in the other 2. It is likely that some untreated animals mixed with treated animals during the post-treatment period. Data from these sheep would bias evaluations of treatment efficacies. Comparisons of pretreatment vs. posttreatment samples within tagged sheep indicated higher efficacies. In the Oregon study, about 9 weeks lapsed between pretreatment and posttreatment collections. Although this was not intended, snowstorms delayed collections. New untreated sheep may have moved in during this period, and some somatic larvae in treated sheep may have matured. Fenbendazole is effective against adult Protostrongylus, but may be less effective against somatic larvae (Schmidt et al. 1979). In dogs, fenbendazole prevents transplacental migration of larval Toxocara canis when fed during the time of larval migration (Burke and Roberson 1983). It is not known whether transplacental migration of Protostrongylus is prevented if fenbendazole is fed daily during the period when larval migration occurs between and ewe and fetus. It may be necessary to feed fenbendazole for a long duration to eliminate most transmission.

Ivermectin at a subcutaneous dosage of 0.2 mg/kg of body weight, and albendazole at an oral dosage of 10 mg/kg of body weight have also been effective in reducing Protostrongylus larvae in feces of infected bighorns (Foreyt and Johnson 1980, Miller et al. 1987), and may also have application in the overall health care of bighorn populations. Since the effects of parasites, especially lungworms, can be severe in bighorn populations, a field deworming program may benefit the health, reproductive status, and survival of a herd, as indicated in this study.

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Table 1. Summary of eggs, larvae, and oocysts recovered pretreatment and posttreatment from bighorn sheep feces Washington (WA), Oregon (OR) and Idaho (ID).

Parasite	State	Year	Pretreatment				Posttreatment				% Reduction of larvae
			No. obs.	(% Pos.)	Larvae, eggs/g mean	S	No. obs.	(% Pos)	Larvae, eggs/g mean	S	
Protostrongylus	WA	1	67	(84)	5.9	8.2	37	(3)	0.1	0.7	98
	OR	1	69	(97)	24.4	24.1	36	(67)	6.8	13.0	72
	ID	1	61	(93)	13.2	18.4	20	(0)	0.0	0.0	100
	WA	2	31	(100)	6.9	7.0	25	(28)	4.2	10.9	39
Nematodirus	WA	1	67	(96)	42.9	44.9	37	(32)	4.1	8.1	90
	OR	1	69	(88)	36.4	33.4	36	(92)	18.5	16.8	49
	ID	1	61	(92)	8.6	6.5	20	(0)	0.0	0.0	100
	WA	2	31	(74)	25.5	28.1	25	(28)	15.4	44.0	40
Trichuris	WA	1	67	(55)	14.2	20.7	37	(35)	2.9	5.0	80
	OR	1	69	(25)	0.9	2.2	36	(14)	0.5	1.1	43
	ID	1	61	(26)	1.6	3.5	20	(10)	0.4	1.1	78
	WA	2	31	(74)	10.4	10.7	25	(28)	4.6	13.3	56
Strongyles*	WA	1	67	(0)	0.0	0.0	37	(8)	0.1	0.4	0
	OR	1	69	(6)	0.4	2.2	36	(3)	3.9	2.3	0
	ID	1	61	(5)	0.1	0.2	20	(0)	0.0	0.0	100
	WA	2	31	(0)	0.0	0.0	25	(0)	0.0	0.0	0
Moniezia	WA	1	67	(4)	0.3	1.5	37	(0)	0.0	0.0	100
	OR	1	69	(6)	4.3	18.4	36	(6)	8.3	29.5	0
	ID	1	61	(31)	16.9	30.8	20	(0)	0.0	0.0	100
	WA	2	31	(6)	0.6	2.7	25	(4)	0.1	0.6	79
Eimeria	WA	1	67	(96)	1034.8	2154.0	37	(89)	286.6	664.9	72
	OR	1	69	(97)	396.0	614.8	36	(100)	676.4	824.4	0
	ID	1	61	(49)	54.0	118.2	20	(40)	133.2	313.4	0
	WA	2	31	(100)	242.9	437.6	25	(96)	140.9	209.3	42

* Includes Haemonchus, Ostertagia, Oesophagostomum, and Trichostrongylus.

Bienn. Symp. North. Wild Sheep
and Goat Counc. 7:125-128.

RECENT ADVANCES IN THE DIAGNOSIS AND TREATMENT OF PSOROPTIC SCABIES IN BIGHORN SHEEP

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Abstract: Psoroptic scabies, caused by mites in the genus *Psoroptes*, has been seen with increasing frequency in recent years in bighorn sheep (*Ovis canadensis* spp.). This disease can cause high morbidity and mortality as evidenced by the ongoing epizootic in the San Andres National Wildlife Refuge, New Mexico. To assist in the control of bighorn scabies, we recently developed a serologic assay which offers promise for identifying scabies-endemic populations, screening bighorns prior to relocation, and monitoring response to treatment. Sustained-release implants of ivermectin are also being used successfully to treat infested free-ranging bighorns, and biobullets containing these implants are being developed.

Psoroptic scabies is an important disease of domestic and wild ungulates caused by infestation with ectoparasitic mites in the genus *Psoroptes*. This paper provides a brief history of the disease and outlines recent developments in diagnosis and treatment. Much information in this paper is presented in greater detail elsewhere, and interested readers should refer to those papers for specific information (Boyce et al. 1991a, 1991b; Jessup et al. 1990).

HISTORICAL OVERVIEW

Early observers were convinced that bighorn sheep contracted scabies from domestic sheep because die-offs occurred following the introduction of domestic sheep and cattle onto bighorn sheep ranges. Epizootics were documented as early as 1859 in Colorado (Packard 1946, Seton 1929, Wright et al. 1933), the 1870's and 1898 in California (Jones 1950), and population declines were seen in Wyoming, Oregon and Montana in the late 1800's (Hornaday 1901, Bailey 1936, Honess and Frost 1942). More recently bighorn scabies has been seen in Nevada, Arizona, Oregon, Washington, and Idaho (Cater 1968, Decker 1970, de Vos et al. 1980, Foreyt et al. 1985). Since 1978, a scabies epizootic has caused the dramatic decline of a bighorn sheep population in the San Andres Mountains, New Mexico (Lange et al. 1980), and in the last 2 years several populations of bighorns in California have been found to be infested with *Psoroptes* sp. (Boyce et al., 1991a). Additional bighorn populations are likely to be found infested as managers examine animals more closely.

The questions of host specificity and species identification of Psoroptes spp. mites remain unresolved. Sweatman (1958) classified Psoroptes spp. mites in North America into 5 species based on location on the host and length of the adult male's outer opisthosomal setae. Researchers have succeeded in transferring mites between host species, and successful cross-matings of *P. ovis* from sheep and *P. cuniculi* from rabbits also suggest that host-specificity is low (Wright et al. 1981, 1983, 1984). Ongoing morphometric and immunologic investigations are providing additional evidence that Psoroptes sp. mites may not be host-specific (Boyce et al. 1991b). In particular, the finding that sympatric mule deer and bighorn sheep shared Psoroptes sp. mites that were morphologically indistinguishable from each other strongly suggests that these 2 hosts may have been infested with the same species (Boyce et al. 1991b).

DIAGNOSIS AND TREATMENT

Psoroptes sp. infestations have typically been diagnosed by examining skin scrapings or ear swabs (National Research Council 1979). Serologic tests for scabies have been developed for cattle, domestic sheep and rabbits, and recently Boyce et al. (1991a) developed a sensitive serodiagnostic test for bighorn scabies. The bighorn seroassay offers promise for identifying scabies-endemic populations, for screening bighorns prior to relocation and for monitoring response to treatment. Once infested animals are identified it may be essential to implement effective control strategies. Ivermectin administered subcutaneously at 200 µg/kg (Ivomec, MSD-AGVET, Rahway, New Jersey) has effectively controlled Psoroptes sp. infestations in cattle, but this formulation has been ineffective in infested bighorn sheep (reviewed by Muschenheim 1988). Our preliminary studies indicate that prolonged, high doses of ivermectin will eliminate mites on bighorn sheep, and subcutaneous implants of ivermectin (Drummond and Miller 1984) are now being used successfully to treat free-ranging bighorns in California. These devices are an effective way to administer ivermectin to free-ranging bighorn sheep because they protect treated animals against reinfestation while other members of the population are being treated. Our efforts are now directed at incorporating avermectin implants into biobullets that will facilitate the treatment of remote, free-ranging populations.

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IVERMECTIN FOR TREATMENT OF PSOROPTIC SCABIES IN ROCKY MOUNTAIN BIGHORN SHEEP

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Abstract: Three herds of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in Wyoming are known to be infested with psoroptic scabies (*Psoroptes spp.*). Eight naturally infested bighorn sheep were captured from one of the known infested herds and fitted with radio collars. Six were treated with ivermectin, 2 served as controls. A year after treatment 5 treated and 2 control animals had no clinical signs of scabies while 1 treated animal had signs of scabies in the ears. Test of the efficacy of ivermectin for scabies control were continued with a captive study. Eight bighorn sheep with clinical signs of scabies were captured, treated with approximately 1000 ug/kg ivermectin, and were held in captivity for posttreatment sampling. Mites were found in samples taken from 6 of the 8 animals taken at the time of capture and treatment. Live mites were observed in samples taken from 1 animal 6 days after treatment and from a second animal 25 days after treatment. No mites were observed in posttreatment samples collected from the other six animals. These results suggest that 1 dose of ivermectin administered subcutaneously may not be effective for control of psoroptic scabies in bighorn sheep. However, other techniques may result in an effective single treatment regimen.

Psoroptic mange, or scabies, is caused by mites of the genus *Psoroptes* and was associated with the decline of bighorn sheep in the United States at the turn of the century (Ward 1915, Wright et al. 1933, Bailey 1936, Seton 1937, Packard 1946). In the late 1800's scabies was present in Rocky Mountain bighorn sheep herds across Wyoming. Major epizootics were reported in the Absaroka, Wind River (Seton 1937) and Bighorn Mountains (Honess and Frost 1942). However, Honess and Frost (1942) reported that there had been no authenticated reports of scabies in bighorn sheep for many years prior to 1942. No more cases were documented in Wyoming until 1963 (Hepworth 1963).

The history of scabies in bighorn sheep in North America is similar to that found in Wyoming. Until the last few decades there were few reports of scabies since the early epizootics. More recently, scabies was associated with population declines on the San Andres National Wildlife Refuge in New Mexico (Lange et al. 1980), in northwest Arizona (Welsh and Bunch 1983), and on the Desert National Wildlife Range in Nevada (Decker 1970). Mites identified as *Psoroptes ovis* were collected from bighorn sheep transplanted from Idaho to Oregon in 1984 (Foreyt et al. 1985).

Three Wyoming herds of bighorn sheep are known to be infested *P. cervinus*; 2 that winter on the North Fork and the South Fork of the Shoshone River in the Absaroka Mountains (Howe and Hepworth 1964, Thorne and Walthall 1982) and the Camp Creek herd south of Jackson (Thorne et al. 1984). Animals from these herds may not be transplanted to other areas unless treatment is demonstrated to be effective. Effective treatment of domestic livestock has involved dipping in acaricide solutions including lindane, toxaphene, and coumaphos (Tarry 1974, Drummond 1985, Meleney 1985). Dipping is not practical for free-ranging wildlife. In New Mexico attempts to dip desert bighorn sheep (*O. c. mexicana*) infested with *P. ovis* by dipping resulted in high mortality (Kinzer et al. 1983).

Ivermectin (22,23 dihydroavermectin B^1)was introduced commercially in the United States in 1983 and has been used extensively to treat a variety of parasites in domestic animals with high levels of efficacy and safety (Campbell and Benz 1984). Ivermectin was used effectively to treat *P. ovis* in cattle (Meleney 1982), elk (*Cervus elaphus*) (Muschenheim 1988), and, at both 500 and 1000 ug/kg, bighorn sheep (Kinzer et al. 1983). However, in domestic rabbits 400 ug/kg was 100% effective against *P. cuniculi* but only 50% effective against *P. ovis* (Wright and Riner 1985).

Ivermectin is believed to act by paralyzing invertebrate parasites (Terada et al. 1984). It may also damage the endocrine system and inhibit reproduction in parasites (Glancey et al. 1982). In domestic cattle, serum levels of ivermectin of 5 ng/ml were present and effective against *Psoroptes ovis* 18 and 21 days after intramuscular injection of 200 ug/kg (Guillot et al. 1986). However, mites taken from animals 1-5 days after treatment with a single intramuscular injection of 200 ug/kg were infective to untreated animals (Guillot and Meleney 1982).

The objective of this study was to test the efficacy of ivermectin for the control of psoroptic scabies (*P. cervinus*) in Rocky Mountain bighorn sheep.

We would like to thank the Wyoming Game and Fish Department, United States Forest Service and the Foundation for North American Wild Sheep for assistance with capture and transport of study animals and for financial support of this project. In particular we would like to thank the staff of the Sybille Wildlife Research and Conservation Education Unit who cared for the animals in captivity and provided the necessary animal restraint for humane and efficient sampling and Sandra Anderson of the Wyoming Game and Fish Department Wildlife Disease Laboratory who assisted with examination of ear swabs and scrapings for mites.

METHODS

This study was conducted in 2 parts. Between 1986 and 1988, 8 Rocky Mountain bighorn sheep were captured and monitored in a free-ranging study conducted on the South Fork of the Shoshone River, approximately 64 km southwest of Cody, Wyoming. During February and March 1989, 8 additional animals were captured on the South Fork of the Shoshone River and transported to the Sybille Wildlife Research and Conservation Education Unit, Wheatland, Wyoming for a captive study.

Bighorn sheep were captured by immobilization as in Muschenheim (1988). All animals exhibited clinical signs of scabies prior to capture including droopy ears; alopecia on the head, neck and back; and exudate in the ears.

Skin scrapings and ear swabs were taken from all animals at capture. Skin scrapings were taken from the peripheral region of the most encrusted lesions, at the junction with normal skin, on the head, body and in the ears. Hair over the sample sights was clipped to approximately 1 cm. Mineral oil was applied to hold debris together. Using a fresh scalpel blade, a skin scraping approximately 1.5 by 1.5 cm was taken until blood showed. Scraped debris was stored in plastic bags (Whirl-Pak Bags, Nasco West Inc., Modesto, CA 95352) and kept refrigerated. Ear swabs were collected from both ears using cotton tipped swabs. Swabs were stored in glass vials and kept refrigerated. All samples were examined within 48 hours of collection for the presence of psoroptic mites. Drawings were made to record areas with lesions and physical appearance.

Mites from skin scraping and ear swab samples were identified by F. C. Wright, (Knipling-Bushland U.S. Livestock Insects Research Laboratory, USDA, Agricultural Research Service, Kerrville, Texas) and R. L. Smiley, (Biosystematics and Beneficial Insects Institute, USDA, Agricultural Research Service, Beltsville, Maryland) (Muschenheim et al., in press).

Free-ranging Sheep

Four bighorn sheep, 3 ewes and 1 yearling ram, were captured during February and March 1986 and 4 additional ewes were captured at the same time during the following year for the free-ranging study. Each year 3 were treated with 30 mg (or 500 ug/kg) ivermectin (Ivomec, Merk and Co. Inc., Rahway, New Jersey 07065) administered subcutaneously at capture and 1 served as a control. All were fitted with radio transmitter collars (Telonics, Telemetry Electronics Consultants, Mesa, AZ 85201-6699) and released.

All animals were relocated during February - April 1987 and 1988. Observations were made on foot at distances of 30 to 200 m for signs of scabies lesions on the body or in the ears.

Captive Sheep

Eight bighorn sheep (7 ewes, 1 yearling ram, and 2 lambs) were captured for the captive study during February - March 1989. At capture all animals were treated with 1000 ug/kg ivermectin administered subcutaneously. The 8 bighorns were transported to the Sybille Wildlife Research Unit, Wheatland, Wyoming. Animals captured and treated on different dates were held in pens separated by 1 empty pen, approximately 15 m. Posttreatment samples were taken as at capture on March 24, one month after treatment at capture. One animal was retreated approximately 90 days after initial treatment. This second treatment consisted of removal of the plugs from both ear canals and infusion of one-half tube ivermectin oral paste into each external auditory meatus.

RESULTS

Free-ranging Sheep

Mites (*P. cervinus*) were found in samples collected at capture from 7 of 8 free-ranging animals. In observations during the 2 year posttreatment period no lesions were seen on the 2 control animals. One animal treated with ivermectin had lesions in the ears from 50 m 1 year after treatment. No lesions were observed on any of the other 5 free-ranging animals.

Captive Sheep

Mites (*P. cervinus*) were observed in the initial samples from 6 of 8 animals brought to the Sybille Wildlife Research Unit. The other 2 sheep had minor lesions indicating scabies, however no mites were found. Most lesions were in the ears or on faces and heads. Two animals had lesions in 10-cm diameter areas around the anus. Lesions on the ear were present from the external auditory meatus to the outer surface and were characterized by yellowish-white dried serous exudate, exfoliated epidermis containing loosened hairs, and offwhite mites. When this crusty layer was removed, the epidermis underneath was red and raw with serous exudate. In some cases the meatus was blocked with a solid plug. Lesions in other areas were similar but generally less severe or extensive.

Live mites were found in samples taken from the ears of 2 of 8 animals during the first month after treatment. No live mites were found in samples from the other 6 animals 25 days after treatment. Positive samples were taken from the ears of a ewe at necropsy when she died 6 days after capture and treatment. Another ewe had live mites in samples from the ears 25 days after treatment and was retreated on May 30. Plugs from both ear canals were removed and one-half of a tube ivermectin oral paste was infused into each external auditory meatus. No live mites were found in samples from this animal on June 23.

DISCUSSION

With free-ranging animals, sheep could not be periodically sampled after treatment for the presence of live mites. Also, a treated sheep could be reinfested from an untreated animal in the herd. To address the first problem we brought animals into captivity where they could be sampled periodically. To address the second problem we treated all animals brought into captivity.

Although Wyoming bighorn sheep have been observed dead or dying with extensive scabies lesions due to *P. cervinus*, morbidity and mortality has not been as high as described with *P. ovis* infestation of desert bighorn sheep in New Mexico and Arizona, or in historic accounts of scabies epizootics throughout the American West. However, scabies poses a threat to 3 infested herds in Wyoming and restricts transplanting of animals from or into these herds.

Reports of scabies in bighorn sheep across North America are increasing. Considering the impact of scabies on wild sheep populations historically this causes concern. Preliminary studies using ivermectin to control psoroptic scabies in desert bighorn sheep were encouraging (Kinzer et al. 1983). However, the limited results of this study contradict the results of previous studies and question the efficacy of a single dose of ivermectin for the treating _Psoroptes_ spp. infestation of bighorn sheep.

Mechanical cleaning of debris from the external auditory meatus followed with topical application of ivermectin paste may be an effective treatment in severely affected animals. Continuation of this study may indicate whether higher doses, prolonged release vehicles, additional injections and/or topical treatments are required to cure animals of _Psoroptes_ spp. and insure against translocation of the disease organism along with it's host.

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PSOROPTIC SCABIES IN BIGHORN SHEEP IN WASHINGTON AND OREGON

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Abstract: In 1988, clinical scabies (*Psoroptes ovis*) was observed in populations of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) in northeast Oregon and southeast Washington, and in California bighorn sheep (*Ovis canadensis californiana*) in southeast Washington. Based on observations of wild sheep in the field and diagnosis of *P. ovis* from skin scrapings from captured sheep, prevalence of infestation was over 50%, but was most severe in the California bighorns. In the 2 herds of Rocky Mountain bighorns, lesions were less severe, and mortality was not observed. In the California bighorns, lesions were extensive, and about 50 of 80 sheep died. Source of the outbreak may have been Rocky Mountain bighorns transplanted from Idaho to Oregon in 1984.

Scabies in bighorn sheep is caused by a surface feeding mite, *Psoroptes ovis*. Lesions are characterized by an exudative dermatitis with scab formation, and result from chronic irritation of the skin caused by mouthparts of the mites, and possibly from an immune response to proteins from the feeding mites. Layers of epidermis with serum, slough from the skin, and the scaley, scab-like lesions are often diagnostic of infection. Lesions consisting of layers of sloughed epithelium within ears usually develop first, and ear canals are often completely filled with debris. Advanced cases of scabies can cause mortality and jeopardize survival of bighorn populations (Lange et al. 1980, Welsh and Bunch 1983). The purpose of this paper is to document the occurrence and prevalence of *P. ovis* in bighorn sheep in Oregon and Washington.

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HISTORY AND METHODS OF EXAMINATION

California bighorn sheep were reintroduced into Oregon and Washington in 1951 and 1957, respectively. Rocky Mountain bighorn sheep were reintroduced into both states in 1971. *Psoroptes ovis*, or lesions compatable with scabies were not identified in bighorns in Oregon or Washington until December 28, 1984, when 27 Rocky Mountain bighorns were transported from the mouth of Cove Creek along the Salmon River in Lemhi County, Idaho to the Wenaha herd in Wallowa County, Oregon (Foreyt et al. 1985). At release, crusty lesions were noted in the ears of 2 sheep, and a scraping was made from the ear of 1, a 3 1/2-year-old ewe. About 75 larvae, nymphs, and adult P. ovis were recovered from the scraping. All sheep were treated with ivermectin at 0.2 mg/kg of body weight intramuscularly before release, but the potential for spread was noted (Foreyt et al. 1985), because the Wenaha herd of Rocky Mountain bighorns is within 16 km of a herd of California bighorns in Cottonwood Creek, Washington, and less than 30 km from a herd of Rocky Mountain bighorns at Joseph Creek (Black Butte), Washington (Fig. 1). Collared sheep have traveled between these populations.

On March 9, 1988, a dead California bighorn ewe, at least 4 years old, was found in the Oregon Wenaha herd near the Washington border (Fig. 1), and was examined at Washington State University (WSU). Approximately 50% of the hair on the head was missing, and crusty scabs were noted on most of the head including the ears, and on the front shoulders and rear legs (Figs. 2-4). Ear canals were blocked with crusty exudative debris. About 25,000-35,000 mites were present on the head where mites were in large, clearly visible clusters (Fig. 4). Mites were identified as Psoroptes sp. based on morphology of the jointed pedicels on the legs (Fig. 5). Representative mites were sent to Dr. Fred Wright, U.S. Livestock Insects Laboratory, Kerville, Texas, who identified them as P. ovis, based on lengths of 58 outer opisthosomal setae (OOS) from 33 adult males (Wright et al. 1984). Mean length of the OOS was 147.4 µm ± 23.31 (S).

Between 1988 and 1990, sheep in the 2 herds of Rocky Mountain bighorns (Wenaha herd in Washington and Oregon, and Joseph Creek herd in Washington), and the herd of California bighorns in Cottonwood Creek were observed by air or on foot for lesions compatable with scabies. Dead sheep were examined for mites and lesions, and 4 sheep were immobilized for examination.

Wenaha Herd

In 1988 the Wenaha herd in Oregon and Washington included about 60 Rocky Mountain bighorns. Scabies related mortality had not been observed. In March, 5 of 35 (14%) observed sheep had obvious lesions compatible with scabies, including alopecia and scabs on the ears, head, neck, or shoulders. In March 1989, 5 of 21 (24%) had lesions, and in March-May, 1990, at least 50% of the sheep had observable lesions. In most cases, only the ears were affected. In April-May, 1990, about 80 sheep were in the Wenaha population, and 4 sheep (2 ram lambs, 1 ewe lamb, and a 3-year-old ram) were immobilized in Oregon with xylaline in a Palmer capture dart, and examined. Lesions were similar on all 4 and consisted of crusty debris in the ears. Live Psoroptes sp. were isolated from all sheep.

Cottonwood Creek Herd

In 1988, this California bighorn herd decreased from about 80 to 30, presumably due to scabies, and poor range conditions resulting from drought. In March 1988, obvious lesions were observed in 13 of 49 (26%) sheep. In January, 1989, 2 sheep were euthanized for examination. Each sheep had lesions on ears, face, neck, and shoulders, and about 400-500 live Psoroptes sp. were isolated from the ears of each.

Joseph Creek Herd

In 1990, 2 sheep, an adult ram and an adult ewe were euthanized and examined. Both sheep were emaciated and weak. Crusty scabs were present in the ears. Seven psoroptes sp were detected from a scaping from the ram, and over 2,000 were detected from ear scrapings from the ewe. This herd is growing rapidly and includes about 160 sheep in 1990. No mortality due to scabies has been detected.

EXPERIMENTAL TRANSFER TO DOMESTIC SHEEP AND A BIGHORN SHEEP

Mites from the 2 California bighorns collected from the Cottonwood Creek herd were transferred to 2 domestic sheep and a Rocky Mountain bighorn ram lamb to test transmissibility. The domestic wether sheep were housed together in a 5 x 8 m indoor room at WSU and the bighorn was housed in a similar room. All sheep were fed alfalfa hay free choice, and had access to mineralized salt and fresh water at all times. Approximately 50 mites mixed in crusty material from the wild bighorns were placed deep in the ear canals of each sheep (25 per ear) with a cotton tipped swab. Thirty days after inoculation, ears were examined with an otoscope, and cotton tipped swabs were rotated within the ear canals and withdrawn and examined for mites under a dissecting microscope (40x). The domestic sheep were maintained for 90 days. The bighorn lamb was maintained for almost 1 year after inoculation, and examined at about 2-month intervals. Mites were not recovered from the domestic sheep, but were recovered at each sampling from the bighorn. Over the one 1-period scaley lesions were present in the ears only. Ears were completely filled with concentric debris, but lesions did not spread to the body.

DISCUSSION

It is likely that the scabies outbreak in Oregon and Washington originated from the transplant to Oregon from Idaho in December, 1984 (Foreyt et al. 1985). Scabies had not been identified in Oregon or Washington before this time, and the initial cases in 1988 were near the 1984 release. Scabies is now present in 3 herds, Wenaha, Joseph Creek, and Cottonwood Creek (Fig. 1), but has significantly impacted only the Cottonwood Creek herd where over 50% of the sheep died in 1988, and very few lambs were observed in 1989. Mortality in these California bighorns was likely due to poor habitat conditions resulting from severe drought, compounded by scabies. Similar observations occurred in Arizona where an increased prevalence of scabies followed a 2-year drought (Welsh and Bunch 1983). Therefore, the impact of scabies may be related to habitat, nutrition, and immunocompetence of infected bighorns. An alternative explanation is that California bighorns are more susceptible than Rocky Mountain bighorns to the effects of scabies. Mortality was not observed in the Wenaha or Joseph Creek herds of Rocky Mountain bighorns, and lesions were generally restricted to the ears. Further evaluation is necessary to determine if there is a difference between subspecies in susceptibility to scabies.

Because scabies can cause significant mortality in bighorns, it is an important management consideration. Management options include: 1) monitor populations to determine infestation rates and mite intensities; 2) treat infected populations with ivermectin by injection or feed formulation at 0.5-1.0 mg/kg of body weight to minimize impacts of infestation; 3) exclude sheep with scabies from transplant programs; 4) treat all transplanted sheep with ivermectin subcutaneously at 0.5-1.0 mg/kg of body weight to minimize the probability of transplanting sheep with live mites; and 5) take no action and endure the consequences of infections.

Ivermectin at a dosage of 0.5-1.0 mg/kg of body weight has been effective against P. ovis in desert bighorn sheep (Ovis canadensis mexicana) in New Mexico (Kinzer et al. 1983a). In cattle treated subcutaneously with ivermectin at 0.2 mg/kg of body weight, live mites could be found on treated animals for up to 20 days after treatment (Wright and Guillot 1984a), and live mites from cattle treated with the same dosage of ivermectin were capable of reproducing on recipient cattle for up to 9 days after treatment (Wright and Guillot 1984b). Residual activity of ivermectin at a subcutaneous dosage of 0.2 mg/kg is approximately 3 weeks (Meleney et al. 1982), with the mean maximum serum concentration of 29 ng of ivermectin per ml at 48 hours after injection (Guillot et al. 1986). Therefore, when treated with ivermectin at 0.2 mg/kg or more of body weight, animals should be separated from noninfected animals for at least 20 days. Also, cattle that have been treated and cured of scabies are just as susceptible to infection as naive cattle after a 2-5 month latent period (Guillot 1987). Therefore, long-term resistance to scabies is not likely to occur after treatment.

Based on reports by Wright et al. (1981), Kinzer et al. (1983g), and on our results, it appears that P. ovis of bighorn sheep are biologically distinct mites, that normally are unlikely to infect domestic sheep or cattle. While transmission to livestock is unlikely, potential transmission to other wild ruminants is unknown.

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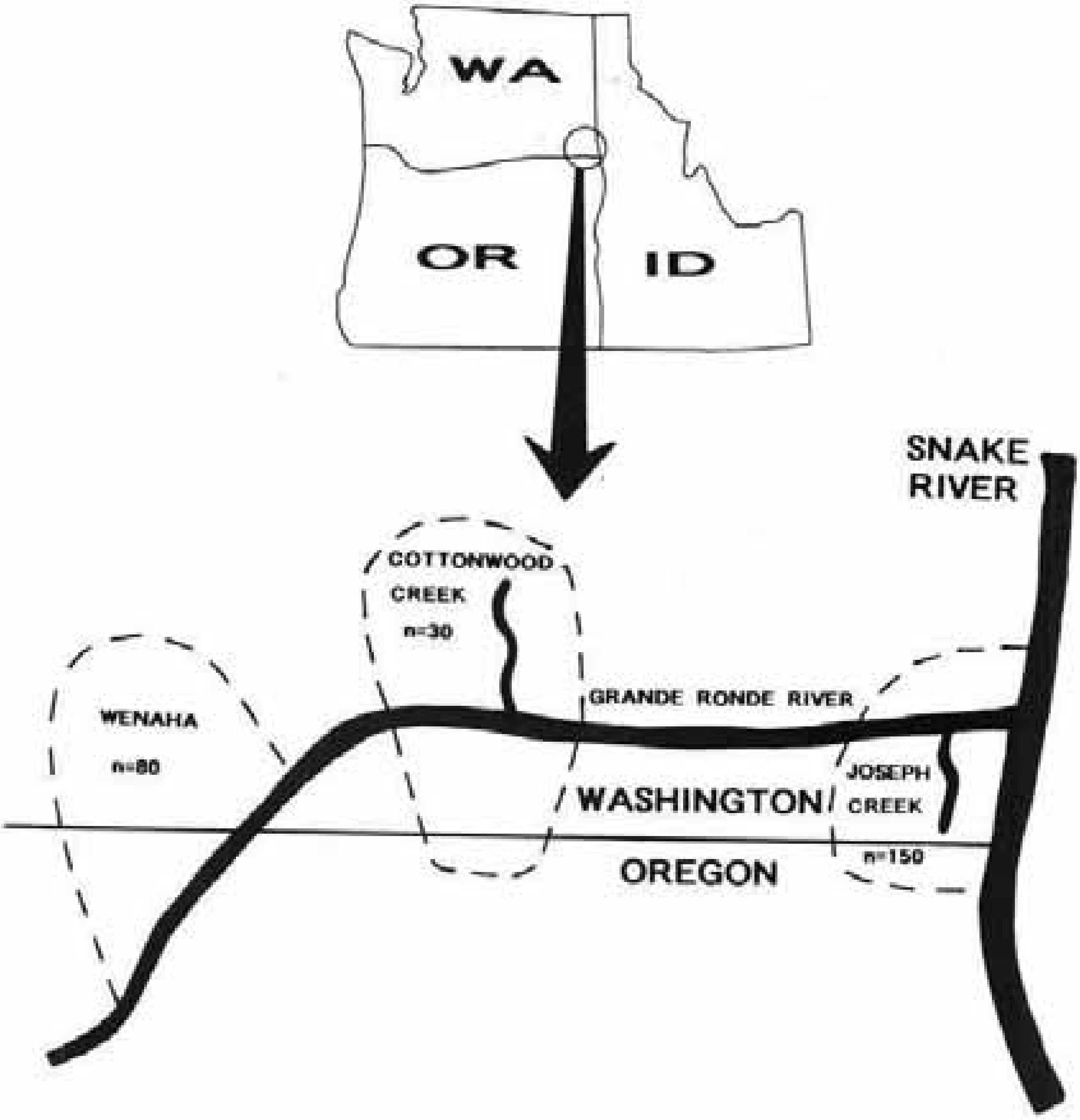

Fig. 1. Location of scabies in 3 populations of bighorn sheep in Oregon and Washington.

Fig. 2. Bighorn sheep with scabies from the Wenaha herd in Washington illustrating generalized alopecia of the ear, muzzle, and around the eye, with excoriations and crust formation.

Fig. 3. Posterior part of the head of bighorn sheep with scabies from the Wenaha herd in Washington illustrating alopecia, excoriations, and crust formation.

Fig. 4. Closeup view of Fig. 3 illustrating alopecia, excoriations, and crust formation with thousands of <u>Psoroptes</u> <u>ovis</u> visible in clusters (arrows).

Fig. 5. <u>Psoroptes</u> <u>ovis</u> from a bighorn sheep. Note the jointed pedicels on the front legs (arrows).

MANAGEMENT AND RESEARCH TECHNIQUES

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A TECHNIQUE FOR IMPLANTING HEART-RATE TRANSMITTERS IN BIGHORN SHEEP

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Abstract: We conducted laboratory experiments, using a domestic ewe, to determine the necessary input sensitivity and optimum location for implanting electrodes for heart rate telemetry of bighorn sheep. A 2-lead electrocardiograph was used to obtain strip-chart recordings of the QRS waveform at 3 superficial lead attachments. A cylindrical heart rate transmitter with fixed electrodes was experimentally implanted in the domestic ewe in a vector between the manubrium and xiphoid. The transmitter was implanted between the subcutaneous fat and muscle, superficial to the rib cage. The transmitter failed on the second day after surgery due to accumulating serosanguineous fluid in a pocket around the electrode(s). The transmitter was restored to operation by suturing through the skin and into the subcutaneous tissue near the electrode(s). Sutures also prevented migration of the implant. The transmitter functioned properly for 4 weeks before being passively expelled due to tissue necrosis caused by pressure at the cranial electrode. The wound healed with only localized infection and without other complications. The ewe was in the third trimester during the experiment and successfully lambed 1 month after the transmitter was expelled. We similarly implanted a heart rate transmitter in a free-ranging bighorn ewe and collected > 200 hours of data before the transmitter was expelled. Bighorn heart rates averaged 55, 78, and 168 beats per minute for resting, foraging and disturbed behavioral states, respectively.

During a 3 year study of a recently established population of bighorn sheep (*Ovis canadensis*) in north-eastern Wyoming we identified vehicular disturbance as a potential limiting factor (Coates and Schemnitz 1988). Harlow et al. (1987) demonstrated that cardiac frequency was an accurate predictor of adrenal responsiveness for bighorn sheep, thus demonstrating that heart rate telemetry could be

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used to quantitatively assess environmental stressors. Proposed highway upgrading through population core-use areas occupied during our study justified analysis of cardiac response of bighorn sheep to vehicular disturbance.

Follman et al. (1982) described a heart-rate transmitter (model EKG-1-2000, Stuart Enterprises, Oceanside, CA) suitable for use in large mammals that was durable, had long range, and was easily implanted under field conditions. However, there was insufficient information available in the literature to conduct a study of cardiac response of free-ranging bighorn to vehicular disturbance. We required additional information on properties of the QRS waveform, including required input sensitivity for the transmitter described by Follman et al. (1982), and optimum location for transmitter placement.

A pregnant, adult-domestic ewe (Ovis aries) was used to obtain the necessary information in a laboratory setting, followed by experiments in the field using a free-ranging bighorn ewe. This paper presents new information on electrocardiology of sheep and provides information necessary for implanting the heart-rate transmitter described by Follman et al. (1982) in bighorns.

Principal funding for the research was provided by the National Park Service Research Center, at the University of Wyoming, Laramie, Dr. K. L. Diem, Director. J. Thomas of the North Bighorn Hospital in Lovell, Wyoming, provided assistance with electrocardiography and reviewed the manuscript.

ELECTROCARDIOGRAPHY AND TRANSMITTER PLACEMENT

A 2-lead electrocardiograph (model EK-5A, Burdick Co., Milton, WI) was used to obtain strip chart recordings for the domestic ewe at 3 superficial lead attachments: manubrium to xiphoid, manubrium to right foreleg, and xiphoid to right foreleg. The first lead placement, manubrium to xiphoid, yielded the waveform of highest amplitude with a peak value of 0.4 mV.

We determined the input sensitivity necessary for heart-rate transmitters in sheep was 0.4 Mv. This input sensitivity is comparable to values reported by Cassirer (in-press) for elk (Cervus elaphus).

The transmitter described by Follman et al. (1982) was cylindrical with fixed, stainless-steel electrodes and overall dimensions of 30 X 160 mm. Considering the cardiological data for sheep, and dimensions of the transmitter, we concluded that the optimum location for implanting this transmitter in bighorn sheep was along the sternum in a vector between the manubrium and xiphoid.

SURGICAL PROCEDURES

Follman et al. (1982) referenced the surgical techniques of Philo et al. (1981) who reported 2 field procedures for implanting temperature-sensitive transmitters in grizzly bears (Ursus arctos). These procedures were rapid and relatively uncomplicated.

In the first procedure, the transmitter was implanted in the back of the neck, perpendicular to the spinal column. Two 5-cm incisions were made parallel to the spine, 8 cm to either side of the dorsal midline. The incisions were carried through the subcutaneous tissue, and a pocket was formed between the incisions by blunt dissection.

In the second procedure, the transmitter was placed free in the abdominal cavity. An 8 cm incision was made immediately posterior to the umbilicus, and the transmitter was implanted in the abdominal cavity.

We elected to use a modification of the first procedure due to possible complications with peritonitis from the second procedure. A domestic ewe was sedated using ketamine and xylazine hydrochloride (0.5-0.75 mg/kg body weight)and restrained in lateral recumbency. Tissue surrounding the surgical site was infiltrated with 15 cc lidocaine-hydrochloride (Vedco Distributing, St. Joseph, Missouri). Sites for the incision were shaved and cleaned with a bacteriostatic agent, betadine.

The 5-cm incision was made 10 cm caudal to the manubrium and a shallow pocket was formed using a minimum of blunt dissection. The cylindrical configuration of the transmitter, and conical shape of the front electrode-cap, helped to form a subcutaneous channel as the transmitter was pushed through the loose connective tissue. The incision was closed with #3 chromic cat-gut suture. A prophylactic injection (7 cc) of penicillin-G benzathine and penicillin-G procaine was administered to prevent infection.

The transmitter functioned well immediately after implantation but failed on the day after surgery due to accumulating serosanguineous fluid at the cranial end of the transmitter. However the transmitter was restored to operation by reducing the size of the pocket and draining the fluid. This was accomplished by suturing through the skin and into the subcutaneous tissue at the cranial end of the pocket. Sutures through the skin and into the subcutaneous tissue at several sites surrounding the transmitter prevented migration of the implant.

The transmitter functioned well for 30 days before being passively expelled due to tissue necrosis. There was only localized infection and the wound healed without complications. Post-surgical care was not necessary. The domestic ewe was in the third-trimester of pregnancy and successfully lambed 1 month after the transmitter was expelled.

A free-ranging bighorn ewe (yearling) was immobilized in April 1989 at Bighorn Canyon National Recreation Area, a National Park Service Unit in north-central Wyoming and south-eastern Montana, using 2 cc of ketamine/xylazine hydrochloride (400 mg/200 mg). Standard precautions were followed to prevent capture myopathy (Jessup et al. 1984). The bighorn ewe was restrained in lateral recumbency and hair was removed from the incision site by plucking and shaving. The site was disinfected using betadine and a prophylactic injection (7 cc) of penicillin-G benzathine and penicillin-G procaine was administered.

Surgery and insertion of the transmitter were as previously described, and collodion was used to cover the suture line and create a barrier for dirt at the incision. After recovery the ewe walked approximately 250 m and laid down, but remained alert.

HEART RATE RESPONSES

The transmitter had a range of up to 2 km depending on topography and juxtaposition of the ewe. For the purpose of data collection we remained as far away as possible while maintaining visual contact with the ewe. Cardiac activity was measured continuously for 60 sec at 5 min intervals in order to estimate mean heart rate associated with 3 behavioral states: resting, foraging and disturbed. Cardiac activity of the bighorn ewe was monitored for > 200 hours before the transmitter was expelled (14 days after surgery).

Resting heart rate averaged (mean of the means) 55 beats per minute (S = 0.7 b.p.m., N = 190). Resting heart rate was analyzed when the ewe was bedded or when it stood motionless (Fig. 1).

Foraging heart rates averaged 78 beats per minute (S = 4.5 b.p.m., N = 182). Foraging heart rates were recorded when the ewe foraged while standing motionless, when it walked across flat ground, or searched for food on a slope (Fig. 1).

Heart rates associated with disturbance averaged 168 beats per minute over a 2 hour period (range 135 - 200 b.p.m., N = 2, Fig. 1). Disturbances were elicited by approaching the ewe on foot and causing it to flee. After the initial flight response we remained as far away as possible while maintaining visual contact.

Disturbance analyses were conducted in this manner on 2 occasions. In both instances the ewe was alone and resting at the onset of disturbance (mean resting heart rate 55 b.p.m.), and heart rate elevated to 135+ beats per minute within 1 minute. Heart rate continued to rise for up to 1 hour after the initial disturbance, reaching peaks of 200 beats per minute. Heart rate remained elevated for 2 hours after onset of disturbances without overt indications of stress (e.g. animal not in alert posture or fleeing). Distance to the observer ranged 1 to 2 km during peak heart rates.

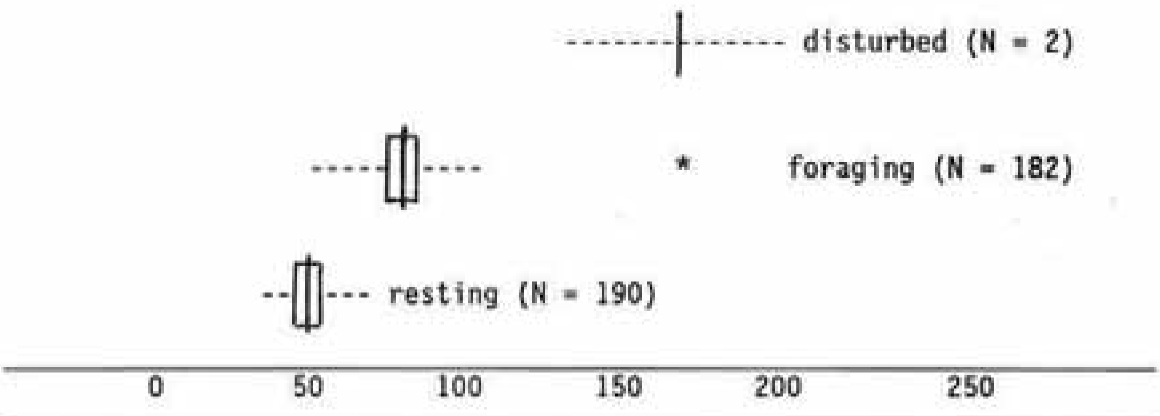

Fig. 1 Heart rates of a free ranging bighorn ewe associated with resting, foraging, and disturbance. Plots show means (center vertical lines), 95% confidence limits (boxes) and ranges (horizontal lines). The asterisk is an outlying data point. No confidence limit is shown for disturbed heart rate since N = 2.

DISCUSSION

Heart rate responses to disturbance were only analyzed on 2 occasions, but this represents the best data of this type currently available for free ranging bighorns. The technique can be performed rapidly in the field but the transmitter described by Follman et al. (1982) is bulky and causes tissue necrosis. Expulsion of the transmitter does result in localized infection, but no complications were involved with either the domestic ewe or free ranging bighorn.

We recommend using an alternate transmitter packaging system, or free electrodes implanted along the sternum as described, where long term data and transmitter retention are desired. Data of this type are needed by managers to correlate heart rate with stress (Harlow et al. 1982) in order to maintain and(or) maximize bighorn populations in sub-optimal habitats.

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TRACKING BIGHORNS WITH SATELLITES: SYSTEM PERFORMANCE AND ERROR MITIGATION

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Abstract: Performance of satellite telemetry in bighorn sheep (*Ovis canadensis*) habitat was described and error mitigation explored. The lognormal mean error of 304 locations was 2.728 km. Errors ranged from 0.445–12.552 km. The 68 percentile error of 3.276 km was significantly greater than the maximum expected value of 1.510 km. Differences between actual and assumed elevations accounted for about 66% of the error. Terrain apparently limited location quality and, therefore, accuracy by limiting the number of uplinks per satellite pass. Errors were bimodally distributed along the east-west axis and generally occurred toward the satellite, probably because actual elevations were much greater than the assumed elevation of sea level. Locations were obtained for up to 60% of satellite passes ≥5° above the horizon. Terrain reduced location efficiency up to 41%; when deployed on an animal, location efficiency declined an additional 43%. Following error "correction" and subsequent indexing to reject outliers, the 68 percentile error was 0.830 km (range = 0.086–2.263 km, n = 226). A bivariate normal model of the residual error was used to develop a weighted utilization distribution (WUD) that reflected the average probability of an animal occurring in a given space during a given period. The resulting model agreed well with visual observations of an adult ewe. Core ranges and specific travel corridors were identified for the ewe.

Bighorn sheep often occur in relatively small populations and occupy patchily distributed habitats. Many such populations may coexist within a region, suggesting that metapopulation theory may be useful for assessing long-term viability and designing conservation strategies. However, metapopulation analyses require knowledge of the distribution of suitable habitats and dispersal of individuals among habitat patches (Gilpin 1987). Such information has been difficult to obtain. Satellite telemetry, used with a Geographic Information System (GIS) and other remote sensing data, may improve the economic and logistic feasibility of acquiring necessary information (Craighead and Craighead 1987, Fancy et al. 1988), but the likely resolution of resulting models remains uncertain. Although satellite telemetry is well suited to tracking gross animal movements (Fedak et al. 1984; Fretay and Bretnacher 1984; Mate 1984; Priede 1988; Craighead and Craighead 1987; Grigg 1987; Marsh and Rathbun 1987; Mate et al. 1986, 1988; Fancy et al. 1988; Stewart et al. 1989), its ability to support studies of local movements and habitat use has not been demonstrated. We describe performance of satellite telemetry in bighorn habitat and explore error mitigation methods.

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STUDY AREA

Tests were conducted in and adjacent to the Many Glacier Valley, Glacier National Park, Montana, between latitudes 48°45' and 48°50' north, and longitudes 113°35' and 113°40' west. The area is characterized by precipitous peaks and glaciated valleys. Elevations range from 1,463–3,052 m. Major valleys are oriented in a generally east-west direction and drain eastward. Orientations of sub-drainages containing test sites ranged from north-south to east-west. Twenty-three test sites encompassed both winter and summer bighorn ranges, and were stratified by aspect and elevation along 7 transects extending from valley bottoms to mountain peaks. Wherever possible, sites were on mountain peaks, at stream intersections, in shallow gullies, or other similarly obvious landmarks that could be located readily using aerial photographs, 7.5 minute USGS topographic maps, an altimeter, and compass. Universal Transverse Mercator (UTM) coordinates were determined for each site using 7.5 minute USGS topographic maps and a digitizer.

METHODS

Accuracy and Sampling Frequency

During April–August 1986, a Telonics ST-2 Platform Transmitter Terminal (PTT) was moved every 3–5 days among the test sites. The PTT was configured for use on bighorn sheep and transmitted 24 hours per day at about 60-second intervals. The collar included a VHF backup beacon. Under the belief that "[e]rrors associated with PTT altitude only take on real significance in the case of balloons" (Service Argos 1984), location calculations assumed the PTT was at sea level. Fancy et al. (1988) give a detailed description of the satellite system.

Errors were calculated as both Cartesian (x_E, y_E) and polar (r_E, Θ_E) coordinates whose origins were the known test site locations. Advertised performances (Service Argos 1988; Clark 1989; R. Liaubet, Service Argos, Inc., pers. commun.) implied that expected error distributions were bivariate normal with (μ_x, μ_y) = (0,0), $\sigma_x = \sigma_y$, and no correlation among σ_x and σ_y (where μ_x and μ_y are the means, and σ_x and σ_y are the standard deviations of the distributions of x_E and y_E, respectively). Expected values for σ_x and σ_y were 150, 350, and 1,000 m for NLOC = 1, 2, and 3, respectively (Service Argos 1988, Clark 1989). Probabilities (P) for the expected distribution are (Batschelet 1981:267):

$$P = 1 - \exp(-c/2) \qquad (1)$$

where

$$c = \frac{(x_E - \mu_x)^2}{\sigma_x^2} + \frac{(y_E - \mu_y)^2}{\sigma_y^2} \qquad (2)$$

To determine if performance was within expected limits we tested 3 null hypotheses: (1) 68% of the r_E were within 226, 528, and 1,510 m for NLOC = 1, 2, and 3, respectively, (2) the θ_E were distributed uniformly, and (3) $(\mu_x, \mu_y) = (0,0)$. A uniform distribution of θ_E is a corollary of the expectation that σ_x and σ_y are equal and uncorrelated. Expected 68 percentile values of r_E follow from equations (1) and (2). They differed greatly from previous studies, which misinterpreted predicted values for σ_x and σ_y as the 1 standard deviation error distances of the r_E. For example, Stewart et al. (1989) stated that predicted performance of the system was such that 68% of the locations are accurate to within 150, 350, and 1,000 m for the 3 location qualities, respectively. Such an interpretation greatly overstates expected accuracy. From equations (1) and (2), it follows that only about 39% of the locations are expected within the distances indicated by Stewart et al. (1989).

Sampling frequencies of sensor and location data, respectively, were calculated as:

$$M_S = M/S \qquad (3)$$

$$L_S = L/S \qquad (4)$$

where S is the number of "available" satellite passes, M is the number of passes in which ≥1 message was received by the satellite, and L is the number of passes in which a PTT location was calculated. We used Telonics Satellite Predictor software and ephemeris data from NASA Prediction Bulletins (NASA Goddard Space Flight Center, Code 513, Greenbelt, Md. 20771) to determine S relative to the Mt. Altyn winter range. Satellite passes with a maximum pass height $(P_H) \geq 5°$ above the horizon were considered "available" to the PTT. We used a 5° threshold because messages may be received when P_H is as low as 5° (K. A. Keating, unpubl. data), and because it is the threshold used by Service Argos to estimate pass frequency and duration (Service Argos 1984). Mate et al. (1986) also used a 5° threshold. Variables L and M were tabulated from Argos dispose files. Due to a Service Argos software problem, multiple locations sometimes were calculated from 1 satellite pass. When this occurred, we acknowledged only 1 location when calculating sampling frequencies. The problem has been corrected since our study was conducted.

Error Mitigation

Correction, indexing, and weighted utilization distributions (WUDs) were explored as error mitigation techniques. They were employed sequentially in the order described.

Error correction.—To "correct" errors, $\hat{r}_E$ and $\hat{\theta}_E$ were estimated from regressions on P_H and θ_S, respectively. The rationale for using P_H and θ_S to estimate errors is presented in the results. We estimated P_H and θ_S using the Telonics Satellite Predictor Software with ephemeris data from NASA Prediction Bulletins. Using $\hat{r}_E$ and $\hat{\theta}_E$ to determine how far and in

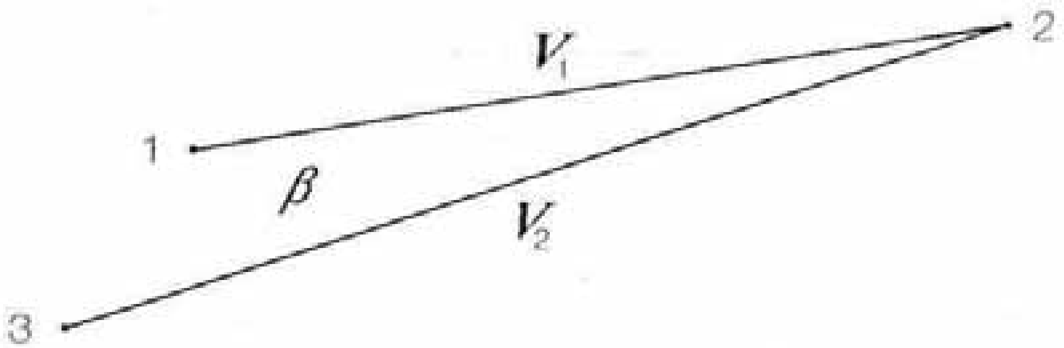

Fig. 1. Schematic representation of 3 consecutive calculated locations (1, 2, 3). The error index for location 2 is calculated from the vectors (V_1 and V_2) and the minimum angle (β) formed by the 3 locations (see text, eq 5).

what direction to "move" locations, coordinates calculated by Service Argos were modified and compared with uncorrected locations to determine the efficacy of the technique.

<u>Error indexing</u>.—To develop an error index (I), we reasoned that data showing a single, relatively large movement, followed by an immediate return to the point of origin, should tend to be more erroneous than data showing localized movements, movements in unrelated directions, or large movements in the same direction. Such a pattern can be identified by examining 3 consecutive locations, from which 2 vectors (V_1 and V_2) and the minimum angle (β) formed by the vectors can be calculated (Fig. 1). Larger errors are indicated as β approaches zero, V_1 approaches V_2, and when V_1 and V_2 are both large. Thus, we calculated I as:

$$I = \left(\frac{V_1 + V_2}{2}\right)\left(\frac{V_{min}}{V_{max}}\right)\left(\frac{\cos\beta + 1}{2}\right) \tag{5}$$

where V_{min} and V_{max} are the smaller and larger, respectively, of V_1 and V_2. When $V_1 = V_2$ and $\beta = 0°$, I attains a maximum value of $(V_1 + V_2)/2$ and, thus, becomes an estimate of r_E under those conditions. As V_{min}/V_{max} approaches 0 or as β approaches 180°, I approaches 0. We hypothesized that I is linear on r_E.

By using 3 consecutive locations to index error we implicitly assumed that an extreme movement is not real unless it is confirmed by either the preceding or subsequent location. Clearly, a second, corroborative location will not always be obtained before an animal returns to a location near its point of origin. Error indexing should therefore lead to underestimating the frequency of extreme, short-term movements. The degree to which such movements are underestimated should depend upon sampling frequency and a species' movement patterns. Sampling frequency may vary with terrain, signal strength, or duty cycle (which is programmed into the PTT and defines the daily and seasonal transmission schedules). Short-term movements should be most seriously underestimated when sampling frequency is low and for species making frequent, long-range forays from one, or between 2, activity centers. Little bias is expected for species making large movements infrequently.

WUD.—The distribution of an animal's probability of occurrence has been termed a utilization distribution (UD) (Van Winkle 1975, Ford and Krumme 1979). Ideally, methods for describing UDs should be probabilistic, nonparametric, and insensitive to sample size (Ford and Krumme 1979). Methods based on relocation distance (Ford and Krumme 1979) and Fourier transformations (Anderson 1982) have been proposed. However, the former is computationally cumbersome and limited to small grids (Ford and Krumme [1979] used a 10 x 10 cell grid), while results of the latter may vary greatly with grid size (Anderson 1982). Both methods assume that locations used to compute the UD are precise. This assumption clearly was untenable for satellite telemetry data.

We proposed a method incorporating the error probabilities associated with each location. It is conceptually analogous to that of Ford and Krumme (1979). Noting that samples are seldom large enough to confidently determine UDs for individuals, Ford and Krumme (1979) suggested that UDs from several individuals be averaged to describe the UD of an idealized individual that typifies the population. They termed the result a "population utilization distribution" (PUD). We suggest that each calculated PTT location has a UD that defines the error probabilities associated with the location, and that the UD is the same among locations or classes of locations. We also suggest that UDs for animal locations can be averaged to determine the UD for an animal during a given period (Fig. 2). Because the resulting UD for an animal reflects error-weighted probabilities, we term the distribution a "weighted utilization distribution" (WUD). Our model of error probability is described in the results, as it is contingent upon results of the other analyses.

Animal Tracking and Data Analysis

To assess performance on an animal, an adult bighorn ewe was collared in the Many Glacier Valley and tracked during Nov. 1986–Dec. 1987. During this period, the PTT was programmed to transmit only 6 hours per day to conserve battery life. Actual movements were documented from visual observations during 1985–1988. Sampling frequency was examined relative to deployment status (on versus off the animal) and time since deployment. Error correction and indexing were applied and a WUD was calculated.

Statistical analyses used SYSTAT™ and SYGRAPH™ (Wilkinson 1988*a*,*b*) software. Significance was assumed at the $\alpha = 0.05$ level. Specific tests are identified in the results. Linear and nonparametric tests were applied according to Zar (1984). Circular statistics referenced Batschelet (1981). GRASS software (U.S. Army Corps of Engineers 1989) was used to develop WUDs from the error probability model.

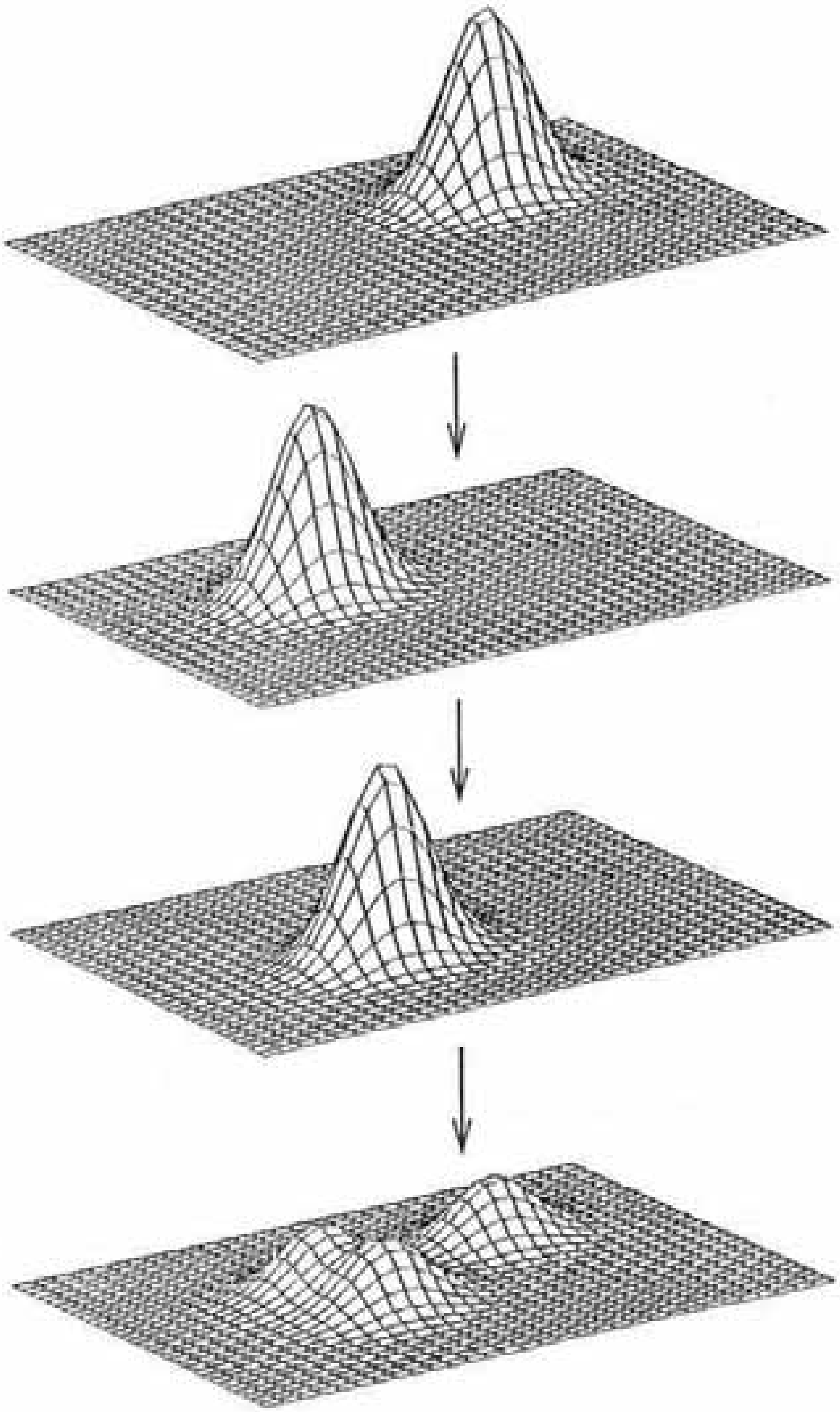

Fig. 2. Construction of a hypothetical weighted utilization distribution (WUD). Shown are 3 hypothetical PTT locations with a binormal model of the error probability superimposed over each location. The binormal model reflects the probability that the PTT was actually located at a point in space other than the calculated location. The WUD is constructed by averaging the probabilities associated with all data points (bottom image).

RESULTS AND DISCUSSION

Accuracy

Accuracy was described from 304 locations (Fig. 3). We rejected the null hypothesis that errors were within expected limits, i.e., 68% within 226 (NLOC = 1), 528 (NLOC = 2), and 1,510 m (NLOC = 3). Normal approximations of the 1-tailed binomial test showed that proportions of locations within expected limits for NLOC = 1 and 3 were less than expected (NLOC = 1: $Z = \infty$, $P = 0.000$; NLOC = 3: $Z = 23.32$, $P = 0.000$). No NLOC = 2 locations were achieved. Errors were considerably greater than have been reported previously. Mate et al. (1986) reported 94% of 46 locations within 0.6 km of the center of an enclosure with a radio-tagged manatee (*Trichechus mantus*), and a maximum error ≤2 km. For 42 locations of 2 PTTs, Craighead and Craighead (1987) reported half-lengths of 1.753 km and 0.516 km for the major axes of the 95% probability ellipses, and 0.405 km and 0.456 km for the minor axes. Fancy et al. (1988), examining 1,265 locations of 12 PTTs, reported a mean error of 0.829 km, with 90% within 1.7 km of the true location and a maximum error of 8.8 km.

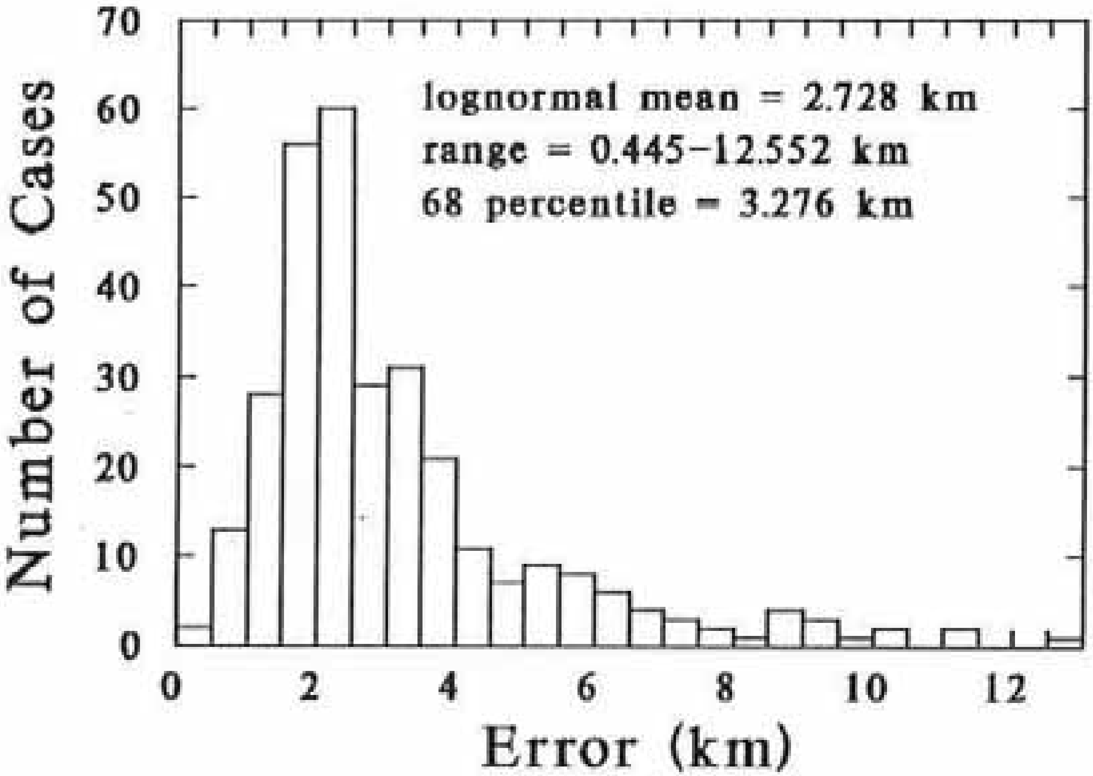

Fig. 3. Distribution of errors for satellite telemetry locations, as determined from 304 locations of a PTT deployed at 23 known sites. Differences between actual and assumed site elevations ranged from 1,462–2,801 m ($\bar{x} = 2,154$ m, SD = 419 m) and accounted for about 66% of the observed error (see text).

The extreme errors we observed were likely caused by erroneous estimates of PTT elevation. Location calculations assumed that PTTs were at sea level, but actual elevations ranged from 1,462-2,801 m. French (1986) found that differences between actual and assumed PTT elevations may affect location accuracy. We therefore hypothesized that r_E was related to the difference (H_E) between actual and assumed PTT elevations. Linear regression revealed no relationship between r_E and H_E ($r^2 = 0.002$, $P = 0.21$). Fancy et al. (1988), examining 1,265 locations of PTTs at elevations of 20–850 m, also found no such relationship, even though location calculations in their study also assumed that PTTs were at sea level. However, neither analysis considered confounding, nonlinear effects of satellite pass height (P_H). From French (1986, Fig. 5), we estimated theoretical errors ($\hat{r}_E$) due to erroneous elevation estimates for 35 combinations of H_E and P_H. For each elevation, $\hat{r}_E$ was related to P_H by an exponential function:

$$\hat{r}_E = ae^{(bP_H)} \tag{6}$$

where a and b are variables, and e is the base of natural logarithms. Using regression analysis, estimates of a and b were obtained for each elevation. Subsequent regressions of a and b on H_E showed that a increased linearly with H_E ($r^2 = 0.997$, $P = 0.000$), the y-intercept of that relationship was equal to 0 ($P = 0.63$), and b was constant with respect to H_E ($P = 0.24$). Equation (1) was therefore restated as a function of H_E and P_H:

$$\hat{r}_E = a'H_E e^{(bP_H)} \tag{7}$$

where a' was a constant defining the relationship of a to H_E, and b was a constant defining the influence of P_H on the error-elevation relationship. Nonlinear regression was used to estimate a' and b, and yielded the following mathematical estimate of French's (1986) theoretical error-elevation relationship ($r^2 = 0.98$, $P = 0.000$), where $\hat{r}_E$ is in meters:

$$\hat{r}_E = 0.134H_E e^{(0.047P_H)} \tag{8}$$

Comparison of r_E and $\hat{r}_E$ indicated a significant relationship between r_E and H_E when effects of P_H were considered ($r^2 = 0.66$, $P = 0.000$). We concluded that about 66% of the error in this study resulted from specifying incorrect elevations, and that significant variations in accuracy may occur within studies as animals move among different elevations.

We also tested the null hypothesis that directions of errors (Θ_E) were uniformly distributed. Because graphic analyses suggested a bimodal distribution of Θ_E, angles were doubled (Batschelet 1981). The hypothesis was rejected following a Rayleigh test ($z = 134.69$, $P < 0.001$) which indicated that errors were distributed bimodally along an undirected axis of about 174° ± 23° (± mean angular deviation, east = 0°). (We note, however, that the Rayleigh test gives only an approximate indication of the true distribution. A scatter plot [Fig. 4A] clearly showed a quadrimodal distribution.) Other studies (Craighead and Craighead 1987,

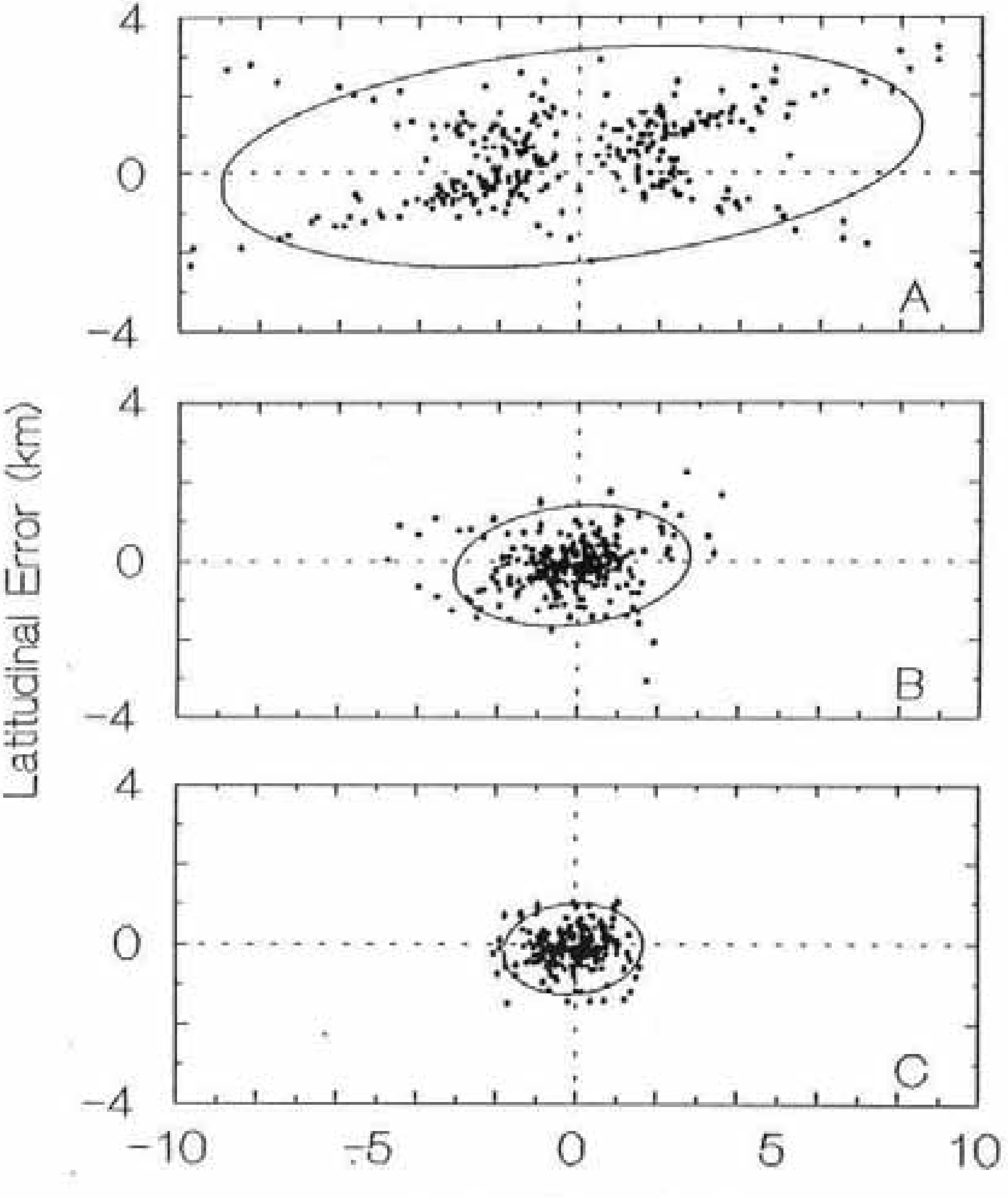

Fig. 4. Scatter plots of location errors for a PTT placed at 23 known sites. Errors were standardized to a true PTT location of (0, 0). Plots are for (A) uncorrected locations (*n* = 304), (B) locations corrected for effects of elevational error (*n* = 304), and (C) corrected locations where the error index (*I*) < 0.906 (*n* = 226). Ellipses are the 95% probability isoclines and assume a binormal distribution of the errors.

Fancy et al. 1988, Priede 1988, Stewart et al. 1989) also reported greater longitudinal than latitudinal error but offered no explanation. In our study, a Rayleigh test indicated that directions of satellite passes at their maximum pass heights (θ_S) also were distributed bimodally, along an undirected axis of about 176° ± 21° ($z = 167.20$, $P < 0.001$), suggesting that errors may have occurred either directly toward or away from the satellite. To test this hypothesis we examined distributions of θ_D, where $\theta_D = \theta_E - \theta_S$. A Rayleigh test indicated that θ_D was distributed unimodally ($z = 260.49$, $P < 0.001$) such that errors tended to occur directly toward the satellite ($\theta_D = 0° \pm 25°$).

Finally, we rejected the null hypothesis that locations were unbiased, i.e. $(\mu_x, \mu_y) = (0, 0)$. Hotelling's 1-sample test indicated that mean location was a biased estimate of true location ($T^2 = 55.03$, $P = 0.000$). Relative to the true location, polar coordinates of the mean location were (496 m, 332°). Fancy et al. (1988) observed a similar northwest bias and speculated that it was due to differences among the Clark 1866 ellipsoid that they used and the World Geodetic System 1984 ellipsoid used by Service Argos. We also used the Clark 1866 ellipsoid to reference site coordinates and, therefore, hypothesized that the bias we observed was due to differences between the 2 ellipsoids. Using National Geodetic Survey's NADCON4 program to calculate differences among ellipsoids in our study area, we found that differences averaged 69.8 m (SD = 0.2 m), almost entirely in the easterly direction. We rejected the hypothesis and concluded instead that differences in ellipsoids likely "masked" part of the longitudinal component of the bias. Polar coordinates of the actual bias were estimated to be (532 m, 325°), relative to the true location. Bias may have resulted from the relationship between θ_E and θ_S, and the particular distribution of θ_S in this study. Expected directions of errors ($\hat{\theta}_E$) were estimated as $\hat{\theta}_E = \theta_S$ (Fig. 5) and indicated that more errors were expected toward the northwest simply because more locations were achieved during satellite passes that peaked in the southeast.

Sampling Frequency

Sampling frequencies were calculated for 1,921 satellite passes where $P_H \geq 5°$ (Table 1). Using normal approximations to compare proportions, we tested 2 hypotheses. First, we rejected the null hypothesis that sampling frequencies were unaffected by terrain. For both M_S and L_S, sampling frequencies varied among valley, mid-slope, and mountain peak sites (M_S: $X^2 = 27.27$, 2 df, $P = 0.000$; L_S: $X^2 = 20.61$, 2 df, $P = 0.000$). A Tukey-type comparison of proportions indicated that M_S was greater at mid-slope than valley bottom sites ($q = 5.42$, $P < 0.001$), and M_S was greater at mountain peak than mid-slope sites ($q = 10.62$, $P < 0.001$); L_S was greater at mid-slope than valley bottom sites ($q = 10.15$, $P < 0.001$), but did not differ significantly among mid-slope and mountain peak sites ($q = 1.59$, $P > 0.20$). For valley bottom versus mountain peak sites, terrain reduced M_S and L_S by about 17% and 41%, respectively. Craighead and Craighead (1987) similarly reported lower location efficiency for PTTs in mountain valleys.

We also rejected the null hypothesis that sampling frequencies were

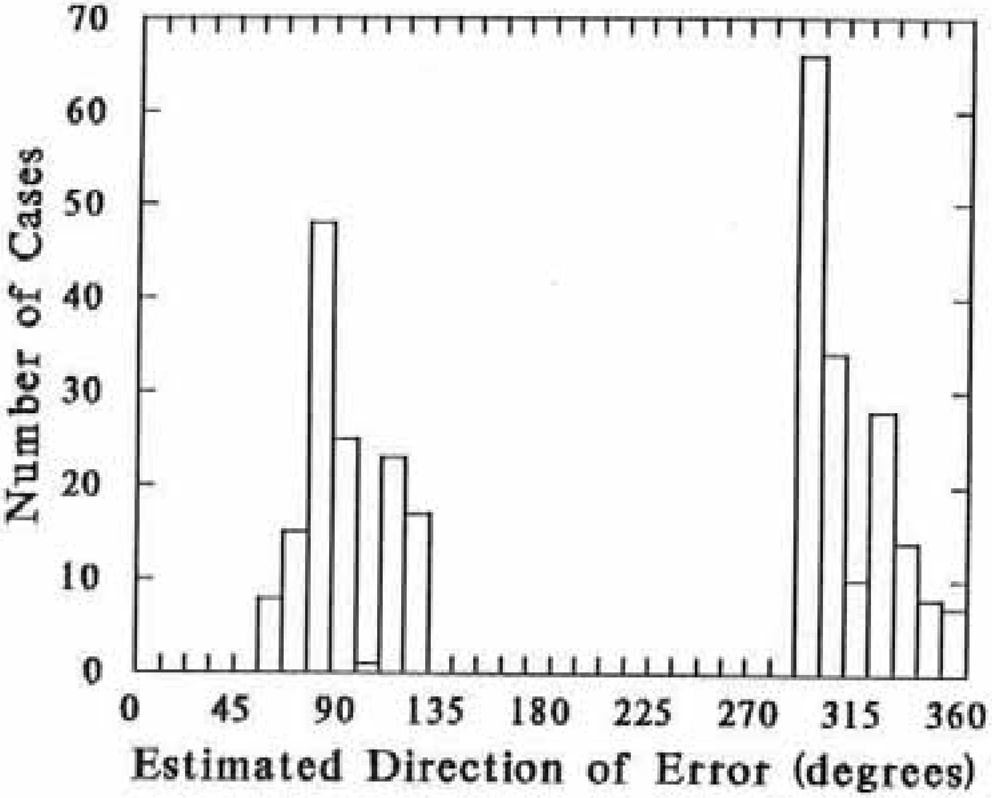

Fig. 5. Distribution of the expected direction (θ_E) of location errors, given the distribution of the directions of satellite passes (θ_S) and the relationship $\theta_E = \theta_S$.

Table 1. Sampling frequencies of sensor and location data for PTT 6160 at valley, mid-slope, and mountain peak sites, and on a bighorn ewe occupying a mid-slope winter range. S is the number of satellite passes "available" ($P_E \geq 5°$) to receive PTT transmissions, M_S is the proportion of passes where ≥1 message was received, and L_S is the proportion of passes in which locations were calculated.

Site	S	M_S	L_S
All Test Sites	454	0.914	0.524
Valley	129	0.822	0.357
Mid-slope	143	0.902	0.573
Peak	182	0.989	0.604
Adult Ewe	1,467	0.768	0.293

the same whether the PTT was deployed on the ground or on an animal. Sampling frequencies for a radio-collared bighorn ewe occupying a mid-slope winter range were compared with mid-slope sampling frequencies from pre-deployment tests (Table 1). When the PTT was deployed on the ewe, M_S declined about 15% and L_S declined about 49%. Differences were significant (M_S: $Z = 3.69$, $P = 0.000$; L_S: $Z = 6.86$, $P = 0.000$).

Sampling frequency is a major determinant of cost-effectiveness. Craighead and Craighead (1987) estimated that satellite telemetry cost about 15 times less than conventional VHF telemetry for tracking caribou (*Rangifer tarandus*), but observed that cost-effectiveness may vary with the number of collars purchased, number of locations made, and study area. Our results indicated that variations within and among study areas may be substantial and that animal use of high elevations may be overestimated due to effects of terrain on sampling frequency.

Error Mitigation

Error correction.—Much of the error in this study was attributed to differences between actual and assumed PTT elevations. We suggest such errors may be partially corrected using estimates of error coordinates ($\hat{r}_E$, $\hat{\Theta}_E$). Because errors tended to occur toward the satellite, Θ_E was estimated as:

$$\hat{\Theta}_E = \Theta_S. \tag{9}$$

As elevational error increases, r_E should increasingly become a quadratic function of P_M (French 1986, Fancy et al. 1988). Using polynomial regression, r_E was estimated as ($r^2 = 0.726$, $P = 0.000$):

$$\hat{r}_E = 2.642 - 0.093P_M + 0.002P_M^2. \tag{10}$$

This relationship should vary among studies depending upon actual elevational error. However, it is probably a good approximation for our study area and illustrates the proposed correction.

Given ($\hat{r}_E$, $\hat{\Theta}_E$), locations were recalculated. Errors for corrected locations were significantly less than for uncorrected locations (Fig. 4B) (Mann-Whitney $U_{304,304} = 81{,}933$, $P = 0.000$) and were unbiased, i.e. $(\mu_x, \mu_y) = (0, 0)$, (Hotelling's $T^2 = 1.99$, $P = 0.75$). The lognormal mean error of the corrected locations was 908 m. There still was no significant difference in accuracies among NLOC = 1 and NLOC = 3 locations (Mann-Whitney $U_{31,273} = 4{,}551$, $P = 0.49$). With 68% of corrected locations within 1,092 m of the true location, accuracy was significantly better than the 1,510 m expected for NLOC = 3 locations ($Z = 3.96$, $P = 0.000$). This suggested that given the correct elevation, performance for NLOC = 3 may be better than advertised by Service Argos. A Rayleigh test indicated corrected locations were distributed bimodally along an undirected axis of about 171° ± 33° ($z = 32.44$, $P < 0.001$), and that Θ_E continued to exhibit a significant, though more variable, relationship to Θ_S ($\Theta_D = 24° \pm 72°$, $z = 13.11$, $P < 0.001$).

We concluded that error correction improved the distribution and

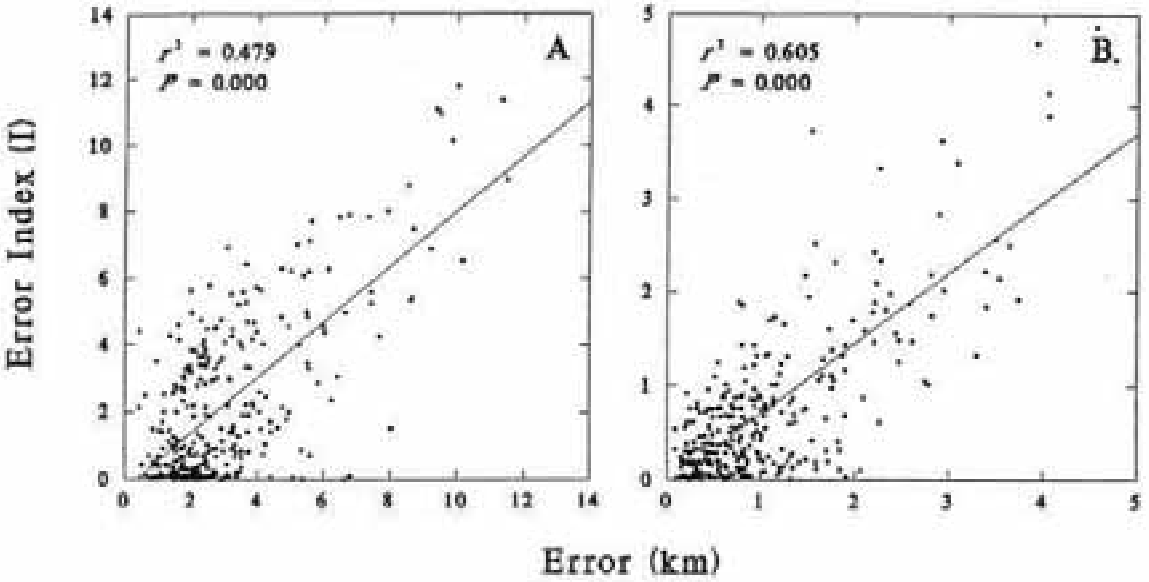

Fig. 6. Relationship of the error index (*I*) to observed error for (A) uncorrected locations, and (B) for locations corrected for elevational error.

precision of locations. It is potentially valuable for mitigating errors when elevation cannot be reasonably estimated in advance, although more universal models of the relationship between error, elevation, and satellite pass height will be required for the method to be broadly applicable. However, it remains preferable to specify the correct elevation prior to deployment.

<u>Error indexing</u>.—Error indices (*I*) (Fig. 1, eq 5) were calculated for 302 uncorrected and corrected locations. Regressions of *I* on error were significant (Fig. 6), suggesting that *I* was a useful index of both raw and residual error. To determine a threshold value for *I*, locations with the largest *I*-values were excluded first and lognormal means of remaining locations were calculated. The resulting relationship of lognormal mean error to sample size suggested that most benefits accrued when about 20–30% of the locations with the largest *I*-values were rejected (Fig. 7). When more than 80% of locations were rejected results became unpredictable. For this study, we used corrected locations and excluded about 25% of the locations ($I < 0.906$) (Fig. 4C). The lognormal mean error of corrected, indexed locations where $I < 0.906$ was 665 m, and was significantly less than for all corrected locations (Mann–Whitney $U_{304,226} = 41{,}106$, $P = 0.000$); 68% were within 830 m of the true location. However, the resulting estimate of the true location was slightly biased (Hotelling's $T^2 = 21.07$, $P = 0.000$), with the mean occurring at polar coordinates (147 m, 242°). We concluded that indexing provided an objective basis for rejecting, with a high probability, the most erroneous locations.

<u>Weighted utilization distributions</u>.—A bivariate normal distribution was used to model residual error following error correction and the

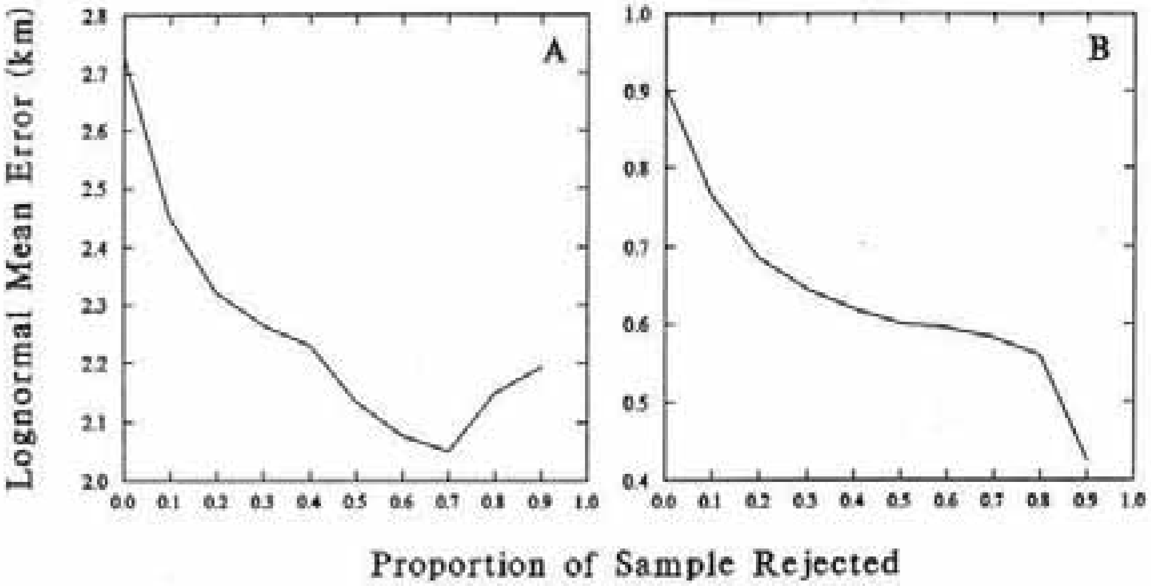

Fig. 7. Relationship among proportion of sample rejected and lognormal mean error, where locations with the largest error indices (I) were rejected first, for (A) uncorrected locations and (B) locations corrected for elevational error.

rejection of locations where $I < 0.906$. The model's probability density is (Batschelet 1981:269):

$$f(x,\ y) = (2\pi\sigma_x\sigma_y)^{-1}[1-(r_{x\cdot y})^2]^{-\frac{1}{2}}\exp[-\tfrac{1}{2}g(x,y)] \qquad (11)$$

where

$$g(x,y) = \frac{1}{1-(r_{x\cdot y})^2}\left(\frac{(x-\mu_x)^2}{\sigma_x^2} - 2r_{x\cdot y}\,\frac{(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y} + \frac{(y-\mu_y)^2}{\sigma_y^2}\right). \qquad (12)$$

Although bias existed following indexing, reasons for the bias were not apparent, nor was it clear that bias was an inherent characteristic of the residual error distribution. Also, the bias was small (147 m). Therefore, we assumed that $(\mu_x,\ \mu_y) = (0,\ 0)$ following correction and indexing. Other parameters were estimated as $\sigma_x = 701$ m, $\sigma_y = 457$ m, and $r_{x\cdot y} = 0.076$, where $r_{x\cdot y}$ is the correlation between σ_x and σ_y. The model was compared with the observed distribution of residual errors from the test data (Fig. 8). With data from the bighorn ewe, it was used to construct a WUD.

Animal Tracking.—During Nov. 1986–Dec. 1987, 395 locations were calculated for a PTT-collared ewe. Sampling frequency varied seasonally (Fig. 9), probably due to effects of terrain and loss of battery power over time. About 1 location per day was achieved when tracking began and the ewe occupied a low- to mid-elevation winter range. Sampling frequency

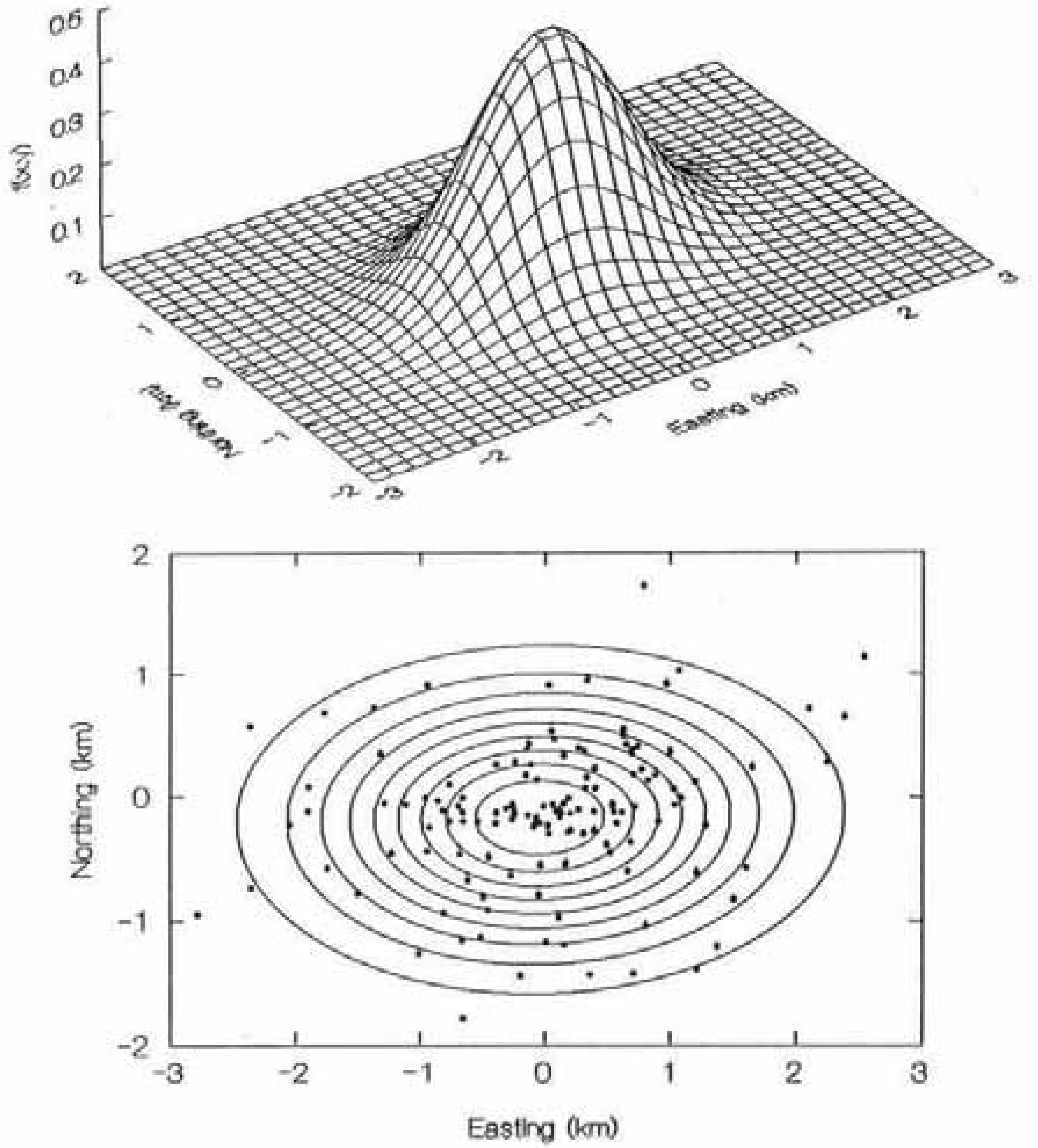

Fig. 8. A bivariate normal model of the distribution of residual error following error correction and rejection of the 25% of locations with the largest error indices (*I*). Both 3-dimensional (top) and 2-dimensional (bottom) views are shown. In the 2-dimensional image, ellipses represent probability isoclines ranging from 0.1 (smallest) to 0.9 (largest) in intervals of 0.1. Observed residual errors (following correction and indexing) from locations of a PTT placed at 23 known sites also are plotted.

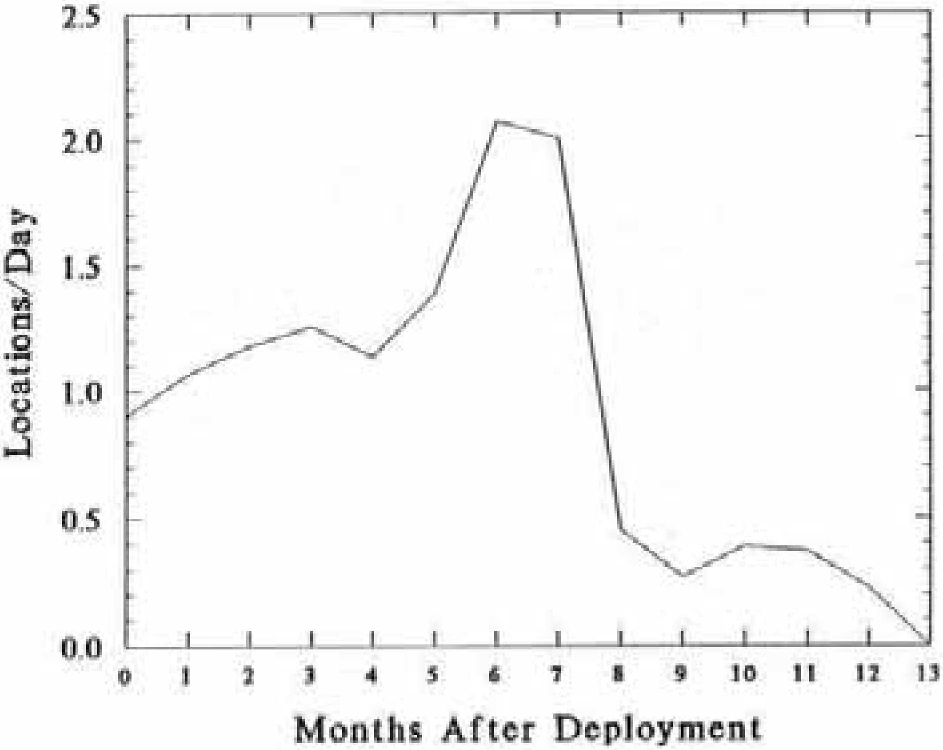

Fig. 9. Variation in sampling frequency as a function of elapsed time since deployment. The PTT was deployed 27 Nov. 1986 and was programmed to transmit 6 hours per day throughout the year.

increased to about 2 locations per day as the ewe moved to lambing and early summer ranges at higher elevations. Although the ewe remained at higher elevations during late summer and early fall, sampling frequency dropped to less than 0.5 locations per day after about 8 months, presumably due to battery failure. Transmissions ended about 13 months after deployment.

Error correction and indexing helped elucidate the ewe's seasonal movements. As expected, uncorrected locations were widely dispersed (Fig. 10A). Elevational error was evident in the clusters of locations east and west of the ewe's winter range, which was centered at UTM coordinates of about 305 km east and 5409 km north (UTM zone 12). After error correction (Fig. 10B), locations were centered approximately around the known winter range on the lower south slopes of Mt. Altyn, and around known spring and summer ranges in the Canyon Creek drainage. Error indexing eliminated a number of apparent outliers (Fig. 10C). It was encouraging that most outliers occurred to the east and west of the major concentrations of locations, as most errors were expected in the longitudinal direction.

The error indexing procedure was modified for analyses of the ewe's movements. As with the test data, a threshold value of *I* was selected so that 25% of the sample was rejected. However, indices were then

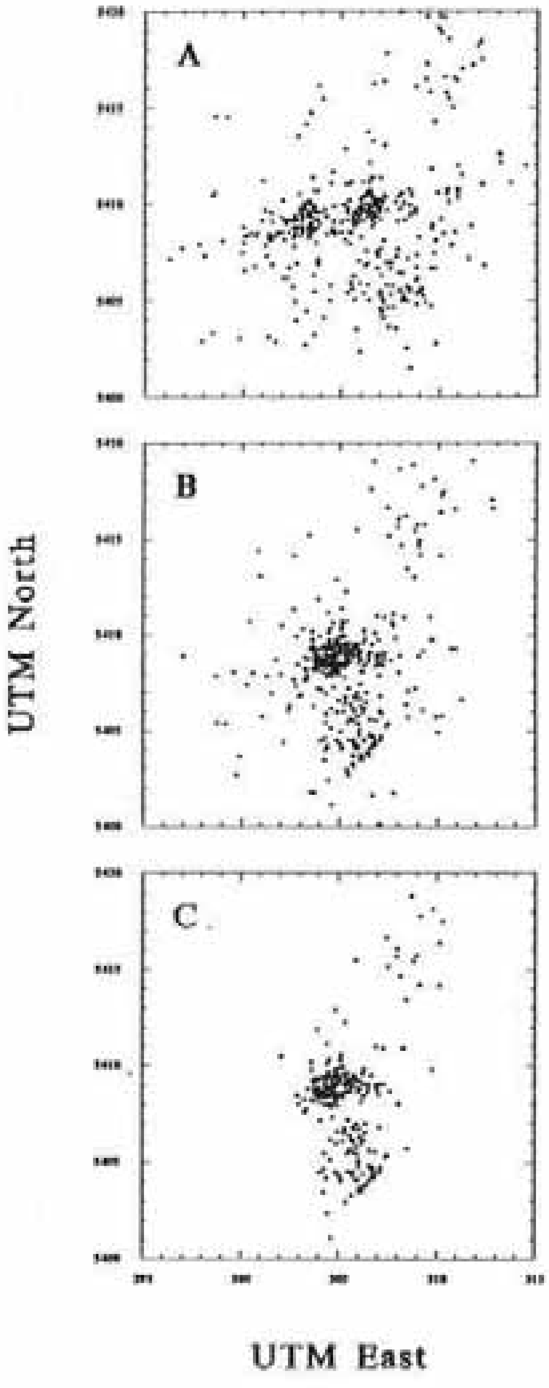

Fig. 10. Distribution of locations for a radio-collared ewe during Nov. 1986-Dec. 1987, showing (A) uncorrected locations, (B) locations corrected for elevational error, and (C) corrected locations with about 38% of the sample rejected based on iterative error indexing (see text).

recalculated for remaining data and additional locations were excluded using the same threshold value of *I*. This was repeated until indices for all locations were less than the threshold value. Three iterations were required and about 38% of the locations were rejected. An iterative approach was used because extreme errors and duplicate locations led to situations not encountered in the test data. Extreme errors (>50 km) occurred when the wrong solution for the location algorithm was selected (each location calculation has 2 possible solutions). Although such errors were correctly identified and excluded as outliers, in several instances smaller outliers (<13 km) occurred immediately before or after an extreme outlier, and in the same direction. The resulting sequence was interpreted by the indexing algorithm as a directed movement where ß approached 180°. Consequently, some obvious outliers were not rejected with only 1 iteration. In other instances, 2 locations were calculated from a single satellite pass. The 2 locations were never identical but often were similar, giving the false impression that a second, independent location had been achieved to corroborate the first.

Iterative indexing resolved these problems but altered the assumptions of the procedure. By using 3 iterations we implicitly assumed that >2 locations may be required to corroborate an apparent movement. This change had a substantive effect in only one instance. A movement of about 10 km occurred in late summer after the battery began to fail and sampling frequency was low. Following indexing and rejection of 25% of the sample, the movement was documented by only 2 relatively distant points which were both rejected after subsequent iterations. Evidence of the movement was lost from the final data set. We chose to accept this limitation for the purpose of describing core use areas within the ewe's home range, as rejection of the additional locations did not alter the outcome appreciably. In the future, the problem may be precluded by altering duty cycles to achieve more even sampling throughout the year, thereby reducing the likelihood that significant movements will be documented by only 1 or 2 locations. Alternatively, extreme outliers (>50 km) probably can be identified and rejected prior to indexing, hence only 1 iteration would be needed. Due to changes in the location algorithms in 1987, multiple locations are no longer calculated from a single satellite pass and should not affect error indexing of post-1987 data.

Finally, we calculated a WUD from the 243 locations that remained after iterative indexing. Core use areas occurred on Mt. Altyn, Mt. Allen, and Yellow Mtn. A WUD was then constructed using only those locations within the core areas (Fig. 11). Sequential locations not within a core area were identified as movements. A separate WUD was constructed for each movement and the "ridge line" of the WUD's statistical terrain was digitized to estimate the likely travel corridor. Approximately 4 corridors were identified. A composite of the core areas and travel corridors among areas was constructed (Fig. 12).

The resulting picture of bighorn movement patterns agreed well with visual observations: the ewe occupied the Mt. Altyn range most of the year, lambing took place toward the south end of the Mt. Allen range in the cliffs above Canyon Creek, and some use was observed on Yellow Mtn. in summer. Visual observations indicated greater use near the head of Canyon Creek (Mt. Allen range) than was evident in the WUD (Fig. 12).

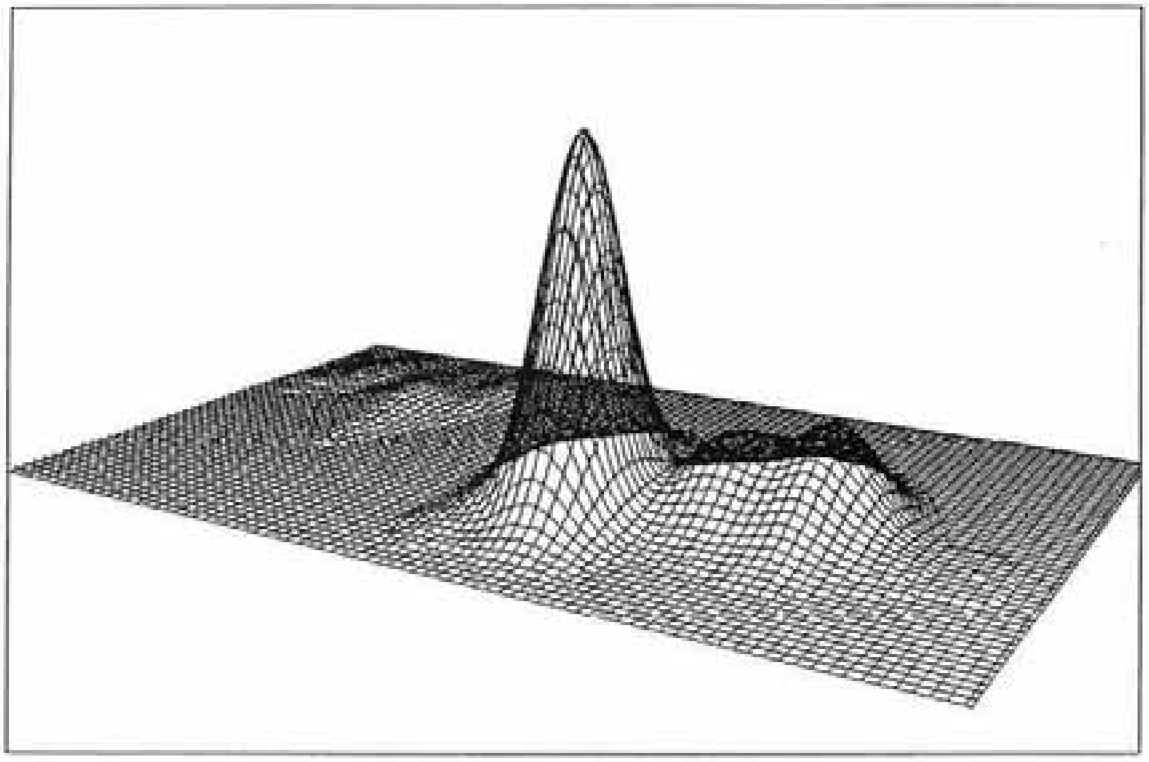

Fig. 11. Weighted utilization distribution (WUD) for core ranges used by a radio-collared ewe during Nov. 1986-Dec. 1987 (250 m UTM grid). The Mt. Altyn winter range is the highest peak, the Mt. Allen lambing and summer ranges are to the right, and summer ranges on Yellow Mtn. are to the left.

However, use of upper Canyon Creek was observed primarily in late summer when sampling frequency was low, presumably due to battery failure. Modification of the PTT's duty cycle to achieve more even sampling throughout the year would likely have resulted in a better picture of late-summer use. Movement corridors between Mt. Allen and Mt. Altyn were confirmed by visual obsetvations and tracks, as was ≈3 km of the corridor leading onto the Yellow Mtn. range. Travel routes identified between Mt. Altyn and Yellow Mtn. were suspected due to the terrain and game trails in those areas, but were not confirmed by sightings. The Windy Creek corridor between Mt. Allen and Yellow Mtn. was unexpected: escape cover is generally poor, the animal had to swim Sherburne Reservoir, and the route is not substantially shorter than alternate routes with good escape cover. Most movements occurred within 1-2 day periods and it is unlikely that travel corridors would have been documented using VHF telemetry.

CONCLUSIONS

Earlier studies (Craighead and Craighead 1987, Fancy et al. 1988) found that satellite telemetry offers important economic and logistic advantages for wildlife research. We concur, particularly if sources of error are recognized and mitigation measures are used. In Montana's East

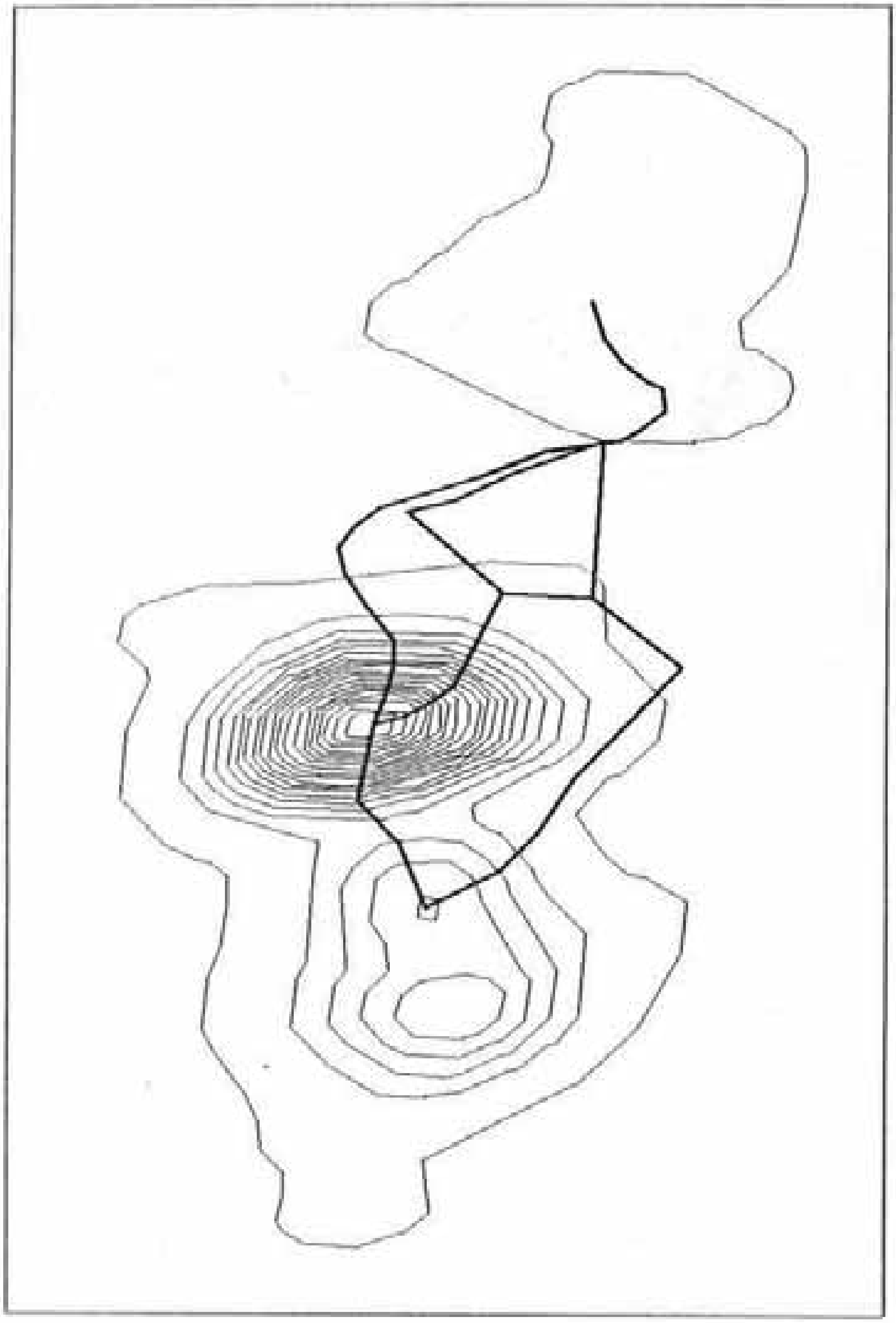

Fig. 12. Core bighorn ranges (thin lines) and their associated travel corridors (dark-lines) in the Many Glacier area, as identified from weighted utilization distributions (WUDs) calculated from 243 locations of a radio-collared ewe (see text). The Mt. Allen range is at the bottom, the Mt. Altyn range is represented by the high concentration in the center, and the Yellow Mtn. range is in the upper right.

Front region, inclement weather and rugged terrain have traditionally confounded telemetry. The 395 locations achieved during a 1-year period for a PTT-collared ewe demonstrated an unprecedented capability to document seasonal movements. Terrain remains a confounding factor, as effects of elevation and topography may greatly impact accuracy and sampling frequency. However, sampling frequency was still >1 location per day and effects on accuracy can be either precluded or mitigated by specifying mean elevation in advance or via corrections. By using WUDs to weight habitat component layers within a GIS environment, we suggest that satellite telemetry data can be used to develop habitat use models and to model the probability of movement among habitat patches and local populations. Coupled with a GIS, such models may be applied over broad landscapes and offer a powerful tool to test and optimize conservation strategies.

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COMPARISON OF HELICOPTER-SUPPORTED CHEMICAL IMMOBILIZATION AND SKID-MOUNTED PROJECTILE NET CAPTURE OF DALL SHEEP IN ALASKA

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Abstract: Helicopter-supported darting to capture Dall sheep in Alaska has frequently failed. Because of serious wounding by drug delivery systems, unstandardized drug doses, long induction times in hazardous terrain, and stressful chases, reported mortalities associated with Dall sheep capture in Alaska have averaged 22%. Physical capture through use of projectile nets appears more promising. We experimented with a skid-mounted projectile net for capture of Dall sheep and found it to have advantages over helicopter-supported chemical immobilization. Fiscal costs appear to be somewhat lower and benefits to sheep considerably greater. We think this system also has human safety advantages compared with shoulder-fired projectile nets.

The need to capture mountain sheep for biological studies has produced a variety of capture methods. These methods are divided into physical capture and chemical immobilization. Dall sheep (*Ovis dalli*) are relatively small, not dangerous, and well suited to physical capture. Physical capture has been especially successful for Dall sheep at mineral licks (Heimer et al. 1980) and bighorn sheep (*Ovis canadensis*) at bait stations (Schmidt 1976). Similarly, use of drive nets for capture of mountain sheep has been successful (Kock et al. 1987). While these methods have been successful, they require concentrations of sheep and extensive logistic and personnel support. Also, these physical methods are not selective.

When selectivity is important in remote areas, chemical immobilization has been preferred. However, chemical immobilization of Dall sheep in Alaska has produced an unacceptably high (13 of 60 sheep darted) mortality rate (Heimer et al. 1980, Singer et al. 1984, this study). Drug delivery systems frequently cause severe wounds in Dall sheep (Heimer et al. 1980), and consistently effective dosages of the best drugs have not been determined. Incompletely immobilized Dall sheep have been common. These sheep are typically more difficult to restrain and handle than sheep not under the influence of immobilizing drugs. Finally, the ability of darted sheep to move into dangerous terrain during drug induction increases risks to both sheep and biologists.

Net-gun capture of individual sheep from helicopters has been developed to overcome these deficiencies (Jessup et al. 1988) and has been effective. However, human safety hazards have been evident in shoulder-fired net-gun operations. The record of accidents involving net guns is not enviable (Clutton-Brock 1986). In response to this poor record, a skid-mounted net gun was developed in New Zealand. This apparatus may provide the benefits of net-gun capture without many of its attendant risks.

We experimented with this net-gun system in capturing Dall sheep in the Alaska and Brooks Ranges of Alaska in both summer and winter and compared its effectiveness with chemical immobilization in both areas. The purpose of this paper is to report on the efficacy of aerial darting and net-capture systems.

METHODS

A Hughes 500D helicopter equipped with the New Zealand-designed projectile net mounted on the left skid was used to capture 10 Dall sheep in April 1988. These sheep were captured at approximately 900-1,500 m elevation with ambient temperatures slightly below freezing in the Alaska Range. Once captured, sheep were blindfolded, an open airway was established, an intramuscular injection of acepromazine maleate (0.2-0.7 cc depending on size of sheep) was administered, and all 4 legs were bound together using a hobble of 2.5-cm nylon strapping secured with lightweight cam-jaw buckles. Sheep were then bled, radio-collared, and released. Typical handling time was 15 min. Flight time, other expenses, and sheep mortalities were recorded.

Sixteen sheep were darted from a Hughes 500D helicopter, 5 during June 1988 in the Alaska Range and 11 during August 1988 in the Brooks Range. Drugs were administered using a 5-cc dart fired from a standard Palmer Cap-chur gun with brown charges. Darts contained 4.5 cc etorphine hydrochloride and 0.5 cc of acepromazine maleate. These sheep were handled as described above even though they had been drugged with M99. Effects of M99 were reversed with intravenous and intramuscular injections of M50-50. Costs and sheep mortalities were recorded.

In August 1989, 12 Brooks Range sheep were captured using the skid-mounted projectile net and the same pilot and same procedures as used in the Alaska Range. Finally, 4 mature rams were captured using the skid-mounted projectile net in April 1990. We considered this a test of the ability to capture specific individuals using this technique. The same pilot and aircraft were used as in the previous trials, and sheep were handled by the same biologist using the same procedures as in the April 1988 capture effort.

RESULTS

Costs and mortalities associated with the skid-mounted projectile net were lower than those attending helicopter-supported chemical immobilization (Table 1).

Table 1. Costs of sheep capture using conventional chemical immobilization and skid-mounted projectile nets.

	Darting	Projectile net
Number of sheep caught	17	26
Mortalities	3	0
Drug costs	$86/sheep	$0.01/sheep
Helicopter cost[a]	$404/sheep	$370.00/sheep
Total capture costs	$490/sheep	$370.01/sheep

[a] Exclusive of fixed-wing spotter aircraft which averaged $150 per sheep captured when used in both operations.

Author's Note

During October 1990, the skid-mounted projectile net was used in the Brooks Range. The net was thrown 33 times; 19 sheep were captured; and the cost per sheep was $278. One capture-related mortality occurred.

DISCUSSION

A major cost-saving associated with the projectile net resulted from practically eliminating drug costs ($86/sheep). Sheep caught with the net were given an intramuscular injection of acepromazine at a cost of about 1 cent per sheep. Other cost-savings were realized because once a sheep was netted it was handled almost immediately. There was no necessity to pay for helicopter time during drug induction of ataxia. No comparisons between flight times in chasing sheep and maneuvering the helicopter have been made, but we think flight time required to establish capture position was less with the skid-mounted net.

Pilots familiar with a variety of helicopter-supported capture systems prefer the skid-mounted net to darting (C. Soloy and L. Larive, pers. commun.). They prefer having the capture target, as well as obstacles, in front of the helicopter, as opposed to positioning a biologist to deliver a dart to a target they cannot see. These pilots think being able to see everything allows them to fly more safely. Soloy and Larive also prefer having control of the capture apparatus and the aircraft even though they must assume responsibility for failed capture attempts.

Much of our cost-saving resulted from procurement, development, and maintenance of the capture apparatus by the helicopter charter operator. The helicopter operator estimated his company's investment in this capture system at $10,000 (L. Larive, Soloy Helicopters, Wasilla, AK, pers. commun.).

Mortality was significantly less (no mortalities in 26 captures) using the skid-mounted projectile net (Table 1). In our sample, mortality associated with darting was 18% (Table 1). This was lower than the reported average of 22% for darting Dall sheep in Alaska (13 of 60), but we believe 18% is still unacceptably high. The higher mortality associated with darting probably results from wounds caused by the drug delivery and from the drug action. We suggest the use of M99 for capture of Dall sheep be discontinued.

The skid-mounted projectile net offers a viable alternative. If available, it is economically advantageous, and the low mortality associated with capture has been encouraging. Further development in the technology of skid-mounted nets for sheep capture will further reduce costs. This capture system works best for animals that run predictably and steadily in front of a pursuing helicopter. The apparatus is designed to throw the net so it encounters the least air resistance ("edgewise" instead of "flat"). When the helicopter matches the speed of an animal running in a predictable straight line, throwing the net ahead of the animal so it runs "into" the net has a high probability of success. Typical success for caribou netting has been 75-80% (C. Soloy, pers. commun.).

However, Dall sheep do not run predictably in front of a helicopter. They dodge, stop, and run back under the aircraft just as it approaches the net-launching position. Consequently, misses are common, with the net often overshooting the sheep. In our experience, capture success was about 20-25%. Increased efficiency in netting would reduce capture expense considerably. We suggest that putting a skirt on the trailing edge of the net may increase capture efficiency. Adding skirts to rocket-propelled projectile nets on the ground has increased efficiency of that technique for quick and elusive species. We think this capture technique is clearly superior to darting Dall sheep and that its promise is yet to be fully realized.

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DESIGN OF AERIAL SURVEYS FOR DALL SHEEP IN THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA

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Abstract: Two problems in estimating abundance of Dall sheep from aerial surveys in the Arctic National Wildlife Refuge were considered:
1) allocating survey effort to attain a specified precision, and
2) estimating the bias in detection visibility of animals. Bootstrap computer simulations (resampling with replacement) were used to appraise variation of estimated sheep density from sample data for different sampling schemes. Dall sheep survey data from prior aerial surveys in the Hulahula drainage and from a 1989 sample aerial survey of the Atigun-Sagavanirktok (Atigun-Sag) drainage were the basis for simulations. The bootstrap simulations indicated that the desired precision of 12.5% for the coefficient of variation of the population estimate could be expected by sampling about 8-10 randomly selected drainages (of sizes comparable to the Hulahula and Atigun-Sag study areas) and surveying approximately 50% of each. Two airplanes were used to independently survey subunits of the Atigun-Sag study area. We estimated the probability that a group of sheep will be detected during a survey by using groups detected during the other survey as test cases. The probability of detection was estimated by logistic regression using size of group as an explanatory variable. Procedures to adjust population estimates for visibility bias are illustrated using data from the Atigun-Sag drainage.

The Arctic National Wildlife Refuge (ANWR) in northeast Alaska was expanded in 1980 from 36,000 km^2 to about 76,900 km^2 (Fig. 1). The central purpose for the refuge is to conserve a variety of arctic fish and wildlife species, including Dall sheep (*Ovis dalli dalli*). About 34,000 km^2 (44%) of the Refuge is Dall sheep range, extending over a mountainous area 360 km (225 mi) long, and up to 177 km (110 mi) wide. Although the ANWR is 1 of Alaska's finest Dall sheep habitats and supports a growing portion of the state sheep harvest (16%), a complete inventory of Refuge sheep populations has not been achieved.

Prior to 1988, the abundance of Dall sheep in the ANWR has been measured using fixed-wing aerial "censuses" to obtain direct counts (Smith

1979, Heimer 1983, Garrett 1987). Sheep on portions of the refuge were counted in July and August when snow cover was minimal and visibility was believed to be most favorable. Because of the extensive sheep range within the Refuge and the brief optimal census period, limited portions of the Refuge could be surveyed in a year under conventional funding levels. In the 1970's, 3 years were required to obtain an initial census of most of the sheep range (14,000 km^2) within the original Refuge (Smith 1979). While these surveys provided valuable information on relative abundance and distribution of sheep, they did not provide a means to monitor population status, or to develop population estimates.

With enlargement of the Refuge in 1980, and subsequent increases in hunting, there is a need to develop alternative methods to estimate the abundance of Dall sheep in the ANWR and monitor changes. We are presenting improved sampling designs for aerial surveys which yield: 1) more efficient data collection and analysis, and 2) estimates of parameters with known bias and precision for Dall sheep abundance in the Refuge.

We assume that a 2-stage cluster sampling plan (Cochran 1977) will be recommended. Sampling effort to achieve a desired precision for sheep density (sheep/km^2) is then a function of: 1) the number of primary units (each approximately the size of the Hulahula or the Atigun-Sag study areas) which are sampled from the ANWR; 2) the number of subunits to be sampled from each primary unit; 3) the variance of sheep density between and within the primary units; and 4) the variance due to estimation of visibility bias. It may be possible to further increase precision by stratification of the primary units. However, only stratification of subunits is considered here.

STUDY AREAS

Historic data were used from 4 Dall sheep aerial surveys conducted during mid-July to early August 1976, 1979, 1982, and 1986 in the Hulahula River drainage (Fig. 2, Smith 1979, Heimer 1983, Garrett 1987). Additional data were analyzed from a June 1989 aerial survey of a subset of the Atigun-Sag River drainage (Fig. 3). Summerfield (1974) and Mauer (1990) described physical conditions of the study areas. We analyzed both data sets to develop recommendations concerning design and analysis of aerial surveys for Dall sheep in the entire ANWR.

METHODS

Fourteen subunits with areas from 93 to 150 km^2 were identified in the Hulahula drainage (Table 1, Fig. 2). Two subunits (9 and 12) were not surveyed every year. Data from the 4 Hulahula surveys were compiled by subunit from original field maps and data forms.

Twenty-two subunits with areas from 18-78 km^2 were identified in the Atigun-Sag drainage (Table 2, Fig. 3). The subunits were classified into high, medium, and low sheep-density strata, based on prior knowledge and observed sheep densities during a preliminary aerial survey with about 0.6 minutes per km^2 by a pilot/observer crew in a fixed-wing Piper Super Cub

Table 1. Numbers of Dall sheep observed during the 1976-1986 aerial surveys of the Hulahula region, Arctic National Wildlife Refuge, Alaska, summarized by subunit.

Subunit ID	Area (km^2)	Number of Sheep Counted				
		1976	1979	1982	1986	Total
1	113.2	35	38	43	86	202
2	130.0	58	49	22	157	286
3	114.4	8	32	57	32	111
4	118.4	33	60	64	104	212
5	93.5	168	121	258	232	679
6	107.7	390	814	583	382	2074
7	107.4	339	201	254	382	1176
8	147.5	103	112	222	363	800
9	101.2	ND[1]	ND[1]	59	31	ID[2]
10	149.9	47	23	71	223	364
11	126.5	192	6	190	372	760
12	130.8	122	ND	60	86	ID[2]
13	140.7	104	72	186	270	632
14	99.1	121	83	125	71	400

[1] No Data; subunit not measured during the particular year.

[2] Insufficient Data; subunits not summed due to missing data.

PA-18. Following stratification, 2 pilot/observer crews in the fixed-wing aircraft independently surveyed a random sample of subunits within the high and medium density strata. One crew conducted an "intensive" survey using about 2.5 min/km^2, while the second conducted a "regular" survey using about 1 min/km^2. In general, the regular survey was conducted at a higher altitude with less circling. Both surveys for each subunit used in analyses were completed within 5 hours of each other. Additional regular surveys were conducted by 1 crew on a larger stratified random sample of subunits from all 3 strata.

Data collected during each survey included the number of groups of sheep detected, number of sheep/group (excluding lambs), locations of groups on topographic maps, composition (mixed, nursery, or rams), number of large males present, and other explanatory variables believed to influence detectability (e.g., measures of topographic relief). Groups were defined as distinct based on location, and sex and age compositions. Immediately after both surveys were completed the pilot/observer teams reviewed observations to determine: 1) groups of sheep detected by 1 team and missed by the other team, and 2) groups detected by both teams. In many cases, groups originally recorded and marked on maps were pooled to account for movement, aggregation, and segregation between surveys based on deductive judgement of the survey crews.

Table 2. Numbers of Dall sheep observed on intensive and regular surveys in the Atigun-Sag area, Arctic National Wildlife Refuge, Alaska, 1989.

Count Block	Stratum[1]	Total Observed Sheep Intensive	Total Observed Sheep Regular
1	High	379	372
3	High		96
13	High	56	54
21	High	56	46
2	Medium		124
5	Medium	114	63
6	Medium		67
8	Medium	87	86
9	Medium	64	51
16	Medium		29
20[2]	Medium	60	29
7	Low		30
10	Low		12
11	Low		8
14	Low		0
17	Low		17

[1] Four additional low-density stratum areas were not surveyed.

[2] Not included in the estimation of visibility bias due to the large time difference between regular and intensive surveys.

Statistical Methods

Simulation methods for estimation of variation between and within drainages.--We simulated the sampling of a large number of drainages with a variable number of subunits per drainage by repeatedly subsampling with replacement from the data i.e., used the bootstrapping procedure (Efron 1982, McDonald et al. 1990). The number of sheep observed per subunit was simulated without correction for visibility bias (Tables 1, 2) under the assumption that variance of the uncorrected counts is approximately equal to variance of counts corrected for bias.

The coefficient of variation (CV) of the density estimate, equal to the standard error of the density divided by the density, was used as a precision criterion. We selected a CV of 12.5%, which corresponds to bounds on a 95% confidence interval of approximately ±25% precision. Graphing the CV plotted against n (number of subunits/primary unit) for various k (number of primary units), we identified the combinations of k and n to be recommended during an aerial survey of ANWR.

Methods for adjusting visibility bias: logistic regression.--The probability that a given group of sheep will be missed during an aerial survey is defined as the *visibility bias* of the group during the survey. Given estimates of the complement (i.e., probability of detecting a group), sample counts may be adjusted for groups missed (Samuel et al. 1987).

An objective of the Atigun-Sag study was to estimate the visibility bias of groups of sheep during regular aerial surveys. The less intense regular aerial surveys might then be conducted on a large sample of subunits and the counts of groups adjusted for groups missed. Given n_1 groups of size 1, n_2 groups of size 2, n_3 groups of size 3, etc. which are detected during the regular survey in a given area, the adjusted number of sheep is

$$T = (\frac{n_1}{p_1} \times 1) + (\frac{n_2}{p_2} \times 2) + (\frac{n_3}{p_3} \times 3) + (\ldots.) \qquad \textbf{(1)}$$

where p_i is the probability of detecting a group of size *i*.

We identified sheep groups seen during the intensive aerial survey as a test set of sheep groups known present in a given subunit of the Atigun-Sag area. These groups were then either detected or missed during the regular survey of the subunit. We assumed that groups sighted during the intensive survey were a random sample of groups present in the study region. No adjustment was made for counting errors (i.e. we assumed that counts of sheep in groups were correct). We also assumed that movement of sheep between subunits during the 2 surveys was detected by the observers or had negligible effect on the estimates.

The visibility bias of sheep groups during the regular aerial surveys within each density stratum was then estimated using a logistic regression model which is a function of measurable explanatory variables (e.g., Neter et al. 1989, Samuel et al. 1987). The candidate explanatory variables included number of sheep in a group during the intensive survey, intensity of the survey (minutes/km^2 spent surveying the subunit), subunit stratum (medium or high), group composition (mixed, nursery, or rams), geology type of substrate and five measures of topographic relief (McDonald et al. 1990). The fit of a model was evaluated by the likelihood ratio test and goodness-of-fit statistics (SAS 1988). Results of the logistic regressions for the medium density stratum were assumed to apply to counts in the low density stratum because no intensive surveys were conducted in the low density stratum.

Methods for adjusting visibility bias: double sampling.--A second technique for adjusting for visibility bias is *double sampling* (Eberhardt and Simmons 1987, Gasaway et al. 1986) in which the quick and less expensive "regular" aerial survey is calibrated by the more accurate, but more expensive "intensive" aerial survey. A ratio of counts from these 2 surveys is constructed from a "small" sample where both are conducted. The ratio is then used to adjust the total number of sheep estimated from a "large" sample where the regular survey is conducted.

Double sampling was used to adjust the estimated sheep abundance from regular surveys in the Atigun-Sag region of the ANWR, June 1989, under the assumptions that no groups are missed during intensive surveys and counting errors are negligible. For subunits where both surveys were conducted, the ratio of the number of sheep seen during the intensive survey (y_i) to the number of sheep seen during the regular survey (x_i), totalled over all sheep groups is

$$R = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} \tag{2}$$

This ratio provides a calibration term with which to adjust the count of sheep detected during regular surveys to the estimated number that would have been detected if the intensive survey were conducted on all sampled subunits. The double sampling procedure was evaluated within each stratum of the Atigun-Sag study area and for the entire study area ignoring stratum boundaries.

RESULTS

Simulations Based on the Hulahula Drainage

Using the bootstrap procedure for resampling subunits from Table 1, the coefficient of variation of the estimated density of sheep was simulated. We considered various combinations of the number of primary units (drainages) to be randomly sampled with the requirement that an equal number of subunits (count blocks) be subsampled from each primary unit. Results of 2 of these simulations (1979, 1982) are plotted in Figs. 4-5, respectively. Based on Fig. 5, we expect that the desired coefficient of variation of 12.5% can be achieved by random sampling about 8 primary units and subsampling about 8-10 subunits from each primary unit. All simulations conducted on the surveys of the Hulahula drainage yielded approximately the same results with the exception of those for 1979 data (Fig. 4). Based on the variation observed in 1979, a larger sampling effort of about 15 primary units and 10 subunits per primary unit would be required to meet the stated goal for precision.

Simulations Based on the Atigun-Sag Drainage

For simple random sampling of the data (Table 2), we expect that the desired precision of CV = 12.5% will be achieved with about 15 primary units and about 6 subunits each (Fig. 6). However, the same sampling effort in stratified random sampling (8-10 primary units with 3 subunits from each of 3 strata) is expected to yield estimates with approximately 12.5% CV (Fig. 7).

Estimation of Dall Sheep Abundance for the Atigun-Sag Drainages

The numbers of sheep counted during regular surveys (uncorrected for visibility bias) ranged from 48-99% of the numbers counted during intensive surveys on units where both were conducted. Correlation analyses revealed that counts from the 2 surveys had correlation coefficients of $r = 0.99$ ($P < 0.02$) for subunits in the high density stratum and $r = 0.54$ ($P = 0.64$) for subunits in the medium density stratum.

The number of sheep in a group was the lone significant explanatory variable in the logistic regressions ($P = 0.02$, medium density stratum; $P = 0.03$, high density stratum). In each stratum, the model selected for estimating the probability of detecting a given group of sheep during the regular surveys was

$$p = \frac{e^{(my)}}{1+e^{(my)}} \tag{3}$$

where m is the regression coefficient, and y is the number of sheep in the group. For example, the probability of detecting a group of size y during the regular surveys in the medium density stratum is given in equation (4) and is plotted in Fig. 8.

$$p = \frac{e^{(0.1504)y}}{1 + e^{(0.1504)y}} \tag{4}$$

The number of groups of size y detected during a regular survey, n_y, was adjusted to n_y / p_y to account for groups of size y which were missed by the regular survey. This adjustment for visibility bias is tedious and no formula is available for estimating the standard error of the estimated total sheep. Because of this problem a jackknife procedure was used within each stratum to estimate the standard error (Krebs 1989, McDonald et al. 1990). The jackknifed pseudovalues within a stratum were computed by: 1) dropping 1 subunit at-a-time from a stratum; 2) fitting the logistic regression model (3) to the remaining data; 3) adjusting the counts of sheep in groups detected during regular survey flights of other subunits in the stratum; and 4) expanding the adjusted counts to the entire stratum. The mean and standard error of the pseudovalues were then computed.

Estimates of total sheep for the high, medium and low density strata were 762 (SE = 234.7), 632 (SE = 28.2), and 198 (SE = 23.5) sheep, respectively. Summing across the 3 strata, the estimate of total sheep in the Atigun-Sag study area, June 1989, was 1592 (SE = 237.6).

Using the double sampling approach, the ratio of sheep sighted in the intensive surveys to the sheep sighted in the regular surveys was 1.325 in the medium density stratum and 1.04 in the high density stratum. We used the ratio 1.325 to make adjustments in the low density stratum. Applying these ratios to the regular surveys, we obtained estimates of 591 (SE = 8.0), 595 (SE = 85.0), and 178 (SE = 53.2) for the high, medium, and low density strata, respectively. Summing across the 3 strata, the estimate of total sheep in the Atigun-Sag study area, June 1989, was 1364 (SE = 100.8).

DISCUSSION AND RECOMMENDATIONS

Adjustments for Visibility Bias

Groups of sheep detected during the intensive surveys were used as test cases for estimating probability of detection during regular surveys. The major problem was that some groups were pooled while the pilot/observer crews were judging which groups detected during an intensive survey were also detected (or missed) during a regular survey. We believe there was a tendency for the pilot/observer of the regular survey to judge that they had also seen these pooled groups when in fact they may have been detecting groups missed during the intensive survey. Also, there was a tendency of the regular survey crew to judge that small groups had moved and were detected in both surveys. The effect of these biases is to overestimate the probability of detection of groups of sheep during the regular survey and underestimate the total abundance of sheep. We therefore believe that the estimate of 1592 Dall sheep (s.e. = 238) for the Atigun-Sag study region, June 1989, is conservative.

While the population estimate (1364 sheep) based on double sampling is still lower, confidence intervals for the 2 estimates overlap. However, we are more confident in the first approach because we believe that 1592 sheep is an underestimate, and it is larger than the corresponding estimate from the double sampling approach. In effect, we believe that a number of Dall sheep were missed during the intensive survey.

Factors Influencing the Probability of Detection

Among several variables tested, only group size was significantly related to probability of detection. Other tested variables may not have been significant because of measurement error or our inability to measure ecological and physical reality. In particular, we expected topographic relief to be related.

Sampling Strategy

Simulations of stratified random sampling of subunits from the Atigun-Sag study region resulted in smaller coefficients of variation of estimated sheep density relative to simple random sampling of subunits from either the Hulahula or the Atigun-Sag study regions. Thus, we were able to attain the desired precision with a smaller sampling effort because densities of sheep were more homogeneous over subunits within strata. We attribute the ability to define strata with more homogeneous distributions to seasonality; the Atigun-Sag region was surveyed in June while the Hulahula region was surveyed in July-August. Regions of "high", "medium", and "low" densities were relatively easy to delineate during the June 1989 study. We recommend that surveys be conducted in early summer using a stratified random sampling procedure within major drainages.

Simulations from the Hulahula survey indicate that precision of CV = 12.5% for sheep density in ANWR can be expected in many years by random sampling of 8-10 subunits in about 8 randomly selected primary units. Simulations of the 1989 Atigun-Sag data indicate that about 9 primary units would be needed with 8-10 subunits each to achieve a CV of 12.5% for both simple random and stratified random sampling of subunits.

Two factors tend to increase the recommended sample sizes: 1) there was higher variation in the 1979 aerial survey of the Hulahula drainage and the desired precision could only be obtained for the highest sampling effort simulated, and 2) the simulations did not include the variation due to adjusting for visibility bias. On the other hand, 2 factors tend to decrease the recommended sample sizes: 1) 27 primary units have been tentatively identified in ANWR and a sample of 8-10 primary units will yield a finite population correction factor which will reduce the CV by about 15% (e.g., (0.85)12.5% CV = 10.6% CV), and 2) stratification of primary units may further reduce variation.

It is impossible to precisely predict the required sampling effort in a future aerial survey of ANWR because data are available from only two drainages and a small number of years. Never-the-less, for a refuge-wide survey of ANWR we recommend that: 1) the refuge be divided into major drainages (primary units) of sizes comparable to the Hulahula and Atigun-Sag study areas; 2) the primary units be stratified into "high", "medium", and "low" sheep density areas based on judgement and prior knowledge; 3) 8-10 primary units be randomly selected in a stratified random design (e.g., 4 units from the high density stratum, 3 from medium density stratum, and 2 from the low density stratum); 4) divide each selected primary unit into subunits which can be surveyed in relatively short periods ($\leq$1.5 hours) when flying at about 1 minute/km^2; 5) pre-stratify all subunits in a given primary unit based on prior knowledge and a preliminary "stratification" survey (e.g., flying at about 0.6 minute/km^2) immediately before the formal survey(s); 6) randomly select 2-4 subunits from each stratum identified for formal survey(s) (e.g., 4 subunits from the high density subunits, 3 from medium density subunits, and 2 from the low density subunits); 7) conduct "regular" surveys in each subunit identified in 6); 8) also, conduct "intensive" surveys on approximately one-third of the subunits identified in 6); and 9) develop models for correction of visibility bias in regular surveys using logistic regression of groups detected (or missed) in the intensive survey on explanatory variables. There are no guarantees associated with recommendations of this nature. We anticipate that refuge-wide estimates will be obtained with CV $\leq$12.5 % based on this design and sampling effort.

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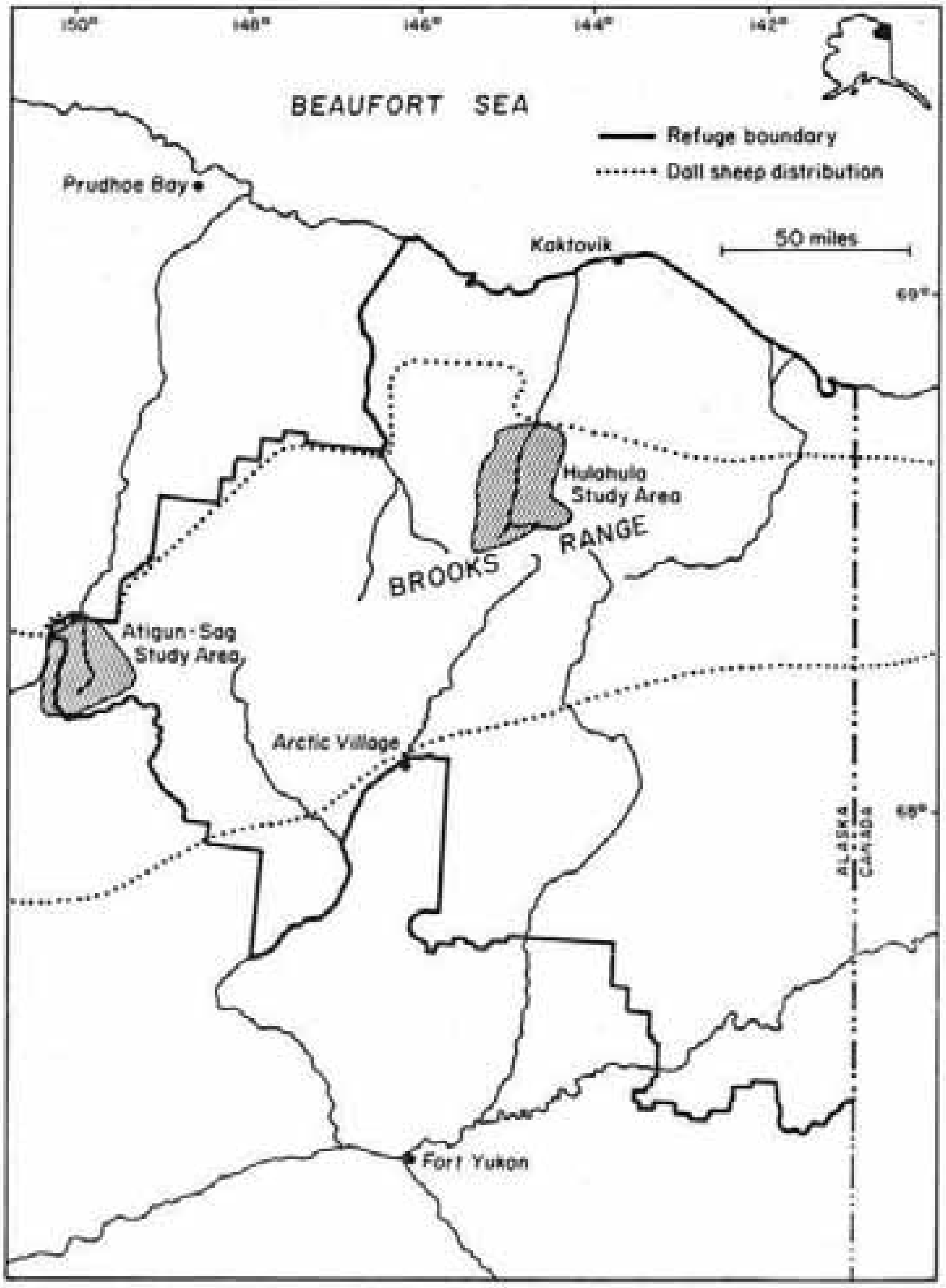

Fig. 1. Locations of 2 study areas within the Arctic National Wildlife Refuge.

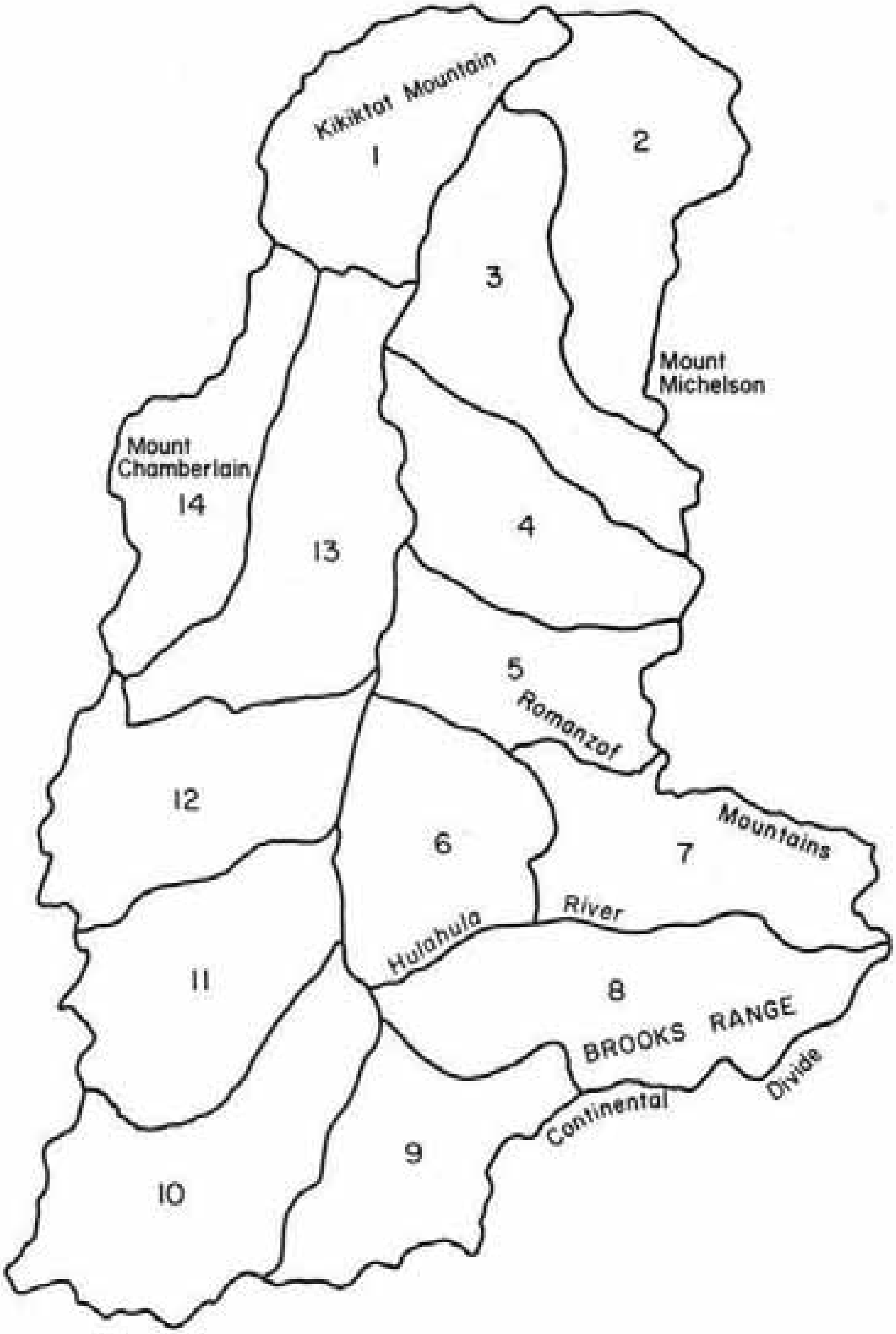

Fig. 2. Hulahula study area with Dall sheep survey subunits outlined.

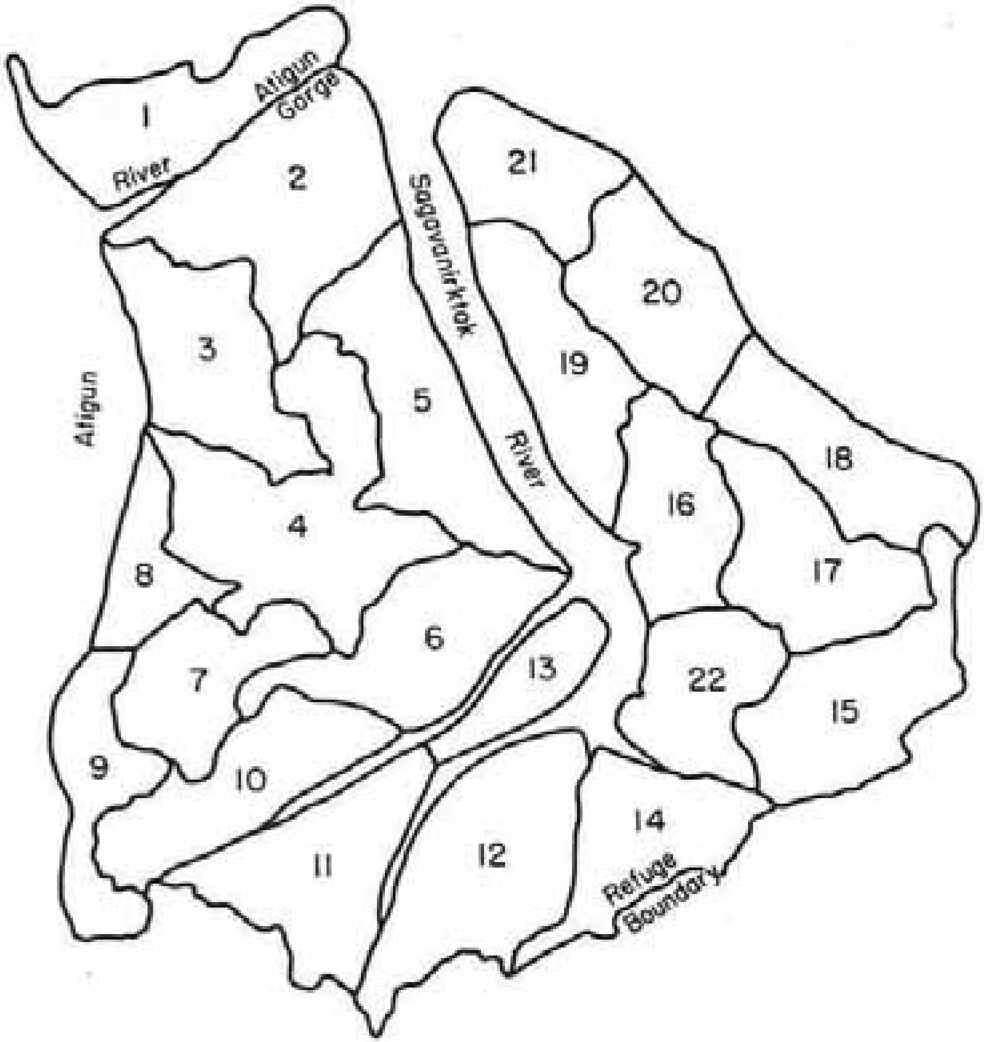

Fig. 3. Atigun-Sag study area with Dall sheep survey subunits outlined.

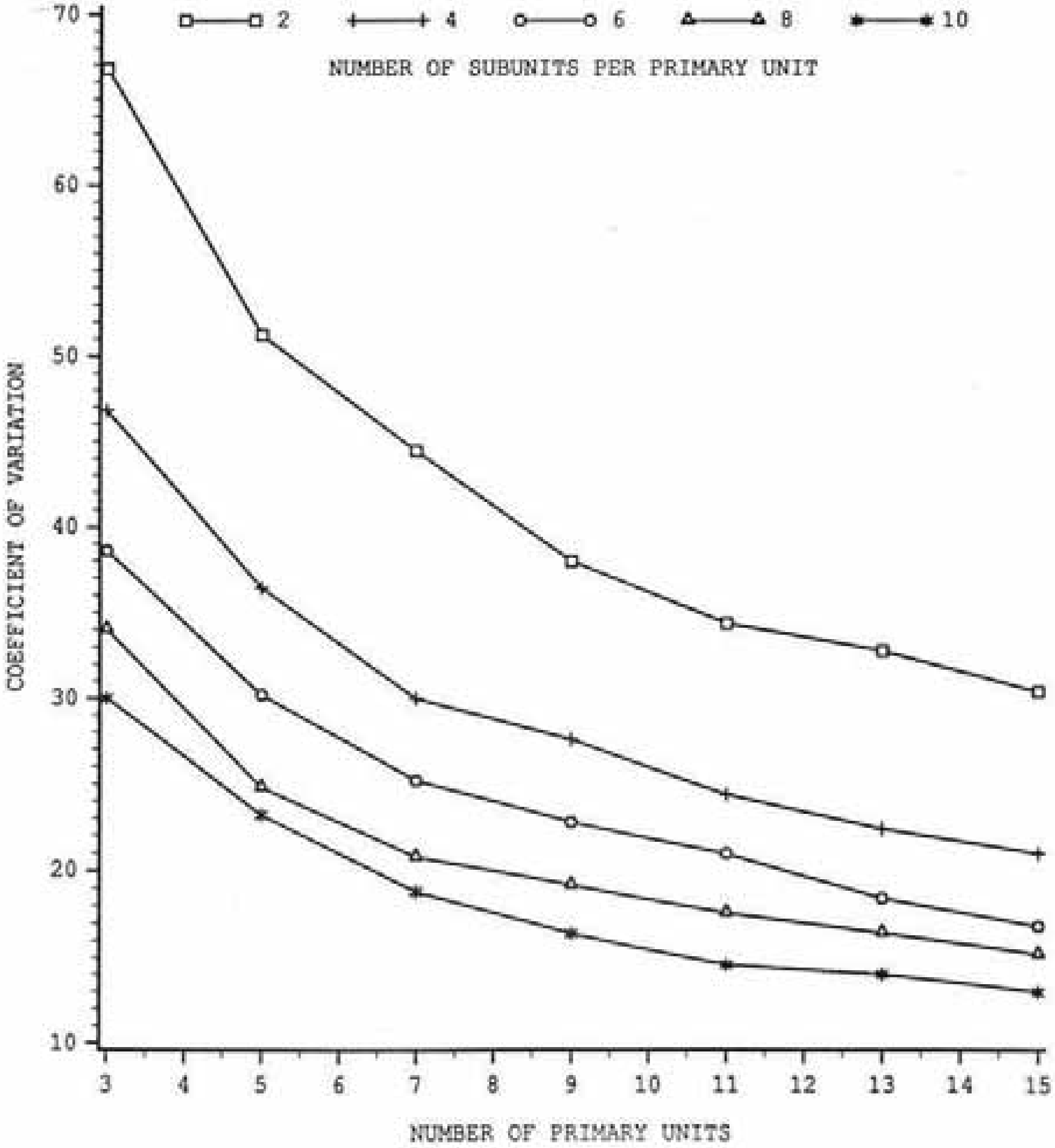

Fig. 4. Simulated coefficients of variation (CV) of estimated Dall sheep density based on simple random sampling of subunits from the Hulahula study area, 1979. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per primary unit.

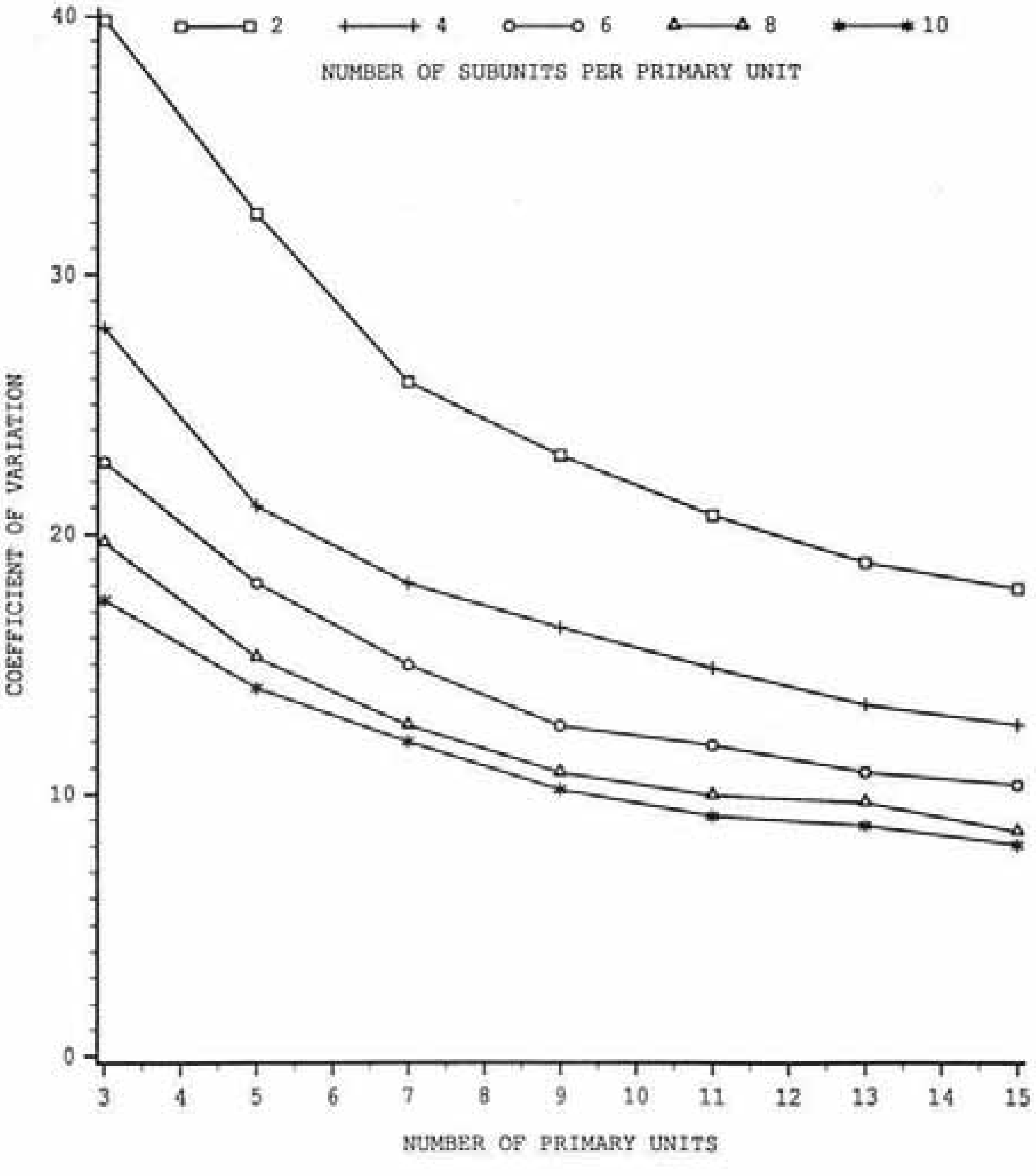

Fig. 5. Simulated coefficients of variation (CV) of estimated Dall sheep density based on simple random sampling of subunits from the Hulahula study area, 1982. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per primary unit.

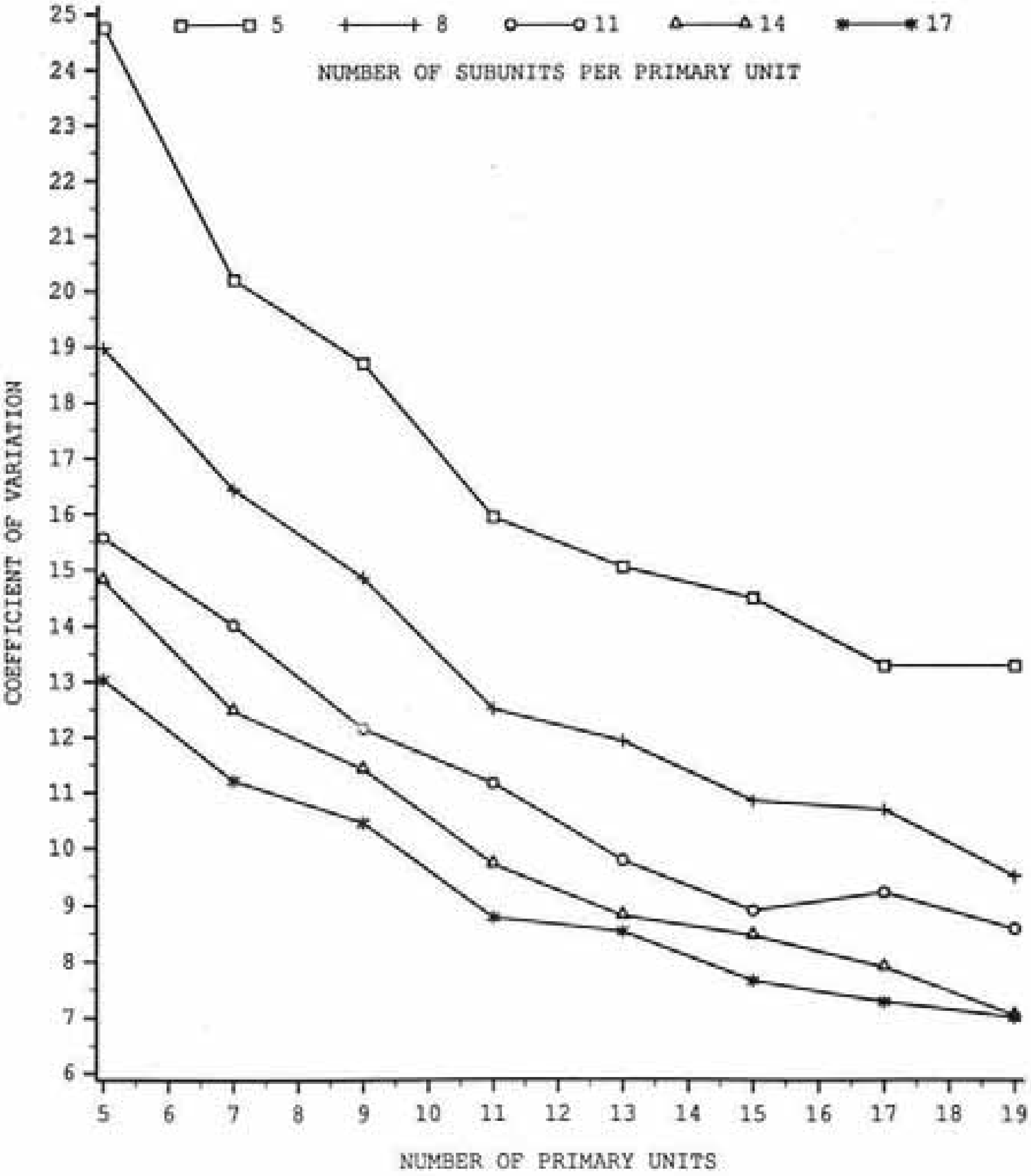

Fig. 6. Simulated coefficients of variation (CV) of estimated Dall sheep density based on simple random sampling of subunits from the Atigun-Sag study area and regular survey data, 1989. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per primary unit.

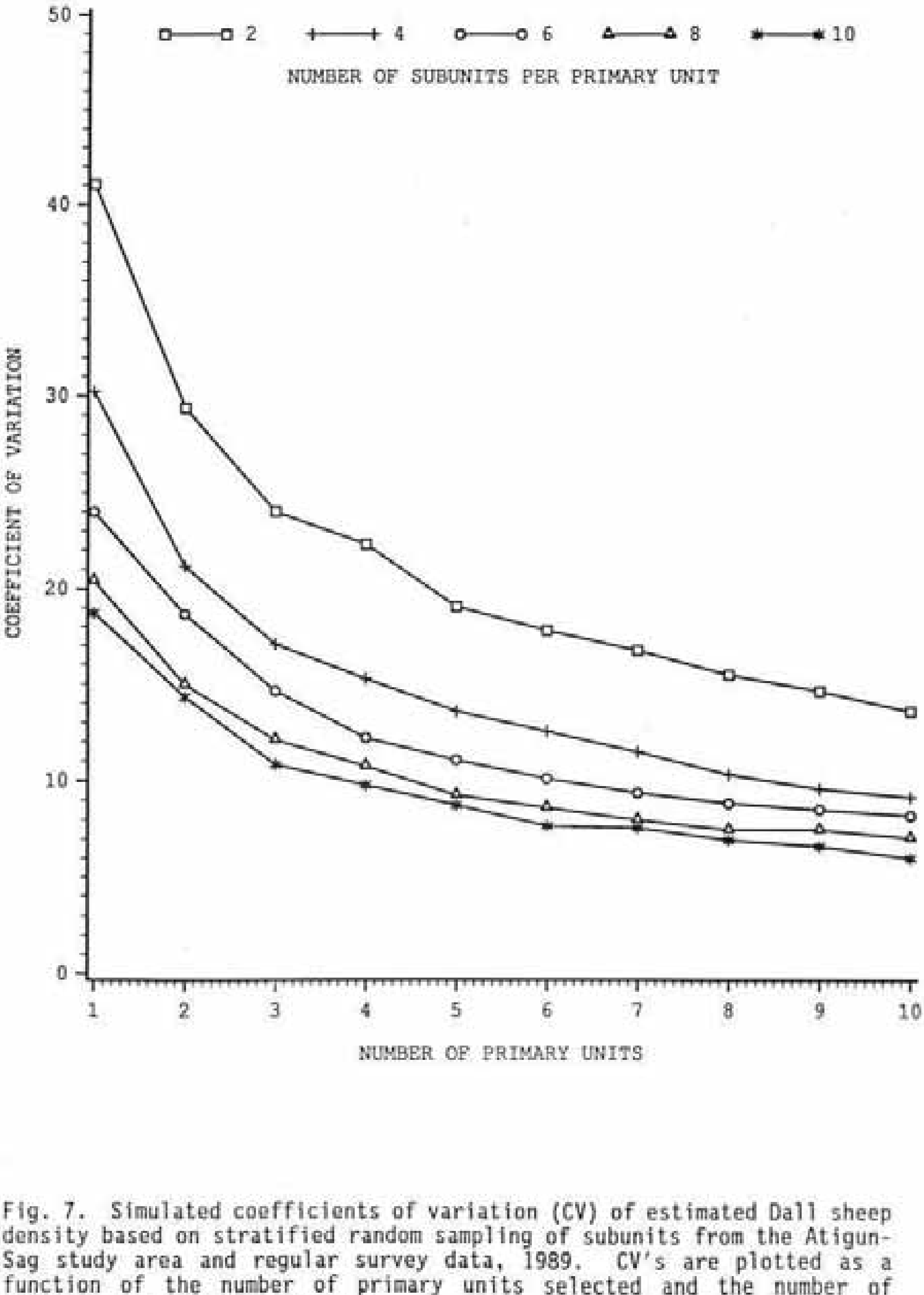

Fig. 7. Simulated coefficients of variation (CV) of estimated Dall sheep density based on stratified random sampling of subunits from the Atigun-Sag study area and regular survey data, 1989. CV's are plotted as a function of the number of primary units selected and the number of subunits surveyed per stratum.

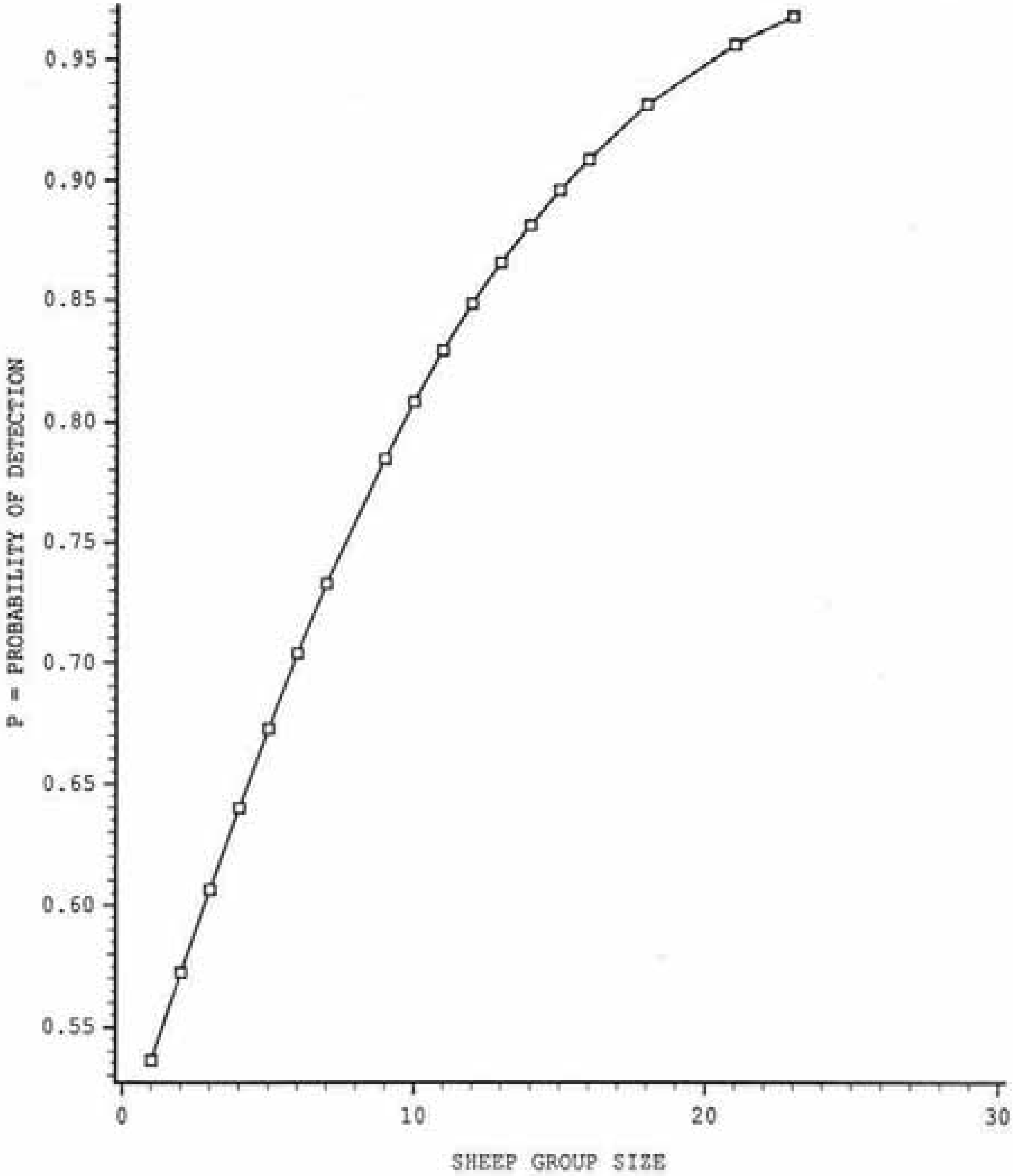

Fig. 8. Estimated probability of detection (Equation (4)) of a group of Dall sheep as a function of number of sheep in the group during the regular surveys of units in the medium density subunits, Hulahula and Atigun-Sag study areas, Alaska.

HABITAT RELATIONS

Bienn. Symp. North. Wild Sheep
and Goat Counc. 7:194-205.

USE OF CLEARCUTS BY ROCKY MOUNTAIN BIGHORN SHEEP IN SOUTHCENTRAL WYOMING

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Abstract: Information on use of clearcuts by a transplanted herd of Rocky Mountain bighorn sheep (Ovis canadensis canadensis) in southcentral Wyoming is presented. Distribution and habitat use patterns were estimated from 352 independent visual observations of 6 marked bighorn ewes from August through October 1987 and 1988. Thirty-eight observations occurred in clearcuts. Chi-square analysis indicated sheep selected clearcuts in proportions greater than availability during August and September. Proximity to escape terrain appeared to influence use of clearcuts by sheep. Recommendations are presented for integrating timber harvest in bighorn sheep habitat management plans.

Open vegetation communities and precipitous terrain with extensive rock outcrops have been identified as important components of Rocky Mountain bighorn sheep (Ovis canadensis canadensis) habitat (Geist 1971, Risenhoover and Bailey 1980, Wakelyn 1987). Use of open habitats near escape terrain reflects the predator-evasion strategy of bighorn sheep, where predators are detected visually and danger is communicated among sheep by visual cues (Geist 1971, Risenhoover and Bailey 1980, 1985, Wakelyn 1987).

Recent evidence suggests habitat conditions have changed considerably on many historical and occupied bighorn sheep ranges. Encroaching forest and shrub vegetation has reduced large open habitats on sheep ranges, due to fire suppression and/or lack of habitat management over the past 50 years (Wakelyn 1987). Wakelyn (1984) suggested habitat loss due to

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vegetation succession was associated with the decline or extinction of 36 herds of bighorn sheep in Colorado. Loss of suitable habitat and cessation of traditional movement patterns constitute important problems currently facing bighorn sheep (Risenhoover et al. 1988).

Restoration and maintenance of sheep habitat may increase populations and/or preclude local extinctions (Peek et al. 1979). Prescribed burning (Peek et al. 1979, Hobbs and Spowart 1984, Hurley and Irwin 1986, Cook et al. 1990) and, more recently, timber harvest (Yde et al. 1986, Young and Yde 1988) have been used to expand bighorn sheep ranges and improve foraging conditions. But no studies have documented responses of free-ranging populations of bighorn sheep to timber harvest. This paper describes sheep use of clearcuts in southcentral Wyoming and provides preliminary suggestions for integrating timber harvest with bighorn sheep habitat management.

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STUDY AREA AND METHODS

The study area occurred in the Encampment River Canyon on the eastern flank of the Sierra Madre Range in southcentral Wyoming, approximately 97 km southeast of Rawlins (Fig. 1). Elevations range from 2,188 to 2,796 m. Annual precipitation averages 37.6 cm and mean annual temperature is 5C in Encampment (Soil Conservation Service, Saratoga, Wyoming).

The Encampment River Canyon is a complex system of valleys and ridges with a diversity of vegetative communities. Bighorn winter range, generally below 2,490 m, consists of windblown ridgetops, rolling foothills, and steep slopes within the canyon. Vegetation is dominated by big sagebrush (Artemisia tridentata)-bitterbrush (Purshia tridentata) shrub communities within the canyon, and black sagebrush (Artemisia nova) and mixed grass/forb communities on the ridgetops. The southern portion of the Encampment Canyon (summer and fall range) is dominated by lodgepole pine (Pinus contorta), Engelmann spruce (Picea engelmannii)-subalpine fir (Abies lasiocarpa), and aspen (Populus tremuloides) forest. These forest communities are juxtaposed with snowbrush ceanothus (Ceanothus velutinus)-chokecherry (Prunus virginianus) and big sagebrush-bitterbrush shrub types. Rock outcrops suitable for escape terrain (> 15 m in height) are sparsely distributed in the river canyon. Detailed descriptions of the study area are presented by Haas (1979) and Arnett (1990).

In 1973, 28 ha of timber were clearcut in 3 units near the Jones Creek drainage in the southern portion of the Encampment Canyon (Fig. 1). Clearcuts were between 2,675 and 2,865 m in elevation, and generally faced south to southwest. Southerly aspects in clearcuts supported orchard

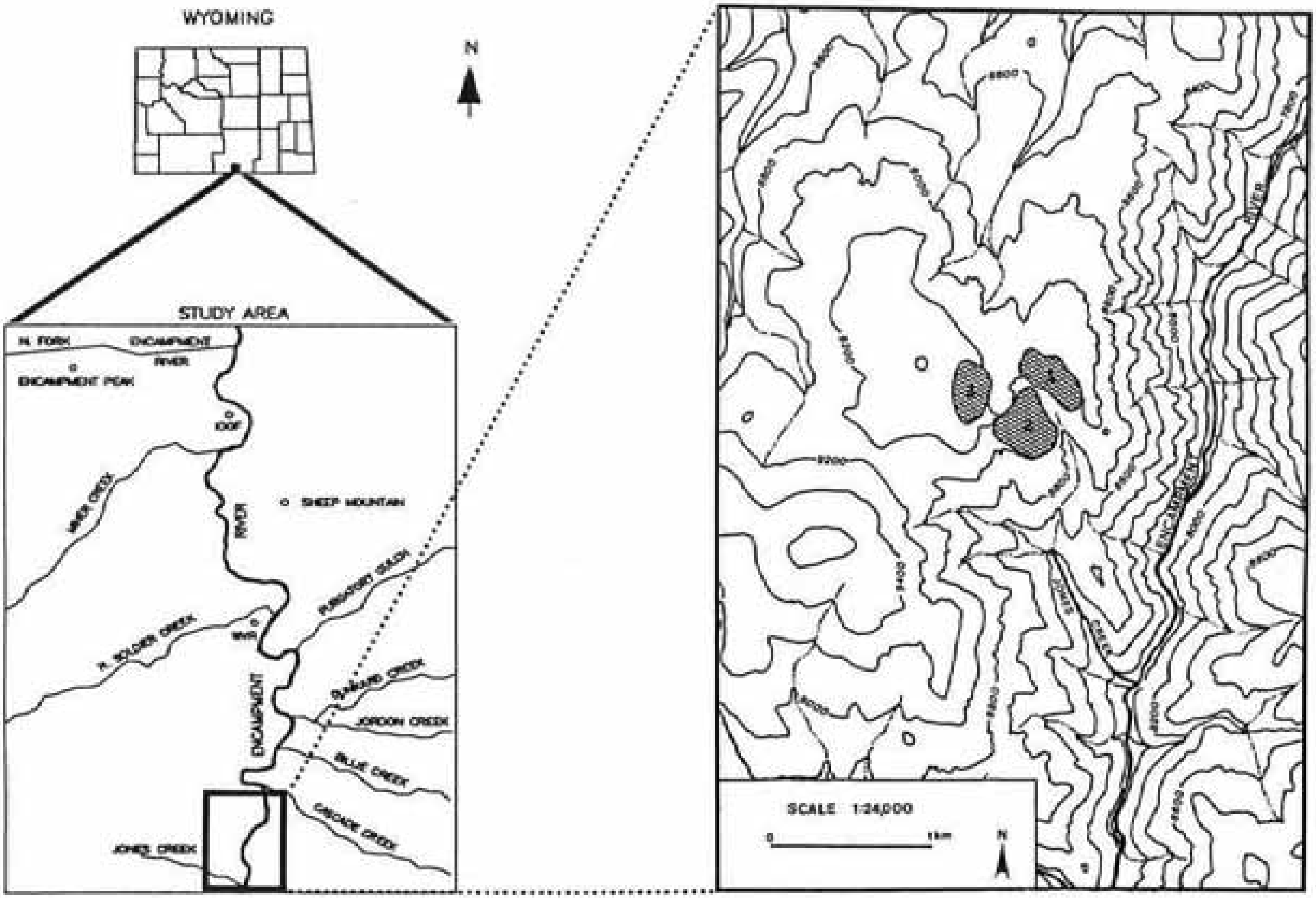

Fig. 1. Location of the Encampment River Canyon study area and 3 clearcuts used by bighorn sheep in southcentral Wyoming.

grass (Dactylis glomerata), spike trisetum (Trisetum spicatum), nodding brome (Bromus anomalus), Wheeler bluegrass (Poa nervosa), Ross sedge (Carex rossii), and silvery lupine (Lupinus argenteus). East aspects were dominated by grouse whortleberry (Vaccinium scoparium), Ross sedge, and lupine. Mesic sites in clearcuts contained King spikefescue (Leucopoa kingii) and Canada wildrye (Elymus canadensis). Before 1988, lodgepole pine, subalpine fir, and aspen saplings (1 to 4 m high) were common throughout the clearcuts.

Two of the 3 clearcuts are being managed by the U.S. Forest Service as permanent openings for bighorn sheep. In early June 1988, all conifer and aspen saplings were cut with chainsaws from clearcuts 1 (C1) and 2 (C2) (Fig. 1). Slash was piled and burned in fall 1988. After saplings were removed, ammonium nitrate fertilizer (approximately 29.6 kg/ha) was applied from a helicopter to half of each clearcut. Saplings were not removed from clearcut 3 (C3) (Fig. 1), but fertilizer was applied.

Sheep habitat selection was determined by monitoring 6 radio-collared adult ewes during August-December, 1987-88. We attempted to locate each marked ewe at least 10 times per month. Marked ewes were visually observed, thus eliminating triangulation errors (Springer 1979). We minimized statistical dependence of relocations by (1) locating a radio-collared sheep only once each day, (2) locating each collared ewe at different times of the day throughout each month, and (3) using a single relocation for groups of sheep containing more than 1 marked ewe (groups were defined as all sheep within 100 m of each other). Available habitat was defined by connecting the outermost relocation points of all marked ewes (Porter and Church 1987), and quantified by measuring the area of each vegetation community with an electronic planimeter.

Data were partitioned by seasons and Chi-square analysis was used to test the null hypothesis that vegetation communities were utilized in proportion to their availabilities (Neu et al. 1974). If a null hypothesis was rejected, Bonferroni confidence intervals were used to identify which vegetation communities were selected, avoided, or used proportionally (Byers et al. 1984).

During the first year of the study, conifer regeneration had not yet been removed from C1 and C2. After observing sheep use of clearcuts, we hypothesized they chose more open sites in clearcuts. We used observations in C1 to test this hypothesis. The outermost boundary of relocations observed in C1 during 1987 defined the used area, while the remaining portion of C1 was considered unused. We randomly selected 20 points in the used and 20 in the unused areas of C1. From each point, we defined an 8 m radius circular plot (0.02 ha), and the number of conifer and aspen saplings was counted and heights measured. A t-test was used to detect differences in number of trees or tree height between used and unused portions of C1.

RESULTS

Collared ewes selected clearcuts during late summer (August-September) but used them in proportion to their area during fall (October-

December) in both years (Fig. 2). Sheep avoided clearcuts during other seasons. In September and October 1987, 21 and 15%, respectively, of all relocations during each month occurred in clearcuts (Table 1). In 1988, 26% of August relocations were in clearcuts, but use decreased as fall progressed. Sheep used clearcuts more extensively during August 1988 and less in September 1988, compared to those months in 1987. Frequency of use differed among the 3 clearcuts. Eighty-four percent of relocations in clearcuts were in C1; 3 and 10% of these observations were in C2 and C3, respectively (Fig. 3).

Used sites in C1 had fewer and shorter trees than did available unused areas (Table 2). But sheep use of C1 and C2 did not increase significantly following removal of conifer regeneration (17 observations in C1 and C2 in 1987, versus 17 in 1988). Although some sheep were observed in portions of C1 which were unused in 1987, they generally used the same area within C1 each year (Fig. 3).

DISCUSSION

Arnett (1990) found bighorn sheep in the Encampment River Canyon preferred more open vegetation communities (e.g., open montane shrub types, windblown ridges, or burns) and consistently avoided aspen and coniferous forests. Other studies corroborate sheep preference for open vegetation types and avoidance of dense shrublands and forests (Thorne et al. 1979, Risenhoover 1981, Brundige and McCabe 1986, Cook 1990). Shannon et al. (1975) reported that abundance of bighorn sheep is negatively related to forest crown closure. MacArthur et al. (1979) and Stemp (1982) found bighorns entering forested areas experience an increase in heart rate, an index to energy expenditure.

Studies clarifying the relationships between bighorn sheep and timber management are lacking. In northwestern Montana, Young and Yde (1988) used a selective timber harvest system (designed to leave 37-74 mature trees/ha), rather than clearcutting, to improve bighorn sheep seasonal ranges. Preliminary information suggests sheep utilize these timber harvest treatments (C. Yde, Montana Dept. Fish, Wildl., and Parks, pers. commun.).

Sheep in the Encampment River Canyon used clearcuts primarily during late summer and early fall, and may have used them more extensively than we documented during this study. Ewes were often observed feeding in clearcuts after they had been located in other vegetation communities earlier in a day. We also observed unmarked groups of sheep in clearcuts.

That sheep selected more open areas within a clearcut and consistently avoided sites with greater tree density and height is probably related to greater visibility (Risenhoover and Bailey 1980, 1985) and forage production (Basile 1975, Dealy 1975, Austin and Urness 1982) in open areas. Although we expected distribution of sheep to extend into formerly unused portions of clearcuts and anticipated increased use of clearcuts after saplings were removed, use in 1988 was generally similar to that in 1987. We are uncertain why sheep used clearcuts more extensively in August 1988, compared to August 1987. However, in

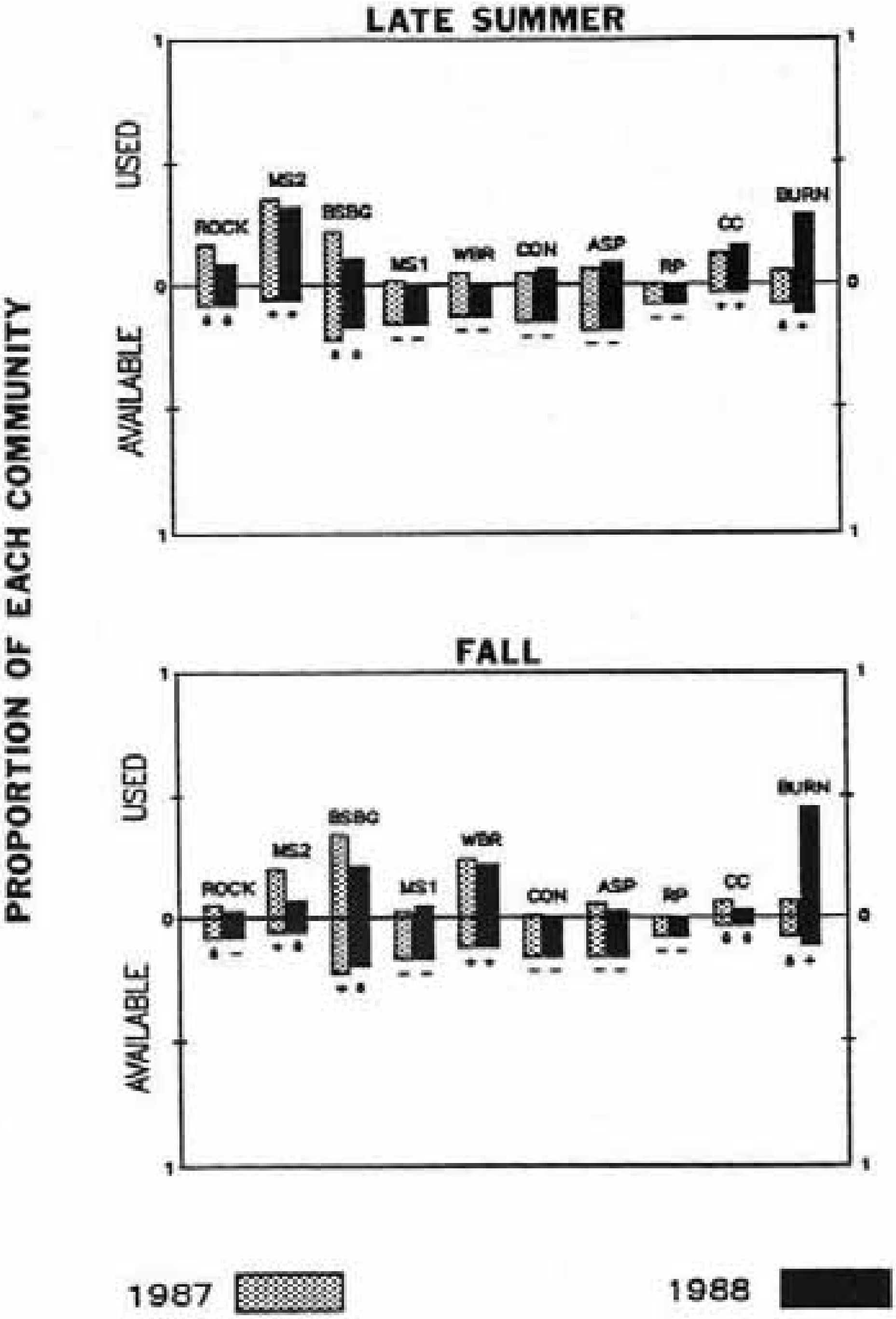

Fig. 2. Habitat use by 6 radio-collared bighorn ewes compared to habitat availability during late summer (August-September) and fall (October-December) 1987 and 1988 (+ = habitat selected, - = habitat avoided, $\underline{P} < 0.05$; 0 = habitat use similar to availability, $\underline{P} > 0.05$). MS2 = ceanothus-chokecherry shrub, BSBG = big sagebrush-bitterbrush/grass, MS1 = serviceberry-mountain mahogany shrub, WBR = black sagebrush/grass (windblown ridge), CON = conifer, ASP = aspen, RP = riparian, CC = clearcut.

Table 1. Use of clearcuts by 6 radio-collared ewes during those months when clearcuts were utilized, Encampment River Canyon, Wyoming.

Year	Month	No. locations in clearcut	Total locations	% use of clearcuts
1987	September	11	53	21
	October	7	46	15
1988	August	14	54	26
	September	3	74	4
	October	3	60	5

Table 2. Sapling density and height in portions of clearcut 1 that were used versus unused by bighorn sheep during 1987, Encampment River Canyon, Wyoming.

Area[a]	$\bar{X}$ density (S.E.)[b]	P	$\bar{X}$ height (S.E.)[c]	P
Used	25 (3.5)	< 0.001	108.2 (5.4)	< 0.001
Unused	101 (9.0)		149.1 (5.1)	

[a] 20 plots per treatment

[b] trees/0.02 ha plot

[c] height in cm

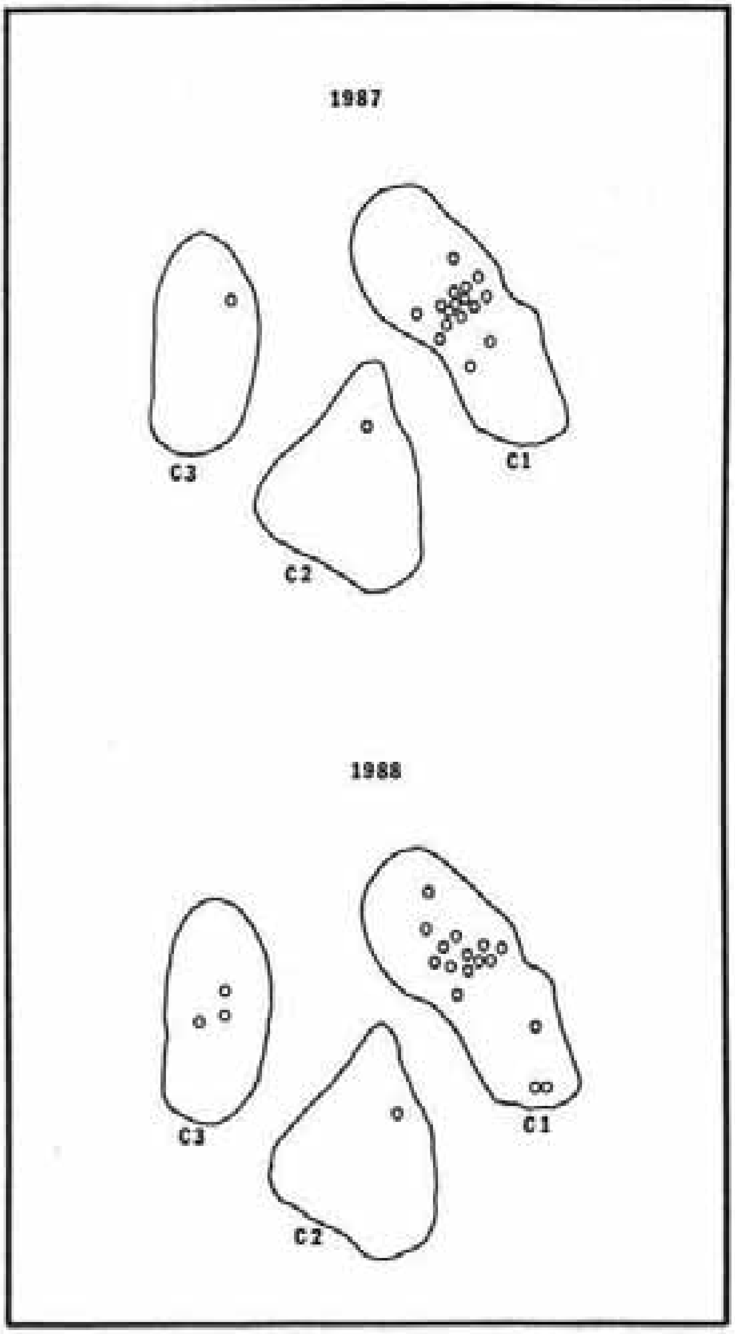

Fig. 3. Distribution of observations of marked bighorn ewes in clearcuts from August to October, 1987 and 1988, showing little change in use patterns before (1987) and after (1988) saplings were removed entirely from clearcuts 1 and 2.

September and October 1988, marked ewes frequented the winter range and utilized prescribed burns more than they did in 1987. Had these ewes remained on the summer/fall range, clearcuts may have been used more extensively during these months in 1988.

Although sample sizes were inadequate to statistically examine variables that influenced selection of clearcuts (e.g., slope, aspect, distance to water), distance from escape terrain apparently is an important determinant of sheep use of clearcuts. Twenty-eight clearcuts occurred within 5 km of the river canyon in the southern portion of the study area. Of these, only 3 were used and 84% percent of relocations in clearcuts were in C1, nearest rock outcrops in occupied sheep habitat. The average distance from relocations to rock outcrops > 15 m in height was 354, 450, and 841 m for C1, C2 and C3, respectively. These distances are further from rock outcrops than sheep typically prefer (Wakelyn 1984), suggesting clearcuts would be used more often if they were located closer to escape terrain.

We speculate bighorn sheep will generally prefer to feed in clearcuts because they provide high-visibility habitat, which facilitates early predator detection, and good forage production and availability, both which improve foraging efficiency (Dale and Bailey 1982, Risenhoover and Bailey 1985). Whether forage quality was elevated in clearcuts, as found by Crouch (1985), is unknown, but increased plant production results in higher nutrient density per unit area, and potentially improves nutrient intake by sheep.

MANAGEMENT RECOMMENDATIONS

Lack of continuous escape terrain, moderate slopes, and dense coniferous forests on the southern portion of our study area restrict bighorns to islands of preferred habitat within the Encampment River Canyon, precluding expansion of the majority of the population to high quality alpine summer ranges in the Sierra Madre mountains (Arnett 1990). Results from this study suggest timber harvest conceivably could be used to expand suitable habitat for bighorn sheep. However, more research is needed to further quantify bighorn sheep-timber harvest relationships, particularly type, size, and placement of silvicultural treatments that would most effectively benefit sheep. Until further research is completed, the following recommendations seem prudent:

1. To ensure that clearcuts will be discovered and used by bighorns, managers should locate areas occupied by sheep and place clearcuts within or near these areas.

2. Sheep exhibit strong affinity to escape terrain, particularly during the lambing/nursery period. Clearcuts should be placed near steep precipitous terrain and rock outcrops (preferably < 300 m) to maximize use by sheep.

3. Conifer saplings within clearcuts intended to benefit sheep probably should be thinned to approximately 125 stems/ha (4 m spacing between trees) within 15 years (Cole 1975, Dealy 1975). This would improve

visibility and maintain understory vegetation, providing more available forage for sheep. Removing all conifer regeneration from clearcuts and maintaining them in a grass/forb community is probably most optimal for sheep, but does not appear necessary to encourage use. A series of timber harvest treatments which maintain open habitat over time may prolong sheep use.

4. Slash in clearcuts should be reduced to facilitate sheep movements, allow early detection of predators, and optimize forage availability.

5. Roads that provide access to clearcuts in occupied sheep range should be closed following timber harvest to reduce human disturbances to sheep (MacArthur et al. 1979).

6. Managers should seed clearcuts with palatible sod-forming grasses to establish herbaceous plant cover and suppress conifer regeneration. Fertilizer could be applied with seed to enhance herbaceous plant production.

7. Timber harvest should occur during seasons when clearcuts are unoccupied or when short-duration disturbance is considered less stressful to sheep.

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USE OF RODENT MIDDENS AS MINERAL LICKS BY BIGHORN SHEEP

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Abstract: We documented regular use of rodent middens as mineral licks by bighorn sheep in south-central Montana. Rodent middens used by bighorns were located in numerous caves (karst holes) used by bighorns as night beds and(or) thermal cover. The concentrations of 6 soluble ions were determined from samples of rodent excreta from middens. Ion concentrations in rodent excreta were compared to concentrations in weathered soil collected from outside the cave (non-lick) and from soil collected inside the cave below the rodent middens (lick soil). Concentrations of calcium, magnesium, potassium, and sodium were 100 times greater in excreta than non-lick soil. Selenium concentrations were highest in lick soil and lowest in non-lick soil. Otherwise, ion concentrations were highest in excreta, intermediate in lick soil, and lowest in non-lick soil. Phosphorus concentrations were low in all samples. Essential minerals are more available at rodent middens because of higher levels in excreta and soil excavated by rodents. In addition, availability of essential minerals may be enhanced due to the secure habitats in which middens are located.

Bighorn sheep (*Ovis canadensis*) were reintroduced into the Northern Bighorn Mountains by the Wyoming Game and Fish Department (WYGFD) in 1972 and 1973. Thirty-nine bighorns were removed from the Whiskey Basin population near Dubois, Wyoming, and repeated releases of 6-8 animals were made from a pickup truck (WYGFD 1982).

In the winter of 1974-1975 a small band of bighorns dispersed from the release area and re-established a population in historic habitat at Bighorn Canyon in south-central Montana. Dispersal involved a movement of approximately 10 air miles, a lake crossing, and recolonization on a wild-horse range. The population had increased to 25 animals by 1985 (Coates and Schemnitz 1985), and 67 animals by 1988 (unpublished data).

During a study of the herd from 1985-1988, use of rodent middens as mineral licks was noted. We are reporting this unusual phenomenon.

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STUDY AREA

Bighorn Canyon National Recreation Area (BICA) encompasses 48679 ha, centered around a 114 km-long reservoir and precipitous canyonland in south-central Montana and north-central Wyoming. Portions of BICA are managed jointly by the NPS and the Bureau of Land Management (BLM) as the Pryor Mountain Wild Horse Range (PMWHR). The 17,402 ha PMWHR supports a population of 120 free roaming horses (*Equus caballus*) (BLM 1984). Access to the southern portion of BICA and the PMWHR is by secondary highway.

Abrupt changes in topography and geology create a mosaic of vegetation consisting of wetlands, shifting riparian communities, desert shrubland, juniper woodland, sagebrush steppe, coniferous forest, and mixed prairie (Knight et al. 1987). Vegetative dominants of the study area include curlleaf mountain mahogany (*Cercocarpus ledifolius* var. *intercendens*), Utah juniper (*Juniperus osteosperma*), sagebrush (*Artemisia* spp.), greasewood (*Sarcobatus* spp.) and a sparse understory of bunch grasses (Lichvar et al. 1985).

Annual precipitation varies from 15-20 cm at the southern portion of BICA to 46 cm at the north. Soils in the south include sandy clay loam in natural riparian areas, limestone and sandstone in the precipitous canyonland, and dolomite in nonprecipitous area. Elevations vary from the mean reservoir level of 1109 m to 2682 m at the East Pryor Mountains. Grey limestone cliffs rise vertically > 335 m from talus slopes at the shoreline of the reservoir (BICA 1981). Eroded sandstone soils and karst topography (irregular limestone region) provide abundant escape cover for bighorns.

METHODS

During 1985, immature rams were observed in a limestone sinkhole, eating soil and licking deposits of rodent excrement, at a rodent midden. From June 1986 through June 1988, 3 radio-collared bighorn ewes enabled us to locate and observe the majority of the ewes daily. We found that ewes frequently bedded in sinkholes at the canyon rim. Rodent middens were present in several sinkholes, and tracks indicated that ewes were using the middens as mineral licks.

Samples of excreta and soil from one of the middens were analyzed to determine the concentration of 6 soluble ions. Ion concentrations in rodent excreta were compared to concentrations in dirt collected below the nest which was excavated by rodents (lick-soil), and in soil collected above the sinkhole (non-lick).

RESULTS

Concentrations of sodium, potassium, calcium, magnesium, phosphorus, and selenium were lowest in non-lick soil. Compared to non-lick soil, concentrations of 5 of the 6 ions were slightly greater to 180X greater in lick-soil, and were 12 -418X greater in excreta. Selenium concentrations were highest in lick soil and intermediate in excreta (Table 1).

Table 1. Soluble ions in rodent excreta, in lick-soil excavated by rodents, and in non-lick soil at a rodent midden used as a mineral lick by bighorns at Bighorn Canyon National Recreation Area, Montana and Wyoming.

	Ion concentration (mg/Kg)					
Sample	Na	K	Ca	Mg	P	Se
non-lick soil	9	27	164	16	3.5	<0.01
lick-soil	1636	760	3896	1648	5.5	0.40
excreta	3592	9950	11906	6692	44.0	0.30

Concentrations of sodium, magnesium and calcium were 12-400X greater in excreta than non-lick soil. Concentrations were 24-180X greater in lick-soil than non-lick soil. Phosphorus concentrations were only slightly greater non-lick soil, but were 12X greater in excreta than non-lick soil. Selenium concentrations were 400X and 300X greater in lick-soil and excreta, respectively, than in non-lick soil.

DISCUSSION

Rodent activity, including nesting and digging, provided excreta rich in sodium, potassium, calcium, magnesium and phosphorus; and also made unweathered, mineral rich soil, available to bighorns. Mineral licks at rodent middens were located in escape cover, thus providing essential minerals in a secure habitat.

In temperate North America, peak use of mineral licks occurs during spring, or with increased vegetative growth (Watts and Schemnitz 1985). The attraction of ungulates to mineral licks during spring has been attributed to disruption of the sodium-potassium balance due to consumption of potassium-rich forage (Weeks and Kirkpatrick 1976).

Spring and early summer rainfall at BICA account for 67 % of the annual precipitation (Knight et al. 1987). Annual production of perennial grasses and shrubs at BICA occurs during this period. Ewes occupied karst topography and frequently used sinkholes with rodent middens after lambing from June through August. Use of mineral licks at rodent middens may therefore be related to sodium craving in response to potassium-rich forage.

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HABITAT EVALUATION PROCEDURE FOR ROCKY MOUNTAIN BIGHORN SHEEP IN THE WESTERN ROCKY MOUNTAINS AND GREAT BASIN REGIONS

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Abstract: Several habitat evaluation procedures have been developed for bighorn sheep. However, none of these procedures specifically addresses the Rocky Mountain subspecies, nor analyzes both the quantity and quality of potential bighorn habitat with regard to minimum viable population (MVP) criteria. This bighorn habitat evaluation procedure combines: 1) a quantitative assessment of bighorn ranges to determine if adequate quantities exist to support a MVP of bighorn sheep, and 2) a qualitative assessment of the defined ranges to predict probable densities of bighorns those ranges can be expected to support. This paper presents a step-wise approach to bighorn habitat evaluation, thereby enhancing the ability of wildlife biologists to make prompt and accurate bighorn habitat assessments.

The precipitous decline of Rocky Mountain bighorn sheep (Ovis canadensis canadensis) following arrival of American settlers in the mid-1800's has been well documented (Buechner 1960). As early as 1880, some bighorn herds had been entirely extirpated, while others suffered sharp reductions in number. Even recently, Jahn and Trefethen (1978) warned that unless more effective management was initiated, an additional loss of 8 percent of all bighorn sheep could be expected over the next 25 years.

The inability to successfully restore bighorn to former ranges in the western United States results, in part, from serious habitat deficiencies which have hampered herd growth and persistence. For example, Utah's reintroduction program has not succeeded in restoring Rocky Mountain bighorn to former ranges in spite of more than 2 decades of effort (Smith et al. 1988). Currently, fewer bighorns exist than the total number transplanted, suggesting that a serious problem exists in the reintroduction program. Probable reasons for transplant failure include: 1) inadequate quantities of total available range, 2) severe competition with other ungulates, 3) contact with domestic livestock, 4) improper juxtaposition of key habitat components, 5) inadequate quantities of 1 or more critical seasonal ranges, and 7) excessive human harassment. Clearly, a more rigorous assessment of proposed reintroduction areas should result in a more successful reintroduction program. This habitat evaluation procedure (HEP) represents an effort to provide bighorn managers with a better tool for assessing bighorn habitat quality.

Although several bighorn habitat evaluation procedures exist (Armentrout and Brigham 1988, Holl 1982, Golden and Tsukamoto 1980, Grunigen 1980), this HEP has been developed because: 1) an exclusive Rocky Mountain bighorn sheep HEP is nonexistent and, 2) none of these other procedures critically examines actual, or proposed, bighorn ranges with regard to the minimum area necessary to support at least a minimum viable population (MVP) of bighorn sheep. A MVP has been defined by Shaffer (1983) as the smallest, isolated population having at least a 95% probability of surviving at least 100 years. Though precise MVP estimates (MVPE) for bighorn sheep are not available, Berger (1990) and Geist (1975) have suggested that bighorn managers should maintain herds of at least 100 to 125 individuals if the herd is to survive and persist over time. Because restoration efforts should strive to establish populations with long-term persistence, this bighorn habitat evaluation procedure rigorously assesses the ability of a proposed site to support at least 125 bighorn sheep. This requirement can be relaxed somewhat, however, if a particular site is situated such that exchange with nearby herds can be expected to occur. Nonetheless, for most transplant populations this will not be the case and each transplant site must be evaluated individually. Schwartz et al. (1986) provide several examples of distances which bighorn have been observed moving between distant herds of southern California, although extrapolation to more forested regions should be done cautiously.

A longer, more detailed version of this HEP is available upon request from the authors. Abbreviating it here has enabled inclusion in the 1990 proceedings which we felt would be of benefit to other sheep biologists.

OVERVIEW OF THE BIGHORN HABITAT EVALUATION PROCEDURE

A diagrammatic overview of this bighorn habitat evaluation procedure is presented in Figure 1. Two essential components comprise this habitat assessment tool: estimation of habitat quantity (Part 1) and estimation of habitat quality (Part 2). It is the combination of these 2 habitat characteristics which determines range carrying capacity. Part 1 is comprised of bighorn habitat requirement-based questions which define probable range area and boundaries. Part 2 utilizes the process of pattern recognition (PATREC) to assess range quality.

Bighorn sheep movements are restricted by both intrinsic (behavioral and physical) and extrinsic factors (fences, geographic barriers, etc). Because bighorn response to habitat variables is fairly predictable, it is possible to estimate probable range size based on a knowledge of bighorn movement delimiters. Although bighorn will occasionally ignore what are typically barriers to movement, managers should not expect portions of range, segregated by known barriers to movement, to contribute significantly to probable bighorn ranges. A proposed bighorn reintroduction site comprised of scattered range segments, crisscrossed with barriers to movement and with key habitat components ineffectively juxtapositioned or absent, would ultimately fail to support a herd capable of long-term persistence. Part 1 presents these normally restrictive barriers and assists in identifying the probable range boundaries, maximum area, and juxtaposition of key habitat components. Part 1 focuses attention on critical aspects of bighorn habitat and helps managers determine a site's ability to provide quality bighorn habitat of the magnitude needed to support a MVPE of sheep.

Bighorn range quality is the expression of complex interactions of many physiographic and biological characteristics. The PATREC approach, often referred to as "PATREC modeling", captures in simple mathematical form the process by which most biologists intuitively assess relative habitat conditions (Grubb 1988). PATREC's output is similar to saying "Based on my experience and knowledge, and given the habitat components and conditions just observed, the probability that the area is capable of supporting high densities of bighorn sheep is______." (Holl 1982). To date, PATREC models have been applied to a variety of wildlife, including bald eagles (Grubb 1988), deer (Kling 1980), sage grouse (Evans 1982), and bighorn sheep (Holl 1982) to name a few. For a thorough description of PATREC, see Kling (1980) and Williams et al. (1977). It is highly recommended that before proceeding with Part 2, background material on PATREC be obtained and reviewed. Particularly helpful is the "User's Guide to PATREC for Habitat Evaluation" (Kling 1980).

Although the most rigorous evaluation of habitat will occur when both Part 1 and Part 2 are applied to an area, it is not required that you do so. Part 1 is the key component of the HEP and cannot be omitted. Application of Part 1, rigorous site analysis, in of itself would greatly assist many bighorn reintroduction programs. Part 2 is more time intensive and requires a more detailed database, but provides some very useful information. Individual users must review their own time and budget restraints to determine how rigorously they can afford to analyze a potential reintroduction site. In many instances, sites being analyzed may never receive Part 2 analysis, having failed to provide either the minimum range quantity necessary to support a MVPE or due to irreparable habitat problems.

METHODS

A step-wise discussion of the bighorn habitat evaluation procedure follows. To shorten this paper, discussion has been minimized and only key literature citations given.

Part 1: Quantitative Assessment Of Available Bighorn Habitat

In Part 1, sequential questions direct the user to: 1) determine the probable range boundaries for an actual, or proposed, bighorn herd, 2) analyze the total area of that range in terms of MVPE criteria, 3) determine if adequate quantities of winter, lambing, and summer ranges exist, and 4) decide if the juxtaposition of habitat components is as needed by bighorn. The following numbered steps match those of Figure 1.

Step 1--Escape terrain is defined as slopes greater than 60% (about 27°), with occasional rock outcroppings whereon bighorn can out-maneuver predators and find secure bedding areas. Rugged escape terrain has been identified as the most critical bighorn habitat component (Van Dyke et al. 1983, Ferrier and Bradley 1980, Wilson et al. 1980), without which bighorn will not flourish (Hansen 1980). Research in northeastern Utah has indicated that 95% of all bighorn activity occurs within 300 meters of cliff escape terrain (Smith and Flinders 1991). Consequently, little is gained by including areas beyond 300 meters from cliff escape terrain in range size determinations. Identifying and delineating all escape terrain and adjacent 300 meter buffer zones satisfies Step 1. Occasionally a segment of range is bounded on 2, or more, sides by escape terrain. In such instances, if the distance between the escape terrain areas is less than, or equal to, 1000 meters, the entire area between should be included as potential bighorn habitat. This is done because bighorn have more escape routes when escape terrain borders more than 1 side of forage areas (Van Dyke et al. 1983).

<u>Step 2</u>--Bighorn movements are restricted by barriers which fall into 1 of 2 categories: natural and man-made. Identify them on the range being evaluated as follows:

A. Natural Barriers

1) Water - Swift and/or Wide Rivers and Lakes: Though Cowan (1940) noted bighorn occasionally swimming, water has been noted elsewhere to effectively halt bighorn movements (Smith and Flinders 1991, Graham 1980, Wilson et al. 1980). Rivers and lakes break continuity of range and should be considered barriers to bighorn range extensions in most cases but must be evaluated individually.

2) Dense Vegetation: Smith and Flinders (1991) and Risenhoover and Bailey (1980) have stated that bighorn sheep will not cross even narrow tracts of dense vegetation, particularly timber. For purposes of this habitat assessment, low visibility areas (of less than 50% horizontal visibility - see Smith and Flinders 1991 for methods used to determine), 100 meters wide, or more, will be considered effective movement barriers to bighorn sheep and should be identified as such.

3) Cliffs - Continuous, Non-Traversable Cliff Complexes: Sheer, vertical cliffs lacking negotiable terrain should be identified as barriers to movement.

4) Valleys or Plateaus: If valleys between areas of escape terrain are wider than 1000 meters, identify them as barriers to bighorn movements. Similarly, plateaus which separate escape terrain areas by more than 1000 meters should be considered range boundaries.

B. Man-Made Barriers

1) Water - Canals, Reservoirs, Aqueducts: Waterways are generally a barrier to bighorn movements. Concrete-lined canal systems, reservoir impoundments and aqueduct structures can create impassable barriers and bighorn death traps (Graham 1980).

2) Impassable Fencing: Fencing can restrict bighorn movements and cause mortality, particularly if rams get their horns entangled. Helvie (1971) reviews the types of fencing which limit bighorn movements. Fence lines must be evaluated individually for impact.

3) Major Highways and High-Use Roadways: Aside from the fencing often associated with major highways and high-use roadways, auto traffic often deters bighorn from traversing these areas (Van Dyke et al. 1983, Risenhoover 1981, McQuivey 1978). Highways must be individually evaluated and those clearly restricting bighorn movements must be considered boundaries of contiguous bighorn ranges.

4) Centers of Human Activity: Airports, dwellings, campgrounds, and ski resorts are examples of centers of human activity which

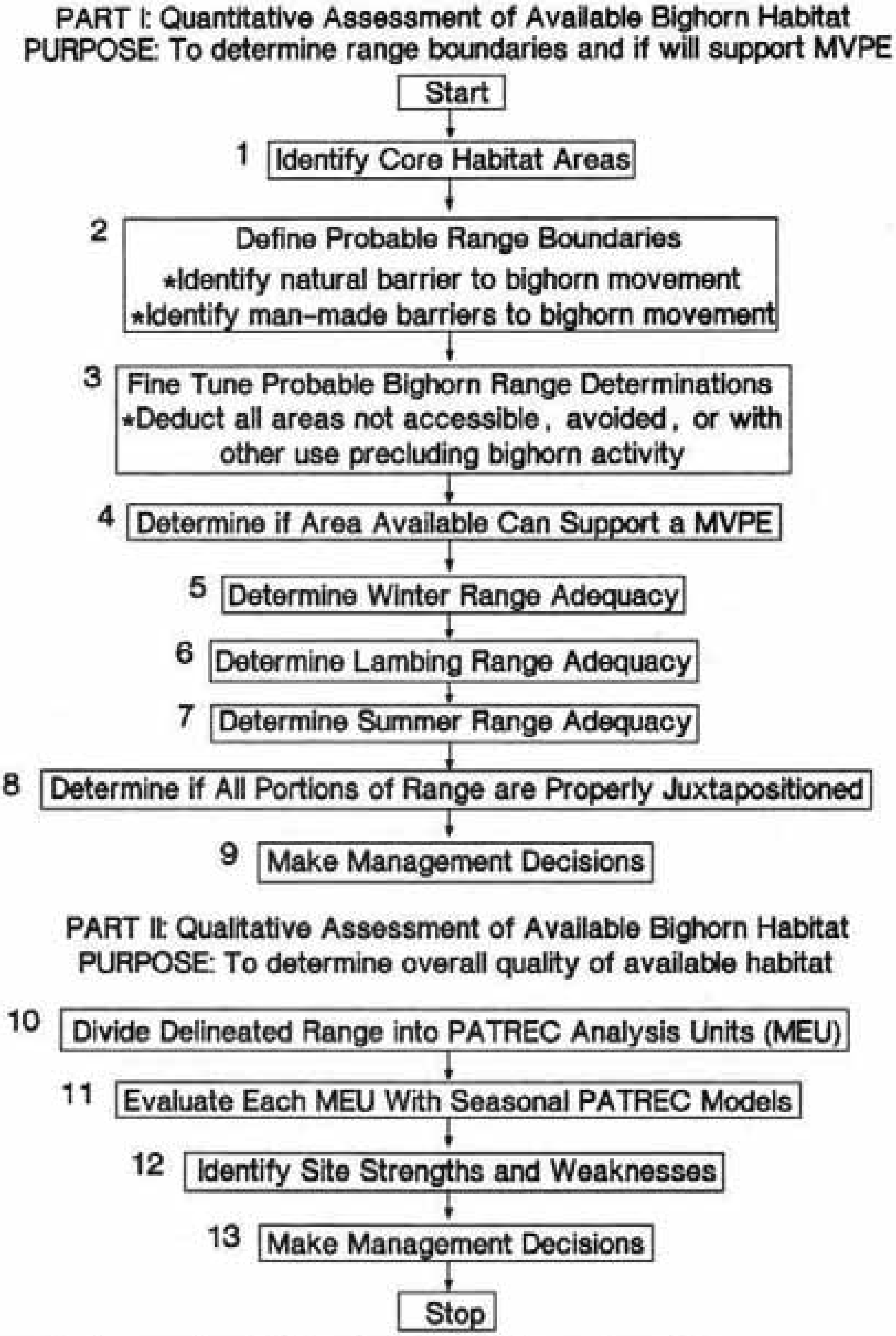

Figure 1. An overview of the Rocky Mountain bighorn sheep HEP.

frequently impact bighorn ranges and preclude bighorn use. Linear arrays of human activity can form barriers to movement. These have to be evaluated individually and range boundaries drawn accordingly.

Step 3--Within the limits of the probable bighorn range boundaries determined thus far, the following areas should be identified and deducted:

A. Areas Beyond 3.2 km Of Bighorn Watering Sources

1) McQuivey (1978) noted that 85 percent of bighorn activity occurred within 3.2 km of water. Brundige and McCabe (1986) reported that all bighorn in Custer State Park, South Dakota remained within 1 km of watering sources. Though not normally limiting to Rocky Mountain bighorn sheep, sparse water resources can impose a delimiter upon range size.

B. A 100 m Wide Buffer Around Areas Of Low To Moderate Human Use

1) Areas typical of low-to-moderate human activity include trails, roads, dwellings, and some campgrounds. Many have noted the negative effect of human activities upon bighorn sheep (Gionfriddo and Krausman 1986, Hicks and Elder 1979). Light (1971) defined "light use" as 0 to 100 visitors a year, "moderate use" as 100 to 500 visitors, and "high use" as over 500 visitors a year on backcountry trails. He reported that bighorn stayed 100 meters or more away from moderate use areas.

C. A 150 m Wide Buffer Around Areas Of High Intensity Human Use

1) Areas typical of high intensity human activity include airports, mines, tramways, campgrounds, ski resorts, and heliports. Identify and buffer these areas with a 150 m zone, excluding it from potential bighorn ranges. These should be evaluated individually in every occurrence.

D. All Plant Communities Typified By Horizontal Visual Obstruction Of Greater Than 50 Percent

1) Work by Smith and Flinders (1991) and Risenhoover and Bailey (1980) has indicated that bighorn avoid areas of poor visibility. Identify these vegetation types and exclude them from bighorn range considerations. Refer to Smith and Flinders (1991) for methods used in determining horizontal visibility within specific vegetation types.

E. All Portions Of Range Allowing Potential Contact With Domestic Sheep Or Goats At Any Time

1) Any portion of range which might allow bighorns and domestic sheep, or goats, to make contact should be excluded from consideration. Contact has been linked to catastrophic die-offs and should be avoided at all costs (Capurro 1988, Foreyt 1988).

F. All Portions Of Range Which Are Occupied By Concentrations Of Elk, Cattle or Bison

1) If portions of potential bighorn range will concurrently have concentrations of elk, cattle or bison present, managers should consider excluding them as potential bighorn ranges. Besides competing directly for the same forage resources (Van Dyke et al. 1983), disease transmission (Jessup 1981), and social intolerance (King and Workman 1984) are additional reasons for excluding potentially sympatric elk, cattle, bison and bighorn ranges from consideration as critical bighorn use areas. That these large

ungulates often totally displace bighorn has been well documented therefore individual conflicts must be carefully evaluated.

After deducting the above areas identified in 3A-3F from the range boundaries defined in steps 1 and 2, the remaining area represents the maximum range available to bighorn sheep if introduced to the area.

Step 4--Is there enough range, regardless of quality at this point in the evaluation, to support a MVPE of at least 125 bighorn sheep? Van Dyke et al. (1983) suggested a maximum density of bighorn sheep of 1.9 per km^2 (5 per mi^2) for the Great Basin in southeastern Oregon. If this held true for other sites of the western Rocky Mountains and Great Basin regions, then a minimum area of 65 km^2 (25 mi^2) of habitat would be required to support 125 bighorn sheep. However, densities ranging from less than 0.4 bighorn per km^2 (1 per mi^2) (McQuivey 1978) to over 27 per km^2 (70 per mi^2) (Demarchi 1965) have been reported in the literature. Unfortunately, all reported densities appear to have been calculated for areas which included both usable and unusable portions of range. For example, McQuivey (1978) calculated bighorn densities using polygons which encircled all observed bighorn sightings for each herd. As a result, he included unusable habitat with the usable portions. Demarchi (1965) reported that although the mean density of bighorn for the Chilocotin River area was 4.7 per km^2 (12.1 per mi^2), key grassland areas supported as many as 27 bighorn per km^2 (70.4 per mi^2). From an extensive literature review and research in northeastern Utah, the following guidelines are suggested:

(1) The area defined in Step 2 (no deductions yet made of unusable portions) should not be expected to support more than an average of 3.9 bighorn per km^2 (10 per mi^2). This means that there must be at least 32 km^2 (12.5 mi^2) of habitat identified to the level in Step 2 to support at least an MVPE of bighorn sheep.

(2) The area defined in Step 3 (all deductions of unusable portions of range) should not be expected to support more than 7.7 bighorns per km^2 (20 per mi^2). This means that there must be at least 17 km^2 (6.5 mi^2) of critical habitat identified to the Step 7 level to support at least a MVPE of bighorn sheep.

(3) Proposed ranges with an abundance of grassland can be expected to support somewhat more than the above estimates, whereas those with less grasslands will probably support less. Minor adjustments in carrying capacity estimates which reflect the abundance of grasslands is justified.

This exercise of estimating a range's approximate carrying capacity serves to alert wildlife biologists of areas which are too small to support at least 125 bighorn sheep. Although these minimum area values are crude estimates at best, they do represent reasonable minimums, and as such, should be seriously considered when evaluating potential bighorn release sites. If a proposed release site is so limited in size that these suggested area minimums cannot be closely matched, or exceeded, bighorn transplant efforts should perhaps be directed on ranges elsewhere.

Step 5--This step directs the user to determine the probable extent of winter ranges present as follows:

A. Select All Areas Within 300 m Of Escape Terrain

1) Areas of up to 1000 m from escape terrain may also be included when bounded on 2 or more sides by escape terrain (see step 1 above).

B. Within Areas Selected in Step 5A, Identify All Areas Receiving Less Than 25 CM Of Accumulated Snow

1) Heavy snow accumulations can render potential winter range areas unusable (Smith and Flinders 1991, Johnson 1983). Research in northeastern Utah indicated that when snow depths exceeded 25 cm bighorns abandoned those portions of winter range, rendering them useless.

C. Of Those Areas Selected In Step 5B, Identify All With Southern Exposures (SW-S-SE)

1) Studies which have addressed winter range requirements have consistently noted that key winter ranges are typified by southern exposures (Smith and Flinders 1991, Johnson 1983). Identify these areas.

D. Determine The Total Area Of Potential Winter Range From Those Areas Which Fit The Criteria In Steps 5A-C Above

1) Add the areas and calculate the total area of available winter range.

Step 5 serves to warn biologists when a proposed release site is deficient in critical winter range area. How much winter range is enough? Coggins (1980) reported winter range densities of 31 bighorns per km^2 (80 per mi^2) for the Lostine River herd of Northeast Oregon. Woodgerd (1964) and Blood (1963) both reported winter range densities of 19 to 23 bighorns per km^2 (50 to 60 per mi^2). In light of these, and other reports, winter ranges should be able to conservatively support 20 bighorns per km^2 (about 50 per mi^2). Therefore, to sustain a MVPE of 125 bighorns a transplant site should have at least 6.5 km^2 (2.5 mi^2) of available winter range.

Step 6--Step 6 directs the user to determine the probable extent of lambing ranges present on the site under evaluation. In some instances, inadequate quantities of lambing terrain have been cited as the ultimate factor controlling bighorn herd size (Hansen 1982). To proceed with Step 6, identify and select those areas meeting the following criteria:

A. All Areas Identified As Potential Escape Terrain

1) These areas were already identified in Step 1 above.

B. Of Areas Identified In Step 6A, Select All Southerly Aspects

1) Lambing areas are most commonly found with southern exposures (Smith and Flinders 1991, Van Dyke et al. 1983, Geist 1971). Research in northeastern Utah indicated that all lambing areas fell between aspects from 100° (ESE) to 225° (WSW). Select those escape terrain areas which fit these aspect criteria.

C. Of Areas Identified In Step 6B, Select Those Which Are Horizontal Visibility Exceeding 80 Percent

1) Visibility was measured along predator approach pathways, not into, or over, cliffs (Smith and Flinders 1991). Bighorns actively select against poor visibility areas.

D. Of Areas Identified In Step 6C, Select All Portions Within 1000 m Of Water Sources

1) Because of the demands of lactation and the inability of young lambs to travel far, water sources need be within, or adjacent to lambing areas (Van Dyke et al. 1983). Research from northeastern Utah (Smith and Flinders 1991) suggested a maximum distance from water of 675 meters, beyond which, the quality of lambing terrain declined rapidly. For this evaluation, areas beyond 1000 meters of water do not contribute significantly to lambing terrain.

E. From Areas Identified in Step 6D, Deduct Those That Are Less Than 2 Hectares (5 Acres) In Size

1) Van Dyke et al. (1983) suggest that ewes select rugged cliff areas for lambing only those which are greater than 2 hectares in size. However, if the area is remote, extremely rugged and harassment is low, parcels of 1 hectare (2.5 acres) may be used (Van Dyke et al 1983). For this bighorn habitat assessment, unless the country is extremely rugged and isolated, areas less than 2 hectares should not be included as potential lambing terrain.

F. Of Areas Which Satisfied Steps 6A-E, Determine The Total Hectares Of Potential Lambing Terrain

1) Sum the total area of probable lambing terrain as identified in steps 6A-E above.

Step 6 assists identification of sites deficient in critical lambing terrain. Though reported bighorn age/sex ratios vary widely, a MVPE population of 125 would have approximately 50 to 60 breeding ewes at best (inferred from data from Smith et al. 1988a, McQuivey 1983). Holl (1982) conducted research which showed that 60 hectares of escape terrain were needed to support 10 ewes in the San Gabriel Mountains of southern California. If this relationship held true for the western Rocky Mountain and Great Basin Regions, at least 300 to 360 hectares (1.2 to 1.4 mi^2) of quality escape terrain would be required to support ewes during lambing. At present, data are unavailable from this region to allow calculation of the ewe-to-hectares of escape terrain relationship. Therefore, it is recommended that at least 360 hectares (1.4 mi^2)of escape terrain, as classified in steps 12A-F, be available for use as lambing terrain.

<u>Step 7</u>--Step 7 instructs the user to estimate the amount and location of summer ranges present on the site being evaluated. In some instances, inadequate quantities of summer range have been cited as the key factor limiting bighorn herd size (Arnett et al. 1990). Summer ranges, as defined here, refer to those areas utilized by all bighorns not involved in lambing activities (May through August). This non-lambing group includes the mature ram cohort (4-year olds and older), yearlings, 2-year old ewes, young rams up to about 3 years of age and barren ewes. While these non-lambing sheep occupy summer ranges, ewes are on lambing ranges. To proceed with Step 7, identify areas meeting the following criteria:

A. Identify Escape Terrain Buffer Areas (up to 300 m from the cliffs)

1) These areas were already identified in Step 1 above, and will be typified by slopes of less than 60 percent.

B. Of Areas Identified In Step 7A, Select Those Which Are Typified By Horizontal Visibility Exceeding 80 Percent

1) Bighorns avoid areas of poor visibility so only those areas of high visibility should be selected as candidates for quality summer ranges.

C. Of Areas Identified In Step 7B, Select All Portions Within 3.2 km Of Usable Water Sources

1) As discussed in 3A above, ranges farther than 3.2 km from water sources do not contribute significantly to bighorn habitat and should be excluded from consideration as summer ranges.

D. Determine The Total Hectares of Potential Summer Range From Those Areas Which Satisfied the Criteria of Steps 7A-C

1) Calculate the total area of ram summer ranges as identified in steps 7A-C above.

Step 7 helps identify areas deficient in summer range quantity. As discussed in Step 6, a MVPE population of 125 bighorns would have approximately 50 to 60 breeding ewes at best (inferred from data from Smith et al. 1988a, McQuivey 1983, Holl 1982), leaving approximately 65 to 75 non-breeding bighorn to occupy the summer range areas. Step 4 indicated that ranges could not be expected to support more than 7.7 bighorns per km^2 (20 per mi^2). Therefore, to support 65 to 75 bighorns on summer range there should be at least 8.4 to 9.7 hectares (3.3 to 3.8 mi^2) of qualifying range.

<u>Step 8</u>--The quantity, quality and juxtaposition of forage, water and escape terrain (the 3 crucial bighorn habitat components) have a strong influence upon bighorn population size and health (Van Dyke et al. 1983, Hansen 1982). In optimum bighorn habitats, water sources and escape terrain are dispersed throughout forage areas thereby promoting herd dispersal and less impact upon plant communities by overuse. If escape terrain, water, or forage is not intermixed throughout a bighorn range, this represents a suboptimal situation. If additionally, other critical elements of bighorn ranges are weakly met or absent (total area, winter ranges, or lambing terrain), the area being evaluated is probably unsuitable for a bighorn reintroduction until management alleviates the problem(s).

<u>Step 9</u>--Part I has provided many opportunities for identification of range weaknesses and strengths. If insurmountable habitat problems were encountered, then further evaluation (application of Part 2) of the proposed bighorn sheep ranges is moot. If, however, the ranges appear to satisfy the minimum criteria discussed, then proceed with Part 2 of this habitat evaluation procedure.

Part 2: Qualitative Assessment Of Available Bighorn Habitat - PATREC

Now that an estimation of the maximum area available for a transplant herd has been determined, an estimate of range quality may be desired. A high quality bighorn range, capable of supporting at least an MVPE of bighorn year-round, must meet the varying needs of herd members seasonally (Holl and Bleich 1982). Because of the varying, seasonal demands experienced by different bighorn cohorts, 3 separate PATREC models have been constructed (Tables 1-3). Three models enable analysis of habitat from each unique perspective.

Part 2 of this procedure has been specifically designed with data obtained from the Bear Mountain bighorn herd of northeastern Utah. Wildlife managers will need to recognize that some habitat-related questions may not be applicable to places other than the Bear Mountain area. However, because each specific PATREC question addresses an important habitat variable, managers should attempt to attain the correct values for that variable for the area in question.

The following discussion is based on the step-wise procedure outlined in Figure 1. The numbers to the left of each step in Figure 1 correspond to the following numbered steps.

Step 10--Divide the identified bighorn habitat polygon(s) into PATREC model evaluation units (MEU) for analysis of habitat quality. PATREC models cannot be "blanket applied" to an entire bighorn range simultaneously. The range must be sub-divided into meaningful analysis units which are then subsequently evaluated. A suggested MEU size is 16.2 hectares (40 acres), although biologists can adjust the MEU's area as needs dictate. However, as MEU size increases, model resolution will become coarser and high quality portions of the range may pass unnoticed or their quality down-graded when averaged with adjacent areas of lesser quality. Nevertheless, each application must be individually evaluated. Mylar overlays on topographic maps can provide the necessary analysis grid of MEU's. A data sheet should be constructed which contains a unique label for referencing each MEU and its associated PATREC posterior probability.

Step 11--Each MEU should be evaluated using the 3 sub-models (Tables 1-3). If a user suspects that adequate lambing terrain is the probably inadequate for a particular site in question, then he may choose to apply only that PATREC sub-model, forgoing the other 2, feeling summer and winter ranges are adequate. Similarly, any other seasonal range suspected of being deficient can alone be analyzed.

Site evaluations compare each site's habitat qualities with the habitat attributes listed in each of the PATREC models. Note that sometimes "OR" separates some attributes. This means that the user may choose any one of the attributes linked by "OR" but none of the others for analyzing the chosen MEU. This is because an underlying premise of PATREC is that individual habitat attributes are independent of one another and in these cases "OR" separates those clearly interdependent. This gives the user freedom to choose the attribute for which the most data are available. If the site meets the criteria of each habitat attribute, then the high and low conditional probabilities associated with each (as listed in the 2 right-hand columns) are used in calculation of the site's overall high and low density probabilities. When habitat attribute criteria are not met by the site, each high and low conditional probability is subtracted from 1.0 and the result recorded for use in subsequent calculations. Referring to Table 1, suppose the MEU being analyzed is not over 7250' in elevation. The probabilities recorded are 1.0 - 0.78 (0.22) for high and 1.0 - 0.30 (0.70) for low.

PATREC model outputs are expressed as a probabilities. These probabilities indicate the likelihood that the tract of land being evaluated will support a high density population and the probability it will support a low density population. The sum of these 2 probabilities (high and low) is 100%, so if a MEU has a 90% probability of supporting high densities of sheep, the likelihood of it supporting a low density population of sheep is 10%. Computations to provide the final outputs are quite simple and can be done by hand, although not recommended. A hand-held calculator or a computer is much faster than by hand. Once the required inventory data (appropriate site characteristics) are gathered from a MEU and compared against the habitat attribute criteria, the resulting conditional probabilities P(ID/H) and P(ID/L)) calculated. P(ID/H) is calculated by multiplying all probabilities listed in the Conditional Probability - High column together. Remember that in some cases 1.0 minus the listed probability is used when the habitat attribute is not met by the site. P(ID/L) is calculated the same way, only using those probabilities listed, or 1.0 minus them when not met, in the right hand column of the tables. Together, these 2 conditional probabilities are utilized in Bayes Theorem as follows:

$$P(H/ID) = \frac{P(H) \text{ X } P(ID/H)}{P(H) \text{ X } P(ID/H) + P(L) \text{ X } P(ID/L)}$$

Where P(H/ID) is the probability that the MEU will support a high density population based on the inventory data. P(H) and P(L) are the probabilities of a high or low density area (prior probabilities) naturally occurring. For all 3 PATREC models the prior probabilities for High and Low have been assigned the values of 0.30 and 0.70 respectively because field experience in northeastern Utah suggests that only 30 percent of the time would one encounter a parcel of land with those qualities which make it of high value for bighorn sheep, the rest is low. These ratios of high to low quality land refer only to land within 300 meters of escape terrain, not beyond it. As discussed, all land beyond 300 meters has a probability near zero of being bighorn habitat at all. These values can, and should, be changed to local situations when the proportion of high to low habitat is clearly different. P(ID/H) and P(ID/L) represent the probabilities the inventory data have a high or low density potential, respectively (conditional probabilities). An example here will illustrate how Bayes Theorem is used.

Suppose a particular MEU was evaluated and it was found that only habitat attributes 2A, 6, and 7 of the spring-summer bighorn ram model (Table 1) were satisfied. To calculate the probability that this site is one which would support high densities of bighorns, the value for P(ID/H) and P(ID/L) must be calculated. Since attributes 2A, 6 and 7 were met by site criteria, use the probabilities recorded in each column. However, when attributes are not met by the site, (numbers 1, 3, 4C, and 5), both high and low conditional probabilities must be subtracted from 1. As a result the following calculations are performed:

$$P(ID/H) = (1-.78)(.67)(1-.89)(1-.67)(1-.67)(.67)(.78)$$
$$= .000922757$$

$$P(ID/L) = (1-.30)(.20)(1-.30)(1-.40)(1-.10)(.01)(.33)$$
$$= .000174636$$

These conditional probabilities are then substituted into Bayes Theorem as follows:

$$P(H/ID) = \frac{(0.3)(0.000922757)}{(0.3)(0.000922757 + (0.7)(0.000174636)}$$
$$= 0.69$$

$$P(L/ID) = 1.0 - 0.69 = 0.31$$

From these inventory data it is concluded that the probability of the MEU being capable of supporting a high density population is 0.69, or 69%. Conversely, the probability of that same area supporting a low density population would be 0.31 or 31%. Simply stated, given the pattern of habitat features present on the site, this site has a greater chance of supporting high densities of sheep than low (69% versus 31%).

<u>Step 12</u>--If through PATREC model analysis habitat deficiencies are identified (the models indicate which attributes are related to high quality habitats), management may choose to focus first on these. Some deficiencies, such as insufficient cliff escape terrain, obviously cannot be corrected.

<u>Step 13</u>--PATREC models provide some insight as to what management could do to improve the area for bighorn sheep. By trying various "What if?" scenarios managers can also get a feel for which project will return the most for their effort. For example, if horizontal visibility if low due to shrub cover, the impact of converting that shrubland to grass by burning or some other method, can be projected by recalculating the resulting probability using the now met attribute's associated probabilities for high and low. In this way, management can get a feel for which habitat project will return the greatest improvement in habitat quality. Cost can also come into consideration. Although a particular habitat treatment may yield the greatest improvement in overall suitability for bighorn sheep, cost associated with that treatment may be prohibitive. However, once the differential in cost is calculated for each management scenario, the plan of action which will return the most for the effort invested will become much easier to determine.

For an entire range, one must sum up the calculated P(H/ID)s for all MEU's and determine the mean value. This value represents the overall range quality and should indicate to managers whether a high or low quality range has been inventoried, what its deficiencies are and give some insight as to how they should be remedied.

This concludes application of Part 2 of the Bighorn HEP. Upon completion of bighorn habitat evaluation, the investigating biologist should know whether or not a site in question could support reintroduced bighorn sheep and what can be done in the event limiting factors need attention.

CONCLUSIONS

Although efforts have been underway for several decades to reestablish Rocky Mountain bighorn sheep to formerly occupied ranges, many transplant efforts have failed. In particular, the state of Utah's Rocky Mountain bighorn sheep reintroduction program, as well as those in other locations, has failed to significantly place bighorn onto former ranges. In order for Utah, and perhaps other western states, to have a more successful reintroduction program a more rigorous, biologically-based, habitat assessment procedure is presented here. In this way doomed-from-the-start reintroductions will be avoided and transplant success greatly enhanced. It is believed that application of this procedure will insure greater transplant success as well as direct management to the most effective habitat treatments.

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Table 1. Habitat evaluation model (PATREC) for spring-summer bighorn ram ranges of northeastern Utah (Prior probabilities P(H) = High = .30; P(L) = Low = .70)

Habitat Attributes	Conditional Probabilities High	 Low
Terrain		
1) The area is over 7250′ elevation.	0.78	0.30
2) The area's average slope is:		
a) less than 6 °.	0.67	0.20
b) 6 ° to 15 °.	0.22	0.20
c) greater than 15 °.	0.11	0.60
3) Less than 50% of the area is comprised of escape terrain.	0.89	0.30
Vegetation		
4a) The area has horizontal visibility greater than 90%.	0.67	0.10
OR		
4b) Tree canopy cover is less than 10%.	0.89	0.60
OR		
4c) Average shrub height is less than 0.5 meters.	0.67	0.40
5) Grass, forb and shrub cover is greater than 15%.	0.67	0.10
6) The area has sage-bitterbrush associations present (must be a combined cover ≥ 10% and > 1 acre in size)	0.67	0.01
7) The area supports greater than 250 kg per hectare (dry weight) of grasses and forbs.	0.78	0.33

Table 2. Habitat evaluation model (PATREC) for fall-winter bighorn ranges of northeastern Utah (Prior probabilities P(H) = High = .30; P(L) = Low = .70)

	Conditional Probabilities	
Habitat Attributes	High	Low
Terrain		
1) The area is over 7000′ elevation.	0.90	0.20
2) The area's average slope is:		
a) less than 6 °.	0.60	0.20
b) 6 ° to 15 °.	0.30	0.01
c) greater than 15 °.	0.10	0.79
3) Less than 20% of the area is comprised of escape terrain.	0.90	0.30
Vegetation		
4a) Tree canopy cover is less than 5%.	0.90	0.40
OR		
4b) The area has horizontal visibility greater than 90%.	0.90	0.40
OR		
4c) Average shrub height is less than 0.4 meters.	0.90	0.40
5) Grass and forb cover is greater than 14%.	0.70	0.20
6) The area supports greater than 300 kg per hectare (dry weight) of grasses and forbs.	0.80	0.10

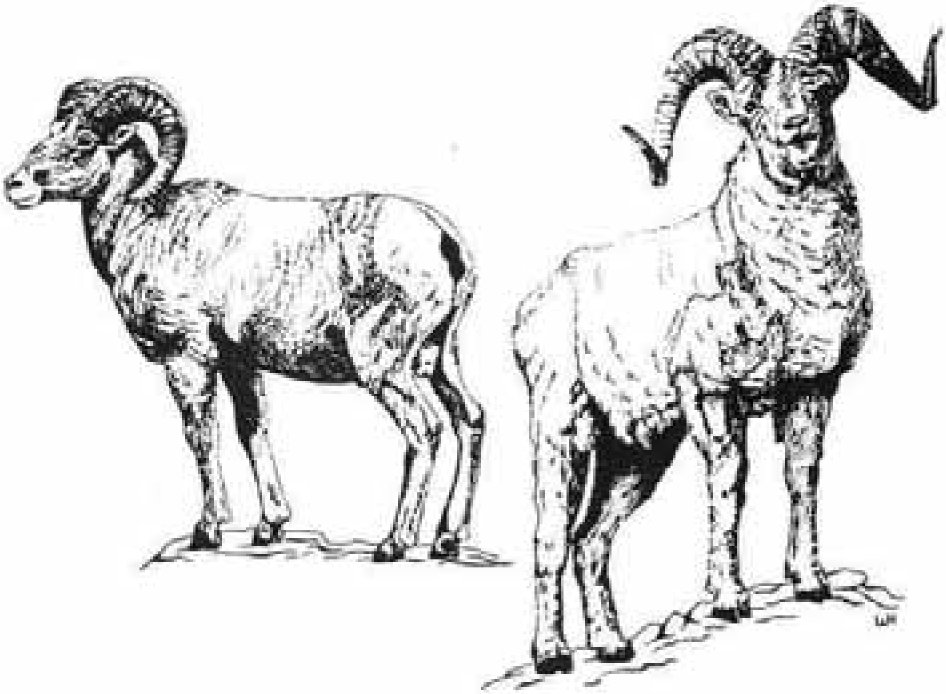
Table 3. Habitat evaluation model (PATREC) for spring-summer bighorn lambing ranges of northeastern Utah (Prior probabilities P(H) = High = .30; P(L) = Low = .70)

Habitat Attributes	Conditional Probabilities High	 Low
Terrain		
1) The area is below 6400' elevation.	0.67	0.44
2) The area's average slope is:		
a) less than 35 °.	0.11	0.33
b) 35 ° to 40 °.	0.77	0.01
c) greater than 40 °.	0.12	0.66
3) More than 75% of the area has aspects between 180-270° from north.	0.67	0.11
4) Water is present on the site.	0.89	0.44
Vegetation		
5a) Tree canopy cover is less than 6%.	0.55	0.33
OR		
5b) The area has horizontal visibility greater than 80%.	0.77	0.99
6) The area has shrub cover less than 6%.	0.99	0.43

WORKSHOP:

HARVEST REGULATIONS

FOR WILD SHEEP



FORWARD TO THE WORKSHOP REPORT ON MANAGEMENT REGULATIONS AND LEGAL DEFINITIONS, NORTHERN WILD SHEEP AND GOAT COUNCIL. CLARKSTON, WASHINGTON 14-18 MAY, 1990.

by

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Management of mountain sheep harvest in North America is accomplished through a bewildering array of regulations and definitions. These regulatory definitions exist for a variety of reasons, and are surprisingly dynamic. Whenever further regulatory changes are considered, seemingly logical questions include: "What are other Provinces or States doing?" "Why are they doing it?," and "How well is it working?" In order to provide current answers to these questions, the Northern Wild Sheep and Goat Council organized a workshop on this topic in 1990.

Presentations were solicited from all participating States and Provinces, and papers were requested. The following collection of papers was submitted.

After listening to the presentations and editing these papers, it is my conclusion that the question, "What are other Provinces or States doing?" is less relevant than why they are doing it and how well it is working. This is because the challenges of mountain sheep management differ, particularly with latitude.

Sheep management challenges south of Northern British Columbia appear to be generally different from those farther north. Northern populations exist in pristine, or near-pristine ecosystems, and are influenced by contrasting climatic influences, forage production regimes, and predator abundance. As a result, management goals, which determine regulatory direction, are oriented toward population maintenance or enhancement in the provinces of northern Canada and Alaska. In these areas, management for harvesting rams as trophies and minor restrictions on hunter participation are the predominant practices.

In most of the Western U.S. and in Southern Canada, mountain sheep do not exist in habitats which approach pristine quality except in small isolated populations or in National/Provincial parks. Many sheep populations have been introduced, and many compete with domestic livestock. These populations often do not have access to routes, or have not developed migratory traditions which take them to alpine ranges. Hence, food resource situations are highly variable. Ironically, the success of transplant programs, antihelminthic drugs, and lack of effective predators in temperate climates has put the lower latitude states and provinces into many situations where management program goals call for population reduction or maintenance at low densities. Furthermore, most harvest is closely regulated by limited-entry permit; and either-sex harvests and "any ram" seasons are becoming increasingly popular.

To compound this irony, the traditional ideal, stalking a mature ram in wild country, which drives sheep conservationists to fund and support these successful sheep enhancement and restoration programs, has frequently produced management situations which diverge radically from the ideal conservationists envisioned. Managers may be well advised to enhance communications with those who support sheep conservation and management programs to minimize the chances this divergence will disrupt a highly productive partnership.

To reiterate, what is being done is less important than why it is being done and how well it is working. Consequently, readers may wish to pay particular attention to the sections on biological rationale and pragmatic considerations. The Council hopes this group of papers will be helpful.

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and Goat Counc. 7:232-239.

DALL SHEEP HARVEST REGULATIONS IN ALASKA 1990

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Abstract: Dall sheep rams are harvested in Alaska as a result of 3 types of recreational hunting experiences: the opportunity to harvest trophy Dall rams, the opportunity to hunt mature rams under aesthetically pleasing conditions, and the maximum assured opportunity to hunt mature rams. In addition, some subsistence sheep hunting occurs for both sexes, and one limited-participation permit hunt for "any sheep" is currently offered. Restrictions on participation, transportation methods, and harvest vary according to management goals and objectives for each type of hunting experience.

Dall sheep (*Ovis dalli dalli*) population maintenance and enhancement are the management objectives in most of Alaska, and harvest of mature rams is the dominant harvest management practice. This is the result of tradition, and the 1989 conclusion of the Alaska Board of Game (the regulatory authority for Alaska's wildlife), that only in unusual circumstances is either-sex harvest a viable hunting management strategy. The Board's position is in substantial agreement with the published working hypothesis for Dall sheep management (Heimer 1988).

EXISTING REGULATIONS

In all of Alaska, except the Brooks Range, recreational hunting is limited to harvest of mature full-curl rams. According to current regulations, the term, full-curl, means:

> (A) that the tip of at least one horn has grown through 360 degrees of a circle described by the outer surface of the horn, as viewed from the side or
>
> (B) that both horns are broken, or
>
> (C) that the sheep is at least eight (8) years of age as determined by horn growth annuli.

In the Brooks Range, the legal minimum horn development required for recreational hunting is 7/8-curl. According to regulations, seven-eighths curl horn means that the horn tip "has grown through seven-eighths of a circle (315°), described by the outer surface of the horn, as viewed from the side, or with both horns broken." In the Brooks Range, where subsistence use follows aboriginal traditions, and in Game Management Units 11 and 14C the legal definition is "any sheep."

Most hunters are limited to 1 sheep per year. Subsistence hunters in the Brooks Range may take 3 sheep per year. In the permit-controlled trophy hunt (Heimer, 1985), successful permit hunters are limited to 1 full-curl ram every 4 years.

BIOLOGICAL/GEOMETRIC RATIONALE

Recreational Hunting Management Rationale

Data gathered in Alaska show that Dall sheep population productivity is significantly and positively correlated with higher ram ratios ($P < 0.01$ from Nichols 1978; $P < 0.02$ from Heimer and Watson, unpubl. data). Other data relating ewe fecundity to environmental variables indicate ram abundance as the most probable cause of this relationship (Heimer and Watson 1986a). Additionally, inference from the behavioral biology of mountain sheep in rut suggests this strong correlation is a plausible result of the presence of more adult rams (Geist 1971). Finally, sustainable ram harvests have increased to previously unexpected levels following changes from 3/4- to 7/8- and then to full-curl harvest regulations in Alaska (Heimer and Watson 1990). Consequently, harvest regulations where population maintenance or growth is a management objective are now designed to assure that ewe fecundity, ram abundance, and age structures are not significantly affected by human hunters.

The behavioral ecology of Dall sheep appears to require the effective presence of Class III and IV rams (Geist 1968) for maximal productivity and survival. Heimer and Watson (1986a, 1986b) observed that compromised ewe fecundity accompanies maximum 3/4-curl harvests (which virtually eliminated Class III rams and lowered ram:100 ewes ratios below 20:100). This decreased fecundity was reversed and subsequently increased to match that of a lightly hunted (at full-curl) population following establishment of the 7/8-curl regulation. The restriction of harvest to 7/8-curl rams protected all rams in Classes I, II, and III and led to observed ram:ewe ratios averaging approximately 40:100. Harvests from these populations increased following experimental restriction to full-curl regulation (Heimer and Watson 1990). Consequently, the Alaska Board of Game has limited recreational harvest to Class IV (full-curl) rams throughout the state except for the Brooks Range.

Geometric Rationale

Dall rams grow horns throughout life, and these horns typically describe a helix, like the threads on a machine bolt. When viewed down the axis of this helix, the outer surface of a full-curl horn describes a circle. As seen from this aspect, the tip of a full-curl ram's horn will "meet" the anterior edge of horn base where it emerges from the hair. Full-curl rams fall into Geist's Class IV, rams which are physically and behaviorally mature (Geist 1968).

The average time required for Dall rams to reach full-curl horn development is 8 years (Heimer and Smith 1975), hence the inclusion of the 8 years of age criterion in the legal ram definition. Age 8 years also corresponds to the age at which ram mortality typically increases in mountain sheep (Geist 1971:295). In summary, rams are made available for harvest only after they have reached full physical and behavioral maturity and have a relatively high probability of natural death. At this point, the average ram has achieved 94% of its maximum expected horn development (Heimer and Smith 1975).

The "both horns broken (broomed)" criterion is included because a significant fraction of Dall rams do broom both horns and might not be available for harvest except under the age criteria if this provision were not included. The frequency of broomed horns among Dall rams increases with age, and it is unusual for a Dall ram to have both horns broken before the age of 8 years or Class IV status (W. Heimer, unpubl. data).

ENFORCEMENT/PROSECUTION

During the last 20 years, an average of 2 arrests per year were made for taking rams less than 3/4 or 7/8 curl (Lt. R. Boutang, Div. Fish and Wildlife Protection, pers. commun.). There are no records of conviction after trial for sublegal 3/4- or 7/8-curl horn violations. Under full-curl regulations, 3 hunters were arrested for taking undersized rams in 1989 and 4 in 1990. None of the hunters charged with these violations has elected to stand trial. All of these cases where prosecutors were willing go to trial have been resolved because the defendants were persuaded to plead guilty.

The low number of arrests for violation of minimum horn size regulations probably reflects the vast size of Alaska relevant to the force of enforcement personnel, the tradition of compliance with regulations among sheep hunters, the abundance of legally harvestable rams, and the vague legal definitions of 3/4- and 7/8-curl horns. The apparent increase in number of arrests under the full-curl regulation is a result of enforcement personnel feeling more confident in arresting violators. Also, prosecutors are more likely to pursue a case to trial because the definition of full-curl is much less subjective (Lt. R. Boutang, Div. of Fish and Wildlife Protection, pers. commun.).

INTERPRETATION TO HUNTERS IN THE FIELD

In the past, the 3/4-, 7/8-, and full-curl regulation have been interpreted to hunters in the field through a line diagram in the regulation book. However, these sketches have been of poor quality and confusing to hunters. They have also compromised prosecutions in the past. These sketches have been replaced by photographs.

During 1984, the first year of experimental full-curl hunting, a significant number of notably young, small rams were taken (approximately 15% of the reported harvest). Following a hunter information program, consisting mainly of distributing a brochure to hunters (Appendix A), the number of small rams fell to approximately 2% of the reported harvest even though the harvest increased by 49%.

PRAGMATIC CONSIDERATIONS

Subsistence Hunting

Subsistence hunting is legislatively mandated in Alaska, and the subsistence hunting regulations have been essentially unchanged since 1980 (Heimer 1985). When these regulations were first established, no information on the effects of subsistence hunting was available. In the presence of a legislative mandate and the absence of data, it was assumed that the effects of subsistence hunting would not negatively affect sheep populations, and subsistence harvest quotas consistent with perceived need were established. A voluntary harvest reporting program was established to monitor subsistence harvest of sheep. Until recently, there has been little obvious indication that the assumptions of 1980 were incorrect. I think this is because subsistence hunting for Dall sheep is not widely practiced and has not been closely studied. The reasons it has not been closely studied include the facts that it is largely confined to National Parks where wildlife management is not an option, that subsistence hunting is a politically sensitive subject, and that it is a low priority given its localized nature.

7/8-Curl and Any-sheep Seasons

Establishment of hunting regulations in Alaska may be the most democratic exercise of wildlife management in the world. Any person, agency, or interest group may submit regulatory proposals to the Alaska Board of Game, and all proposals are considered by the Board according to a predetermined schedule. The Alaska Department of Fish and Game submits proposals, advises the Board of their biological/management relevance, and often makes recommendations for acceptance or rejection of the proposals submitted by others. After consideration of all inputs, the Board of Game, a politically appointed "citizen's board", establishes the regulations it determines to be best. Under this system, regulations are established for a variety of reasons. Some serve biological rationale and promote attainment of clearly defined management objectives. However, some regulations occur as results of the democratic process and have less clear-cut management relevance. Professional managers should view these regulations as "benign noise" which accompanies the "true signal" ideally defined by carefully laid management plans. The 7/8-curl regulation in the Brooks Range and any-sheep season in management Subunit 14C near Anchorage illustrate the complexity of regulatory decision making under the Alaskan system.

The 7/8-curl regulation persists in Alaska's Brooks Range, not because of a compelling biological justification, but because of a common public misperception that Brooks Range sheep are slow-growing and small. The common misconception is that because the Brooks Range is the northernmost sheep habitat in Alaska, sheep living there must be on the ecological as well as the geographic margin of their range. Hence, this premise predicts the Brooks Range should produce rams with smaller, slower growing horns. This folklore has been perpetuated by popular writers who have published it in the hunting press (e.g., Gilcrest 1986). In fact, size and quality of ram horns from the Brooks Range are average compared with other areas of Alaska (Heimer and Smith 1975).

Data published by these authors indicate the mean expected volume, the best indicator of size, for average Alaskan Dall rams at maximum development is 2,151 cc. The expected maximum volume calculated for rams from the Brooks Range averaged 2,111 cc. Hence, by this measure, rams from the Brooks Range are only 40cc smaller than the average Alaskan Dall ram. Heimer and Smith (1975) found 7 of 18 areas within Alaska produced rams which were smaller than rams of the Brooks Range. However, Brooks Range rams do have relatively slow early horn growth, but compensate through prolonged rapid growth later. The age at average maximum growth (Heimer and Smith 1975) is 5 years for all other areas in Alaska, but 6-7 years in the Brooks Range. The result is rams of average size and typical horn development. Consequently, there is no biological justification for maintaining the 7/8-curl horn regulation in the Brooks Range.

The influence of the commercial-use industry also contributed to the Alaska Board of Game's reluctance to implement a full-curl regulation in the Brooks Range. Some members of the guiding industry maintained their livelihoods would be compromised if they had to limit harvest to full-curl rams according to their understanding of the full-curl regulation when the issue was first debated (Alaska Department of Fish and Game 1989).

Another example of democratic process is the any-sheep season in the Chugach Mountains. Repeated aerial surveys indicate sheep population sizes in this area of the Chugach Mountains near Anchorage have increased. As a result, some managers, applying the classical assumptions of cervid management, assume these ranges are overstocked or approaching nutritional carrying capacity. Hence, they recommended population reduction.

This area (Subunit 14C) is climatically influenced by the maritime weather of nearby Cook Inlet, and some managers consider these sheep populations likely candidates for a natural weather-mediated catastrophe. Consequently, managers with a maximum-use orientation suggested liberalized seasons and bag limits be established to allow human use of the standing crop before it could be decimated by weather events.

Yet another consideration is that this area produces outstanding mature rams as trophies. Given unprecedented numbers of sheep counted in the area, some biologists advanced the argument from Geist (1971) that ram trophy size will be maximized when ewe populations are well below nutritional carrying capacity. These biologists also favored population reduction.

Others pointed to the absence of data on range condition, lamb production, yearling recruitment, adult survival, and change in ram trophy quality which would suggest an impoverished population on an overexploited range. In spite of population growth, overall sheep densities on these ranges appear close to the mean reported for North American Dall sheep, 1.6 sheep/sq km (Hoefs and Cowan 1979). These biologists also cited studies which indicate horn size and quality in Alaskan Dall sheep are not functions of density-dependent nutritional constraints (Heimer 1983; Heimer and Watson, unpubl. ms.).

Further complicating this decision was the fact that accomplishing a purposeful and significant population reduction in this area through hunting is a practical impossibility. These populations live within a state park where nonconsumptive use is a high priority and participation in hunting is already regulated by a limited-availability permit drawing (Heimer 1985).

After considering of all these perspectives and weighing anticipated public reaction, the Alaska Department of Fish and Game decided not to propose any changes from the existing season limiting harvest to mature rams. Still, a proposal to reduce the density of sheep in the area was submitted by members of the Alaskan public. After deliberating, the Alaska Board of Game, for the reasons it considered most relevant, established the either-sex season for permit holders, and the season ran as scheduled. Hunters, in addition to taking a typical harvest of 49 rams with 7/8-curl or larger horns, took 31 smaller rams and 15 ewes in 1989. Clearly, this harvest from a population estimated at 2,500 sheep did not effect a significant overall population reduction. Increased public benefit accrued to those hunters (many of whom hunted with bow and arrow) who were successful in taking a sheep which would have been protected under more restrictive regulations. Still, the future of this approach to sheep harvest and population management is uncertain because of the general disfavor it has awakened among hunters who believe strongly in the traditional rams-only approach to harvest.

Try as sheep managers may to direct management along rational or data-based paths according to well-defined management plans, differing interpretations of data and unforeseen developments are certain to arise. These circumstances require constant vigilance and ever-expanding knowledge on the part of managers and users alike and maintain wildlife management in Alaska as a dynamic and perpetually interesting human enterprise.

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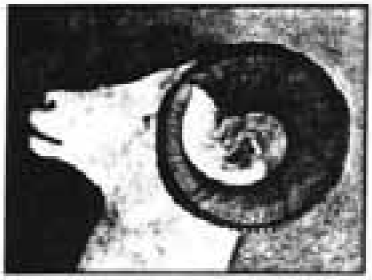
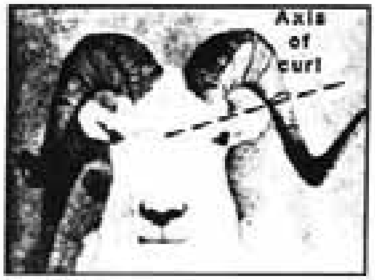
APPENDIX A

HORN "TIPS"
How to Identify a Full Curl Ram
(or the size of any ram)

The Alaska Game Regulations define a full curl horn as "the horn of a mature male Dall sheep, the tip of which has grown through 360 degrees of a circle described by the outer surface of the horn, as viewed from the side or with both horns broken."

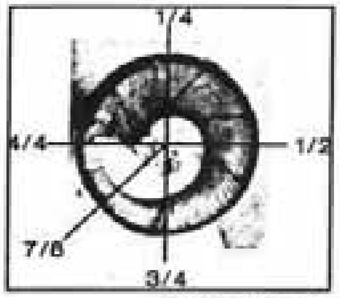
Ram horns (which are never shed) grow in a helix, like threads on a bolt, out from the head. For a ram to be full curl, the outer surface of the horn as viewed from the side must describe this perfect circle.


Full curl horn describes a circle.



Horn must be viewed along the axis of the curl to see the perfect circle.

It takes an average of 8 years for the ram's horn tip to form a circle as seen from the side. Rams with both horns broken are included in the definition of full curl. These rams are usually very old and they will die before their horns will again grow to full curl.



You can determine the degree of curl of any sheep horn by looking for the outline of the perfect circle and seeing how far around that circle the tip has grown. A 7/8 curl ram will have horns which describe 7/8ths of a circle. Three quarter (3/4) and 1/2 curl rams will have horns describing smaller portions (arcs) of the circle. Very young rams have 1/4 curl horns, similar to those of ewes.

It is important to look for the perfect circle. Less-than-full curl horns can be viewed from an angle which makes the the horn tip line up with the base. When viewed this way, the outer surface of the horn will NOT form a perfect circle. Instead, it will form a flattened circle, or ellipse.


This horn is not full curl.

If you are not sure the ram you are watching meets the minimum legal horn size for your hunting area, DON'T SHOOT.

Bienn. Symp. North. Wild Sheep
and Goat Counc. 7:240-243.

BIGHORN SHEEP HARVEST REGULATIONS IN ALBERTA - 1990

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Abstract: During the past decade in Alberta there has been an annual harvest of approximately 450 bighorns at a 1:1 sex ratio. The ram harvest is restricted by a "4/5-curl" regulation and the non-trophy harvest is restricted by permits for ewes and lambs. Problems with definitions and enforcement have been generally resolved.

BACKGROUND

There are approximately 6,000 bighorn sheep outside of the National Parks in Alberta that are available to sheep hunters. There is an unlimited entry for trophy rams for residents only and during the last decade approximately 2,800 resident hunters have harvested an average of 190 rams annually. About 90 trophy ram permits are issued to non-Canadian hunters who harvest an average of 40 rams per year. In addition, there is a non-trophy sheep season where approximately 800 limited entry permittees harvest an average of 225 ewes and lambs annually.

CURRENT REGULATIONS

The legal definitions for harvestable bighorn sheep in Alberta are as follows: trophy rams are taken under a "4/5-curl" restriction that is defined as "a male bighorn sheep with horns, one of which is sufficient size so that a straight line drawn from the most anterior point of the base of the horn to the tip of the horn passes in front of the eye when viewed in profile." A non-trophy sheep is defined as "a female bighorn sheep or a male bighorn sheep under the age of 1 year."

BIOLOGICAL/GEOMETRIC RATIONALE

With respect to the biological rationale for the horn curl law, there was none when the regulation was first introduced in 1956. The curl regulation in Alberta was the result of our neighboring province, British Columbia, introducing a 3/4-curl regulation in 1954. Apparently there was a strong demand by hunters for rams with larger horns. In Alberta there was no horn size restriction on bighorn rams prior to 1956. However, in that year we also introduced a 3/4-curl regulation to accommodate the demand for older trophy rams in the population.

The biological rationale for harvesting older rams developed later in response to the courts asking what difference does it make to the welfare of sheep herds if small rams are harvested? Our reply was that by restricting the male harvest to older rams it allowed them to reach sufficient age and size to segregate and lead younger rams to separate ranges that were not competitive with nursery herds.

Following the curl size regulation we developed a biological rationale for harvesting non-trophy sheep (Wishart 1970). Since ram production is dependent on the health and productivity of the nursery herds, our harvest strategy shifted towards maintaining the nursery herds at or near optimum production. Limited entry permits for ewes and lambs (non-trophy sheep) were introduced in 1966.

The 3/4-curl regulation was changed to a "4/5-curl" regulation in 1968. A "4/5-curl" describes that portion of a circle based on the smallest diameter of an ellipse that is presented by a ram's horn when it is viewed in profile (Figure 1). The "4/5-curl" when viewed through the axis of the horn actually describes a 3/4-curl.

There is considerable variation in the direction of the central axis of the helical ram horn where it extends from the skull. The diversity of horn angles often makes it difficult for a hunter to position himself at right angles to the central axis of a ram's horn, that is, if he is required to make a decision on what portion of a circle is circumscribed by the horn. To avoid problems in interpreting a portion of a circle, Alberta began in 1959 to use an alignment of the 3 reference points in the "4/5-curl" definition, i.e., the front of the horn, the eye, and the tip of the horn.

ENFORCEMENT/PROSECUTION

The "4/5-curl" regulation became relatively easy to enforce when compulsory registration began in 1971. Since that time, all successful ram hunters have been required to submit their ram heads to Fish and Wildlife offices for legal assessment and measurement. Since 1983, horns of all harvested bighorn rams have been required to be marked with a permanent horn plug.

Prosecution of a violator that harvests a ram with illegal horns has become more difficult in recent years as a result of having to prove that the hunter did not show "due diligence in determining the legality of the ram before he shot it." If due diligence is proven by the hunter to the satisfaction of the judge, then the case is usually dismissed. However, if it is demonstrated in the courtroom that his ram is sublegal, then the animal is turned over to Fish and Wildlife. There are about 6 cases a year in Alberta that involve sublegal ram horns.

With respect to enforcement of non-trophy sheep regulations, there is no compulsory registration and the opportunity for prosecution is a very rare event. Violations are generally due to mistaken identity between yearling rams and adult ewes.

INTERPRETATION TO HUNTERS IN THE FIELD

The legal ram and non-trophy sheep definitions have been presented to the hunters along with diagrams, photographs, or drawings on the summary pamphlets of the hunting regulations each year. Some enforcement problems developed because of poor illustrations of legal heads (Figure 2). These problems have been generally reduced in recent years with improved presentations.

PRAGMATIC CONSIDERATIONS

Extenuating circumstances which modify legal definitions, enforcement, and prosecution occur on occasion when a large old ram is taken that falls short of a "4/5-curl". In these cases a decision to prosecute becomes a discretionary call on the part of the enforcement officer since there is no minimum age for legal rams in Alberta. The officer then has to consider the intent of the curl regulation which is to harvest mature or older rams.

The "4/5-curl" regulation is considered an optimum size limit for the management of bighorn rams in Alberta. The horns of the youngest rams that are harvested are at or near the point of brooming. The average age of rams harvested under this regulation is 7 years and the average horn length is 82.5 cm or 32.5 inches (Wishart 1986).

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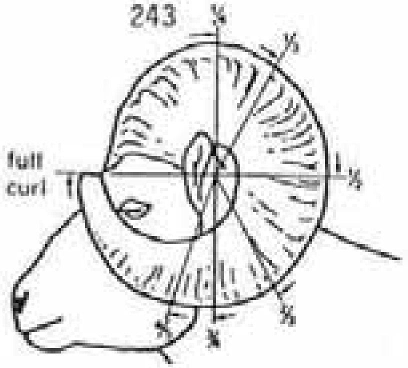
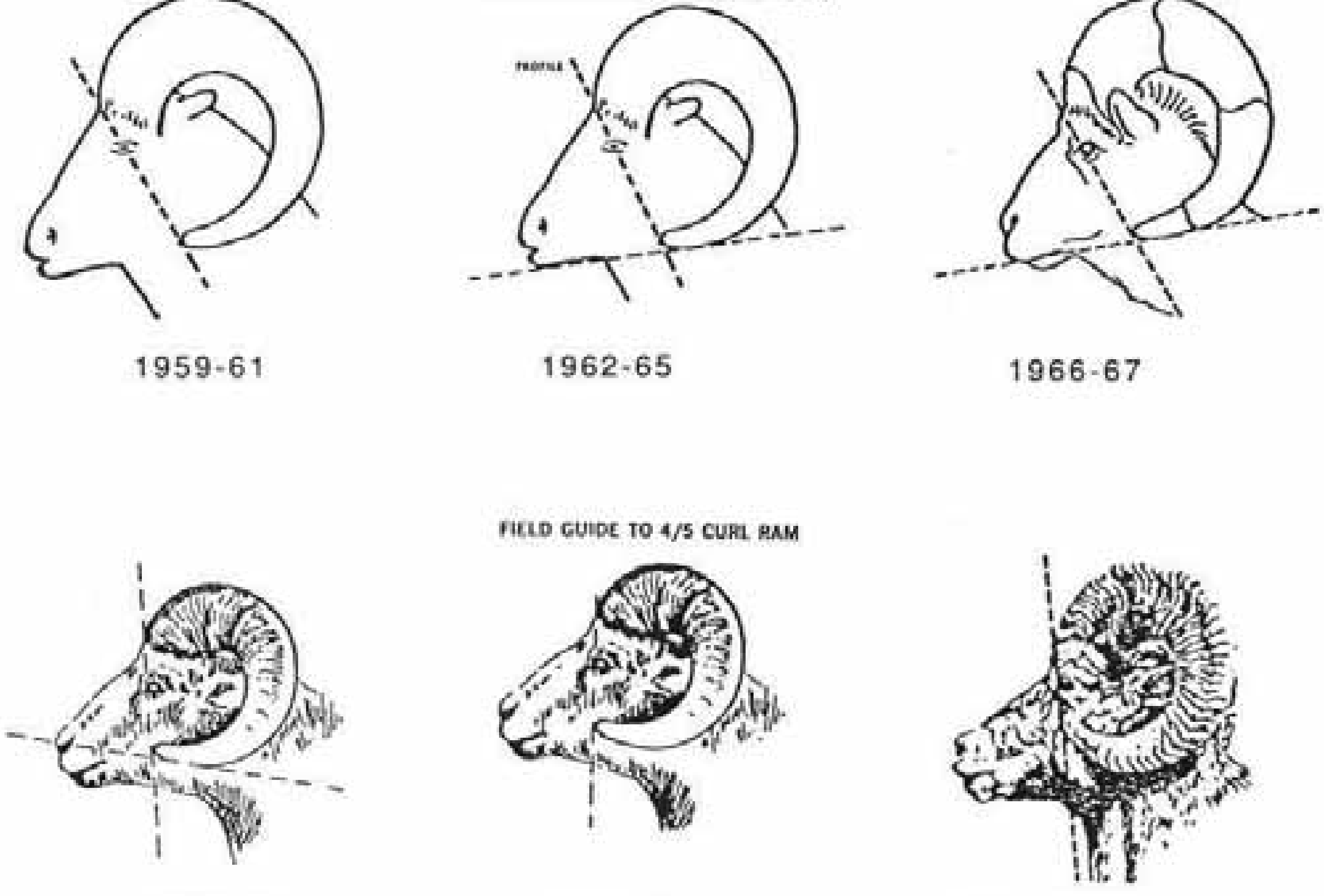


Figure 1. Various fractions of a full curl ram horn when viewed in profile at a right angle to the medial plane of the head.

FIELD GUIDE TO ¾ CURL RAM



1959-61

1962-65

1966-67

FIELD GUIDE TO 4/5 CURL RAM

1968-69

1970-78

1979-89

Figure 2. Variations in illustrations of legal ram heads in Alberta from 1959 to 1989.

Bienn. Symp. North. Wild Sheep
and Goat Counc. 7:244-245.

LEGAL BIGHORN SHEEP DEFINITIONS

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Abstract: In Idaho, bighorn sheep harvest is restricted to rams with 3/4-curl or larger horns. Participation is regulated by lottery permits. Horn pinning identification is required.

BACKGROUND

The bighorn ram is considered by many hunters to be one of the prized animals in North America. The premier status of bighorn sheep is based on the difficulty of hunting in severe terrain, the challenge of finding a large ram, and a relative scarcity of sheep hunting opportunities. Sheep traditionally are hunted under conservative regulations in most of North America. Idaho has followed this tradition and restricted harvest to limited entry hunts for 3/4-curl and larger rams since 1970. To allow the harvest of older rams with broomed horns, regulations were changed in 1984 to include 3/4-curl and larger horns and/or rams over 4 years of age (any ram with 3 or more annual rings visible on the horns).

CURRENT REGULATIONS

Only bighorn sheep rams having 3/4-curl or greater horns or exceeding four (4) years of age may be taken.

Permittees successful in bagging either a Rocky Mountain or a California bighorn ram are prohibited from drawing for the subspecies again. Unsuccessful permittees may reapply after a 2-year waiting period. In order to improve drawing odds, applicants for bighorn sheep permits cannot apply for any other controlled hunt species.

BIOLOGICAL/GEOMETRIC RATIONALE

Legal Description

A ram shall be considered 3/4-curl if an imaginary line extending downward from the front of the base of the horn through the center of the eye socket intersects any portion of the horn.

ENFORCEMENT/PROSECUTION

The court decides extenuating circumstances for rams under 4 years old which are short, as described above.

INTERPRETATION TO HUNTERS IN THE FIELD

Successful controlled hunt applicants are required to view a videotape about judging a legal ram.

PRAGMATIC CONSIDERATIONS

Any hunter taking a bighorn ram must leave that portion of the skull plate containing the upper 1/2 of the eye socket naturally attached to both the horns until after the horns have been pinned by the Department.

Any horns presented for pinning which are from a 3-year-old or younger ram which do not appear to meet the 3/4-curl regulation are measured by placing a straight object such as a ruler from the front of the base of the horn across the center of the eye socket. If the line does not intersect either horn when placed through the center of the eye socket but does intersect at least one horn when placed over the rear corner of the eye socket, the person receives a warning.

Bienn. Symp. North. Wild Sheep
and Goat Counc.7:246-248.

CALIFORNIA BIGHORN SHEEP HARVEST REGULATIONS IN NORTH DAKOTA 1975-1990

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Abstract: Harvest of the re-introduced California bighorn populations is controlled by permit and limited to 3/4-curl and larger rams. Hunters are trained to identify legal rams in classes for those obtaining permits.

BACKGROUND

Bighorn sheep, Ovis canadensis auduboni historically inhabited the Badlands of what is now western North Dakota. Such notables as Lewis and Clark, Maxmillan, Audubon, and Theodore Roosevelt observed and recorded bighorns along the Missouri River and in the Badlands adjacent to the Little Missouri River (Boldt et al. 1973); however, few bighorns remained on the Great Plains by statehood in 1889. The last recorded sheep was taken in 1905 (Murdy 1957). Their extirpation was probably due to hunting, heavy homesteading, and settlement of the Badlands (including competition from and association with domestic livestock) (Boldt Op. cit.).

In 1956, 18 California Bighorns (Ovis canadensis californiana) were translocated from British Columbia to Magpie Creek in the northern Badlands of McKenzie County, North Dakota (Murdy Op. cit.). Since that time, 23 transplants have been made into 10 other areas of the Badlands. These 10 bighorn population centers support an aggregate of about 300 animals.

The 44th session of the North Dakota Legislative Assembly enacted the law allowing for the first managed harvest of bighorns in North Dakota in 1975. It limited the number of residents-only permits to 12 each year and allowed for the harvest of "mature" rams with 1/2-curl or greater horn development (North Dakota Century Code 1975). It also omitted landowners living within an open hunting area from receiving preference in the lottery for one of these once-in-a-lifetime licenses. Each hunter was to be accompanied by a Game and Fish Department employee who would designate what animal was a legal target. There was a sunset clause of June 30, 1977 attached to this legislation. The 45th Legislative Assembly revoked many of these restrictions, including the 1/2-curl minimum; however, it retained the resident-only provision and the once-in-a-lifetime hunt opportunity clause in the new law enacted at that time (North Dakota Century Code 1977). An amendment to this law was passed by the 49th Legislative Assembly that authorizes the auction of one bighorn permit to the highest bidder, resident or nonresident to North Dakota (North Dakota Century Code 1985).

Harvest Summary

Since the first managed season in 1975, 91 bighorn permits have been issued to 87 resident applications by lottery and 4 nonresidents through the auction process. These permittees harvested 86 bighorns for a cumulative hunter success of 94.5% for the 11 seasons held during the intervening 15 years 1975-1989 (seasons were not held in 1980, 1981, 1982, and 1983).

CURRENT REGULATIONS

Since 1977, all hunting seasons have specified 3/4-curl or larger rams as legal game. However, North Dakota's management of bighorns has not always accommodated managing strictly for trophy value. The 44th Legislative Assembly included the 1/2-curl minimum in the original law that authorized an annual bighorn hunting season in both 1975 and 1976. Subsequently, they established the present 3/4-curl regulation.

BIOLOGICAL/GEOMETRIC RATIONALE

Three-quarter-curl rams harvested in North Dakota have ranged in age from 3.5 years to 9.5 years with a median age of 6.5 years (the average age is about 1 year less than this).

Data indicate that horn development of bighorns in North Dakota can reach entry level 3/4-curl dimensions in as little as 3.5 years but more commonly at 4.5 years. Rams remaining in this geometric equivalent classification through age categories older than this do so because of brooming (horn breakage). The 3/4-curl segment of the harvest over the years has accounted for exactly 1/2 (50%) of the animals legally taken.

Horn curls larger than 3/4 of a circle equivalent and through the 7/8-curl category include rams that have been harvested at ages from 5.5 to 11.5 years with a median age of 8.5 years and an average age of about 7.5 years. All rams with horn sizes in this category have been broomed to a greater or lesser degree. They represent 35.8% of the bighorns harvested since 1975.

Only 6 (7.1%) rams harvested in North Dakota have been classified as full-curl animals. They have ranged in age from 7.5 to 13.5 years. Both the median and the average age of these animals is in the 10.5 year range. Additionally, each of these animals exhibited some degree of brooming.

ENFORCEMENT/PROSECUTION

There have been no arrests made involving infractions of existing regulations by bighorn sheep permittees in North Dakota.

INTERPRETATION TO HUNTERS IN THE FIELD

Prior to each hunting season (usually the evening before the season opens) an informal hunting meeting is held and each permittee is urged to attend. Among other things, the meeting is for the purpose of instructing hunters on identification of legal rams in the field. The instructional method works. Of all rams harvested, 6 (7.1%) had horns less than 3/4-curl and they were all taken during the 1975-77 time frame when 1/2-curl rams were legal. The remaining animals were 3/4-curl rams or larger.

PRAGMATIC CONSIDERATIONS

In view of the fact that bighorn habitat is a finite commodity in North Dakota, and that the continued expansion of the range for this game animal through translocation efforts is only remotely possible, it is the opinion of this writer that recreational hunting of bighorn rams will never be afforded to all North Dakotans who may wish this opportunity. A case in point is the 4,544 residents who applied for one of the 7 lottery permits offered at the recent 1990 Bighorn Drawing. The once-in-a-lifetime ram permit will likely remain in effect.

At some point in time, bighorn ewes may have to be harvested through recreational hunting. Up until now, nonconsumptive harvest of ewes and lambs has occurred through trapping and translocation efforts and the separate herds have generally been maintained at or below prudent levels. This will change when acceptable, unoccupied release sites no longer exist. When this occurs, recreation hunting of all bighorns may become a necessary reality.

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Bienn. Symp. North. Wild Sheep
and Goat Counc.7:249-251.

DALL SHEEP HARVEST REGULATIONS IN NORTHWEST TERRITORIES, 1990.

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Abstract: Non-native Dall sheep harvest is limited to 3/4-curl or larger rams to minimize impact on populations. Natives may harvest sheep with no restrictions. Native harvest is for food and is thought to be 20-30 ewes and lambs per year.

BACKGROUND

Dall sheep (Ovis dalli dalli) occupy the Mackenzie and Richardson Mountain ranges in the westernmost part of the Northwest Territories. There are thought to be approximately 7,000 sheep in these areas (Poole and Graf 1985), however, recent population data are available for only the most southerly and northerly parts of the Mackenzie Mountains and for the Richardson Mountains.

CURRENT REGULATIONS

In the Mackenzie Mountains, all non-native harvesting is restricted to 1 "male adult Dall sheep", having horns which are 3/4-curl or larger, per year. Non-native harvesting is currently not permitted in the Richardson Mountains. The definition of a legal sheep under the NWT Wildlife Act is: "male adult Dall sheep", meaning a male Dall sheep bearing at least one horn that is 3/4-curl or larger, determined on the basis of a straight line drawn from the anterior aspect of the base of the horn to the tip of the horn, and when viewed from the side:

(i) if such straight line passes in front of the posterior aspect of the eye socket, that horn shall be deemed to be a 3/4-curl horn, and;

(ii) where the horn is a broken, worn, or incomplete horn, it shall be deemed to be a 3/4-curl horn if such straight line, when drawn to the logical projected tip of the horn, would pass in front of the posterior aspect of the eye socket",

In order that curl can be assessed after the animal is processed in the field, the regulations require that "the horns (be) attached to the head with the eye sockets intact".

In addition, the regulations state that "No person shall possess or export, or receive for export, to a place outside of the Territories, Dall sheep horns unless the horns have a numbered metal plug inserted by an officer, in the form and manner approved by the Superintendent", and

"No holder of a taxidermist license shall receive or have in his or her possession, Dall sheep horns unless the horns have a numbered metal plug inserted by an officer, in the form and manner approved by the Superintendent".

Native hunters may harvest, for food, sheep of any age or sex throughout the year in both the Mackenzie and Richardson Mountains.

BIOLOGICAL/GEOMETRIC RATIONALE

The management goals for Dall sheep are; 1) to maintain abundant and productive populations of Dall sheep in their natural habitat, and 2) to encourage the wise use of Dall sheep within the limits of sustainable yield. Decisions on whether to manage populations for harvesting opportunity or trophy quality have not been made.

Harvesting restrictions on rams, whether they be quotas or horn size, are basically to ensure sufficient mature rams for maximal productivity. Quotas or more restrictive horn size regulations do not appear to be necessary at the current time as recent surveys in 2 of the most heavily hunted ranges revealed ram:ewe ratios of 40 rams per 100 nursery sheep (includes juvenile males) and 83 rams per 100 nursery sheep (Case 1989). With no restrictions on the number harvested in these areas, over 95% of the sheep taken have been greater than full-curl. The reasons for this could be many: lack of demand, inability of the outfitter to handle additional clients, or a decision by the outfitter to maintain low volume, high quality hunts.

Harvest pressure on Dall sheep is considered to be light throughout the Mackenzie Mountains. There are a few convenient access points where pressure is higher, however, hunter and outfitter reports suggest there has been no change in hunter success or trophy quality in these areas.

ENFORCEMENT/PROSECUTION

There have been no arrests made under the 3/4-curl regulation during the past 10 years.

INTERPRETATION TO HUNTERS IN THE FIELD

The 3/4-curl regulation is interpreted to hunters using a line drawing in the annual summary of the regulations. The regulation has generally been considered straightforward, although accurate assessment depends on obtaining the appropriate view of the animal.

PRAGMATIC CONSIDERATIONS

Under the Northwest Territories Act, natives in the Northwest Territories are permitted to hunt sheep for food without restriction. The harvest by natives for food is not monitored, however, discussions with Department of Renewable Resources staff suggest the harvest is in the order of 20-30 sheep, most of which are ewes or lambs.

Natives land claims are approaching settlement in the western Northwest Territories. Under the Wildlife Provisions of this agreement, a Wildlife Management Board will be established to ensure user involvement in all regulation changes and management decisions. The priorities of this board and of the Government of the Northwest Territories are likely to remain with other more highly utilized species for the near future. As a result, Dall sheep research and management programs in the Northwest Territories are likely to remain at a small scale for the foreseeable future.

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Bienn. Symp. North. Wild Sheep
and Goat Counc. 7:252-255.

BIGHORN SHEEP HARVEST REGULATIONS IN OREGON: MANAGEMENT CONSIDERATIONS

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Abstract: Limited hunting of rams has occurred in Oregon since 1965. The primary harvest regulation through this period has been 3/4-curl or larger. A recent (1990) attempt to change to an "any ram" regulation failed due to opposition from bighorn sheep hunters. Within current management strategies, the 3/4-curl regulation is not based on biological considerations but rather on social attitudes of the bighorn hunting public.

BACKGROUND

Bighorn sheep were extirpated from Oregon by the late 1940's. Current populations are the result of reintroduction efforts. The original source of California bighorn sheep (*Ovis canadensis californiana*) was acquired from Williams Lake, British Columbia in 1954. All transplants within Oregon are from this stock. Rocky Mountain Bighorn (*Ovis canadensis canadensis*) stock has been acquired from Alberta (1971), Idaho (1979, 1982, 1985), and Colorado (1990). All hunts are by permit only with limited numbers of permits allocated to those herds large enough to provide surplus rams.

Most populations have not yet expanded into all available habitat so there is no need to use hunting as a population control method. Trapping and transplanting are currently used for necessary population control with surplus animals used to reestablish new populations on historic ranges.

CURRENT REGULATIONS

The current legal animal definition as published in hunting regulations, is a "ram with 3/4-curl or larger horn, or an old ram with heavily broomed horns with blunt ends less than 3/4-curl". Hunters are allowed only one opportunity in a lifetime.

This regulation has been used since the first hunt was authorized in 1965; however, we had a 1/2-curl regulation for 2 years in one hunt area (total of 20 permits) and an "any ram" regulation in 2 hunt areas for 1 year (total of 3 permits). Both deviations from the 3/4-curl rule occurred with California bighorn ram hunts. Ten of 12 rams taken during these hunts were 3/4-curl or larger indicating the hunter tends to select for larger rams. The 3/4-curl rule is interpreted to mean that the horns of a ram extend through 270 degrees of a circle when viewed from the side.

In most cases, 4-year-old rams have horns large enough to make them legal using this definition.

Because significant brooming occurs with the California subspecies, the regulation was modified in 1976 to allow taking old rams with broomed horns when in actuality the horn is less than 3/4-curl. A "blunt end" is interpreted as the broomed horn tip being as least one inch wide at the end, measured from the dorsal to the ventral side of the horn tip. At the same time, the 1/2-curl regulation in effect for 1974 and 1975 was dropped. The intent of this regulation modification was to allow taking of older rams which had horns less than 3/4-curl and may never attain 3/4-curl size before being lost to old age.

There has not yet been a need to apply this modification to Rocky Mountain bighorn rams.

BIOLOGICAL/GEOMETRIC RATIONALE

Aside from ensuring protection to adult ewes from being mistakenly shot, there is no biological basis for the 3/4-curl rule in Oregon under current management strategies.

The 3/4-curl regulation was originally adopted in Oregon in 1965 because that was the regulation employed by most other states and provinces that were then hunting bighorns. The 1/2-curl regulation used in 1974 and 1975 was adopted in an attempt to allow taking of older rams with heavily broomed horns. Subsequently, the heavily broomed regulation replaced the 1/2-curl regulation. The experimental "any ram" regulation was successfully employed in 2 hunts in 1989. All hunters (3) took rams at least 3/4-curl in size. In 1990, we recommended to the Fish and Wildlife Commission that all California bighorn hunts employ an "any ram" bag limit. However, public opposition influenced the Commission to retain the 3/4-curl regulation.

Current permit allocations are quite conservative and in the past have ranged from one to 18 permits per herd range. In all cases, even if all permit holders were successful in taking a ram, the result would be that less than 20% of the total ram population would be removed by hunting in a single season. If this should occur, adjustments in permit allocations would be made the following year.

Post season (pre-rut) ram ewe ratios are seldom below 40 rams/100 ewes. Consequently, we do not believe our hunting season harvest is having an adverse impact on bighorn breeding performance. The bighorn hunting season is a "trophy" hunt and quality of the hunting experience is of importance to the hunter as well as the Department. Most of Oregon's bighorn herds occupy a relatively small geographic area (10-50 mi^2).

In order to minimize hunter crowding and maintain a quality hunt, permits are allocated with this in mind. Consequently, for a given hunt area, total permit numbers maybe split into 2 or more separate hunt periods. Currently, most hunts range from 9-12 days in length. During the harvest seasons all hunting of other big game species is not allowed in an effort to prohibit party hunting. When hunting of other big game species is considered, there is not time for more than 2 or 3 bighorn hunt periods in a given year. To summarize, current bighorn hunting strategies do not approach taking the maximum biological surplus, so horn-curl regulations are not needed to maintain a minimum ram:ewe ratio. Additionally, horn-curl regulations put hunting emphasis on older-aged, larger-horned animals which may be detrimental to the overall social structure or horn quality of bighorn sheep herds.

ENFORCEMENT/PROSECUTION

All hunters must check out when they have completed their hunt, whether successful or not. At the time of checkout, successful hunters must have the head permanently marked (pin in one horn) as proof that it was legally taken.

Since 1965, 482 bighorn rams have been harvested in Oregon. Of these, only 8 have been sublegal. Prosecution of the individuals taking these sublegal rams has been quite variable over the years:

1). Five individuals were not cited because the biologist checking out the animal determined the curl length, although short, was close enough to 3/4-curl and did not warrant a citation. Additionally, in these situations, the biologist preferred to see the ram brought in by the individual rather than see it be left to spoil in the field and have another legal ram harvested by the same individual.

2). Two individuals were cited into local courts, fined a minimal amount, and allowed to retain their harvested rams.

3. One individual was fined, had his hunting rights revoked for 2 years, and had the entire bighorn ram carcass confiscated.

The problem with enforcement of the regulation has been with inconsistency throughout the history of the regulation which indicates that, even within the Department, there are mixed views of the validity of the regulation.

INTERPRETATION TO HUNTERS IN THE FIELD

Any person successful in drawing a bighorn sheep permit is required to attend an orientation session prior to the hunt. The hunter is briefed on such things as the history of bighorn sheep management in Oregon, bighorn behavior, biology/ecology, hunter ethics, and legal requirements.

At that time, the hunter is shown photographs and examples of legal vs. sublegal rams, and the geometric descriptions of the curl regulation are described in detail. The entire process takes about 2 hours.

PRAGMATIC CONSIDERATIONS

Our assessment of the 3/4-curl regulation is that it is primarily a social regulation. There is a perception by Oregon's bighorn sheep hunters that an "any ram" regulation will overharvest rams in the younger age classes, which in time would result in a reduced supply of older rams in specific populations. This perceived reduced ram supply would result in a reduction of permits and hunting opportunity in the future. There also is the feeling that the "any ram" regulation makes bighorn sheep hunting a "non-trophy" hunt. Consequently, sheep hunting enthusiasts oppose a change in the regulations.

Based on our experience with the "any ram" regulation of 1989, we believe ardent bighorn hunters select for the largest possible ram regardless of the minimum requirement. Additionally, permit numbers are tightly controlled, and we believe that even within a specific hunt in a specific year, if all tagholders took young (less than 3-year-old) rams, there would not be any significant effect on the total ram population either biologically, or with future hunting opportunity. Likewise, in theory, taking of a younger ram would allow an older ram to survive and may result in larger trophies being available.

The problem with an any curl regulation is basically twofold. First, if a hunter does shoot a sublegal ram, there is a risk that he will leave the animal in the field and possibly go on to kill an additional ram without being apprehended by enforcement personnel. This can be perceived as a loss of future hunting opportunity as well as a potential loss of an additional ram.

The second problem involves our 1-permit-in-a-lifetime requirement. We publicize the fact that bighorn sheep occupy rugged habitats, and encourage the hunter to be in good physical condition. However, all individuals may not be able to attain adequate physical condition to allow them to hunt until they kill a 3/4-curl or larger ram. If the hunter has had to pass up the opportunity to take a smaller ram because of the regulation, he may not harvest a sheep.

Bienn. Symp North. Wild Sheep
and Goat Counc.7:256-258.

MOUNTAIN SHEEP HARVEST REGULATIONS IN UTAH 1990

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Abstract: Utah has both Rocky Mountain and the desert subspecies of mountain sheep. However, Rocky Mountain bighorn have never been legally hunted in modern times in Utah. Current desert bighorn regulations stipulate that any ram is legal, although taking older rams is encouraged. As a result, no arrests have occurred due to illegal bighorn kills. The "any ram" regulation appears to function as biologically sound because hunter preference is for the oldest of rams and mortality is assumed to be more compensatory than additive. Utah hunters and wildlife enforcement authorities are satisfied with the current regulation. When a Rocky Mountain bighorn hunt does occur, chances are good it to will be an "any ram" regulation.

BACKGROUND

Two subspecies of mountain sheep (*Ovis canadensis canadensis* and *Ovis canadensis nelsoni*) inhabit remote, wilderness areas of Utah. Desert bighorns inhabit the canyon, slickrock, and mesa country of the Colorado River system in southern Utah. The Rocky Mountain bighorns occur sparsely in isolated, northern mountain habitats. Perhaps as many as 800 desert bighorns occur in 6 separate herds across southern Utah. Utah's desert bighorn sheep are native, never having been pushed to extirpation, although several herds have vanished. The Utah Division of Wildlife Resources' (UDWR) goals for management of bighorn sheep include providing recreational hunting opportunities to the public. Consequently, legal hunting of the desert subspecies dates back to 1967. Since 1967, as many as 25 permits having been issued annually, though the average is about 10. Last year (1989), a total of 11 permits were issued. As such, bighorn hunting amounts to less than 0.01% of the licensed hunting activity in the state.

Approximately 400 Rocky Mountain bighorn sheep compromise 8 northern Utah herds. All native Rocky Mountain bighorn sheep were extirpated in the mid-1970s (Smith et al., 1988); hence, these sheep are non-natives, imported from sources outside the state. Reintroduction efforts, first begun in 1966, have been moderately successful. The resultant herds are isolated from one another and occupy habitats of low-to-moderate quality. Population numbers are still low and considered vulnerable to extinction via stochastic events. For these reasons, the UDWR does not currently conduct hunting of the Rocky Mountain bighorn subspecies. The current program emphasizes restoration of Rocky Mountain bighorn to former ranges and careful management of those herds already re-established. When hunting of the Rocky Mountain race is instituted, it will most likely mirror current desert bighorn regulations. There has never been a legal Rocky Mountain bighorn hunt in Utah in modern times.

CURRENT REGULATIONS

From the inception of legal hunting for desert bighorns in 1967, until 1985, sport hunting was limited to mature rams only. A mature ram was defined as either 7 years-of-age <u>or</u> scoring at least 144 Boone and Crockett (B&C) points. Age was to be determined via horn annuli counts, with compensation estimated for broomed and broken tips. Estimating a B&C score (a composite score comprised of 7 separate measurements) in the field is obviously quite error-prone, particularly the closer a ram gets to the 144 minimum. Consequently, "several hunters just barely squeaked by" (J. Guymon, UDWR, Wildlife Biologist, pers. commun.), and a few did not. In the 17-year period (1967-1985) that these regulations were in force, 2 illegal kills occurred by well-meaning hunters who overestimated the target ram's actual age or B&C score. Subsequently, sheep were seized, fines were issued, and once-in-a-lifetime hunters became bitterly disappointed. Due to the difficulty of determining age and score afield, UDWR adopted new, simpler regulations in 1985. The new regulations read "Any ram will be legal; however, permittees are encouraged to take trophy size rams." Additionally, it is unlawful for any person to apply for or possess a bighorn sheep permit who has previously obtained a bighorn sheep permit in Utah. The UDWR also requires that hunters have at least a 15X scope mounted on their rifles to assist ram identification and aging. This "any ram" regulation is presently under consideration for adoption in Arizona and Nevada as well.

BIOLOGICAL/GEOMETRIC RATIONALE

Presently, desert bighorn harvests are considered to be well below a level which could adversely impact the herds from which they are taken. Due to the extreme difficulty of censusing desert sheep populations, annual censuses are assumed to account for only 30-50% of the actual population present in each area. For example, on the Escalante Bighorn Unit Survey this year, 100 sheep were seen. Biologists estimate that the actual number is probably between 150 and 200. Nonetheless, only 2 permits will be issued, which is quite conservative. The other desert bighorn herd quotas are equally conservative. Therefore, no adverse effects are predicted upon herd population dynamics.

Bighorn hunters are primarily interested in trophies, and try to take the largest ram possible. Data since 1985 indicate that this is indeed the case-with the small rams being about 3/4-curl. Consequently, the UDWR feels that this regulation results in mortality which is most likely to be compensatory rather than additive.

ENFORCEMENT/PROSECUTION

There have been no arrests for violation of the current regulations.

INTERPRETATION TO HUNTERS IN THE FIELD

In spite of clearly-defined regulations, hunters are still required to attend a 3-hour indoctrination meeting prior to the opening day of the bighorn hunt. During this time, hunters are taught to identify the most mature rams and encouraged to focus their hunting efforts on this age group. Sharp, clear photos are used for illustration.

Utah has developed an objective bighorn ram harvest regulation which better serves the hunter and the state agency than the formerly-used subjective regulations. The regulation allows for the taking of young and sexually mature rams from the herd; but in practice, hunters generally harvest older rams. In this way, mortality is considered to be compensatory rather than additive. Hunters select the trophy they prefer and are very supportive of the present law.

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Bienn. Symp. North. Wild Sheep
and Goat Counc.7:259-265.

THINHORN SHEEP HARVEST REGULATIONS IN THE YUKON, 1990

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Abstract: Thinhorn sheep are managed as trophy animals. Harvest is restricted to rams of at least 8 years of age or with full-curl horns for several biological and fiscal reasons. Compulsory inspection of harvested horns is required. Differing definitions used in the field and in court cause minimum confusion, but require further work.

BACKGROUND

In the Yukon, thinhorn sheep (*Ovis dalli* sp.) are managed primarily to maintain natural densities. Each year licensed resident hunters take an average of 69 rams while guided nonresidents shoot an average of 161 rams, from a total Yukon population of approximately 22,000 sheep. While the licensed harvest is relatively small, the resident harvest, in particular, is localized in easily accessible areas. Harvest by aboriginal peoples is unregulated, but recent studies indicate that the magnitude of the harvest is small and primarily of rams (Quock and Jingfors 1988).

With the relatively small harvest, many of the current sheep hunting restrictions in the Yukon reflect hunter demand, rather than the status of the population. Also, the Fish and Wildlife Branch has expressed the opinion that liberal hunting restrictions must be accompanied by larger operating budgets to manage the populations more intensively (more population monitoring and more research). The government is unwilling to commit more resources to managing sheep unless the demand for more liberalized hunting of ewes or non-trophy rams to allow for more meat hunting opportunities is apparent. There is no demand for non-trophy sheep. In the 2 opinion surveys conducted since 1979, less than 25% of the resident hunters desired more liberal seasons or harvest of non-trophy sheep.

As part of an on-going management program, the Yukon Fish and Wildlife Branch closely tracks the number of rams shot annually, their average age, and the hunting effort and success. As well, we closely monitor a number of sheep populations to determine changes in population size and composition in relation to hunting pressure.

CURRENT REGULATIONS

Since 1981, all sheep harvested by licensed hunters must be "full-curl" or have attained 8 years of age. The description used to define full-curl actually describes an arc of 315° (7/8-curl) but is termed full-curl for the sake of simplicity: "When viewed from the side, with anterior horn bases in alignment, a full-curl ram has at least one horn that extends beyond a line drawn between the center of the nostril and the lowermost edge of the eye" (Figure 1).

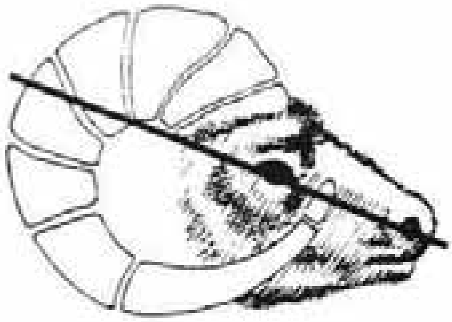

Figure 1. Full-curl ram as depicted in the Yukon Hunting Regulation Synopsis.

Nonresident hunters must obtain the services of licensed outfitter/guides who operate in designated concessions, but resident hunters are free to hunt in any open area. The exception is a small area in the southwestern Yukon where hunting effort is regulated through a limited-entry draw system. Any resident hunter who was not issued a permit in the previous year may enter the permit hunt lottery.

Throughout the Yukon, the bag limit is restricted to one ram per license holder per year. The season extends from 1 August to 31 October. The horns of all sheep shot must be submitted to the Fish and Wildlife Branch for inspection and insertion of a numbered metal plug.

BIOLOGICAL RATIONALE

There has been considerable controversy among North American sheep biologists concerning the extent to which liberalization of ram hunting can occur without negative impacts to the population, and the extent to which liberalized hunting can increase the annual sustainable harvest (Nichols 1984; Heimer et al. 1984; Heimer and Watson 1986; Murphy et al. 1990). One side of the argument is based on a theory put forward by Geist (1971) that suggests that the removal of older-aged males from a population will result in social disorder among the younger males who have neither the experience nor the horn mass to establish an undisputed dominance hierarchy, leading to a dramatic increase in male interactions with both females and other males. The end result is males expend needless energy, jeopardize their ability to survive the winter, and persistently harass ewes, which may minimize the chance of successful copulation.

The risks borne by liberalized hunting include lower productivity, decreased survival of young rams, and a further skewing of the sex ratio toward females. Observations of thinhorn sheep in the rut in the Yukon and the MacKenzie Mountains of the Northwest Territories found small, widely scattered groups (Barichello et al. 1987; G. Calef, pers. comm.). Generally, 1 or a few rams were courting a small group of females. Under such circumstances, the consequence of a more liberalized ram harvest may be a severe impairment of reproductive potential.

In the Yukon, we believe a more fitting question than that of negative impact is that of net benefit. If the gains in allowable harvest through liberalized hunting are minimal, then the risk of population detriment due to social disruption may be unnecessary. We have estimated that the average natural mortality of young rams (3-8 years) is low (less than 10%). Therefore, a 3/4-curl rule would provide only limited opportunities over a full-curl rule as 90-95% of 3/4-curl rams live to become full-curl rams.

Side view photographs of harvested rams with unbroomed horns submitted for inspection have allowed us to assess the relationship between horn-curl and age. Ages within each of 3 horn-curl classes (1/2, 3/4, and 4/4) were determined for 862 ram skulls to provide frequency distribution of ages in each horn-curl category. Full-curl rams are predominantly older than 6 years (93.2%); 85% of all rams had attained legal status before achieving their 9th annuli; 55% of rams became legal in their 7th or 8th years (Figure 2).

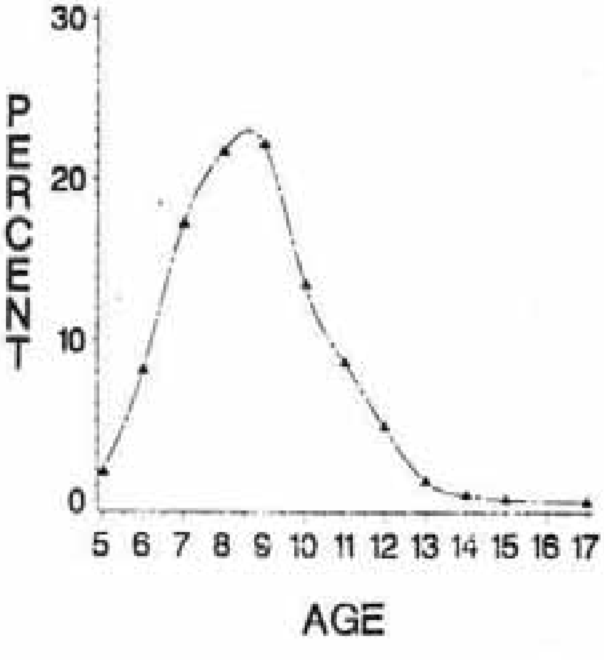

Figure 2. Distribution of ages at which Dall sheep rams attain legal status, expressed as a percent.

Since implementing full-curl restrictions, the Yukon harvest of thinhorn sheep has modestly increased while the age distribution has been relatively stable. The average age of the harvest is 8.7 years, with a range from 5 to 17 (Figure 3). Populations of sheep in hunted areas have also shown relative stabilities of numbers and sex ratio, despite variation in lamb production (Burles and Hoefs 1984) and relative sizes of each ram curl-class (Barichello and Carey 1988). Hunting effort (number of hunters and number of days hunted) and success (as measured by days hunted per hunter and number of days per ram killed) have also been relatively stable.

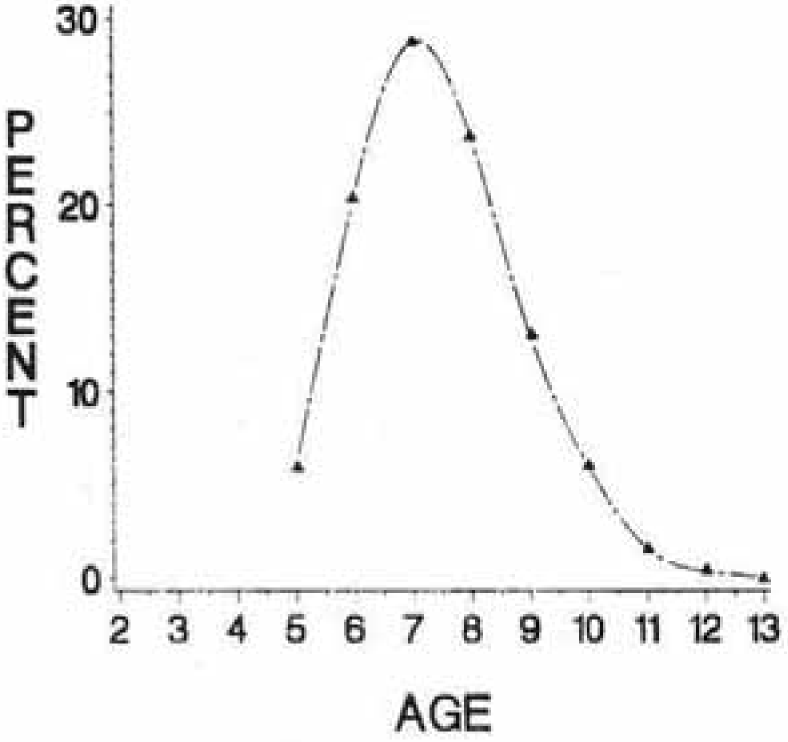

Figure 3. Age distribution of the licensed harvest of Dall sheep rams in the Yukon, expressed as a percent.

Comparisons between hunted and unhunted populations have revealed no difference in lamb production or mortality rates of 8+-year-old rams (Barichello et al. 1987; Hoefs 1984). Differences, however, have been observed of mortality rates of 3- to 8-year-old rams; the estimated mortality of young rams in hunted populations exceeds 10% while in unhunted populations is less than 10% (Barichello et al. 1987). We believe hunting mortality is additive to natural mortality in the young cohorts while hunting of 8+-year-old rams is largely compensatory mortality. Still, the removal of full-curl rams less than 8 years old has not had a negative impact on productivity or population trend.

In summary, a full-curl rule that selects for old-aged males appears not to jeopardize population well-being; it provides an allowable harvest only marginally less than a more liberal and riskier 3/4-curl rule; it costs little to implement as frequent monitoring of population may be unnecessary; it escalates the monetary value of the trophy resource, and it imposes minimal harassment on nursery groups, and is therefore more compatible with wildlife viewing opportunities.

ENFORCEMENT/PROSECUTION

As part of the compulsory inspection, each set of horns is examined to verify its legal status. To do this, the skull, including the eye socket, must be attached to the horns. It is then placed in a horn jig,(Merchant et al. 1982) to allow for a standardized assessment (Figure 4). The plane formed by the skull and horn jig when the skull is secured mimics the imaginary line between the nostril and the eye used as the field definition. We believe this jig overcomes legal problems associated with the variability of viewing the horn at different angles.

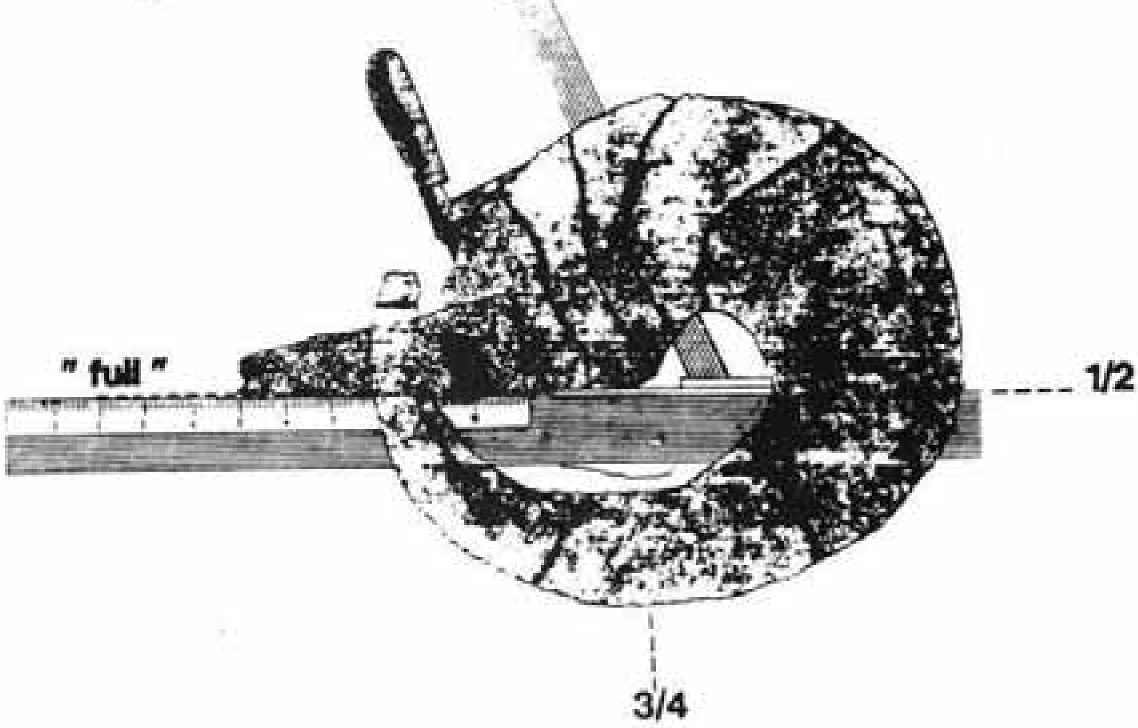

Figure 4. Depiction of Dall sheep horns secured in the measuring jig.

There are, on average, approximately 6 reported infractions of the full-curl rule each year. Of these, 5 are committed by nonresident hunters. Since nonresidents usually choose not to contest the charges and appear in court at a later date, there have been very few cases brought before the courts. Generally, only verbal warnings are issued if the horn is less than 2cm under the legal size. In the cases where rams are legal on the basis of age rather than horn size, the hunter is made aware of the fact, in an attempt to avoid problems in the future.

Problems have been encountered in association with the prosecution of full-curl rule infractions. The defense of "due diligence" is often used in cases of this sort; the hunter need only convince the court that he made an honest attempt to correctly interpret the regulation and honestly did not believe himself to be in error. While the age/annuli relationship is constant, in borderline cases it may be difficult to testify that there is absolutely no possibility of doubt in the age determination, especially in broomed rams, where the lamb tip and possibly the first annulus are missing.

INTERPRETATION TO HUNTERS IN THE FIELD

One point needs clarification: the hunter is asked to assess legality according to a side-view perspective and horn geometry in relation to an imaginary line. However, the law is enforced according to the geometry of the horn in relation to the horn jig. We need quantified evidence of the relationship between horn configuration in relation to the imaginary line drawn from the eye through the nostril.

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MOUNTAIN

GOATS

Bienn. Symp. North. Wild Sheep and
Goat Counc.7:266-273.

WYOMING BEARTOOTH MOUNTAIN GOAT STUDY

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Abstract: A mountain goat (Oreamnos americanus) population in northwestern Wyoming was studied during May-November, 1989. This herd is located in the Beartooth Mountains east of Yellowstone National Park. Goats occur in four major drainages. A minimum population of 141 goats was determined. Kid production was higher than previously documented, with kid:nanny ratios of 121:100 in the spring to 80:100 in the fall. Several nannies with twins and one set of triplets were observed. Remains of 7 goats were found during the study. Bighorn sheep (Ovis canadensis) also occupy this area. Seventeen bighorn sheep were observed grazing with 58 mountain goats. No dominance hierarchy was evident from bighorn sheep and mountain goat interactions.

The mountain goat herd was established through immigration from a mountain goat transplant in 1942 into the Beartooth Mountains near Red Lodge, Montana. Eight hunting permits are currently allocated for this herd unit. During the past 5 years, there has been a noticeable expansion of mountain goats in northwestern Wyoming. Confirmed observations have increased within and outside the Beartooth herd's range (Wyoming Game and Fish Department). Mountain goats have been reported along the North and South Fork drainages of the Shoshone River, and one observation was confirmed in the Wood River drainage, 104 km (65 mi) from the herd's range. These areas include critical habitat for important bighorn sheep populations. Range expansion by goats also concerns Grand Teton and Yellowstone National Parks. An "exotic" like the mountain goat might compete with indigenous bighorns and would not be welcome in the parks (Ball 1988). Mountain goats may not be desirable in certain mountain ranges in Wyoming. Confirmed sightings of mountain goats outside of known range in recent years may be indicative of changes in herd population dynamics.

The proportion of females in the harvest has been increasing in the Beartooth herd. During 1982-1987, the proportion of nannies increased from 12.5% (n = 1) to 71.5% (n = 7). It is not known if this trend is due to changes in hunter assess or to a change in goat sex ratios, or both. Correct harvest may be crucial to prevent herd decline. Mountain goat herds are easily reduced by even moderate hunting (Kuck and Pehrson 1977, Adams and Bailey 1982, Swenson 1986).

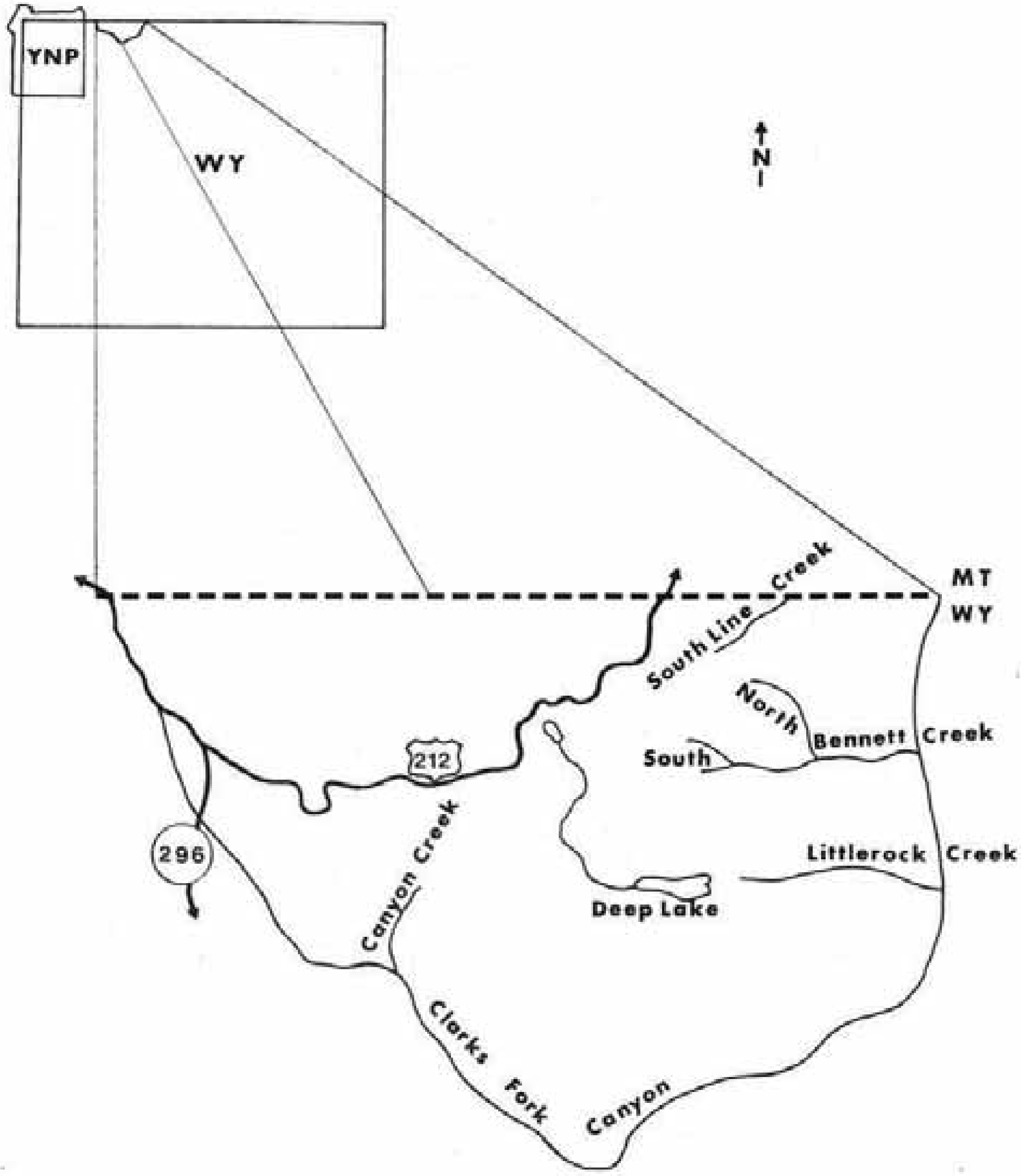

Fig. 1. Location of the Beartooth Mountain Goat Study area in northwestern Wyoming.

No population model exists for the Beartooth herd. Trend counts are often incomplete or unsuccessful because of the difficulty in locating the animals. The range map for this herd does not delineate winter range, parturition areas, yearlong range or crucial areas. Better data are needed for management decisions.

The objectives of this study were (1) to determine the distribution of mountain goats in the Beartooth herd range; (2) to determine the sex-age composition of the mountain goat population; and (3) to obtain a minimum population estimate of mountain goats in the Beartooth herd range.

Funding for this study was provided by the Montana Chapter Safari Club International, Wyoming Chapter Foundation for North American Wild Sheep, and the Wyoming Game and Fish Department. A camp trailer was provided by the Bureau of Land Management. Radio collars and flights were provided by the Forest Service.

STUDY AREA

The study area is located in the Beartooth Mountain Range of northwestern Wyoming, east of Yellowstone National Park and west of Clark, Wyoming. The southern boundary is the Clarks Fork of the Yellowstone River and the northern boundary is the Montana state line. Because of limited funding, efforts were confined to that part of the study area south of the Beartooth Highway (HWY 212, Fig. 1). Elevations within the area range from 3,413 m (11,200 ft) on the Beartooth Plateau to 1,341 m (4,400 ft) in the Clarks Fork Canyon.

METHODS

Each drainage of the study area was observed systematically from the ground during consecutive days from daylight to dusk. This reduced the probability of duplicate observations of goats that might move along a canyon. During spring, snow prevented movement of goats between drainages. During the summer when goats could move between drainages, adjacent drainages were observed in the morning and evening, respectively, to avoid duplication.

Mountain goats were classified as males, females, and unknown in the adult, 2 1/2, and yearling age classes, or as kids (Smith 1988). Females older than 2 1/2 were classified as nannies. Nanny:kid ratios were based on classified females only. Unclassified mountain goats that may have been nannies were included in (nanny + unclassified):kid ratios and compared to observed nanny:kid ratios. An aerial survey was conducted on July 7, 1989 to obtain an initial estimate of population size and to locate areas of concentration.

Marked Mountain Goats

Radio collars were attached to 2 mature females captured by darting using carfentenal and xylazine. Eight mature females and yearlings were marked with orange or blue paint using a CO_2 pistol and paint balls. Visually marking goats provided a basis for determining movement patterns, but should also assist hunters to avoid harvesting females. Goats were approached to within 18 m for marking. In addition, 2 goats were individually identifiable due to a missing horn and an injured eye.

RESULTS

Paint Marking

Goats marked with paint could be identified by color and placement. After nanny goats were hit with a paint ball, they ran a few feet or to nearby goats. Most goats were marked in summer. Longer guard hairs of the winter coat's covered paint markings by fall.

Mountain Goat Distribution

Mountain goats or evidence such as shed winter hair was found in each of the 4 major drainages in the study area. These drainages are the Clarks Fork of the Yellowstone River, the southern boundary of the herd unit; Littlerock Creek, which includes Deep Lake; South and North Bennett Creek; and South Line Creek which flows into Montana (Fig. 1).

In the Clarks Fork Canyon goats extend as far west as Canyon Creek and as far east as 4.4 km east of the canyon mouth during the winter (Fig. 1). No goats were observed south of the Clarks Fork Canyon during the spring or summer. However, during fall a nanny and yearling were seen on the south side of the Canyon. Recent reports indicate that some mountain goats use the south side of the Canyon.

Mountain goats were seen along the Littlerock Creek drainage, with concentrations in the Deep Lake area during the summer. Although they are occasionally reported upstream from Deep Lake, I did not see goats in this area. No goats have been reported downstream (east) of Deep Lake in Littlerock Creek; however, I found goat hair in this area in spring. No goats were observed in this drainage during the fall trend count, although the Deep Lake area was not surveyed.

I observed mountain goats in the North and South Forks of Bennett Creek at the higher elevations during the spring, summer, and fall. Mountain goats have been observed by landowners at lower elevations (1,120 m) during the winter. Mountain goats have been observed during the spring, summer, and fall in the South Line Creek drainage and along this drainage into Montana during the winter.

Spring range of mountain goats ranged from 3,048 m (10,000 ft) in the Line Creek drainage to 1,603 m (5,260 ft) in the Clarks Fork Canyon. During the summer, goats were found up to 3,127 m (10,260 ft) in the Deep Lake area, while other goats were located as low as 1,165 m (5,300 ft) in the Clarks Fork Canyon. During the fall, goats ranged between 3,024 m (9,920 ft) in the Line Creek and 1,463 m (4,800 ft) in the Clarks Fork Canyon.

Seven marked or recognizable mountain goats were located between 2 and 6 times during 12 July - 18 November. The longest observed movement was by a radio collared female #0, who traveled from Line Creek about 13 km to south of Deep Lake. The greatest distance between observations of radio collared female #3 was 2.7 km.

Concentrations of mountain goats ranged from a lone individual to 58 goats along the rim of Fall's Creek, a tributary of the Clarks Fork Canyon. A concentration of 42 goats was observed in the Deep Lake area during the summer. The largest group of mountain goats observed during the fall was 19 goats in the Clarks Fork Canyon. One hundred five goats were counted in the Clarks Fork Canyon during the fall.

Population Composition

One hundred and forty goats were classified (Table 1). A minimum of 5 sets of twins was observed during the spring. On October 6, 1989 a set of triplets was observed in the Clarks Fork Canyon. The spring nanny to kid ratio was 121:100, but 87:100 if the unclassified adults were included as adult females. This ratio does not include the 30+ goats observed in North Bennett Creek because a number of kids were observed but could not be accurately counted. Nanny to kid ratios during the summer were 134:100 or 84:100 including unclassified adults. Nanny to kid ratios during the fall were 80:100 or 73:100.

Table 1. Seasonal composition of mountain goats in the Beartooth mountain goat herd range south of the Beartooth Highway (212), 1989.

	Adult			2 1/2 year old			Yearling			Kid	Unk
	Male	Female	Unk	Male	Female	Unk	Male	Female	Unk		
Spring	13	23	9	1	1				15	28	32[a]
Summer	7	29	17	2	3		2		22	39	
Fall	26	45	4	7	4		2	6	10	36	

[a] Group of goats spooked and counted from photo.

Minimum Population Estimate

A minimum population of 121 goats was calculated during the spring while goats were still on their winter range. During the summer, at least 125 different goats were observed. During the fall when most goats were presumed to be on winter range, a minimum population of 141 was observed. This estimate does not include goats north of the Beartooth Highway and 31 goats north of the highway along the Montana state line.

Mountain Goats and Bighorn Sheep

Bighorn sheep were observed in the Clarks Fork Canyon during the spring, summer, and fall. During the summer, 2 ewes and 3 lambs were observed within 68 m (225 ft) of mountain goats. In late July, 17 bighorn sheep were grazing with 58 mountain goats in an alpine meadow. In August a young ram was observed near 4 mountain goats in South Bennett Creek.

DISCUSSION

Distribution

Several mountain goats have been located outside the currently estimated herd range. Individual goats have been reported 64 km south of the herd unit along the North and South Fork drainages of the Shoshone River near Cody; one goat was confirmed 104 km south of the herd unit in the Wood River drainage southwest of Meeteetse, Wyoming. Two mountain goats were observed on the south side of the Clarks Fork Canyon during fall. Habitat along the south side of the canyon is more forested with less herbaceous vegetation and more cliff faces and talus slopes. This terrain may not supply adequate forage during the winter and may also accumulate more snow due to its north aspect. The distribution and number of mountain goats south of the herd's known range are unknown at this time.

Mountain goats concentrate in the Deep Lake area of Littlerock Creek during the summer. The Deep Lake area is timbered along the rim, with interspersed grassy meadows providing abundant forage. During fall the Deep Lake area was not surveyed. It is assumed that mountain goats do not winter there. Future locations on radio collared goat #0 could verify whether Deep Lake is a wintering area.

No goats were observed east of Deep Lake during the summer, but past observations indicate that Littlerock Creek may be a migration corridor into the Beartooth Plateau during spring and fall.

Population Dynamics

During the spring while goats were still on winter range, group sizes were small and goats less active, simplifying counting and classifications. I could not accurately classify goats during summer because of large group sizes and greater activity of individuals. Mountain goats were best classified during fall because of smaller group sizes and characteristically stained hindquarters of rutting billies.

Kid:nanny ratios were higher than previously reported. Kid:adult ratios of 23:100 were reported for this herd unit and for the adjacent Montana goat herd. These ratios have been obtained from flights and may be biased due to movement of goats and to the tendency for kids to be hidden underneath nannies. The decrease in nanny to kid ratios over the summer from 121:100 to 80:100 may be due to natural mortality.

A set of triplets was observed in October below the Switchback Ranch of the Clarks Fork Canyon. This ranch has irrigated meadows which, if used by the goats, could contribute to high productivity.

Prior to this study, this population was estimated at 75 to 100 mountain goats (Wyoming Game and Fish Department). Observations for both the spring and summer demonstrate the population to be at least 140 goats. Most of the goats south of the Beartooth Highway were assumed to have been observed.

Mountain goats and Bighorn Sheep

Mountain goats and bighorn sheep were observed feeding and bedded in close proximity. Bighorn sheep and mountain goats were observed during the summer grazing as close as 27 m (90 ft). Yearling goats were seen playfully chasing protective ewes with lambs. Mountain goats displaced bedded ewes and lambs, after which these goats were displaced by 2 young rams.

During the fall, 7 mountain goats walked through an area where 5 bighorn sheep were grazing. Goats and bighorn sheep were within 4.5 m (15 ft). An adult billy that was pursuing an adult nanny charged about 3 steps towards a ewe that ran about 4.5 m (15 ft) and then began feeding. It appears that adult males of goats or sheep can displace females of goats or sheep. This displacement occurred only when goats and sheep where within 3 m (10 ft) but did not prevent access to feeding or resting areas.

Mortality

Remains of 7 mountain goats were found. Six were found in the Clarks Fork Canyon. These included 3 yearling or older carcasses from the spring, 2 partial skulls of adult goats from 1988 or older, and a kid that died in mid-November. Causes of death were not determined for any goats. A goat found this spring appeared to die from a fall. The kid discovered in November was determined to have died from an unspecified type of pneumonia according to analysis from the State Veterinary Lab. A goat (yearling or older) found in Line Creek may have died in a rock slide.

Domestic Livestock

Three hundred sixty cattle were grazed on summer range north of Littlerock Creek. Cattle grazed along canyon rims where mountain goats had been observed, but no interaction between the species was seen. Eight hundred domestic sheep were trailed into summer range north of the Beartooth Highway. Two feral, male goats were observed in the Clarks Fork Canyon during October and November. These feral goats approached mountain goats within 4.5 m (15 ft) before the mountain goats walked away and eventually left the area.

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MIRROR-IMAGE STIMULATION -- WHAT CAN WE ASCERTAIN ABOUT MOUNTAIN GOAT SOCIAL STRUCTURE?

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Abstract: Nine free-ranging and 5 zoological-garden-enclosed mountain goats (*Oreamnos americanus*) were exposed to a 59 x 79 cm fixed-mirror to elucidate behavior associated with intraspecific interaction and dominance hierarchy. Observations were from $\leq$ 10 m either by eye or study of video recordings. Agonistic, excitatory, and investigatory behaviors were exhibited in apparent response to the mirror. In free-ranging animals, kids exhibited no agonistic behaviors, adult females exhibited 0.47 agonistic behaviors per exposure (56.4% of the behaviors were agonistic), and a 2-year old male exhibited 0.59 agonistic behaviors per exposure (68.4% of the total behaviors were agonistic). Numbers of agonistic, excitatory, and investigatory behaviors were not significantly different between females and the male, but kids were less agonistic and more investigatory. Agonistic behavior and age appeared to be positively correlated with rank in females. The zoo-enclosed animals exhibited no agonistic behaviors, and fewer types of behaviors and a greater proportion of investigatory behaviors than did the free-ranging animals.

Intraspecific interactions and dominance hierarchies in North American wild bovids, especially in females, have received limited study (Bennett 1986, Chadwick 1977,Dane 1977, Holmes 1988, Masteller and Bailey 1988, Risenhoover and Bailey 1985, Rutberg 1986, Singer 1977). Rutberg (1986) addressed dominance and fitness in bison (*Bison bison*) cows. Geist (1971:196) mentions dominance in female bighorn sheep (*Ovis canadensis*). Dominance hierarchies in female mountain goats are often considered, possibly because of their aggressiveness (Chadwick 1983, Stevens 1983).

Most observations of dominance hierarchies in mountain goats have been made on free-ranging animals interacting under supposedly unmanipulated conditions (unaffected by human observers). Some workers (Fisler 1977, Masteller and Bailey 1988) have used both artificial and spatially limited resources to attract animals where close proximity increases interactions. Another approach is to elicit response using mirror-image stimulation (Gallup 1968, Svendsen and Armitage 1973). Here, I report the responses of free-ranging and zoo-enclosed mountain goats to mirror-image stimulation (MIS) and their relevance to intraspecific behavior and a dominance hierarchy.

S. Bassow and E. Hashimoto provided field assistance with the free-ranging animals. G. Tischbein photographed some trials. R. and L. Reiner provided field support. B. Cavender and D. Parman provided support in trials of zoo-enclosed animals. J. A. Bailey provided helpful editorial comments. L. Lovett prepared the manuscript. This was part of a larger study on habitat selection and activity patterns of

sympatric mountain goats and mountain sheep, funded by Colorado Federal Aid in Wildlife Restoration Project W-153-R-1.

STUDY AREA

Free-ranging animals were part of the Mt. Evans introduced herd in central Colorado about 50 km westsouthwest of Denver. Elevation was 3,835 m. A saltlick had been established and used by the animals for 2-3 years. An observation shelter (surplus half-sized army bus) had been regularly positioned within 10 m of the lick, and the animals were well habituated to it. The zoo-enclosed animals were in an approximately 0.1-ha enclosure at the Denver Zoological Gardens.

METHODS

Free-ranging

Of 9 free-ranging animals, 4 were individually collared adult females (estimated ages = 2, 4, 6, and 11), 1 was an unmarked 2-year old male, and 4 were unmarked kids. A 59 x 79 (w x h) cm framed-mirror was mounted upright against a wooden box structure positioned about halfway between the lick and the observation shelter. Once positioned, large rocks were placed inside to stabilize the structure (breaking and/or toppling mirror were possibilities). The mirror was covered by a curtain that could be lowered or raised by a line to initiate and terminate a trial. This precluded unwanted exposure before observers were ready. Once a group with at least 1 collared goat had arrived at the lick and the observers were out-of-sight in the shelter, the curtain was dropped and responses to mirror-images recorded and selectively photographed.

Zoo-enclosed

Of 5 zoo animals, 4 were individually ear-tagged adult females (ages = 5, 5, 6, and 8), and 1 was a 4-year old male. For these trials, which were intended to increase sample size and provide a more controlled environment than with the free-ranging goats, the mirror (same as described above) was placed in the mountain goat enclosure about 10 m from a video system (Reed et al. 1973). Once the video system was activated and the mirror positioned, the observer stayed out of sight in a housing containing the video system. Visual observations were recorded with each video recording for later identification of animals (eartags could not be discerned on the video) and enhancement of behavioral interpretation. The video recordings were later replayed and behavioral response frequencies tabulated.

RESULTS

Free-ranging

Six trials were completed with 9 animals in groups of 3-6 goats from 7 July - 20 September 1984. Trials ranged 18-53 minutes depending on how long a group remained in the area and interacted with the mirror. The 4 females, male, and 4 kids, had totals of 9, 1, and 6 bouts in front of the mirror, and 112, 44, and 66 exposures to the mirror, respectively (Table 1). The 4 kids were associated (likely maternally) with 3 of the 4 adult females.

Behaviors exhibited in apparent response to the MIS were classified as agonistic, excitatory, or investigatory (Table 1). Of the behaviors exhibited by adult females and the 2-year old male, 56.4 and 68.4 percent, respectively, were agonistic. Adult females and the male exhibited 0.47 and 0.59 agonistic behaviors per exposure, respectively. Kids exhibited no agonistic behavior. There was no significant difference in numbers of agonistic, excitatory, and investigatory behaviors between females and the male ($\chi^2 = 3.748$, df = 2, $P > 0.10$), but kids were significantly less agonistic and more investigatory ($\chi^2 = 102.017$, df = 2, $P < 0.005$). Of the 3 females greater than 2 years old, 11-year old 1^{11} exhibited significantly more agonistic behavior than 6-year old BD ($\chi^2 = 6.065$, df = 2, $P < 0.05$) and 4-year old O ($\chi^2 = 43.539$, df = 2, $P < 0.005$). Similarly, BD exhibited more agonistic behavior than O ($\chi^2 = 10.959$, df = 2, $P < 0.005$), although sample sizes are small (Table 1).

Table 1. Animal(s), number of bouts, exposures, and behaviors exhibited to mirror-images.

			Agonistic				Excitatory			Investigatory			
Animal	Bouts[1]	Exp[2]	Low ear	OT[3]	,Pt[4]	Pt[5]	Tail-up	Jerk[6]	Paw[7]	Lick mirror	Muzzle to mirror	Stare[8]	Head mvmt[9]
Free-ranging													
1^{11}	5	56	2	0	25	19	0	2	4	0	0	0	0
O	2	15	0	0	0	0	9	1	0	2	2	0	0
V	1	7	0	1	1	0	1	0	0	4	0	0	0
BD	1	34	2	0	3	0	0	0	4	0	0	0	0
TOTAL A♀s	9	112	4	1	29	19	10	3	8	6	2	0	0
2 yr ♂	1	44	20	0	6	0	0	6	3	0	0	0	0
4 kids	6	66	0	0	0	0	1	1	0	0	23	6	2
Enclosed - Zoological gardens													
White	16	81	0	0	0	0	7	0	0	-	-	16	12
Blue	7	69	0	0	0	0	2	0	0	-	-	12	1
Purple	20	91	0	0	0	0	4	0	0	-	-	41	7
Yellow	17	60	0	0	0	0	12	0	0	-	-	30	5
TOTAL A♀s	60	301	0	0	0	0	25	0	0	-	-	99	25
4 yr ♂	20	38	0	0	0	0	4	0	0	-	-	15	3

[1] Defined as being < 5 m from front of mirror for > 5 sec.

[2] Exposures defined as apparent looking at mirror image during bout.

[3] Orientation threat as defined by Chadwick (1977:78).

[4] Slight present threat (PT as defined by Chadwick 1977:78).

[5] Intense present threat (PT as defined by Chadwick 1977:78).

[6] A sudden start or movement of head away from mirror image.

[7] Paw ground.

[8] Stare or look at mirror ($\geq$ 5 sec.).

[9] Back and forth head movement.

Considering dominance interactions, age, and number of neonates of the 3 females greater than 2 years old involved in the MIS and 10 additional collared females in the study area during 1983 and 1984 (Reed unpub. data), some aspects of a dominance hierarchy emerge. Specifically, 1^{11}, BD, and O ranked number 1, 9, and 10, respectively, in 1983 and 5, 8, and 9, respectively, in 1984 (Tables 2-4). This hierarchy is consistent with greater agonistic responses in that 1^{11} was the most agonistic and of highest rank, BD was considerably less agonistic and of lower rank, and O was least agonistic and of lowest rank. Furthermore, the 1983 and 1984 hierarchy ranks of these 3 females were similarly consistent with their ages (i.e. greater age, higher rank; Table 4). However, of all 13 animals in which dominance had been determined (Table 4), there were no significant regressions of rank on age for 1983 ($T = -1.86$, df = 9, $P = 0.09$) or 1984 ($T = -0.99$, df = 7, $P = 0.36$). Also, of the 13 animals, there were no significant regressions of rank on number of neonates for 1983 ($T = -1.18$, df = 9, $P = 0.27$) or 1984 ($T = -1.49$, df = 7, $P = 0.17$) and rank on an "age/number of neonates" index (Table 4) for 1983 ($T = -1.89$, df = 9, $P = 0.09$) or 1984 ($T = -1.61$, df = 7, $P = 0.15$).

Table 2. Outcome of dominance interactions between 11 collared female mountain goats, ages 2-10, Mount Evans, 1983.

	Losses												
	1^{11}	M	FG	3	N	BK^{I}	F	4	BD	O	B	Total wins	Rank
WINS													
1^{11}			8	1				1	1		1	12	1
M					1	2	1				1	5	2
FG						5		1			3	9	3
3								1		1		2	4
N											1	1	5
BK^{I}	5								1	1		7	6
F												0	7
4												0	8
BD												0	9
O												0	10
B									1	1		2	11
Total losses	5	0	8	1	1	7	1	3	3	3	6	38	

Table 3. Outcome of dominance interactions between 9 collared female mountain goats, ages 3-11, Mount Evans, 1984.

	Losses										
	FG	N	K	P	1^{11}	B	3	BD	O	Total wins	Rank
WINS											
FG				3						3	1
N					1				2	3	2
K								2		2	3
P									5	5	4
1^{11}									2	2	5
B							1		1	2	6
3										0	7
BD						1				1	8
O										0	9
Total losses	0	0	0	3	1	1	1	2	10	18	

Table 4. Rank, age, and number of neonates of 13 collared mountain goats, Mt. Evans, 1983 and 1984.

	Rank		Age		No. of neonates		Age/no. neonate index ([a÷5] + n)[3]	
Animal	1983	1984	1983	1984	1983	1984	1983	1984
1^{11}	1	5	10	11	1	2	3.0	4.2
M	2	-[1]	6	7	1	0	2.2	1.4
FG	3	1	7	8	1	1	2.4	2.6
3	4	7	5	6	1	0	2.0	1.2
N	5	2	5	6	1	2	2.0	3.2
BK[1]	6	-	8	9	1	-	2.6	-
F	7	-	2	3	0	-	0.3	-
4	8	-	3	4	1	0	1.6	0.8
BD	9	8	5	6	2	1	3.0	2.2
O	10	9	3	4	0	1	0.6	1.8
B	11	6	7	8	0	0	1.4	1.6
K	-	3	9	10	0	2	1.8	4.0
P	-	4	2	3	0[2]	1	0.3	1.6

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[1] Undetermined.

[2] Estimate based on age.

[3] Equation for combining age (a) and no. of neonates (n).

Zoo-enclosed

Four trials were completed with 5 animals in the mountain goat enclosure from 20 February - 26 April 1986. Trials ranged from 20-52 minutes depending on an objective of ≥ 20 minutes and how long animals interacted with the mirror. The 4 females and the male had totals of 60 and 20 bouts, and 301 and 38 exposures to the mirror, respectively (Table 1). Behaviors exhibited in apparent response to the MIS were divided into the same categories as those of the free-ranging animals except that 2 investigatory behaviors, "lick mirror" and "muzzle to mirror," could not be determined because of the mirror's position perpendicular to the video and observer's line-of-sight. No agonistic behaviors to MIS were observed in either the females or the male. Of the 3 excitatory behaviors, only the "tailup" behavior was observed (25 and 4 times for the females and male, respectively, Table 1). The investigatory behaviors, 124 and 18 for the females and male, respectively, were exhibited in greater proportion than those of the free-ranging animals (Table 1). No statistical tests were made between the 3 categories of behavior or the responses of individual animals because of limited sample sizes.

DISCUSSION

It has been suggested that most of the intraspecific social interactions in mountain goats are aggressive, and that males tend to dominate females and older goats dominate younger ones (Chadwick 1983, Dane 1977). But are these relationships based on age or other factors significantly linear as has been suggested for a majority of hierarchies (Jackson and Winnegard 1988)? Furthermore, there is a need to examine the development of dominance relationships (Chase 1980, 1985). Thus, what are the behavioral processes that lead to hierarchy formation?

In this study dominance ranks were determined for only 2 consecutive years, whereas an animal's life-long interactions, as well as previous maternal dominance, would provide a better basis for estimating how, if not why, dominance hierarchies are maintained in mountain goats. Additionally, the limited sample sizes reported here for both the number of interactions in each of the years and the number of animals and trials may not adequately describe the variation of these phenomena. But the study provides a basis for hypotheses about differences between sexes, between females of different ages and reproductive states, and the difference between free-ranging and zoo-enclosed animals.

It is hypothesized that the greater the number of agonistic behaviors elicited from MIS in free-ranging animals, the higher the rank in a dominance hierarchy. Also,age appears positively correlated with rank in females. Although it is attractive to ascribe higher status with having at least 1 neonate, no pattern emerged to support this hypothesis. Other factors including dominance of dam, early separation from dam, development of dominance via cohort interactions, body size, vigor, and inherited characters may be related to rank.

Intraspecific interactions and a dominance hierarchy may influence mountain goat distribution, fitness, and ultimately population size. Also, interspecific competition may be complicated by individuals that occupy different ranks within their own species' hierarchy. Intraspecifically low-ranking individuals may act the same way interspecifically, at least with individuals of their size (Fisler 1977). Social mechanisms in mountain goats may have evolved to regulate population size, especially in the absence of important interspecific competition and predation. An understanding of such phenomena is important for effective management of this species.

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PERSPECTIVES ON MANAGEMENT OF ISOLATED MOUNTAIN GOAT POPULATIONS WITH HIGH NONCONSUMPTIVE VALUES: THE PEND OREILLE LAKE, IDAHO, CASE STUDY

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Abstract: A population of mountain goats (_Oreamnos americanus_) occupies cliffs along the south shore of Pend Oreille Lake in northern Idaho. This population was established from 16 animals transplanted in 1960, 1962, and 1965. Population estimates using mark-recapture techniques indicate 54 goats were present in 1985. This population should be managed as a closed, isolated herd. A Leslie matrix analysis based on data from trapping approximately 65% of the population was used to estimate potential offtake given several scenarios of survival and fecundity. A plan to remove 3 to 5 goats, including 2-3 adult nannies, from this population annually should be implemented. If survival or fecundity rates are unchanged, the population is predicted to stabilize at about 75% of its current level, or about 38 goats. If survival rates or fecundity rates increase, as is likely, the higher level of 5 goats will be an appropriate offtake. In addition new stockings should be considered at 10-20 year intervals. This population is below minimum viable levels and will not survive over the long term without management.

Mountain goats are occasionally transplanted to areas where their primary values are nonconsumptive. In other cases, natural populations have high nonconsumptive values and harvest is a secondary consideration. The histories of several introduced mountain goat populations (Houston and Stevens 1988, Swenson 1985) suggest that the sequence of population growth described by Caughley (1970) may be an appropriate model of how this species responds following transplanting. This model suggests that the population will interact with forage resources, altering the vegetation and ultimately limiting the population. The model predicts that introduced mountain goat populations which are not managed appropriately will achieve an initial population high, followed by a decline and eventual levelling off with the population fluctuating according to a weather-forage interaction.

A management strategy to disrupt this irruptive sequence with the goal of retaining a larger population than would occur if the sequence were allowed to occur would be useful for managing mountain goats where nonconsumptive values are emphasized. The assumption is that if the forage is not allowed to deteriorate to some equilibrium which controls goat numbers, then a greater abundance, or quality, of forage would support more goats over the long run. This would provide greater nonconsumptive values from the population, assuming more goats in better nutritional status is a measure of value. It may also maintain the habitat in a more acceptable condition, depending upon the nature of vegetation change that would occur if the irruptive sequence was permitted.

The purpose of this study was to estimate offtake for an introduced mountain goat population which would stabilize it below a probable irruptive high. The population occupies a 5.3 km^2 cliffy area on the south side of Pend Oreille Lake, Idaho. Naylor (1988) reported that by 1985, this population appeared to be approaching the asymptotic high that precedes a decline, based on kid production/survival and available population trend data.

This population originated from transplants of 16 goats in 1960, 1962 and 1965. Six billies, 7 nannies, and 3 adults of unidentified sex were transplanted. Winter aerial surveys in 1973, 1976, 1981 and 1984, counted 14, 19, 37, and 38 goats, respectively, in the area.

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METHODS

During summer 1984 and 1985, 29 mountain goats were captured at a salt lick in 2 Clover style deer traps (Clover 1956). Sex and age of each animal were determined following Brandborg (1955), and animals were individually marked. Reproductive status was assessed by presence of absence of kids at the trap site. From October 1984-August 1985, 112 censuses were conducted using a multiple capture-recapture method (Schnabel 1938) with 95% confidence limits calculated from Ricker (1975). Visual sightings of 7 radio-marked animals were used as recaptures to reduce bias associated with using trap recaptures (Flyger 1959). Censuses were conducted from a boat travelling slowly about 150 m from shoreline. Slopes were searched with binoculars by 2 observers who verified their sightings with each other to avoid double counting.

A Leslie matrix model (Leslie and Ransom 1940) was used to determine rate of increase. Survival and fecundity rates were based on the age composition of the trapped sample, augmented with a literature search. The model was run on a computer for 20 iterations which sufficed to smooth the age structure obtained from the sampled population and to stabilize trends in age-sex composition.

Different levels of offtake were then explored to determine their effects on finite rate of increase and population size. Survival and fecundity rates were then altered to simulate potential compensatory responses to levels of offtake.

Accessible shrubs on the cliffs were surveyed to obtain a species list and to estimate utilization and degree of hedging. We assumed that current conditions would provide evidence concerning the vegetation-goat interaction.

RESULTS

Minimum breeding age for the 20 females was 4 years (Table 1). Seven of 13 females >4 years of age were pregnant or had kids. Three of 6 radio-collared nannies lost their kids during the 1984-85 seasons. Two nannies lost kids in summer, while a third lost hers in January. Two kids from radio-collared nannies survived their first year and 1 kid's fate was undetermined.

Known adult mortalities consisted of 2 billies, 4.5 years and 9.5 years old, and a 10+ year-old nanny. The younger billy was found in the lake below the cliffs with a crushed skull and other abrasions indicating a fall. The older billy was found in March 1985 alive but emaciated and died the next day. The nanny was killed during an archery hunt (2 permits annually).

Census data reflected goats at least 1 year old (Table 2). The annual kid crop was estimated by counts of 12 kids in 1984 and 10 in 1985. The Schnabel estimate of the mean number of goats 1 year old or more was 42 (20-78, $P<0.05$), for a total mean summer population estimate of 52. Among surveys, 12% and 22% of the observed goats were radiocollared and between 11-33 goats were observed.

The first Leslie matrix model used fecundity rates of 0.5/year, survival rates of 0.55 for kids, 0.75 for billies >1 year, and 0.95 for nannies >1 year (Table 3). Age at first reproduction was 4 years for females. The initial population was set at 52, and the resulting finite rate of increase of 1.027 indicated a slowly increasing population. When an annual harvest of an adult billy and an adult nanny was applied to this population, it stabilized at 54 goats (Table 3). Harvest of 2 adult nannies and 1 adult billy (4% of the adult population) caused this population to decrease slowly from 52 to 38 in 20 iterations representing 20 years (Table 3).

The population stabilized at 54 when kid survival was decreased to 0.45, assuming no harvest (Table 3). When all survival rates were decreased 0.1, the population declined to 20 animals in 10 years, with the finite rate of increase being 0.904. If survival rates were kept at original levels and fecundity rates were decreased 0.1, the population stabilized at 49 individuals. If fecundity rates were decreased 0.15, the population declined to 44 individuals at 10 years and the finite rate of increase was 0.975.

When fecundity rates were increased 10% to simulate a population response to harvest, the population then stabilized at 49 individuals with a 4% harvest consisting of 2 billies and 2 nannies. When fecundity rates were set equal to the initial run and survival was increased by 0.10 for all age classes, the population stabilized after 20 iterations at 51 individuals with a 9% harvest of 4 individuals (2 billies and 2 nannies).

When fecundity rates and survival rates were both increased by 0.10, the population stabilized at 55 after 20 iterations with an offtake of 10% or 2 billies and 3 nannies.

Utilization of shrubs that were able to be sampled safely ranged from 0-30% of leaders browsed (Table 4). Rocky mountain maple, oceanspray and common ninebark were the most heavily used shrubs. Heavily browsed shrubs are found in widely scattered areas, but occasionally two shrubs of the same species were found adjacent to each other with only one showing severe browsing.

DISCUSSION

Of an estimated 44 adults, approximately 65% of the population was trapped over the 2-year period. This suggests that the age structure was as representative of the population as is practical to obtain unless a complete capture is attempted. The fact that this population is readily accessible, readily observed, is habituated to using a salt lick, and occupies a small area contributed to the high proportion that was trapped.

Census information represented visibility biases as well as seasonal fluctuation of the population in the area. Probably December-February has the least immigration or emigration to other areas because snow conditions impede movements. Observations during that period indicate a very clumped distribution. The high estimate in November may be due to rutting activities during which these goats use the more open cliff face and are consequently more visible, or reflects immigration to the study cliffs of goats occupying nearby isolated habitats. Vegetative conditions also influenced goat observations because dense deciduous shrub stands adversely affect observation.

The density estimate of 18.5 goats/km^2 in the core of the habitat is among the highest recorded. Stevens (1983) reported 14 goats/km^2 in Olympic National Park on 1 ridge. Chadwick (1979) reported 1.2 goats/km^2 in Glacier National Park. Rideout (1974) reported 0.6-1.1 goats/km^2 in a western Montana habitat, and Fox (1979) reported 1.3 goats/km^2 in a southeast Alaska study area.

Our population models suggest that relatively small changes in fecundity or survival will affect rate of increase of this small population. Changes in survival rate have a greater effect on trend than does variation in fecundity. A change in mortality of 2-3 animals/year can significantly affect this population. Density-related responses in initial breeding age, litter size, or age ratios were shown for populations in Olympic National Park (Houston and Stevens 1988), the Absaroka Range in Montana (Swenson 1985) and in Colorado (Adams and Bailey 1982).

Caughley (1970) postulated that when a population exhibiting an irruptive sequence entered the final stage, the mean size around which it stabilized would be significantly lower than the size at which it peaked prior to the decline. The Pend Oreille goat population may have approached the asymptotic level and be ready to decline. It is at a very high density relative to other populations. Recruitment to the population appeared low, and no twins were observed. Age at sexual maturity was high.

This population is isolated from other mountain goat herds by extensive forests. While marked goats were observed to disperse to patches of habitat adjacent to the study cliffs, probabilities for interchange with other populations are considered low.

A management strategy for maintaining goats on these cliffs should include a plan to remove between 3-5 goats, including 2-3 adult nannies, each year. Following severe winters, the lower numbers may suffice, while during normal or more mild winters, higher levels may be appropriate. If no changes in survival or fecundity rates occur, the population will stablize at approximately 75% of its currently estimated level, or around 38 goats. This could be an initial goal of the management program. If survival rates or fecundity rates increase, as we predict they will, the higher level of 5 goats including 3 nannies would be an appropriate offtake, and higher levels may be needed. The population should be monitored to determine production and survival of kids.

Inbreeding depression may eventually decrease productivity and survival, and new stock, perhaps consisting of 2 billies and 3 nannies, should be considered for transplanting onto these cliffs. This may have to be accomplished at 10-20 year intervals.

The strategy of not actively managing this goat population will eventually result in a highly reduced density and probably extirpation. The amount of habitat is too small and too isolated to maintain a population without management.

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Table 1. Sexes and ages of mountain goats captured at Pend Oreille Lake study area, June-July 1984, and May 1985.

AGE	MALE	FEMALE	REMARKS
1	0	4	
2	2	2	
3	3	1	
4	1	1	
5	2	2	1 with kid
6	0	5	2 with one kid each
7	1	3	1 pregnant, 1 with yearling
8	0	1	1 with kid
8+	0	1	
TOTAL	9	20	

Table 2. Population estimates from monthly censuses at Pend Oreille Lake study area. Estimates are for goats greater than 1 year old.

Month	No. of Surveys	Total No. of Goats/day	Obs. Marked Goats/day	(%)	N	95% Conf. Limit
Jan	15	29.6	5.06	(17)	41	35-51
Feb	11	22.9	4.09	(18)	39	30-53
Mar	12	23.5	4.30	(18)	38	33-49
Apr	10	32.5	5.20	(16)	43	48-56
May	4	23.8	3.75	(16)	38	26-64
June	6	24.8	3.16	(13)	45	33-72
July	19	11.8	2.63	(22)	27	20-35
Aug	7	15.3	2.00	(13)	43	27-74
Sep	no censuses					
Oct	8	22.5	3.25	(14)	47	33-70
Nov	14	27.4	3.28	(12)	57	44-78
Dec	6	30.5	4.66	(15)	45	37-66

Table 3. Leslie matrix projections of the Pend Oreille Lake mountain goat population using different harvest, survival, and fecundity rates. Initial population size was 52, and minimum breeding age was 4 for females.

FECUNDITY RATES	SURVIVAL RATES			OFFTAKE		FINITE RATE OF INCREASE	POP. SIZE AT 20 ITERATIONS
	Kids	Adults					
		Females	Males	#	%		
0.5	.55	.95	.75	0		1.027	96
0.5	.55	.95	.75	2	3	1.000	54
0.5	.55	.95	.75	3	4	0.987	38
0.55	.55	.95	.75	2	4	1.000	49
0.5	.65	.99	.85	4	9	1.005	51
0.55	.65	.99	.85	5	10	1.014	55
0.5	.45	.95	.75	0		0.997	54
0.5	.45	.85	.65	0		0.904	7
0.4	.55	.95	.75	0		0.994	49
0.35	.55	.95	.75	0		0.975	33

Table 4. Common shrubs and estimated utilization on accessible sites, Pend Oreille Lake study area.

Species	Utilization(%)
Rocky mountain maple *Acer glabrum*	30
Servicebery *Amelanchier alnifolia*	15
Kinnikinnick *Arctostaphylos uva-ursi*	0
Red-osier dogwood *Cornus stolonifera*	5
Oceanspary *Holodiscus discolor*	20
Syringa *Philadelphus lewisii*	15
Ninebark *Physocarpus malvaceous*	25
Chokecherry *Prunus virginiana*	0
Wood's rose *Rosa woodsii*	0
Snowberry *Symphoricarpos albus*	15

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GUIDELINES of THE NORTHERN WILD SHEEP AND GOAT COUNCIL

The purpose of the Northern Wild Sheep and Goat Council is to foster wise management and conservation of northern wild sheep and goat populations and their habitats.

This purpose will be achieved by:

1) providing for timely exchange of research and management information;

2) promoting high standards in research and management; and

3) providing professional advice on issues involving wild sheep and goat conservation and management.

I The membership shall include professional research and management biologists and others active in the conservation of wild sheep and goats. Membership in the Council will be achieved either by registering at, or purchasing proceedings of, the biennial conference. Only members may vote at the biennial meeting.

II The affairs of the Council will be conducted by an Executive Committee consisting of: three elected members from Canada; three elected members from the United States; one ad hoc member from the state, province, or territory hosting the biennial meeting; and the past chairperson of the Executive Committee. The Executive Committee elects it's chairperson.

III Members of the Council will be nominated and elected to the executive committee at the biennial meeting. Executive Committee members, excluding the ad hoc member, will serve for four years, with alternating election of two persons and one person of each country, respectively. The ad hoc member will only serve for two years.

The biennial meeting of members of the Council shall include a symposium and business meeting. The location of the biennial meeting shall rotate among the members' provinces, territories and states. Members in the host state, province or territory will plan, publicize and conduct the symposium and meeting; will handle its financial matters; and will prepare and distribute the proceedings of the symposium.

The symposium may include presentations, panel discussions, poster sessions, and field trips related to research and management of wild sheep, mountain goats, and related species. Should any member's proposal for presenting a paper at the symposium be rejected by members of the host province, territory or state, the rejected member may appeal to the Council's executive committee. Subsequently, the committee will make its recommendations to the members of the host state, territory or province for a final decision.

The symposium proceedings shall be numbered with 1978 being No. 1, 1980 being No. 2, etc. The members in the province, territory or state hosting the biennial meeting shall select the editor(s) of the proceedings. Responsibility for quality of the proceedings shall rest with the editor(s). The editors shall strive for uniformity of manuscript style and printing, both within and among proceedings.

The proceedings shall include edited papers from presentations, panel discussions or posters given at the symposium. Full papers will be emphasized in the proceedings. The editor will arrange for reviews of these papers. A limited number of abstracts may be included at the editor's discretion. The editor will set a deadline for submission of manuscripts.

Members of the host province, territory or state shall distribute copies of the proceedings to members and other purchasers. In addition, funds will be solicited for distributing a copy to each major wildlife library within the Council's states, provinces and territories.

IV Resolutions on issues involving conservation and management of wild sheep and goats will be received by the chairperson of the Executive Committee before the biennial meeting. The Executive Committee will review all resolutions, and present them with recommendations at the business meeting. Resolutions will be adopted by a plurality vote. The Executive Committee may also adopt resolutions on behalf of the Council between biennial meetings.

V Changes in these guidelines may be accomplished by plurality vote at the biennial meeting.