NORTHERN WILD SHEEP AND GOAT COUNCIL

Proceedings of the Eleventh Biennial Symposium

APRIL 16-20, 1998

Whitefish, Montana

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FOREWORD

The eleventh biennial symposium of the Northern Wild Sheep and Goat Council as attended by 101 registrants representing 10 States and 4 Canadian Provinces and Territories. Session chairmen were responsible for reviewing each manuscript and in their session and submitting the final papers to an editor. Final versions of the papers were left to the discretion of individual authors.

Effects of Nonhunting Disturbance

WINTER RECREATION AND HUMAN DISTURBANCE ON MOUNTAIN GOATS: A REVIEW

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Abstract: Human activities can disturb wildlife. Many wildlife species including mountain goats (*Oreamnos americanus*) are most vulnerable to human-caused disturbances in the winter. Recreation can have detrimental effects on goat populations during winter. A review of literature on human disturbance and goat winter ranges led to the hypothesis that conflict between goats and most recreation types are rare because of spatial segregation. Use of helicopters for winter recreation may pose a threat, and in those cases, special guidelines may be needed to avoid disturbance.

INTRODUCTION

As human activities expand into wildlife habitat managers struggle to understand the effects of these activities and minimize impacts. The effects of human recreation on various wildlife species have been documented in many situations (Knight and Gutzwiller 1995). Alterations of behavior, induced by human disturbances, can affect physiology, distribution, habitat use, fecundity, and population health (Penner 1988, Knight and Gutzwiller 1995). Some human-caused disturbances of mountain goats have been investigated; however, little is known specifically about the effects of winter recreation on mountain goats.

Mountain goats are one of the least understood of all big game mammal species in North America (Eastman 1977, Chadwick 1983). Management has principally focused on the need for better population information and methods for setting harvest (Brandborg 1955, Eastman 1977, Wigal and Coggins 1982). Eastman (1977) assessed research needs for goats and found non-hunting impacts, resulting from human disturbance, ranked within the top third among management priorities, but very little had been done on the subject.

DOCUMENTED DISTURBANCE

Based on the potential for disturbances to wintering goat populations, area restrictions, closures and other mitigation measures were enacted to minimize winter recreation including foot, snow machine and helicopter travel on the Sawtooth National Forest and Sawtooth National Recreation Area in Idaho (USDA Forest Service 1997, Hamilton *et al.* 1996). Observations of ski, helicopter, and snowmobile use near wintering mountain goats suggested a significant level of disturbance was occurring (Hamilton Pers. Comm.)

Beyond this case, mostly anecdotal reports are the basis for conclusions specific to winter recreation. The general effects of human disturbance on mountain goats were examined for context. Some goat populations were adversely affected by logging (Chadwick 1973, Hebert and

Turnbull 1977, Smith and Raedeke 1982) and mineral, coal, gas, and oil development (Hebert and Turnbull 1977, Pendergast and Bindernagel 1977, Smith 1982, Joslin 1986). In these cases, declines in goat populations occurred when developments were in or near goat habitats. The mechanisms for population declines were not always clear. However, they seemed to be related to improved access for hunting or poaching (Chadwick 1973, Foster 1977, Hebert and Turnbull 1977, Smith and Raedeke 1982, Smith 1994), abandonment of habitat due to alterations or disturbance (Chadwick 1973, Hebert and Turnbull 1977, Pendergast and Bindernagel 1977), or continual stress as a result of human presence (Joslin 1986).

Controlling human access was often suggested as the management tool potentially having the greatest effects on the long-term health of mountain goat populations (Chadwick 1973, 1983; Eastman 1977, Hebert and Turnbull 1977, McFetridge 1977, Wigal and Coggins 1982, Joslin 1986, Haynes 1992). Joslin (from Haynes 1992) states, "motorized access in or near mountain goat habitat is probably the single biggest threat to goat herds throughout North America."

Several authors looked at goats affected by proximity to people, traffic and noise during summer (Holroyd 1967, Singer 1978, Thompson 1980, Singer and Doherty 1985, Pedevillano and Wright 1987). Goats have shown tolerance, and in cases without harvest or harassment, the ability to readily habituate to humans on foot and road traffic (Bansner 1978, Stevens 1983, Singer and Doherty 1985, Pedevillano and Wright 1987, Penner 1988). Goats approached on foot were either mildly evasive, tolerant or curious (Brandborg 1955, Holroyd 1967, Thompson 1980, Pedevillano and Wright 1987).

Penner (1988) wrote that "goats are adaptable and can habituate to potentially adverse stimuli if they are gradually acclimatized and negative associations are avoided." This was best achieved when stimuli sources were localized and highly predictable (Penner 1988, Singer 1985). Sudden, loud noises from traffic (Singer 1978, Singer and Doherty 1985, Pedevillano and Wright 1987), blasting, drills (Singer 1985, Penner 1988), and helicopters (Penner 1988, Cote' 1996) elicited extreme alarm responses from goats habituated to human presence.

SPATIAL CONSTRAINTS

Due to narrow habitat requirements, goats on winter range are vulnerable to disturbances by winter recreationists (Smith 1982, Chadwick 1983, Smith 1984, Wigal and Coggins 1988). The principal factors in mountain goat mortality seemed to be winter severity and snow depths (Adams and Bailey 1982, Wigal and Coggins 1982, Swenson 1985). Snow depth and snow morphology was often the underlying factors in causes of death that included the availability of winter forage and its effect on body condition (Brandborg 1955, Edwards 1956, Holroyd 1967), the frequency of intra specific interactions and its resulting levels of stress (Petocz 1972, Chadwick 1977, Kuck 1977, Smith 1977, Foster and Rahs 1982), the susceptibility to accidents including avalanches and falls (Holroyd 1967, Chadwick 1983, Smith 1984), the susceptibility to disease and parasites (Wigal and Coggins 1982), and the susceptibility to predation (Brandborg 1955, Holroyd 1967, Foster and Rahs 1982). Accidents related to avalanches; rock, snow, and ice fall; and precipitous falls appear to account for most natural deaths (Brandborg 1955, Holroyd 1967, Chadwick 1983, Foster and Rahs 1982, Wigal and Coggins 1982, Smith 1984).

The principal factors in mountain goat winter range habitat selection seem to be close proximity to cliff habitats and low snow accumulations (Brandborg 1955, Smith 1977, Smith 1994). Thus, winter habitats were often steep and rocky, located on south-facing slopes and exposed to wind and sun (Brandborg 1955, Chadwick 1973, Gilbert and Raedeke 1992, Smith 1994, Varley 1995). Brandborg (1955) noted that goats in Montana and Idaho used, "the lowest available winter ranges that provide preferred combinations of broken terrain and vegetative cover." Smith (1977) found wintering goats in the Bitterroot Range used cliff habitats >70% of the time observed. Kuck (1977) found the selection of winter habitat for goats in the Lemhi Mountains of Idaho was determined by the physical, snow shedding characteristics of an area rather than the forage types present.

Wintering goats severely restrict their movements, so that their distribution is often confined to critically small islands of habitat (Kuck 1977). In the Bitterroot Range, 36 goats occupied a linear distance of 5 km throughout the winter (Smith 1977). Similarly, 17 wintering goats used 3.5 ha in the Swan Range of northern Montana (Chadwick 1973). In very severe winters, goats will continue descending to lower elevations (Rideout 1977), while in Alaska they ascended to windswept ridges or mountain tops (Hjeljord 1973).

Goats typically migrated between summer and winter ranges each fall and spring (Brandborg 1955, Holroyd 1967, Kuck 1977, Smith 1977, Wigal and Coggins 1982). These migrations were often short, elevational shifts to adjacent areas (Holroyd 1967, Chadwick 1973, Varley 1995). The use of transitional ranges between summer and winter ranges is atypical (Kuck 1977). In the Rocky Mountains, summer ranges were often high elevation settings, such as the tops of mountain ridges and peaks above timberline (Brandborg 1955, Holroyd 1967, Wigal and Coggins 1982). In the Greater Yellowstone area, summer ranges are typically between 2,500 and 4,000 meters in elevation. During the summer months, goats used alpine meadows, slide-rock slopes, talus, and cliff ledges, and usually avoid timbered areas (Saunders 1955, McFetridge 1977, Thompson 1981, Varley 1995).

POTENTIAL CONFLICTS

Although human activities can cause detrimental disturbances to mountain goat populations, few documented cases refer specifically to winter recreation. Due to the remote and rugged nature of goat wintering habitats in the Greater Yellowstone area, recreational use of such areas appears to occur at low levels.

Mountain goat habitats are inaccessible to most winter recreationists for several reasons. Many occupied goat winter ranges occur within established National Forest Wilderness areas within which motorized travel is strictly prohibited. In other cases the terrain is simply too rugged for most people. For recreation, humans tend not to seek the combination of rocky, rugged terrain and low-snow conditions required by mountain goats. Rather, users prefer the deep snow conditions avoided by goats. The discrepancy in site preferences appears to be a factor in mutual avoidance by goats and humans during winter. However, a few human activities may potentially result in conflicts.

Unlike other recreation forms, ice-climbing opportunities are often found in goat winter ranges, but the effects of this activity are unknown. Ice climbing is highly localized at specific sites and predictable in its occurrence. These two characteristics may facilitate goat tolerance of human presence. Therefore, ice-climbing may not pose a significant threat to mountain goats.

Snowmobiles and helicopters can effect goat behavior, depending upon the proximity and duration of the disturbance (Singer and Doherty 1985), Pedevillano and Wright 1987, Cote' 1996). Assessing management considerations similar to and including the Sawtooth National Forest case, the Idaho Department of Fish and Game (1990) identified helicopter use for transporting skiers as an activity potentially detrimental to goats. In general, helicopter use in the near vicinity of goats has resulted in disturbance. Helicopters should be flown no closer than 2-2.5 km from areas where goats are known to be wintering in order to avoid disturbances (Haines 1992, Cote' 1996).

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A REVIEW OF THE POTENTIAL EFFECTS OF WINTER RECREATION ON BIGHORN SHEEP

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Abstract: Since 1994 managers in the Greater Yellowstone Area have assessed winter recreational use. Of particular interest to the public and park managers is how winter recreation impacts wildlife. A team of biologists from the Greater Yellowstone Area reviewed a number of wildlife issues and developed possible management guidelines to limit winter recreation impacts to wildlife. This paper is a review of the potential impacts of winter recreation to bighorn sheep (*Ovis canadensis*). Stresses from humans add to the natural stresses incurred by sheep during the winter and may cause displacement of bighorns from critical winter ranges, reduce productivity or limit foraging to times of day that require more energy. Some management suggestions were to limit the use of winter range by humans (possibly only allowing access on trails or roads), allow no dogs on winter range, expand the protection of current winter ranges, institute temporal regulation on human access and monitor activities on winter ranges to assess if bighorns are being displaced.

INTRODUCTION

Non-consumptive outdoor recreation increased substantially over the past few decades (Boyle and Samson 1985). The effects from winter recreational use to the natural environment are a point of disagreement among the public. The Greater Yellowstone Coordinating committee (GYCC) formed an interagency team of forest and park staff from the Great Yellowstone Area (GYA), to assess the following concerns: overcrowding, visitor conflicts and resource damage (snowmobile exhaust and noise, impacts to wildlife) in the document, *Winter Visitor Use Management: A Multi-Agency Assessment* (GYCC 1997). Biologists from the national forest, national parks and states in the GYA formed a working group in January 1997 to further address winter recreation impacts to wildlife.

The wildlife working group utilized a number of bibliographic reviews (with summaries and management recommendations) that pertained to how wildlife and the natural environment may be impacted by winter recreation activities (Bennett 1995, Biodiversity Legal Defense Foundation 1996, Caslick 1997). There was disagreement as to whether these bibliographic reviews contained information significant to winter use impacts on wildlife. Each biologist addressed different topics and prepared a short paper that described the possible impacts from winter recreation and management actions to prevent these impacts. These are being compiled into the report *The effects of winter recreation on wildlife: a literature review and assessment* (GYCC, in press). Bighorn sheep were of concern, since populations in the GYA and specifically Yellowstone National Park (YNP) were at lower numbers than in the past. Managers wanted to better understand how recreation may affect sheep and if this activity limited these populations.

Many populations of bighorn sheep in the GYA declined over the past 20 years (Meagher et al. 1992, Jones 1994, Legg 1996, Irby pers. Comm., Roop pers. Comm., Stewart pers. Comm.). Most recently the population in the Madison Range by quake Lake, Montana declined during the winter of 1996-97 (Irby pers. Comm.). Disease, predation, and human impacts, such as destruction of habitat, recreation on seasonal ranges, and illegal hunting contribute to these unstable populations. Losses of habitat and migration routes are primary factors facing bighorn sheep management (Constan 1975, Horejsi 1976, Martin 1985, Reisenhoover et al. 1988, Envir. Prot, Fish Wildl. Serv. 1993). Many different stressors (natural and human caused) affect bighorn sheep during the winter. Limiting the impacts by humans during the winter may be important for maintaining bighorn populations of the GYA.

ASSESSMENT OF WINTER RECREATIONAL USE

In the GYA, the following winter recreational users and use may affect bighorn sheep: hikers, wildlife photographers/observers, ice climbers, hunters, snowshoers, skiers, snowmobilers, sled dogs heli-skiing, and humans with dogs. In YNP, skiers have disturbed sheep at high elevation winter ranges, and the public ahs access year long to lower elevation winter ranges with main roads going through them. Recreation near or on bighorn winter ranges may affect sheep most during the rut, during severe winter conditions, and in the spring during the lambing season.

Limited information was available about the direct impacts of winter recreation on bighorn sheep. Literature has shown some impacts. In Montana, snowmobiles may have contributed to a decline in a bighorn population where they added to the natural stresses incurred during the winter (Berwick 1968). Hayden (1992) recommended that snowmobiles not be permitted within 1609 meters of goat habitat on the Beartooth Plateau, Montana. Intense recreational activities reduced desert bighorn occupancy of an area in the San Gabriel Mountains of southern California (Light and Weaver unpublished, in Hicks and Elder 1979). The distance between humans and bighorns, the elevation of the humans in relation to the bighorns, and bighorn herd size are important factors determining the reaction of bighorns when approached by humans (Hicks and Elder 1979). Boyle and Samson (1985) noted that climbing on or near bighorn escape terrain can affect the sheep. Thus, increased activities of ice-climbers in the vicinity of a bighorn winter range on the Shoshone National Forest concerned managers. Horejsi (1976) stated that improved access and more leisure time has increased recreational activities such as hiking with a dog and snowmobiling, which resulted in more terrain to wild sheep. Greater impacts resulted from people following the sheep onto their escape terrain.

Heli-skiing, where helicopters transport skiers to remote sites may have detrimental effects on bighorn sheep. Heli-skiing does not occur legally in the GYA. Studies of birds, mountain goats, wild sheep, deer, elk and wolverines showed impacts to wildlife from low flying aircraft. Exposure to helicopters and their noise increased energy expenditure, reduced fat accumulation, changed the animal's physiological condition, elevated heart rates, decreased survivorship, altered habitat use and distribution, interrupted torpor or hibernation, caused either acute or chronic hearing loss, and/or caused groups to separate (Horejsi 1975, MacArthur et al. 1979, Knight and Cole 1995).

Several studies discussed the impacts of aircraft to mountain sheep and mountain goats. Goats did not habituate to repeated overflights. They remained alert and did not forage while the helicopter was present. Groups separated, and individuals were injured while fleeing the area (Cote' 1996). Cote' recommended a 2-kilometer buffer around mountain goat herds to decrease the harmful effects to the goats from helicopters. Similar impacts to goats were discussed in the environmental assessment of helicopter skiing in the Ketchum Ranger District, Idaho (USDA 1996). Joslin (1986) noted that helicopters used for seismic exploration affected mountain goats.

Bighorn sheep may be affected similarly. Jorgensen (1988) documented that bighorns abandoned winter range during the preparation of the 1988 Winter Olympics. Helicopter flights, avalanche blasting and human activity on ridge tops displaced the sheep to less optimal habitats. Sheep did, however, return after those activities ended. Bighorns were affected in the Grand Canyon by helicopter over-flights (Stockwell and Batemen 1991). In YNP helicopters and low flying aircraft cause bighorns to exhibit behaviors similar to those described for the goats (Ostovar pers. Comm.).

Recreational activities caused increased heart rates in bighorn sheep. (MacArthur et al. 1982) and/or displacement from preferred foraging areas into less optimal habitat (Horejsi 1976, Hicks and Elder 1979). During the winter, sheep typically forage during the warmest part of the day to minimize energy loss. Unfortunately, this time period is when humans recreate and are more likely to be in conflict with sheep. If sheep alter foraging activities, spatially and/or temporally, they increase their exposure to predators and add to the many stresses accumulated over the winter (USDA 1996). Decreased energy intake and increased energy expenditure may lead to reduced productivity, death by starvation, lowered resistance to disease and predation (Caslick 1993). Effects of human disturbance may be an additive factor in lowering the survivability in sheep (Horejsi 1976).

POTENTIAL EFFECTS

The following is a summary from the review literature of the potential effects to bighorn sheep from winter recreation.

1) Bighorns may limit their use to a small area of escape terrain or abandon high quality winter range, if it is used heavily by humans. These limitations will decrease available habitat and increase exposure to predation.

2) Recreation-caused stress during critical winter months may lower bighorn survivability.

3) Human use on the range during the breeding season could interfere with breeding.

4) During the lambing season, recreation could displace ewes into less optimal habitat, exposing lambs to predators and harsher weather conditions.

5) Developments along migration corridors or on winter ranges may decrease the already limited habitat available for the sheep.

6) If bighorns are unable to forage during the day because of recreationists, the sheep will require more energy to forage during evening hours, when it is colder.

7) Heli-skiing and other overflights may prove detrimental to sheep by increasing energy expenditures, reducing fat accumulation, changing an animal's physiological condition, elevating heart rages, decreasing survivorship, altering habitat use and distribution, causing either acute or chronic hearing loss, and causing groups to separate.

MANAGEMENT GUIDELINES IN REFERENCE TO WINTER USE

From the review of the available literature, management guidelines were suggested. Management guidelines may vary by site, depending on terrain, accessibility, and the type of recreational use.

1) Limit the approach to the critical areas of sheep habitat. To help eliminate some of the stress and habituation possibilities associated with humans, YNP implemented a closure within 100 meters of escape terrain on a winter range in northern Yellowstone.

2) If winter range is used heavily by people, disturbance may be minimized by limiting human activities to roads or trails (MacArthur et al. 1982).

3) Allow no dogs on any sheep winter range (MacArthur et al. 1982). If allowed into an area, they must be on a leash (Harris et al. 1995).

4) Protect and expand remaining bighorn habitat and ensure integrity of migration corridors.

5) Provide special protection during brief critical periods, such as during breeding, lambing and severe winter weather (Horejsi 1976, Boyle and Samson 1985).

6) Monitor activities, such as ice climbing, wildlife photography/observation or hiking that occur on lower elevation winter ranges. If bighorns are displaced, the area may need to be closed.

7) Skiing, snowmobiling, mountaineering and snowshoeing will most likely only affect bighorns wintering at higher elevations. The encounters between these recreationists and bighorns may be infrequent enough that there would be little to no impact to the animals. If use increases at these higher elevation ranges, the managers will want to monitor the situation.

8) Depending upon the site, managers should implement a 1609 meter buffer from snowmobiles near bighorn sheep escape terrain (Hayden 1992).

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Habitat and Habitat Enhancement

WILDLIFE RECLAMATION PLANNING

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Abstract. Reclamation of coal mines in the Alberta foothills has resulted in range expansion and increased population for bighorn sheep as well as new habitat for other species. These modified habitats take on more significance when put in context with range losses experienced by bighorn sheep in North America during European settlement. A review of the steps required for wildlife reclamation planning is presented and illustrated by case studies involving three existing and one planned coal mine located in the subalpine and upper boreal-cordilleran ecoregions of Alberta. 1) Reclamation begins prior to the disturbance with a comprehensive wildlife inventory and ecological land classification. 2) Umbrella species are chosen for wildlife reclamation planning and long-term monitoring. Species with very specific habitat requirements are also identified for specialized reclamation activities. 3) Preplanning activities are initiated if required. 4) A conceptual reclamation plan is prepared with the input of professionals knowledgeable in mining, soil, vegetation, and ecological processes. Restoration is not usually possible given the scale of coal mining so a pragmatic ecosystem approach is adopted that attempts to integrate procedures that restore pre-mine habitat condition, replace habitat function, and exchange certain components for others of similar benefit. Examples of wildlife reclamation techniques and their benefits are discussed within the mining environment. 5) During active mining, several initiatives are undertaken that promote the wildlife use of the final reclaimed landscape. 6) Post-mine planning for the reintroduction of human activity to the reclaimed landscape and its wildlife will ensure that benefits persist into the future.

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HABITAT USE AND MOVEMENTS OF MOUNTAIN GOATS AS DETERMINED BY PROTOTYPE GPS COLLARS, ROBSON VALLEY, BRITISH COLUMBIA

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Abstract: Conventional aerial telemetry on ungulates living in mountainous terrain is often restricted by poor weather, the requirement for daylight, and the high costs and dangers associated with repeated aircraft flights. In late July 1997 we deployed 2 prototype global positioning system (GPS) collars on adult nanny mountain goats (*Oreamnos americanus*) living in the Robson Valley in east-central British Columbia. The collar's GPS receiver was programmed to determine its location every hour. About every 2 weeks we located the goats from a fixed-wing aircraft using the collar's VHF transmissions. The GPS function of the collars on goats 9701 and 9705 lasted 24 and 49 days and provided 163 and 917 locations, respectively. The collar on goat 9705 had a higher daily observation rate than 9701 (78.9% vs. 26.9%; $P < 0.001$), lower mean positional dispersion of precision (PDOP) (3.6 ± 0.05 vs. 4.2 ± 0.17; $P = 0.0002$), and proportionately more 3D vs. 2D fixes (and presumably more precise locations; 66.7 vs. 30.1%; $P = 0.001$). These differences may have been related to the position of the goats relative to steep cliffs and satellites. Goats 9701 and 9705 ranged over 400 and 800 m in elevation, respectively. Comparing 6 hour periods during the day, goat 9705 was at lower elevations from midnight to 0600 hr (2068 ± 11.5 m vs. 2127-2176 m during 600 – midnight; $P < 0.001$), moved less from noon to 1800 hr (196 ± 14.4 m/hr) and more from 1800 to 2400 hr (253 ± 18.7 m/hr; $P = 0.049$). Goat 9701 showed no daily pattern of elevation use or movement rates. The hourly movements of goat 9705 provided an index of the disturbance caused by both capture and aerial relocations. Goat 9705 moved about 70% farther in the 24 hours after aerial relocations (mean hourly movement 232 ± 27.7 m/hr) compared with presumably undisturbed periods before relocations (137 ± 12.3 m/hr; $P = 0.002$), and over 3 times further in the period after capture and collaring (474 ± 96.2 m/hr) compared to undisturbed periods ($P= 0.002$). Although mean elevation and slope of GPS and aerial telemetry locations did not differ for either goat ($P > 0.17$), the range in elevation determined from aerial telemetry was only 62% of the range using GPS positions and the range in slope only 19-49%. Less than 9% of GPS positions put goats in commercial forests [primarily lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*)]. Although the locations obtained using GPS collars are likely biased by habitat, e.g., vegetation and terrain, this paper provides examples of how GPS technology could benefit a host of studies, including research into disturbance, examination of movement rates or night-time habitat use, and documentation of rarely used habitats.

INTRODUCTION

Conventional aerial telemetry using very high frequency (VHF) transceivers has been used in many studies to obtain information on mountain goats (*Oreamnos americanus*) (e.g., Singer and Doherty 1985, Haynes 1992, Hopkins et al. 1992, Festa-Bianchet et al. 1994, Smith 1994). However, telemetry on ungulates living in mountainous terrain is often restricted by poor weather, the requirement for daylight, and the high costs and dangers associated with repeated aircraft flights (Heimer 1994). Resultant data thus may be biased by sampling only portions of the day or during good weather. Given the cost and difficulty in relocating animals where ground access is restricted, location sample sizes in these studies tend to be less than ideal. The fright and hiding responses by goats to aircraft noted by researchers (summarized in Côté 1996) also brings into question the impact of aerial relocations on goat behaviour.

Use of global positioning system (GPS) technology for automated tracking of large animals may permit researchers to study interactions of animals with their habitat at a level of detail not previously attained. GPS-collar performance has been field tested in various boreal forest types and on moose (*Alces alces*) in Ontario, Minnesota and Alaska (Rempel et al. 1995, Moen et al. 1996, 1997, Rempel and Rodgers 1997). Earlier GPS collars were not suitable for mountain goat or mountain sheep (*Ovis* spp.) sized animals because of high mass (1.8 kg; Moen et al. 1996). However, recent technological changes have enabled development of GPS collars <1.0 kg in mass, more suitable for mid-sized mammals.

Forestry activities are increasing in the mountains surrounding the Robson Valley in east-central British Columbia (BC). To better manage and mitigate potential conflicts between the forestry industry and mountain goats, we initiated a study in 1997 to examine low-elevation forest use by goats in the Robson Valley, including seasonal variations in forest use and identification of mineral licks of importance to goats (Poole 1998). Specific objectives during 1997 included testing 2 prototype GPS collars, which we report on here.

STUDY AREA

The Robson Valley mountain goat study area flanks the Rocky Mountain Trench, which separates the Rocky Mountains to the east and the Cariboo Mountains to the west (centred on McBride at 53°22'N, 120°15'W). The area consists of a number of biogeoclimatic zones: Sub-Boreal Spruce (SBS) and Interior Cedar-Hemlock (ICH) zones in the Trench, through the Englemann Spruce-Subalpine Fir (ESSF) zone to the Alpine Tundra (AT) zone with increasing altitude. Treeline generally is at 1900-2150 m. Climate varies with elevation. In the Trench and valley edges hybrid white spruce (*Picea glauca* x *engelmannii*), subalpine fir (*Abies lasiocarpa*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) are the dominant trees, with extensive stands of lodgepole pine (*Pinus contorta*) due to frequent fire disturbances (MacKinnon et al. 1992). Higher up the mountainsides spruce, subalpine fir and lodgepole pine dominate, with scattered stands of whitebark pine (*Pinus albicaulis*) at the highest elevations. Douglas-fir (*Pseudosuga menziesii*) trees are found throughout the area. In the AT zone conifers are only present in stunted krummholz forms.

METHODS

Capture and collaring

We tested prototype GPS collars developed by and in co-operation with Advanced Telemetry Systems (ATS, Isanta, Minnesota). The collars weighed 950 g, and were equipped with a VHF transmitter. The collar's GPS receiver was programmed to determine its location every hour and store the locations in the collar's on-board memory. The collars stored horizontal position, date, time, positional dilution of precision (PDOP), satellite data, fix mode [2- or 3-dimensional (2D or 3D)], and the time required to obtain a fix. Horizontal dilution of precision (HDOP), which relates to the expected quality of the position estimate based on satellite configuration geometry (Rempel et al. 1995, Moen et al. 1996), was not obtained. PDOP cannot at present be used to censor locations prone to higher error because there is apparently no correlation between PDOP and accuracy, however, it is possible that the PDOP information could be incorporated into a filtering scheme in the future (N. Christensen, ATS, personal communication). The collars operated in auto 2D/3D mode, meaning that if signals from ≥4 satellites were obtained a 3D fix (latitude, longitude, and elevation) was taken, otherwise if only 3 satellite signals were obtained a 2D fix (latitude and longitude) was taken using the elevation obtained from the last 3D fix (Rempel et al. 1995). 3D locations generally have less location error than 2D locations (median error 45.5 vs. 65.5 m, respectively, Rempel et al. 1995; mean error 43 vs. 83 m, respectively, Moen et al. 1996). The collars generally attempted to acquire a fix for ≤96 seconds. If unsuccessful, a maximum of 2 retry attempts was made at 15-minute intervals for that programmed GPS interval. GPS collars were removed from the animals by a remotely fired mechanism after the collars signalled that battery power was too low for GPS function. Data required for differential correction were not collected in the current version of the collar, but will be available in future models (C. Kochanny, ATS, personal communication).

We captured goats with a hand-held netgun using a Hughes 500 helicopter. The maximum duration of pursuit was set at 5 minutes; generally animals initially were pushed slowly to terrain appropriate for capture, and were run for <1 minute prior to netting. Each animal was then hobbled, blindfolded, and fitted with horn guards prior to processing. We aged captured goats by counting the number of distinct horn annuli plus the fainter kid annuli formed at 6 months of age (Stevens and Houston 1989). We affixed numbered, orange Allflex eartags to each ear. We released captured goats generally within 20 minutes of netting.

We located the goats using standard aerial telemetry procedures (Mech 1983, Kenward 1987) about every 2 weeks from a Cessna 337 using the collar's VHF transmissions. Flights were often scheduled late in the evening and early the following morning to save ferrying costs and maximize the likelihood of locating goats at mineral licks (Singer and Doherty 1985). Goat locations were recorded using the aircraft's GPS. The general habitat of the location was also recorded.

GIS analyses

Aerial relocation and GPS fix data were imported into a geographic information system (GIS) for mapping and spatial analysis. All data were standardized to the NAD83 datum. Using the GIS with forest cover and TRIM base maps, the following habitat parameters were examined for each goat relocation and GPS fix: elevation, average location aspect (in 90° intervals centred on the four cardinal directions), slope, and the forest cover attribute of the polygon. Forest cover mapping in the study area classified polygons into 3 broad attribute descriptors: non-productive, meaning the area is not capable of supporting commercials forests (e.g., alpine, alpine forest, or rock); non-forest, meaning that the area is not currently forested but is capable of supporting commercial forests (e.g., a logged area that is not sufficiently restocked); or commercial forest. Where applicable, the leading tree species, projected age and height class of the stand also were examined.

Data summarisation and analyses were performed using SAS software (SAS Institute Inc. 1988). Non-parametric tests were used when data were not normally distributed. Statistical tests were considered significant at $P < 0.05$. Means are presented with associated standard errors (SE).

RESULTS

We placed GPS collars on 2 nannies on 26 July 1997. We estimated goats 9701 and 9705 to be 6 and 5 years old, respectively. No obvious capture-related injuries were detected. We relocated goats 9701 and 9705 by aircraft 10 and 13 times, respectively, between 31 July and 10 November; the GPS function was working for 4 and 7 of those relocations, respectively. The 2 GPS collars were removed in October and November.

The GPS function of the collars on goats 9701 and 9705 lasted 24 and 49 days and provided 163 and 917 fixes, respectively (Table 1). The GPS success and fix quality differed markedly between collars. The collar on goat 9705 had a higher mean daily observation rate compared with 9701 ($t = 14.6$; $P < 0.0001$), lower mean PDOP ($t = 3.8$; $P = 0.0002$), and proportionately more 3D versus 2D fixes (and therefore presumably more precise locations; $\chi^2 = 78.4$; 1 df; $P = 0.001$)(Table 1). There was no relationship between PDOP and distance moved from the previous location for goat 9701 ($P = 0.82$); for goat 9705 the relationship was significant but explained almost none of the variation ($r^2 = 0.01$, $P = 0.003$). Mean distance moved between fixes was similar for 2D and 3D modes for goat 9701 ($t = 0.49$, $P = 0.62$), but was greater for 2D mode compared with 3D mode for goat 9705 ($t = 2.37$, $P = 0.02$; 2D mode 259 ± 14.3 m; 3D mode 219 ± 8.8 m).

Table 1. GPS collar data from mountain goats in the Robson Valley. The collars were programmed to take a GPS location every hour. PDOP is the positional dilution of precision.

Goat no.	Days functioned	No. locations	Fixes/day 0 (SE)	Observation rate (%)	PDOP 0 (SE)	% 3D fixes
9701	24	163	6.5 (0.86)	26.9	4.2 (0.17)	30.1
9705	49	917	18.9 (0.43)	78.9	3.6 (0.05)	66.7

Over a 24-day period goat 9701 used about 1.5 km of each of 2 parallel ridges spaced 1 km apart (Fig. 1). Most of the fixes were on the west slopes of the ridges, although occasionally ridgelines and valley bottoms were used. The movement between ridges was made 6-7 August, 12 days after collaring.

Goat 9705 moved about 5.5 km after capture and collaring, and spent 5 days along 1 cliff system northwest of the capture area (Fig. 2). Subsequently (and immediately after the first aerial relocation) the goat returned to the capture area where it spent the remaining 6 weeks of the GPS collar's life along a 5.5 km stretch of mountainside.

Goats 9701 and 9705 ranged primarily over 400 and 800 m in elevation, respectively. Goat 9705 was initially at a lower elevation for the first 5 days after collaring, but returned to higher elevation closer to the original capture area. Comparing 6 hour periods during the day, goat 9705 was at lower elevations from midnight to 0600 hr compared with other time periods (ANOVA $F = 15.6$, 3,913 df, $P < 0.001$; Table 2). Goat 9701 showed no daily pattern of elevation use ($F = 1.8$, 3,158 df, $P = 0.16$).

Table 2. Mean elevation (m) over 6-hour periods and totaled for goats 9701 and 9705, as determined by GPS collars.

	Goat 9701			Goat 9705		
Time period (hr)	*n*	0	SE	*n*	0[a]	SE
2400-0600	39	1815	25.4	245	2068a	11.5
0600-1200	35	1787	18.8	230	2127b	12.1
1200-1800	34	1751	21.3	209	2176c	11.1
1800-2400	54	1814	20.0	233	2151bc	12.1
Total	162	1795	11.0	917	2129	6.0

[a] Means denoted by the same letter are not significantly different (Ryan's Q multiple range tests, $P < 0.05$)

Goat 9701 on average used steeper ground than goat 9705 (Mann-Whitney $U = 8.41$, $P = 0.0001$; Table 3). Goat 9701 used less steep slopes during the periods from 1800 to 0600 hr ($F = 10.74$, 3, 158 df, $P < 0.0001$); goat 9705 showed no pattern in slope use during the day ($F = 1.03$, 3, 913 df, $P = 0.38$).

Table 3. Mean percent slope over 6-hour periods and totaled for goats 9701 and 9705, as determined by GPS collars.

Time period (hr)	Goat 9701			Goat 9705		
	n	$\bar{x}$[a]	SE	*n*	$\bar{x}$	SE
2400-0600	39	78a	8.2	245	65	2.0
0600-1200	35	129 b	8.0	230	65	2.0
1200-1800	34	113 b	7.7	209	68	2.4
1800-2400	54	82a	6.0	233	69	1.9
Total	162	98	4.0	917	67	1.0

[a] Means denoted by the same letter are not significantly different (Ryan's Q multiple range tests, $P < 0.05$)

Aspect use differed between goats ($\chi^2 = 235.9$, 3 df, $P < 0.0001$; Table 4). West-facing slopes were heavily used by goat 9701 ($\chi^2 = 89.1$, 3 df, $P < 0.0001$) and south-facing slopes were used more often by goat 9705 ($\chi^2 = 42.1$, 3 df, $P < 0.0001$). Aspect use may have been a function of the structure of the mountain block inhabited by each goat. Goat 9701 lived on fairly steep-sided ridges aligned in a north-south direction, while goat 9705 lived on a more rounded block oriented in an east-west direction.

Table 4. Distribution (%) of aspect of locations for 2 goats wearing GPS collars, Robson Valley. Aspect based on 90° intervals centred on the 4 cardinal directions.

Goat no.	*n*	North	East	South	West
9701	162	12.4	13.6	0.6	73.5
9705	917	23.8	19.9	38.4	18.0

Distance moved between fixes differed among 6 hourly periods during the day for goat 9705 ($F = 2.6$, 3,751 df, $P = 0.049$) but not for goat 9701 ($F = 0.3$, 3,71 df, $P = 0.85$), where smaller sample size likely weakened the analyses (Table 5). Goat 9705 moved on average less distance during the period from noon to 1800 hr and further during the 1800 hr to midnight period.

Table 5. Mean distance (m) moved hourly over 6-hour periods and totaled for goats wearing GPS collars, Robson Valley[a].

Time period (hr)	Goat 9701			Goat 9705		
	n	$\bar{x}$	SE	*n*	$\bar{x}$[b]	SE
2400-0600	16	242	53.8	205	231ab	16.1
0600-1200	19	215	93.5	195	206ab	12.4
1200-1800	13	162	31.2	160	196a	14.4
1800-2400	27	195	28.1	195	253 b	18.7
Total	75	204	28.3	755	223	7.9

[a] Locations separated by <1:15 hr used for calculation of hourly movement rate.

[b] Means denoted by the same letter are not significantly different (Ryan's Q multiple range tests, $P < 0.05$)

The hourly movements of goat 9705 provided an index of the disturbance caused by both capture and aerial relocations. Twenty-four hour periods after capture and before and after aerial relocation were compared (Table 6). Goat 9705 moved about 70% further in the 24 hours after aerial relocations compared with presumably undisturbed periods before relocations ($t = 3.15$; $P = 0.002$), and over 3 times further in the period after capture and collaring compared to undisturbed periods ($t = 3.48$; $P = 0.002$). Three of 5 of the longest hourly movements recorded for goat 9705 were within the 24-hour periods after aerial relocations. Longer distance movements after aerial relocation were often not immediate, but occurred during the following dawn or dusk up to 12 hours after disturbance. Observation rate for goat 9701 was too low to examine hourly movement patterns.

Table 6. Mean distance (m) moved hourly by goat 9705 within 24 periods after capture, and before and after aerial relocations, as determined by GPS collar.

Period	n	0	SE
Capture	22	474.2	96.22
Before relocation	77	136.5	12.25
After relocation	107	232.1	27.68

Fifty-three percent (*n* = 162) of GPS fixes from goat 9701 were in the AT subzone, with the remainder in the ESSFmm1 (moist, mild) subzone/variant; GPS fixes for goat 9705 were 88% in AT and 12% in ESSFmm1 (*n* = 917).

Less than 9% of GPS fixes placed goats in commercial forests (Table 7). Almost 90% of fixes from both goats were in polygons with the alpine non-productive forest attribute. Forest cover polygons designated as alpine forest were comprised only of subalpine fir for goat 9701 (*n* = 12) and either pure subalpine fir or subalpine fir/lodgepole pine stands for goat 9705 (*n* = 20). Goat 9701 was found in subalpine fir/spruce stands in all 4 cases where it was located in commercial forests. Lodgepole pine and subalpine fir dominated forest cover polygons where goat 9705 was located, with Douglas-fir and whitebark pine found in lower proportions (Table 8). Most (64.6%) commercial forest stands were mature in projected age class (81-140 years), while 11.4% were old aged stands (>140 years) and 24.1% were immature (21-80 years)(*n* = 79). All subalpine fir and Douglas-fir dominated stands were mature or old aged, and all lodgepole pine dominated stands were immature or mature in age.

Table 7. Distribution (%) of forest cover attributes in polygons containing GPS collar locations from mountain goats in the Robson Valley.

Goat no.	*n*	Alpine	Alpine forest	Commercial forest	Other[a]
9701	162	90.0	7.4	2.5	0
9705	917	89.3	2.2	8.2	0.3

[a] Other included non-productive brush and non-productive burn.

Table 8. Distribution (%) of the first and second leading commercial tree species (by gross volume) in forest cover polygons containing GPS locations from goat 9705, Robson Valley.

	n	Lodgepole pine	Subalpine fir	Douglas-fir	Spruce	Whitebark pine
Leading species	75	70.7	26.7	2.7	0	0
Second species	73	26.0	45.2	12.3	8.2	8.2

Comparison of GPS and VHF data

The GPS receiver provided vastly greater numbers of locations compared to the aerial relocations of the VHF transmissions. During the period when the GPS collars were functioning, 162 GPS fixes were obtained for goat 9701 compared with 4 aerial relocations. Similar figures for goat 9705 were 917 fixes and 7 relocations. Thus, comparisons of the results obtained using the 2 techniques were compromised by vast differences in sample sizes. Home range size comparisons were not possible due to the small number of aerial relocations, but it was obvious that the GPS collars demonstrated greater use of the habitat by the goats (Figs. 1, 2).

GPS fix accuracy and aerial telemetry accuracy was not field-tested. However, 11 aerial relocations occurred concurrent with functioning GPS collars (some relocations using VHF signals occurred after GPS functioning had ceased). The time difference between acquisition of GPS fix and relocation ranged from 8 minutes to 1.5 hours, thus varying degrees of movement between the 2 locations were expected. Five aerial relocations were taken <15 minutes of a GPS fix. Time and distance between GPS fix and relocation were, respectively: 8 minutes and 52 m (GPS fix first); 10 minutes and 92 m (relocation first); 10 minutes and 226 m (GPS fix first); 14 minutes and 90 m (relocation first); 14 minutes and 432 m (GPS fix first).

PDOP is apparently not related to accuracy, but 2 cases of suspicious movements by goats had high PDOP values. On 30 July sequential GPS fixes showed goat 9701 moved 512 m horizontally dropping 300 m elevation down a slope and across a valley in 2 hours, then return 511 m to almost the exact spot in 3.5 hours; the PDOP for the suspect movement was 8.1 (2D fix). On 10 September goat 9705 moved 1151 m in 1 hour to an area not frequented at any other time during the study, then returned 1198 m in the next hour to within 55 m of the original location; the PDOP for this outlier was 8.8 (2D fix). Both movements are within the travel ability of mountain goats, but both appear suspect. Less than 2.8% of GPS fixes had PDOP ≥8.0 (n = 1079), and most high PDOP values were associated with 2D fixes (77%, n = 30).

Mean elevation of locations as determined by GPS fixes and aerial relocations did not differ for each goat (t-test, $P > 0.64$), but aerial relocations captured only 62% of the range in elevation used for each goat as determined by the GPS fixes. Similarly, mean slope of locations did not differ for each goat by location method ($P > 0.17$), but aerial relocations captured only 49% (goat 9701) and 19% (goat 9705) of the range of slope use determined by GPS fixes.

Comparison of use of alpine and commercial forests as determined by GPS fixes and aerial relocations is difficult given the small sample sizes of aerial relocations. Only 1 relocation of goat 9701 was in a subalpine fir alpine forest, and no relocations were in commercial stands. The GPS collar placed goat 9701 in subalpine fir alpine forests 12 times (7% of fixes), and in subalpine fir commercial forests 4 times (2%). Goat 9705 was relocated in lodgepole pine dominated alpine forests once and was not found in commercial forests. The GPS collar placed goat 9705 in fir alpine forests on 20 occasions (2.2% of fixes) and in fir and pine commercial forests on 75 occasions (8.2%).

DISCUSSION

The GPS collars provided more detail on goat movements than possible through conventional telemetry. They appear to have provided a relatively systematic assessment of habitat use regardless of weather conditions with biases (primarily differences in observation rate based on habitat and terrain) that can be at least partially quantified (Rempel et al. 1995). Use of GPS collars would minimize aircraft disturbance, and possibly give a "truer" representation of animal behavior and movements compared to conventional telemetry using aircraft. The GPS collars would also tend to detect unique or rare movements more often, such as visits to licks.

Location data derived from GPS collars are not without their biases, including variable observation rates related to satellite signal interference by vegetation and terrain, and differing location accuracy depending upon 2D or 3D location mode and signal strength as measured by HDOP (Rempel et al. 1995, Moen et al. 1996). An assessment of location error was not possible with these data, nor was the ability to censor data by removing fixes with high HDOP to increase accuracy. The suspect locations with high PDOP values suggest that further examination of the relationship between PDOP and location accuracy is warranted.

GPS collar data suggested use of lower elevation sites during hours of darkness (goat 9705), and provided a more complete picture of the area and range of elevations used by each goat and the distance and timing of movements. The data presented here also suggest that aerial relocations have a significant effect on subsequent mountain goat movements, and that the effect may not be immediate. The GPS data suggested that although some longer distance movements occurred immediately after aerial relocation, on several occasions it was the following dawn or night that the longer movements occurred. Other researchers have noted the fright and hiding responses to aircraft (summarized in Côté 1996).

Costs of locations derived from GPS collars compared with conventional VHF collars and aerial relocation flights are difficult to compare. GPS collars cost roughly \$4,000-\$5,000 CDN, while VHF collars are approximately \$400. Our relocation flights cost approximately \$1,100-\$1,300 to locate 6 to 16 goats. Using a hypothetical 6 GPS and 6 VHF collars, the costs for collars and flights for 20 aerial relocations would be approximately \$24,400, while 6 GPS collars would cost \$24,000 - \$30,000. However, depending upon the frequency of GPS location attempts and the observation rate, the GPS collars could provide more than 6,000 locations (1,000 per collar) compared to 120 using aerial VHF telemetry. Costs will vary greatly depending upon aircraft type and ferry costs.

MANAGEMENT RECOMMENDATIONS

The primary objectives of this ongoing study are to examine seasonal variation in forest use and locate previously unknown mineral licks, preferably in areas where forestry development is slated but has not yet occurred. GPS collars appear to provide the best opportunity to locate mineral licks in undeveloped valleys where human access is difficult and aerial spotting is tough. GPS collars would also more readily detect lick use at night (Singer 1978). GPS collars deployed in late winter or spring would cover the critical spring/early summer period when lick use appears to be greatest (Hebert and Cowan 1971, Singer and Doherty 1985). Collar deployment should be prioritized for valleys where forestry development is slated and mineral lick information is lacking. Although both sexes should be sampled to examine differences in terrain, habitat and lick use between sexes, spring deployment of collars should target males to avoid disturbance to pregnant nannies or neonatal kids. Winter use of lower elevation forests can also be more efficiently addressed using GPS collars.

The GPS collars used in this study were set to obtain a location every hour because of field-test timing constraints, resulting in shorter overall length of coverage. Subsequent GPS collars should be set to obtain a location 3-4 times a day, or on a staggered 3 times in 25 or 26 hour schedule, to enable roughly equal sampling throughout the day and longer coverage period. Differentially correctable signals would increase the accuracy of the location data (Moen et al. 1997, Rempel and Rodgers 1997), that may aid in locating mineral licks. However, implementation of differential correction can involve increased costs in data handling, decreased battery-life expectancy, and fewer usable locations (Rempel and Rodgers 1997). Collection of HDOP by the GPS receiver would enable some censoring of position accuracy, at least in 2D fix mode (Rempel et al. 1995, Moen et al. 1996). Field tests of GPS collars in mountainous terrain have not been conducted, and may be useful to assess the influence of vegetation, terrain and collar type on location accuracy and location capture success (Moen et al. 1997). Preliminary results from this study suggest that GPS technology should prove of great benefit to studies not only on mountain goats but other mountain ungulates as well. These studies could include research into disturbance, examination of movement rates or nighttime habitat use, and documentation of rarely used habitats.

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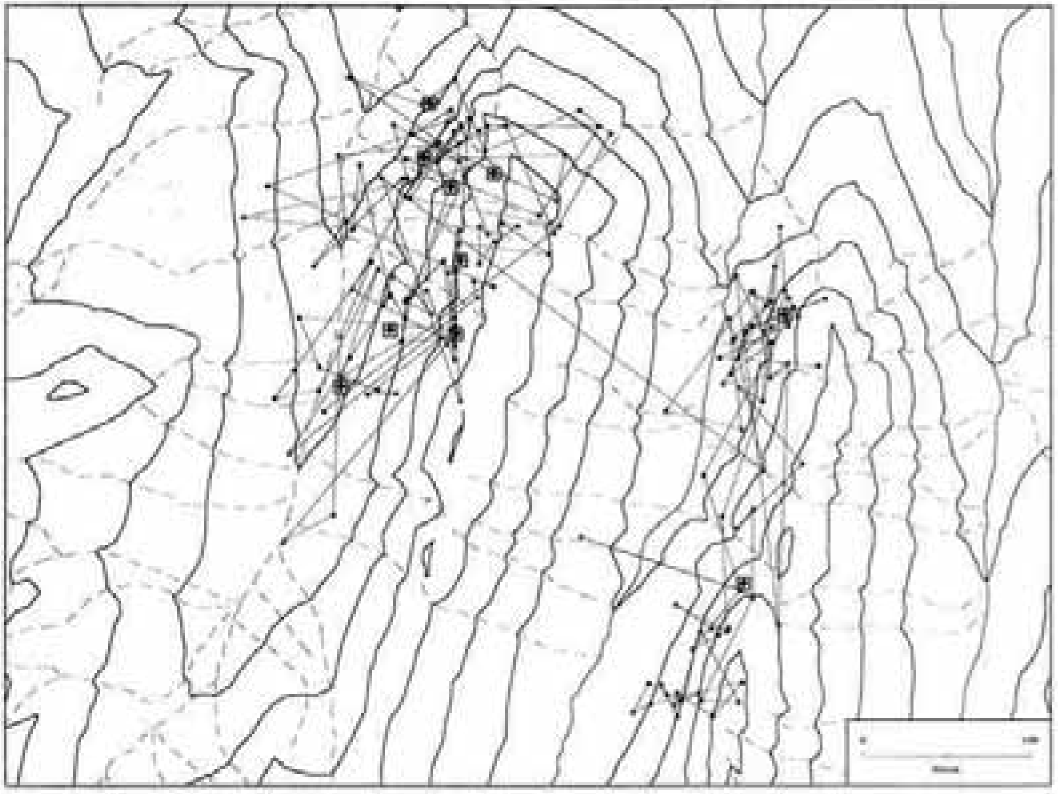

Fig. 1. GPS fixes (circles) and VHF relocations (diamonds within a box) for goat 9701, Robson Valley. GPS fixes cover 26 July – 18 August 1997, VHF relocations cover 31 July – 7 October 1997.

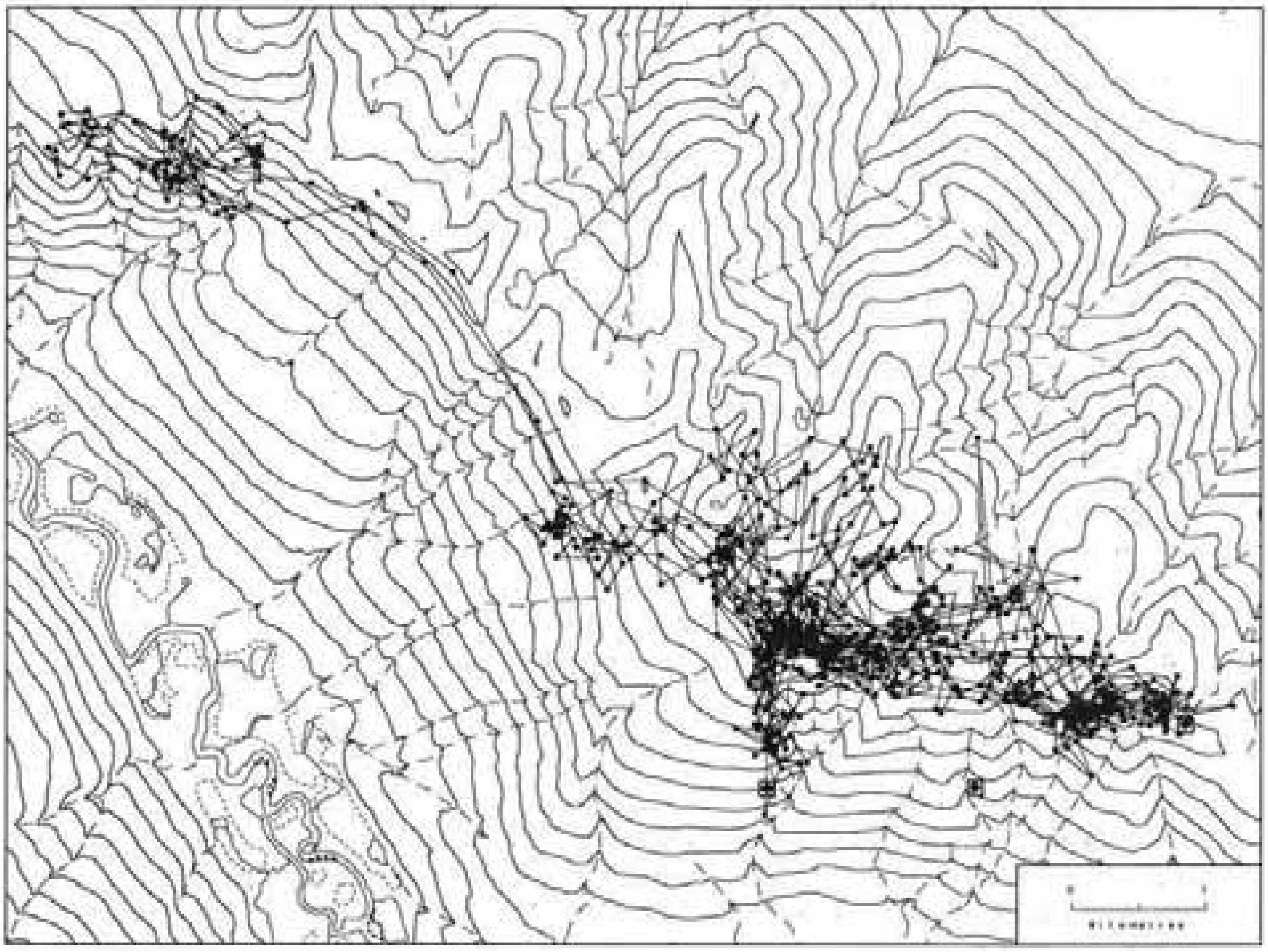

Fig. 2. GPS fixes (circles) and VHF relocations (diamonds within a box) for goat 9705, Robson Valley. GPS fixes cover 26 July – 12 September 1997, VHF relocations cover 31 July – 10 November 1997.

EVALUATION OF BIGHORN SHEEP AND MULE DEER HABITAT ENHANCEMENTS ALONG KOOCANUSA RESERVOIR.

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Abstract. Habitat enhancement projects were initiated along Koocanusa Reservoir in 1984 in an effort to increase bighorn sheep and mule deer populations. This report evaluates the efficacy of these efforts by measuring and analyzing the responses of vegetation and deer and sheep populations before and after habitat manipulations. An evaluation of vegetation responses indicated that shrub frequency and volume measurements decreased in response to manipulation except for palatable species such as serviceberry and spiraea, which increased. Herbage production and understory cover composition both increased initially, but returned to pre-treatment levels within 2 years. Bighorn sheep responded by increasing utilization of treatment units and adjacent habitat. A change in overall distribution of mule deer seemed to occur, but was less apparent than for sheep. Four deer changed from a migratory to a resident pattern, 3 shifted established winter home ranges, and the proportion of deer using spring and fall transitional ranges decreased from 69% pre-treatment to 0% post-treatment all suggesting a positive response by deer. Home range sizes were variable over time for both species and revealed no clear relationship to habitat manipulation. Sheep and deer population estimates over the study period were variable, but did not support the hypothesis that populations should increase in response to habitat manipulations. Bighorn natality and recruitment declined over the study period. Natality for mule deer also declined between the pre-treatment to post-treatment periods. There was no significant decline in survival for sheep during winter and spring between treatment periods. Survival rates for mule deer declined between periods, but not significantly. Age structures from mule deer harvest data indicated declining recruitment and a stable to declining population. Bighorn sheep group composition suggested a decrease in recruitment and a declining population. Results of monitoring indicated that sheep and deer exhibited a positive behavioral response to habitat manipulation, but a long-term improvement in population dynamics was not evident from the data. Managers should reconsider their original mitigation goals of a 33% increase in mule deer and bighorn sheep populations.

Submitted to a refereed journal for publication.

FIRE'S PLACE AND USE IN HABITAT AND MANAGEMENT WITHIN THE SUN RIVER AREA OF WEST-CENTRAL MONTANA

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Abstract: Bighorn sheep (*Ovis canadensis canadensis*) in the Sun River area of west central Montana represent one of the largest native populations in the state. Habitat types utilized by this population include old burn areas. Most of these sites are the result of wild fires occurring before 1920 when significant fire suppression was realized. Since then, conifer encroachment, often significant, has remained relatively unchecked in many areas. This may result in reduced bighorn sheep habitat amounts and/or efficiencies. The ability to manage fire coupled with a greater understanding and tolerance of fire's natural role as a changing force may provide land managers the option of fire as a habitat manipulation tool.

INTRODUCTION

A review of past and current fire presence and management in the Sun River area of west-central Montana expands on the philosophy that fire is a natural and necessary component of this ecosystem. By reviewing the historical presence of fire, the current absence of fire, how those conditions have impacted the environment and, presumably the wildlife, managers have taken great strides in recognizing and utilizing fire as an ally on at least one region of the Rocky Mountain East Front.

The Sun River bighorn sheep (*Ovis canadensis canadensis)* herd is one of the largest native populations in the world. While the current population is below target, past research efforts have put the site potential at over 800 animals (Frisina 1974). Documented Native American presence and utilization of resources in the Sun River area goes back to at least 1600 AD (Picton and Picton 1975). That resource appreciation, to include hunting and nonconsumptive opportunities associated with bighorn sheep continues today.

Just as the history of bighorn sheep in the Sun River area is relatively easy to document, so is fire. It is well documented that burned habitat types have been and continue to be a significant part of year round range for bighorn sheep in the Sun River area (Erickson 1972, Frisina 9174, Schallenberger 1966). Likewise, it is relatively easy to capture the considerable habitat changes that have taken place since significant fire suppression was initiated. Researched estimates of open areas lost to conifer encroachment have run as high as 30% of historical bighorn sheep habitat (Schirokauer 1996).

It is no stretch to recognize bighorn presence in the Sun River area, the value of that presence to the human environment, the historical coexistence of sheep and fire, the relatively recent exclusion of that fire and obvious signs of what that exclusion has done to the environment. With these realizations in hand, it is difficult to argue against fire as a necessary component of this ecosystem. While the philosophy of fire's natural role has long enjoyed some amount of scientific acceptance, the proposed scale of managed fire in the Sun River area is quite new and is the most recent step in the progressive application of prescribed fire on the Rocky Mountain District of the Lewis and Clark National Forest.

DISCUSSION

The vegetation that makes up the Rocky Mountain Front has had a long history of fire. Prior to 1920, an average of 10,000 acres burned annually. Through the 20's, 30's and 40's, after the inception of fire suppression, that number was reduced to 200 acres burned on average every year. Through the 50's. 60's and 70's that average was reduced even further to less than 50 acres per year.

In 1982, the Prescribed Natural Fire Policy (PNF) was implemented in the Bob Marshall Wilderness Complex with the signing of the Scapegoat/Danaher PNF Plan. After 17 years under this PNF plan, 71, 761 acres have burned (99.5% of them in 1988) for an average of 4221 acres per year. This helped bring natural fire back into the Bob Marshall Wilderness Complex.

In 1982, the Rocky Mountain Ranger District started conducting prescribed burns to accomplish a variety of resource objectives. These burns have been conducted to improve habitat for bighorn sheep, elk (*Cervus elaphus*), mule deer (*Odocoileus heminonus)* and grizzly bear (*Ursus arctos)*, reduce fuel loadings and to help restore fire's role in shaping the vegetation along the Rocky Mountain Front. These burns have been designed to regenerate grasslands, aspen stands and shrub fields and to reduce conifer encroachment. Since 1982, fifteen burns have been conducted with 4260 acres being treated. Two thousand acres were scheduled for treated by fire for the spring of 1998, outside of the Wilderness Complex.

The Rocky Mountain Ranger District is planning to expand its use of prescribed fire into the Wilderness Complex in 1999. The district performed an Environmental Analysis (EA) to analyze sing management ignited fire in the Bob Marshall Wilderness Complex. This project is the proposed South Fork Sun Burn. It is 16,500 acres in size and is located entirely within the Scapegoat Wilderness. The district is considering introducing management ignited fire into 10,000 of the 16,000 gross acres. The public has been and will continue to be involved in the process.

The objectives for this project are two-fold. The first is to make the wilderness boundary more defensible against wildfire escaping the wilderness and burning onto nonwilderness portions of the National Forest and possibly onto private land. Second, if the boundary is made more defensible from the standpoint of fire escape, natural ignitions will more likely be allowed to burn under the PNF program uninitiated in this area in 1981.

Prior to formally announcing this project, the District considered other treatments. These treatments included the use of prescribed fire and logging to reduce the risk of fire escaping the wilderness. Also considered was the history of lightning-caused fires not being allowed to burn and re-establish fire's role in this portion of the Bob Marshall Wilderness Complex.

Managers of wild sheep and goat herds interested in using fire to improve habitat must consider certain physical limitations. For example, fire managers will not allow an underburn of an open stand of mature Douglas fir with regeneration growing up in it. Also not allowed is stand replacement of aspen or burning of young Douglas fir interspersed with sparse grass or other fuel. On the other hand, fire can be used to rejuvenate decadent rough fescue stands or to underburn even-aged Douglas fir or ponderosa pine stands. Fire can be used to create a mosaic in even- aged mature stands, or to rejuvenate shrub fields. As the difference between what can and cannot be burned is often unclear, sheep and goat manager should coordinate with fire managers when selecting areas for burn projects.

Fire has been a major influence in shaping the vegetation and the wildlife using that vegetation along the Rocky Mountain Front. Sheep have used many of the areas that have experienced fire. We have been using fire to help maintain the native vegetation along the Front, but nowhere near the extent to which it burned prior to fire suppression. While exact outlines of the relationship are far from clear, sheep numbers have declined with the decline in areas burned along the Front.

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DISEASE

FIELD TREATMENT OF BIGHORNS DURING PNEUMONA DIE-OFFS

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Abstract. Experience in the Lostine River, Oregon die-offs of 1986-87 and Hells Canyon die-offs of 1995-96 indicates field treatment of bighorns showing signs of respiratory disease with antibiotics and other drugs can improve herd survival. Survival rates of treated Lostine bighorns was 94% and Lower Hills Canyon 66%. A bighorn sheep emergency response team is proposed to address future disease outbreaks. Additional field testing with different drug combinations, as well as evaluation of survival rates of treated versus nontreated animals is needed.

INTRODUCTION

The purpose of this project is to rapidly respond to bighorn disease outbreaks to improve survival. Experience in the Lostine die-off of 1986-87 and the Hells Canyon die-off of 1995-96 indicates field treatment of bighorns showing signs of respiratory disease with antibiotics and other drugs can improve herd survival. Lostine bighorns were captured in a corral trap and given antibiotics and other drugs and released back on their range. The survival rate was 94% in animals receiving treatment. During the Hells Canyon die-off, 72 bighorns were captured using a helicopter and netgun and treated with antibiotics and other drugs. They were then trucked to holding facilities at the Idaho wildlife Health Lab in Caldwell. No animals died the first 16 days even though at capture time some were so sick they were unable to stand. Unfortunately, disease eventually killed 64 animals in the holding pens. We believe survival would have been better if they had been released back into the wild immediately after treatment. In Lower Hells Canyon, Oregon, 6 bighorns were captured using a helicopter and netgun; treated with antibiotics; radio collared and released. Four of six bighorns are alive at this writing. Two animals died two months and four months post treatment. Non-treated collared bighorns (transplants) in the area died and mortality rates exceeded 80% in the rest of the herd. This management practice appears to improve survival of bighorns in pneumonia outbreaks. However, additional field testing with different drug combinations, as well as evaluation of survival rates of treated versus non-treated animals is needed,

Capture Team

This should be a professional netgun crew unless animals are acclimated to corral traps. A back up system of Wildlife Department netgunners and local experienced helicopter pilots should be in place since rapid response is essential.

Treatment and Handling Team

This should be made up of veterinarians and biologists with experience capturing, handling and treating bighorns. They need to be able to respond to a request for help rapidly. The team should have ready access to drugs and equipment needed to treat a minimum of 30 sheep.

Area Covered

The response team would have primary responsibility in the Idaho, Oregon and Washington area but could be requested by other agencies. This technique will not be feasible in some remote herds. Land classification (wilderness designation) may preclude the use of helicopters for capture without federal land manager's approval.

Drug and Testing Protocol

Antibiotics, Ivermectin and other drugs will be used to treat sick bighorns captured as recommended by qualified veterinarians. A statistically valid sample of untreated sheep will be used as the control. Radio collars or ear tags will be put on all animals capture if funding is available (Appendix II).

Disease testing will include blood samples, pharyngeal swabs, fecal and scabies samples (Appendix II).

Monitoring

Test bighorns will be located weekly for the first 3 months after capture and treatment to determine survival rates. Mortalities will be located as soon as possible to determine the cause of death. Collared bighorns should be located as needed through the first year following capture and treatment. Lamb survival to 3 months of age should be determined for treated versus untreated animals if possible. Results will be summarized in a completion report and published.

Table 1. Estimated cost of capturing 30 bighorn sheep.

Costs	**Per Bighorn**	**Total Cost***
Helicopter capture	$400	$12,000
Drugs for treatment	$23	$690
Test kits & lab costs	$109	$3,270
Radio collars	$250	$7,500
Aircraft rental	$100/hour 20 hrs. month (3)	$6,000
Aircraft rental	$100/hour 10 hrs. month (9)	$9,000
Seasonal personnel	6 mos/includes vehicle & operations	$17,000
Miscellaneous supplies		$300
TOTAL	**$1,860**	**$55,800**

*For budget purposes it is assumed 30 bighorns will be captured.

Regular personnel salaries should be provided by agencies, but if local veterinarians are used there may be additional costs. Also, jet boat rental may be needed if disease outbreak occurs along the Snake River. Seasonal personnel will also be needed for monitoring.

Media

Once a disease outbreak has been documented, the Hells Canyon Bighorn Sheep Restoration Committee should be contacted to identify capture, treatment and handling teams, staffing resources, helicopter availability and financial resources. The state where the outbreak is occurring should take the lead in identifying someone to handle media contacts to avoid the distribution of misinformation. All media contacts would be referred to the one designated person. If this disease outbreak involves more than one state then the designated media personnel need to communicate frequently to ensure a consistent flow of information.

Appendix I

Lostine Bighorn Disease Outbreak 1986-87

1. Thirty-two bighorns were treated with antibiotics via Palmer capture dart (5), corral trap (21) or both (6) with antibiotics in the capture dart given first to free ranging animals.

2. Ninety-four percent of animals treated with antibiotics survived. All 3 mortalities were bighorns in poor condition that received antibiotics (LA200) via capture dart. No sheep captured in the corral trap and treated died.

3. Thirty-four bighorns (20ewes, 2 lambs, 12 rams) of an estimated 100 sheep survived (40 dead bighorns were found).

4. All but 5 survivors were treated at least once with antibiotics Clocillin (7) or L. A. 200 (27), some received both drugs when captured multiple times.

5. Of the 5 untreated bighorns, two adult ewes were with the herd during the outbreak, had disease symptoms but survived. The other ewe and a ram were fist seen with the herd in May 1987 after the sheep had recovered. The other animal, a ram, came to the Lostine Range the following winter.

6. Eight surviving animals received L. A. 200 from a Palmer capture dart (usually their first antibiotics).

7. Average dosage given:

Yearling rams/adult ewes	8 cc LA200 1.5 cc Ivermectin 10 cc Gentamyacin 1.5 cc Banamine
Lambs	4 cc LA200 0.5 cc Ivermectin 5 cc Gentamyacin 1 cc Banamine
Rams (2-1/2 & older)	10 cc LA200 2 cc Ivermectin 11 cc Gentamyacin 1.5 cc Banamine

Appendix II

Biological samples to be taken from bighorn sheep captured for disease treatment.

Type of Sample	Amount	Purpose	Disposition
Bacterial	1 pharyngeal swab	Pasturella classification	Caine Veterinary Research & Training Center
Blood	2 red-tops (20 cc) 1 green top (10 cc) 1 blue top (7 cc)	Antibody evaluation, serology, serum banking DNA selenium	Idaho Dept of Ag. Lab Wildlife Health Lab Ag Canada/U of I
Fecal	10+ pellets	parasitology	Washington State University
Ear swabs	1	parasitology (scabies)	Washington State University

Appendix III

Recommended Drug Dosages (Dr. Dave hunter):

Adult Ewes and Yearling	8 cc LA 200/2 sites (6 cc if given by dart gun)
Rams	2 ½ cc Ivermectin (Ivomec Merck Co) 2 cc Bose

Lambs	4 cc LA 200 (4 cc if given by dart gun) 1 cc Ivermectin 1 cc Bose
Rams (2 ½ years)	10 cc LA 200 – 2 sites (6 cc LA 200 if given by dart gun) 3 cc Ivermectin 3 cc Bose

Vendors providing animal capture services

1. Idaho Helicopters, Inc
   2471 Commerce Avenue
   Boise ID 83705
   (208) 344-4361 (office)

2. Valley Helicopter Service LLC
   Jim Pope
   POB 54
   Clarkston WA 99403
   (509) 758-1900 (office)
   (509) 243-444 (home)

3. "Doc" Sutherland
   (403) 352-9689

4. Gary Beck
   Cheney WA
   (509) 448-9705

5. Wildlife Management Services
   James Innes
   (801) 766-0721

Treatment and handling team

Tim Schommer/Kevin Martin
Vic Coggins/Pat Matthews
Pat Fowler
Francis Cassirer

A COMPARISON OF POPULATION AND HEALTH HISTORIES AMONG SEVEN MONTANA BIGHORN SHEEP POPULATIONS

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Abstract: We compared detailed population and health histories between seven bighorn sheep populations. Data from partial health histories of other bighorn sheep populations are also presented. The Tendoy Mountains and Quake Lake sheep herds are small herds (<200) of low density that experienced epizootic pneumonia outbreaks. The Highland-Pioneer and Lost Creek sheep herds are larger herds (200-400) of higher population density experiencing recent epizootic pneumonia outbreaks. Upper and Lower Rock Creek and the Perma-Paradise sheep herds are larger herds (200-400), with high densities but have not experienced a recent epizootic. Total population, sex and age composition, serologic profiles, bacteriologic investigations and mortality causes were examined and compared between each herd unit. Diagnostic evaluations were conducted during each epizootic pneumonia outbreak experienced during the study. Each epizootic event appeared to be characterized by unique combinations of either bacterial, viral or parasitic infections acting in combination to create clinical disease. Population parameters implicated in transmission of disease are discussed.

INTRODUCTION

One of the most significant problems associated with bighorn sheep management is the unpredictable and often devastating effects of epizootic events caused by pneumonia. Epizootics due to respiratory disease have been reported from many Rocky Mountain bighorn sheep (*Ovis canadensis*) herds throughout the North American Continent (Thorne et al.1982, Onderka and Wishart 1984, Bailey 1986, Andryk and Irby 1986, Coggins 1988, Spraker et al. 1984, Festa-bianchet 1988). Lungworms, bacteria (especially *Pasteurella* spp.), respiratory viruses, associations with domestic livestock and various types of stress are often reported as the cause of these epizootic events (Foreyt et al. 1994, Foreyt and Jessup 1982, Spraker et al. 1984, Forester and Senger 1964, Thorne et al. 1982).

In Montana bighorn epizootic disease events have been reported in several bighorn herds since 1924 (Forrester and Senger 1964). Early investigations of these events focused on the importance of lungworms as the pathogen responsible, hence the references to lungworm-pneumonia complex (Marsh 1938, Forrester and Senger 1964, Becklund and Senger 1967, Forrester 1971). During the mid 1980's a series of die-offs occurred along the Rocky Mountain Front (Andryk and Irby 1986, Worley et al. 1988). Limited diagnostic investigations indicated that these mortalities resulted from *Pasteurella* spp. and lungworm infections. It was hypothesized that the epizootic events during that period started with the transmission of a pathogen from bighorn populations in Canada and Glacier National Park that experienced similar die-offs in the early 1980's (Andryk and Irby 1986). However, lack of diagnostic evaluation of sheep mortalities and the absence of any prior health history information from the Canada and Glacier National Park herds prevented an accurate and complete determination of the factors that caused respiratory disease in these bighorns.

To improve our ability to monitor bighorn herd health and provide adequate diagnostic services during mortality events Montana Fish, Wildlife and Parks (MFWP) Wildlife Research laboratory, the Montana Department of Livestock Diagnostic Laboratory and Veterinary Molecular Biology at Montana State University (MSU) implemented several memorandums of agreement (MOA). The MOA's were not structured to strictly apply to bighorn herd health monitoring. However, they provided the opportunity to determine herd health parameters for several bighorn sheep herds as requested by various agency biologists. As a result of this program seven herd units were monitored to determine several basic health parameters and evaluate causes of mortality.

Several epizootic events occurred in southwestern Montana during the 1990's. Mortalities caused by pneumonia occurred in 1991 in the Tendoy Mountains, 1993 in Lost Creek, 1994 in the Highland-Pioneer Mountains, and 1996 near Quake Lake. During these events MDFWP attempted to assess the causative pathogens involved. In addition some health data were available to compare between herd units and evaluate changes in health parameters that might explain the factors causing die-offs. This paper presents the information available from four recent die-offs and compares these data with health information from three other herds that have not undergone a recent epizootic event.

Our objectives were: (1) to refine a general health monitoring technique applicable to bighorn sheep herds in Montana (2) to identify bacterial, viral, and parasitic pathogens common to bighorn sheep. (3) to compare health parameters between herds that have experienced recent epizootics and those that have not undergone recent die-offs. (4) to measure changes in the trends of various health parameters over time. (5) to search for common bighorn sheep population parameters that might have value for predicting epizootic events.

STUDY AREA

The study area encompasses bighorn sheep habitat within the entire state of Montana. Bighorn sheep habitat in Montana is highly variable ranging from low breaklands (700 m) found along the Missouri breaks of eastern Montana to the lower mountain valleys (1500 m) and high rocky peaks (3900 m) of the Rocky Mountain Cordillera that transects western Montana.

Through intensive management and frequent transplants the number of bighorn sheep herds in Montana has been expanded from 14 established herds in 1950 (Couey 1950) to over 40 herd units in 1998. Bighorn herd sizes range from 30 to nearly 1000.

METHODS

All bighorn sheep mortalities were investigated as opportunity allowed. Sheep from various regions that could not be transported immediately were frozen whole in regional freezers for later transport. Individual sheep were necropsied at the MFWP Wildlife Laboratory or the Department of Livestock State Diagnostic Laboratory to determine causes of mortalities. Epizootic events were evaluated by collecting tissue specimens from mortalities during a field necropsy and, if possible, from hunters and biologists or by transporting whole carcasses to the laboratory for necropsy. Gross lesions were submitted for histopathologic examination, routine bacteriologic culture and virus isolation. Histopathology was performed by board certified pathologists from the State Diagnostic Laboratory.

Herd health monitoring was performed when animals were captured for translocation or field research. Blood was drawn from the jugular vein, a pharyngeal swab was taken from the tonsilar crypt and fecal samples were collected. Each animal was inspected for external parasites or indicators of other health problems. Fecal collections from sheep bedding areas or from radio monitored study sheep were collected from individual sheep within some herd units to monitor trends in parasite loads.

Blood samples were transported to the MFWP laboratory and centrifuged to extract serum. Whole blood samples are submitted to the State Diagnostic Laboratory for hematology. Standard large animal serum chemistries are performed. Standard approved serum tests were conducted to determine antibodies for *Brucella abortus*, *Brucella ovis*, Bluetongue, Infectious Bovine Rhinotracheitis (IBR), Bovine Virus Diarrhea (BVD), Para Influenza-3 (PI3), Bovine Respiratory Syncytial Virus (BRSV), Ovine Progressive Pneumonia, and Leptospirosis (eight serovars). Excess blood serum was archived for future testing.

Fecal samples were refrigerated and transported to the MFWP laboratory. A modified Baermann procedure was used to determine the number and relative concentrations of lungworm larvae shed by each animal (Dinaburg 1942, Beane and Hobbs 1983). The modified Lane fecal flotation procedure was used to recover ova and oocysts from feces (Dewhirst and Hansen 1961). Cover slips from each tube were examined under light microscope to determine the number and type of ova and oocysts present.

Bighorn sheep populations were monitored through annual or periodic aerial census conducted during the winter by MFWP biologists. The population survey methods implemented and timing of surveys was variable within the winter period occurring from December through April depending upon suitable flying conditions and funding. Summarized data from each flight included a total count of all sheep and a classification of rams, ewes and lambs when possible. Ram and lamb per ewe ratios were calculated using the data sets provided for each herd unit.

RESULTS

Population Histories

Population and health histories were completed for seven populations of bighorn sheep in Montana. There was considerable variation in the quality of population data sets, the frequency of surveys and data reporting standards that affected our ability to make detailed comparisons between herd units. However, we were able to determine gross trends in population size and ram/ewe and lamb/ewe ratios for most units. All herd units increased in total population size during the period 1985 until the early 1990's. All herds, with the exception of the upper and lower Rock Creek units, declined in population at some time from the early 1990's to present. The Rock Creek herds appear to be somewhat stable (Figure 1). The Plains unit appears to have increased, then stabilized. Various forms of management were implemented to control growth including increased hunter harvests and capture and removal for transplanting sheep to other populations in Montana.

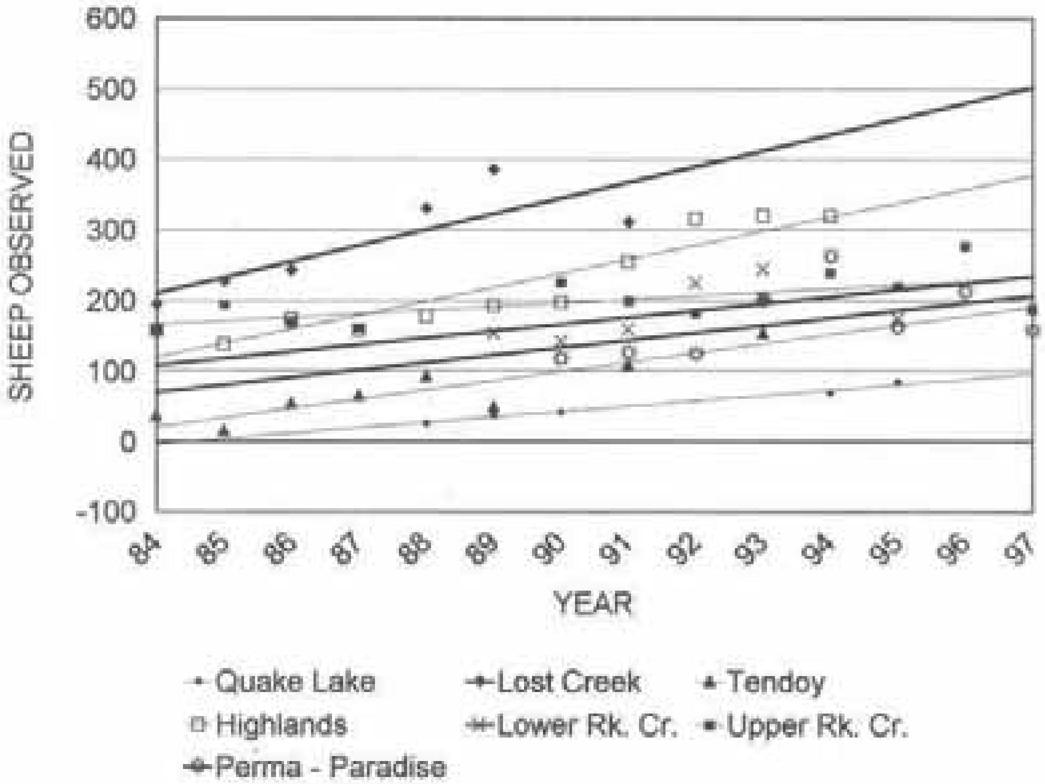


Figure 1. Linear regression total sheep counts conducted in the winter to early spring for sheep herds in western Montana.

Highlands-Pioneers Herd Unit

Native populations of bighorn sheep were extirpated from the Highland-Pioneer Mountains in the early 1900's. Sheep were reintroduced to the area in 1967 when 27 sheep were transplanted from the Sun River. The initial transplant population was supplemented with 31 sheep in 1969. The population expanded in size and range up through the mid 1990's so that sheep today extend across the Big Hole River and into the foothills of the Pioneer Mountains. The number of males in the population grew and the herd became well known for it large trophy quality rams. The number of sheep was estimated between 350-400 (Weigand 1994, Semmens 1996) (Figure 2). Harvests were increased in 1992 and 1993 to 39 and 40 sheep. In addition, 35 sheep were captured and transplanted from the population in 1992 to reduce sheep numbers. In 1993 the population was at an all time high. Parasitology data indicated an increased lungworm load and some significant gastrointestinal parasites within the population (Hoar 1995). By late November 1994, sheep hunters in the area reported observing clinical signs of pneumonia. Diagnostic work from two sheep mortalities confirmed pneumonia complex with strong evidence of chronic lungworm infection. Sheep mortalities continued to be recorded from December 1994 through March 1995. The population declined by 87 percent and the current population contains less than 50 individuals (Figure 2).

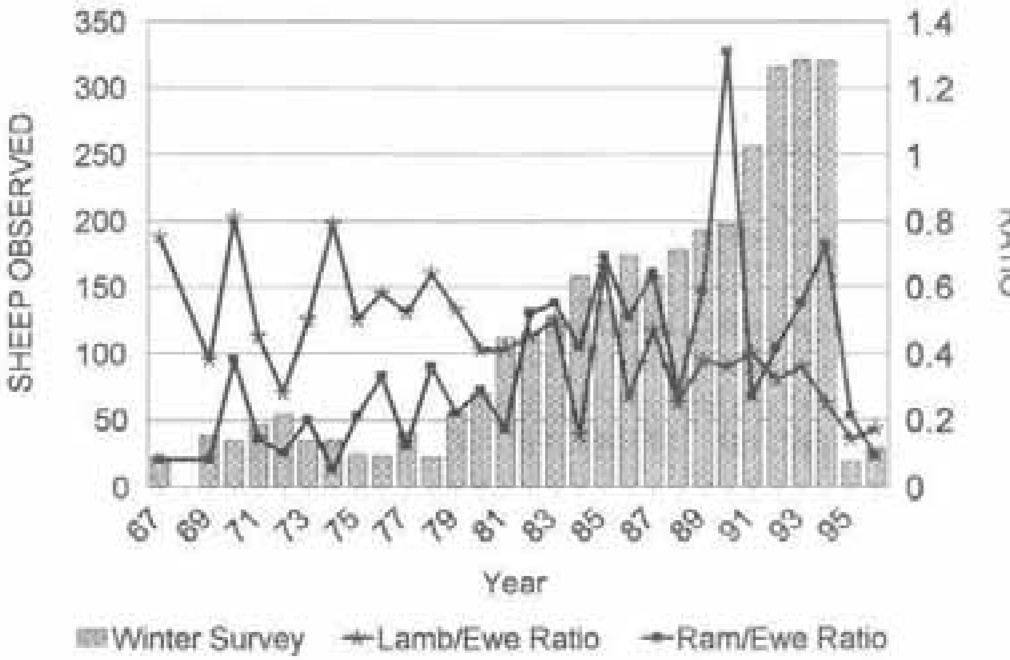


Figure 2. Highland - Pioneers sheep herd total winter survey counts with lamb /ewe and ram/ewe ratios.

Lost Creek Herd Unit

Bighorn sheep were established in the Lost Creek area when 25 bighorns were transplanted from the Sun River herd unit into Olson-Foster Gulch in 1967 (Mussehl and Howell 1971). Forty to sixty sheep were reported for this unit in 1971 and 1972 (MFWP unpub report). Eighty sheep were observed on the winter range in 1974. This population grew to about 138 sheep by 1978 and increased to approximately 386 sheep by 1989 (Dan Hook, pers. Comm.). In an attempt to reduce the population, 60 sheep were captured in February 1991 and transplanted to other sheep herds in Montana. In October 1991 hunters began reporting bighorn sheep with clinical signs of pneumonia. Sheep were observed with respiratory disease from October through December. The population declined and surveys the winter of 1992 indicated fewer than 150 sheep survived the epizootic. Lamb production was depressed for several years and the population has decreased slightly or remained stable since 1991. The survey for 1997 indicated a total sheep count of 130 individuals (Figure 3).

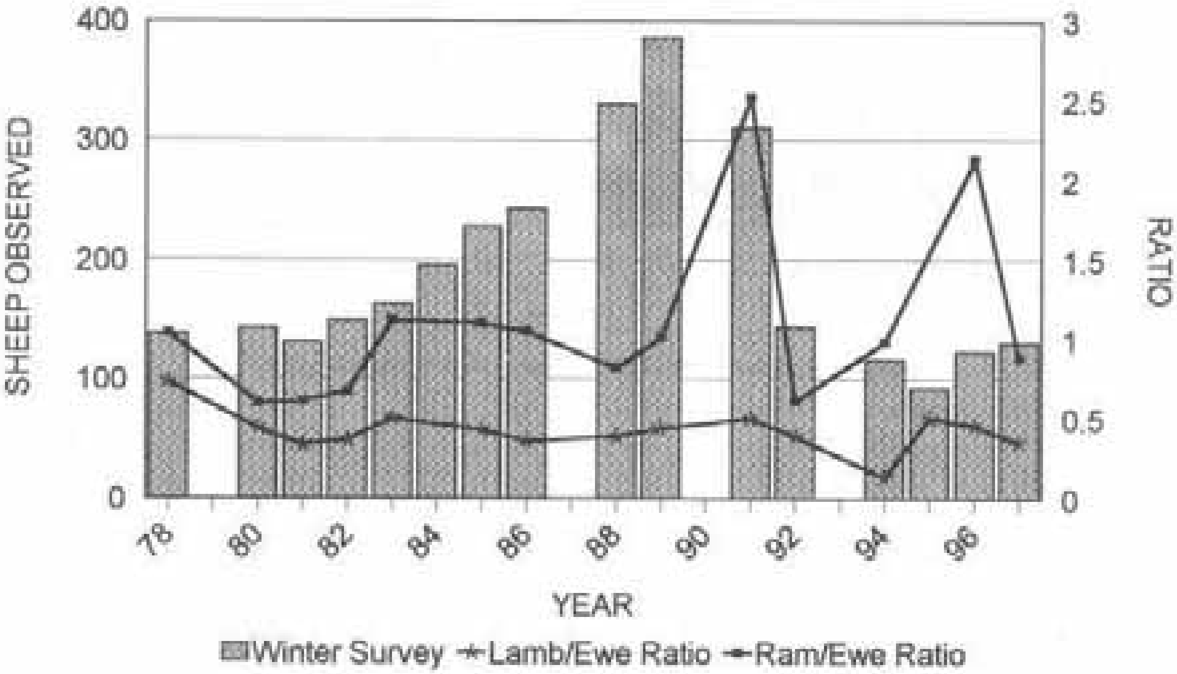


Figure 3. Lost Creek sheep herd total winter survey counts with lamb/ewe and ram/ewe ratios.

Tendoy Mountains Herd Unit

Thirty-six sheep were initially transplanted into the Tendoys in 1984 from Rock Creek. In 1985 this herd was supplemented with 15 sheep from the Perma-Paradise bighorn sheep herd. This population grew rapidly to 92 sheep in 1988. The first hunting season was established in 1988, with 3 either sex permits issued. This quota continued until 1991 when it was increased to 5 either-sex permits and 10 ewe/lamb permits. In 1993, a pneumonia epizootic eliminated approximately 75% of the population (Figure 4). The epizootic event occurred from September through December. The hunting season was subsequently closed.

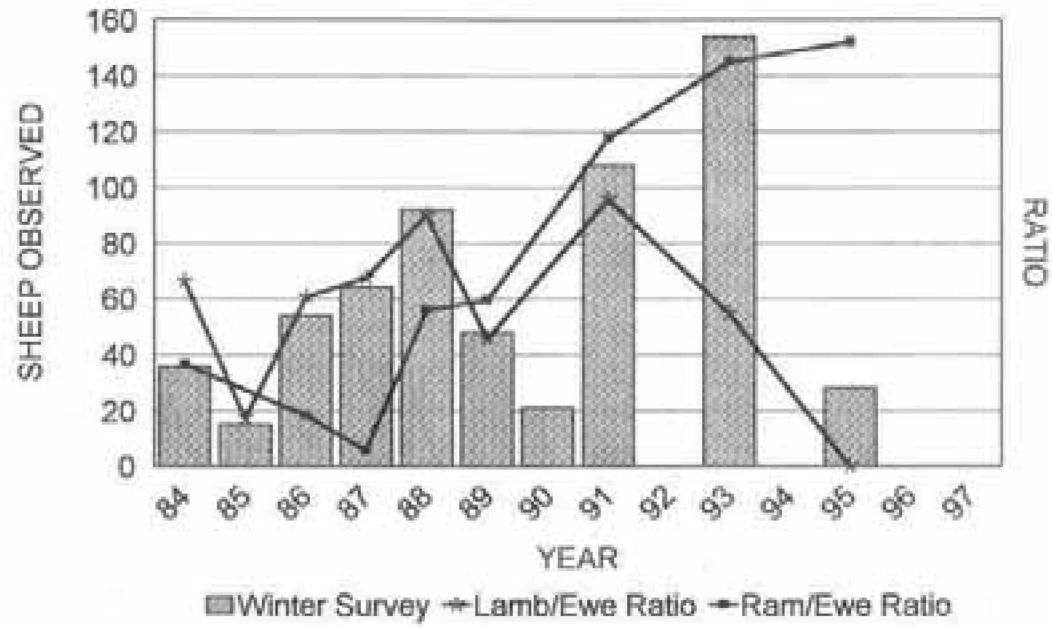


Figure 4. Tendoys sheep herd total winter count with lamb/ewe ratios and ram/ewe ratios.

Quake Lake Herd Unit

The population known to winter near Hebgen Dam was reported to be 28 sheep in 1949 and was referred to as the Hilgard herd (Couey 1950). Beuchner (1960) noted that the Hilgard population remained small in years prior to 1960. In December 1981 a survey indicated the population was at least 59 (Roy 1992). The herd went through a die-off in the early to mid 1980's (Kurt Alt, pers. comm.). The loss of sheep went unnoticed until sheep were no longer observed on the winter range. By 1987, only five sheep were observed where more than 50 had wintered less than a decade before. A small remnant of about 16 sheep survived near Hebgen dam and in the Henry's Lake area (Kurt Alt pers comm.). The population was augmented in 1989 with 23 sheep from Thompson Falls and again in 1990 with 18 sheep from Lost Creek. A third supplement of 26 sheep from Wildhorse Island was released in December, 1993. A severe winter in 1996-97 produced high snowpack and the population went through a weather/pneumonia related die off reducing the population to less than 25 animals. Most of the sheep mortality was during the months of January and February following significant snow accumulations. A February 1998 survey counted only 12 ewes with 3 lambs (Figure 5). A few other sheep are known to be scattered throughout the former range of this herd.

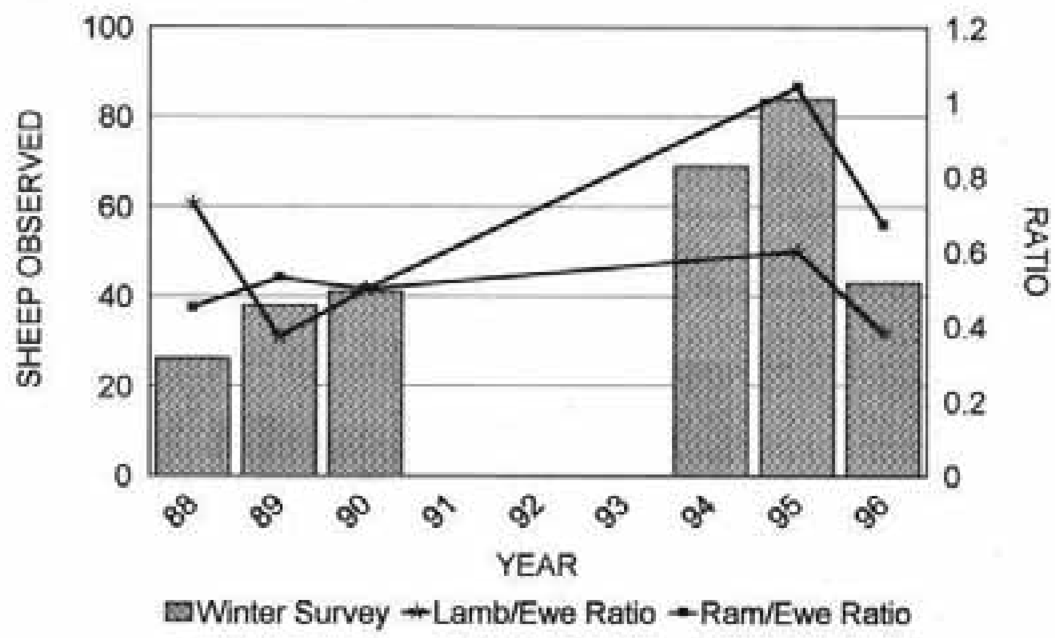
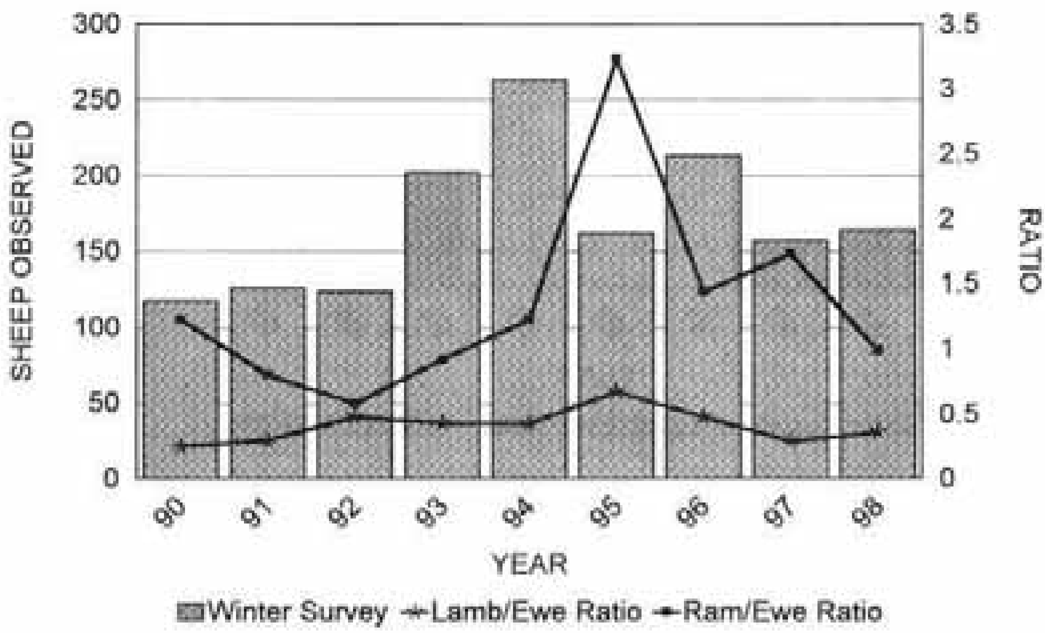


Figure 5. Quake Lake sheep herd winter survey total counts with lamb/ewe and ram/ewe ratios.

Perma-Paradise

Brown (1974) indicates that native bighorn sheep were observed near Plains since 1808 by many early travelers visiting the Thompson River country. Couey (1950) reported an estimate of 25 sheep for this population located in a 4-mile area north of the Clarks Fork of the Columbia River and east of the Thompson River. Between 1949 and 1959 bighorn sheep apparently disappeared from the area. In May, 1959 a transplant of 13 bighorns from the Sun River reestablished sheep in the Thompson River area (Brown 1974). In September, 1959 an additional six sheep from Wildhorse Island were released. The Perma-Paradise herd unit was established in 1979 when the Flathead Indian Reservation introduced 20 bighorn sheep into the area. Early surveys in 1988 discovered that the population had expanded to nearly 100 animals (Tom Lemke, pers.comm.). By 1990 the population was 190 animals and grew to about 480 sheep from 1990 to 1994 (Sterling pers. comm.). In March 1995, 45 sheep were captured near Perma and transplanted to other sheep herds in Montana. The population has declined to slightly over 200 animals since 1995. No reported epizootic events have been reported in this herd (Figure 6).

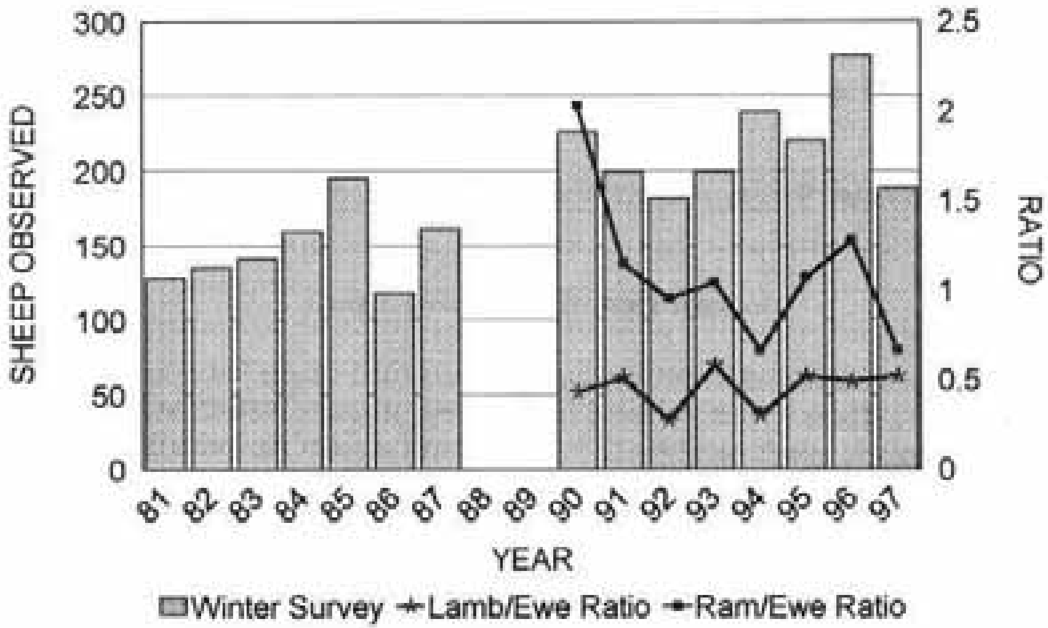
Figure 6. Perma-Paradise sheep herd winter survey total counts with lamb/ewe and ram/ewe ratios.



Upper and Lower Rock Creek

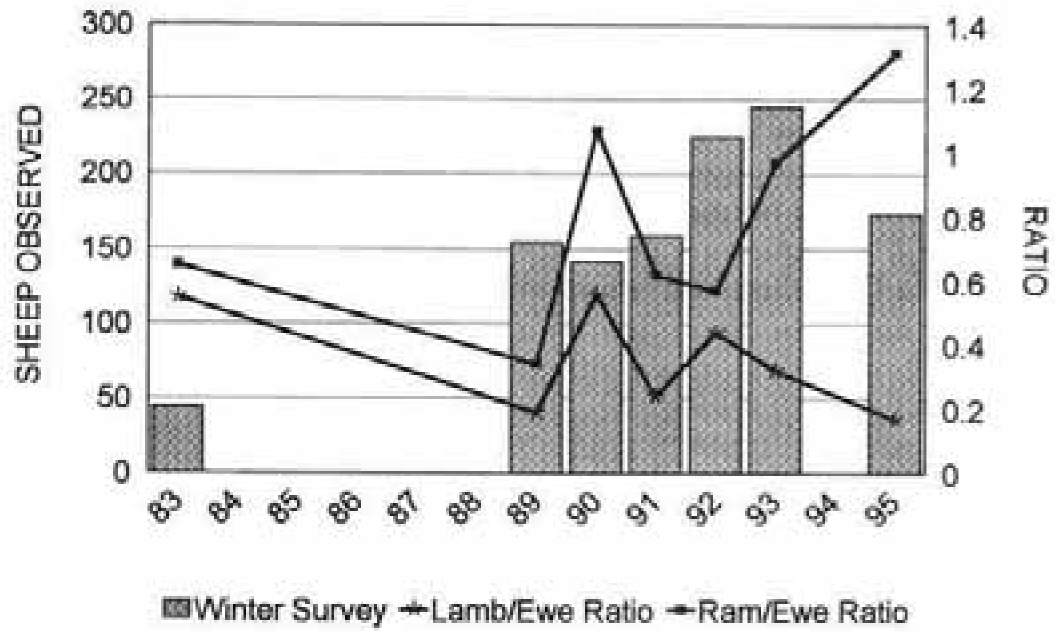
Couey (1950) reported a group of 40 sheep in the head of Rock Creek near Philipsburg. This native population was apparently much larger at one time (Couey 1950, Aderhold 1968). Bighorns were said to be more plentiful than deer prior to 1895 (Berwick 1968). The number of bighorns in Rock Creek declined in 1915 but began increasing by the 1940's (Berwick 1968). The population declined again in the 1960's from about 200 sheep to less than 15 (Berwick 1968, Cooperrider 1969). It was reported that the major cause of the decline was deterioration of the habitat. The Rock Creek sheep herd was supplemented with a transplant of 31 sheep from Sun River in 1975. In 1978, 76 sheep were observed in the upper Rock Creek drainage and the population was estimated to be approximately 100 sheep (Butts 1980). This sheep herd grew steadily from 100 sheep in 1978 to 277 in 1996 (Dan Hook, pers. comm.). In March 1996, 45 sheep were captured and transplanted to other herds from the upper Rock Creek herd unit. Surveys in 1997 indicated that 188 sheep remained in the upper Rock Creek herd (Figure 7).

Figure 7. Upper Rock Creek sheep herd winter survey total counts and lamb/ewe and ram/ewe ratios.



In January 1979, 25 sheep were transplanted from Wildhorse Island to the lower Rock Creek drainage (Butts 1980). The lower Rock Creek herd grew from 25 sheep to 268 in 1996 (Mike Thompson, pers. comm.) (Figure 8). In February 1997, 34 bighorn sheep were captured and transplanted to other sheep herds from the lower Rock Creek herd.

Figure 8. Lower Rock Creek sheep herd winter survey total counts with lamb/ewe and ram/ewe ratios.



Mortality Patterns in Epizootic Events

Carcass searches were conducted in the Highlands-Pioneers and Quake Lake pneumonia epizootics (Table 1) . There were differences in the timing of recent die-offs at Quake Lake and the other recent epizootic events monitored. In Quake Lake most of the mortality occurred in January through February and was evenly distributed among age and sex groups. The Highland-Pioneers die-off began in October and extended into March. The Tendoy and Lost Creek die-offs started in September and October continuing into December. Mortalities in the Highland-Pioneers, Tendoy, and Lost Creek epizootic events were weighted toward lambs in the early periods then shifted into adult ewes as the epizootic continued.

Table 1. Sex and age patterns for mortalities investigated in the Quake Lake and Highlands-Pioneers die-offs.

	Males%	Ad. Females%	Lambs%
Quake Lake Jan. (N=19)	47.4	42.1	10.5
Quake Lake Feb. (N=18)	38.9	38.9	22.2
Highlands-Pioneers Dec.-Jan. (N=53)	26.4	51.0	22.6
Highlands-Pioneers Feb.-Mar. (N=65)	23.1	72.3	4.6

Kidney fat indexes were determined from bighorn sheep carcasses for the Quake Lake herd unit during the pneumonia epizootic. The mean kidney fat index for 14 sheep necropsied in January was 36.5% (range 1.0-169.9). This declined in February to 3.4% (range 1.0-18.8). Data on sheep condition was not available for the other herds during the die-off period.

Comparison of Herd Health Histories

Bacteria

Cultures of lung tissue from bighorn mortalities during individual pneumonia epizootics yielded a variety of bacteria (Table 2). The most common bacteria, *Pasteurella multocida* and *Pasteurella haemolytica*, were isolated from 16.6% to 71% of the lung tissue submitted. *Pasteurella haemolytica* isolates were commonly bio-type T. *Pasteurella haemolytica* type A2 was isolated from bighorn sheep during the Highland-Pioneer epizootic event. Bighorn sheep from this herd unit shared habitat with domestic sheep during all seasons. Other common bacteria isolated include *Streptococcus* spp. and *Actinomyces pyogenes*.

Pharyngeal swabs taken from healthy bighorn sheep populations resulted in cultures of bio-type T *P. haemolytica* and various sero-type combinations of 3,4,10, and 15 (Table 3). The percentage of swabs in which *P. haemolytica* was successfully cultured varied among herd units sampled and ranged from 7% to 46%.

Table 2. Culture results from lesions within lung tissue prosected from bighorn sheep during epizootic events in Montana, 1990-97.

Herd Unit	P. mult.*	P. haem.*	Bio-Sero Type (*P.haem.*)	Other
Lost Creek	1/19	7/19	T 3,4 T 3,4,10	Corynebacterium, Streptococcus, Actinomyces, Aeromonas
Tendoys	1/6	0/6	Not Attempted	Streptococcus, Actinomyces
Highland-Pioneer	4/12	6/12	A2 T 4,10,15 T 4,10 T 3,15 T 3 T 4	Streptococcus
Quake Lake	8/14	10/14	T 3, 4	Actinomyces, Moraxella

* Data indicates number positive / number tested.

Table 3. Biotype and sero-type of *Pasteurella haemolytica* cultures from pharyngeal swabs taken from captured bighorn sheep in Montana, 1990-97.

	Year	No. Pos.	No. Tested	Bio-type	Sero-type
Perma-Paradise	95	3	44	T	4 and 10, 15
Upper Rock Cr.	96	4	45	T	3, 15
Lower Rock Cr.	97	11	34	T	3
Wildhorse Island	93	58	125	T	4 and 3, 4
Tom Miner	95	2	10	T	4 and 4, 10

Viruses

Serologic evidence for respiratory virus antibodies were found in all bighorn sheep herds tested (Table 4). The most common respiratory viruses affecting bighorn sheep were PI3 and BRSV. We did not begin routine testing for BRSV until 1995. For those herds tested since 1995 for BRSV all have shown a high sero-prevalence. Sero-prevalence for BVD appeared to be herd specific. We found high sero-prevalence for BVD in the Lost Creek and Perma-Paradise herd.

Sero-prevalence did not uniformly compare with virus isolation results (Table 5). Although sero-prevalence for PI3 indicated significant challenge for bighorn sheep in the Highlands-Pioneer herd unit prior to an epizootic it was not recovered from lung tissues. Sero-prevalence for BVD was indicating potential viral challenge for bighorn sheep in the Lost Creek herd unit and BVD was isolated from 74% of the lung samples submitted to virology.

Table 4. Serologic prevalence for antibodies for respiratory viruses in captured Bighorn Sheep from Montana, 1990-97.

	IBR	PI3	BVD	BRSV
Lost Creek	1.8	76.8	100.0	--
Highlands-Pioneers	0.0	91.7	45.8	--
Perma-Paradise	0.0	47.7	100.0	81.8
Upper Rock Creek	0.0	48.9	0.0	73.3
Lower Rock Creek	0.0	58.8	0.0	100.0
Tom Miner	0.0	60.0	30.0	100.0
Gardiner YNP	0.0	66.6	0.0	86.6
Milltown-Bonner	0.0	55.2	0.0	72.4
Wildhorse Island	35.2	10.7	0.0	--

Parasites

Larval shedding for *Protostrongylus* spp. was monitored in fecal samples from nine different sheep herds in Montana. We observed larval shedding in all herds tested using Baermann techniques (Table 6). In addition, adult *Protostrongylus* spp. were identified either grossly and/or in histologic sections of lung tissue for the Highlands-Pioneers, Tendoy and Quake Lake herd units. All herds experiencing a pneumonia epizootic exhibited some level of *Protostrongylus* spp. infection with the exception of the Lost Creek herd. There was no evidence supporting significant lungworm infection during this particular epizootic.

Table 5. Results from virus isolation attempts from bighorn sheep lungs prosected during epizootics in Montana, 1990-97. Viruses tested for are Infectious Bovine Rhinotracheitis (IBR), Para Influenza-3 (PI3), Bovine Virus Diarrhea (BVD) and Bovine Respiratory Syncytial Virus (BRSV).

Herd Unit	IBR	BVD	PI3	BRSV
Lost Creek	0/19	14/19	2/19	0/19
Tendoys	3/6	1/6	0/6	0/6
Highland-Pioneers	0/9	0/9	0/9	0/9
Quake Lake	0/15	0/15	6/15	1/15

* Table data represents number successful isolations / number of attempts

Table 6. *Protostrongylus* spp. larval shedding from various bighorn sheep herds in Montana, 1990-1997. Mean larval density per gram of fecal material (LPG) counts conducted using Baermann techniques.

	Mean LPG	% Positive
Highlands (1)	116.6	100.0
Highlands (2)	1.2	26.5
Quake Lake	0.2	33.3
Upper Rock Creek	28.0	77.7
Lower Rock Creek	184.0	91.2
Perma-Paradise	5.1	89.7
Wildhorse Island	6.0	100.0
Pryor Mtns	5.5	40.4
Milltown-Bonner	153.0	100.0
Missouri Breaks	8.3	83.8

1/ Testing conducted prior to epizootic in 1994-95

2/ Testing conducted after treatment with anthelmintics in 1995-96.

Bighorn sheep parasites recovered from gastro-intestinal tracts or identified through fecal flotation include *Protostrongylus rushii, Protostrongylus stilesi, Marshallagia marshalli, Ostertagia ostertagi, Ostertagia trifurcata, Nematodirus abnormalis, Nematodirus davtiani, Chabertia ovina, Moniezia, Skrjabinema* and *Trichuris spp.* The abomasal nematode *Marshallagia marshalli* was the most significant gastro-intestinal parasite found infecting many bighorn sheep herds in Montana (Table 7). *Wyoming tetoni* was the only cestode identified in any sheep herd recently examined from Montana (Hoar et al 1996). *Eimeria crandallis, Eimeria ahsata, Eimeria ovinoidalis, Eimeria intricata, Eimeria granulosa* and *Eimeria ovina* were frequently found in fecal samples from the Upper Rock Creek herd unit indicating potentially significant coccidian infections for many sheep in this herd.

Table 7 Gastro-intestinal parasites identified in various sheep herds in Montana, 1990-97

Herd Unit	Parasite
Tendoy Mtns.	**Marshallagia**, Nematodirus, Eimeria
Quake Lake	Nematodirus, Moniezia
Lost Creek	**Marshallagia**, Nematodirus, Trichostrongyles
Highland-Pioneers	**Marshallagia**, Nematodirus, Ostertagia, Chabertia, Trichuris, Eimeria, Cestoda
Wildhorse Island	**Marshallagia**, Nematodirus, **Ostertagia**, Strongyloides, Haemonchus, Coccidia, Trichuris, Trichostrongylus
Upper Rock Creek	**Marshallagia**, Nematodirus, **Eimeria**, Skrjabinema
Lower Rock Creek	**Nematodirus**, **Coccidia**, Trichuris, dorsal spined larvae (P. odocoilei ?)
Pryor Mtns.	Marshallagia, Nematodirus, Strongyloides

* Bold indicates intensity sufficient to cause clinical parasitism.

DISCUSSION

Schwantje (1986) suggested several methods for monitoring bighorn herd health and recommended that monitoring should be considered only as corollaries to the study of population dynamics and range condition trends. We examined the population data for seven sheep herds to evaluate population parameters or changes in parameters that might indicate when bighorn sheep populations become susceptible to respiratory disease. Unfortunately, the data available were often incomplete for some herd units and did not yield to detailed quantification. Total population trend from four herd units that experienced epizootic events increased at about the same rate as two populations that did not experience any epizootic event during the study period. Not all herd units undergoing rapid population increase experienced an epizootic event during the study period (e.g. Perma-Paradise).

Population management designed to reduce sheep populations through capture and increased harvest in the Highland-Pioneers herd and the Lost Creek herd prior to epizootics did not prevent respiratory disease. Both of these populations went through a serious epizootic event following attempts to reduce the population. These management adjustments may not have decreased population density sufficiently or in adequate time to provide a favorable effect and prevent disease. Special population management for the Rock Creek and Perma-Paradise herd units was implemented as well. It is difficult to say that reductions in the size of the Rock Creek and Perma-Paradise herd units reduced density sufficiently to prevent an epizootic but overall population trend for these herds has been more stable and neither population experienced an epizootic event following high population numbers. Thorne et al. (1982) indicated that population control to prevent overcrowding of sheep is important but reducing the concentration and amount of time sheep spend on critical range is more important. We did not examine density trends for these populations but agree that concentrating sheep for long periods may be the most significant factor predisposing sheep herds to respiratory disease. Measuring densities as well as total numbers of sheep on critical ranges among various herd units or between years within a herd unit may be the best population parameter for predicting risks for pneumonia epizootics.

Trends in lamb/ewe ratios were highly variable among different populations examined in this study but remained relatively stable within all populations except following epizootic events when they declined. Reduced lamb production and recruitment for 2 years following a pneumonia die-off has been reported in other study areas (Onderka and Wishart 1984, Coggins and Mathews 1992, Ryder et al. 1994).

Bighorn sheep herds in Montana are frequently managed to protect trophy quality rams. Healthy sheep herds and those experiencing epizootics in Montana reported between one and three rams per ewe. Although supportive data are not presented here we hypothesize that managing for high numbers of rams in bighorn populations could have significant disease implications. Rams are inclined to travel further, exhibit rutting behavior conducive to respiratory disease transmission, and are more likely to interact with domestic sheep during breeding season. In addition, a single pneumonic ram can associate with many ewes during one breeding season. In Montana at least 4 cases of young rams breeding with domestic sheep have been reported since 1990. These rams may be exposed to highly virulent pathogens and return to infect bighorn ewe/lamb groups. Further work is needed to evaluate the role of bighorn rams in the transmission of respiratory disease.

Bacterial pathogens commonly associated with pneumonia complex in bighorn sheep were ubiquitous in Montana. *Actinomyces pyogenes, Pasteurella haemolytica* and *Pasteurella multocida* were commonly found in bighorns during epizootics and also in healthy sheep. Other studies have indicated that these bacteria are commonly isolated from many ruminants whether respiratory disease symptoms exist or not (Siflow et al. 1994, Miller et al. 1991, Queen et al. 1994). *Actinomyces* and *Pasteurella* are recognized opportunists capable of causing disease if an animals immune system is compromised (Queen et al. 1994). Respiratory disease which involved these opportunistic bacteria where involved in three of the four epizootics we studied.

Pasteurella haemolytica along with stress factors has long been recognized as a significant component of pneumonia epizootics in bighorn sheep (Spraker et al. 1984, Miller et al. 1991). There are many identified strains of *Pasteurella haemolytica* with varying differences in virulence (Silflow et al 993). *Pasteurella haemolytica* bio-type T and various sero-types 3,4,10, and 15 were most commonly found in both healthy and diseased sheep in Montana. *Pasteurella haemolytica* A2 was identified in only one epizootic, occurring where domestic sheep are known to share habitat with bighorn sheep. *Pasteurella. haemolytica* A2 has been determined to be highly pathogenic to bighorn sheep (Foreyt and Silflow 1996, Silflow et al. 1994).

The respiratory viruses PI3, BVD, IBR and BRSV are found throughout Montana in a wide range of domestic and wild animals. In bighorn sheep we found serologic evidence for all four respiratory viruses but found that bighorn sheep were primarily exposed to PI3, BVD, and BRSV. Virus isolation from lung tissue prosected during mortality investigations indicates that PI3 and BVD were probably involved in some manner with two pneumonia epizootics in Montana bighorn sheep. The high sero-prevalence for BVD virus and isolation of the virus from numerous lung tissues implicate BVD, in concert with *Pasteurella* spp., as a significant pathogen in the Lost Creek epizootic. A cursory examination of the literature failed to locate any records implicating BVD in sheep pneumonia despite repeated evidence of serologic prevalence (Foreyt et al. 1996, Howe et al. 1966, Parks et al. 1974). Several studies have isolated PI3 from bighorn sheep with clinical disease (Parks et al. 1972, Jessup 1985). We isolated PI3 from bighorn sheep with clinical disease in the Quake Lake and Lost Creek herd units.

Parasites, in particular *Protostrongylus* spp., have often been implicated in pneumonia epizootics (Marsh 1938, Buechner 1960, Forrester and Senger 1964). Evidence presented in this study indicates that all herd units tested exhibited mild to moderately high lungworm loads. The Highland-Pioneers presented higher lungworm loads than other sheep herds in Montana prior to a pneumonia epizootic. However, of the seven herds tested, the lower Rock Creek herd unit exhibited the highest lungworm loads and has not experienced a recent pneumonia epizootic. Fecal samples from 15 sheep in the Lost Creek herd unit were negative for lungworm in 1988 (Roy 1992) and lungworms were not detected during gross examination or histopathology during a pneumonia epizootic in 1991. Lungworm burden alone did not predict the occurrence of pneumonia epizootics. Schwantje (1986) suggests that local reactions to focal injury from lungworms may increase the risk of bacterial infection by opportunistic pathogens. Bighorn sheep herd units with chronically high lungworm infections should be considered at risk for pneumonia. Lungworm larvae loads and prevalence as well as gastrointestinal parasites may be good indicators of crowding and could provide some insight into the susceptibility of a herd unit to pneumonia epizootics (Worley et al. 1988).

Mild to relatively high lungworm and enteric parasite loads were identified in several Montana bighorn sheep herd units (Hoar et al. 1996, this study). Most of the parasites identified have been previously reported in bighorn sheep from North America (Becklund and Senger 1967, Worley and Seesee 1992). Dorsal spined larvae, probably larvae from the muscle worm *Paralaephostrongylus odocoileus,* were found in bighorns captured in 1997 from Lower Rock Creek. This parasite has not been previously reported in Montana bighorn sheep. However, recent examinations of mule deer from similar areas in northwestern Montana have also identified dorsal spined larvae (MDFWP unpublished data). Coccidiosis was evident in sheep from the Upper Rock Creek herd, but no known mortalities attributed to coccidiosis have occurred. Although no recent pneumonia epizootics have been observed, the Rock Creek bighorn sheep herds demonstrated parasite loads that may cause clinical disease and at high sheep density may increase the risk for pneumonia.

Each pneumonia epizootic in Montana we evaluated demonstrated unique characteristics and yielded a complex of pathogens that resulted in respiratory disease (Table 8). The Lost Creek herd pneumonia epizootic resulted from a combination of bacterial and viral infections without evidence of a significant parasitic infection. This was contrasted to the Highlands-Pioneers pneumonia epizootic which was preceded by significant parasitism which likely predisposed these sheep to opportunistic bacterial infections. The Highlands-Pioneer pneumonia epizootic was also characterized by a unique infection with the highly pathogenic *Pasteurella haemolytica* type A2 as well as the more common type, T-3,4. It is likely that the cytotoxic A2 isolate originated from domestic sheep that share habitat with these bighorn sheep yearlong. Several reports of bighorn rams breeding with and mingling with domestic sheep ewes were recorded prior to the pneumonia outbreak. Domestic sheep have been implicated in the development of bighorn sheep pneumonia in several studies (Callan et al. 1991, Foreyt et al. 1994). Domestic sheep and bighorns coexisted in the Highlands-Pioneers for nearly 20 years before a pneumonia outbreak. However, this population of bighorns had dramatically increased recently, improving the probability of transmission.

Table 8 Summary of findings for 4 bighorn sheep epizootics in Montana, 1990-1997.

Herd Unit	P. mult.	P. haemo.	Other Pathogens	Factors	Mortality*
Lost Creek	Yes	T-3,4,10	BVD, Mild Lungworm Range Condition	Density	>150 (55%)
Tendoys	Yes	No	IBR, Mild Lungworm	Unknown	>100 (75%)
Highlands	Yes	T-3,4,10,15 A-2	Lungworm	Density Domestic Sheep	>300 (87%)
Quake Lake	Yes	T-3,4	PI3	Winter Malnutrition	>50 (60%)

* Indicates the approximate number of mortalities followed by the percentage of the herd mortality in parenthesis.

The Quake Lake pneumonia epizootic occurred during a very severe winter resulting in greater than average snowpack on winter ranges. Bighorn sheep in this unit were forced to low elevations and were frequently obstructing traffic along a highway. This epizootic occurred during the middle of a severe winter which sets it apart from the other recent pneumonia epizootics that developed during the fall. Diagnostic evidence indicated that various combinations of bacterial and viral pathogens acted opportunistically following the winter stress and chronic malnutrition. Malnutrition was evidenced by the significant decline in kidney fat indexes.

Recent pneumonia epizootics were documented in supplemented native herds as well as herds established through transplant programs. Two herd units discussed, Quake Lake and Upper Rock Creek, supported a few native sheep before they were supplemented with transplants. All other bighorn herd units were established through the introduction of transplanted sheep. The source stock for these herd units was variable and did not come from herds with evidence of respiratory disease. Pneumonia epizootics in Montana were not restricted to long established herd units but affected newly established herd units such as the Tendoy Mountain herd which had been established for only 10 years.

In conclusion, our investigation supports previous work indicating that clinical respiratory disease in bighorn sheep results when the right pathogens, susceptible hosts and an appropriate environment combine. We found many opportunistic bacterial and viral pathogens causing pneumonia in Montana sheep. Parasitic infections in Montana bighorns also periodically cause low level chronic stress depending on population size and density, predisposing sheep to pneumonia (Worley et al. 1988). In addition to the wide variety of pathogens associated with respiratory disease, there were many different habitat and environmental factors uniquely affecting each individual herd unit in Montana, creating complex and variable stresses on bighorn populations. Annual standardized population surveys, environmental monitoring and detailed health data from each herd unit provided a relatively complete picture of specific factors that may increase the risk for pneumonia epizootics and may lead to preventative management. We recommend expanding this preliminary program of population and health monitoring to additional herd units to improve risk management for respiratory disease and prevent the tremendous loss of bighorn sheep due to pneumonia epizootics.

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PREDICTING SUMMER LAMB MORTALITY IN FREE RANGING BIGHORN SHEEP

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Abstract: Summer lamb mortality occurs for several years following a *Pasteurella* associated bighorn die-off. Factors influencing this summer lamb mortality are not well understood. Lamb mortality studies conducted after a die-off have been hampered by low sample sizes due to the difficulty in locating dead lambs and culturing uncontaminated bacteriology and virology samples. Summer lamb mortality was evaluated in the Wenaha herd of Rocky Mountain bighorn sheep in Oregon. A technique was developed to maximize the number of fresh lamb carcasses found in summer. The focus of searches for lamb carcasses was guided by behaviors of bighorn sheep rather than random searches, close distance observations, or a focus on scavengers. Lamb carcasses less than 24 hours old and critically ill lambs were located through recognition of behavioral cues of lambs, their dams, and their social group. Since carcasses were located and preserved immediately after death, post-mortem bacterial contamination was minimized. *Pasteurella trehalosi* (*Pasteurella haemolytica* biotype T) biogroups 2b and 2 were cultured from lungs of 3 dead lambs that were less than 7 weeks old. The use of behavioral cues to locate sick or dead lambs was particularly effective since bighorn groups were widely spaced and most observations were made from long distances due to terrain and habitat.

INTRODUCTION

Die-offs of Rocky Mountain bighorn sheep populations (*Ovis canadensis*) from pneumonia have been associated with *Pasteurella haemolytica* bacteria (Onderka and Wishart 1984, Bailey 1986, Coggins 1988, Akenson and Akenson 1992, Ryder et al. 1992, Cassirer 1996). The pneumonia caused a high mortality rate in all age-classes and resulted in poor lamb recruitment for several years following the die-off. A high rate of lamb mortality during summer was responsible for the post die-off poor lamb recruitment (Festa-Bianchet 1988, Akenson and Akenson 1992, Coggins and Matthews 1992).

Following a die-off, lamb carcasses can be collected, tissues examined, and bacteria and viruses cultured to identify the active pathogens responsible for lamb mortality, and potentially the pathogen associated with the die-off. Unfortunately, in free ranging bighorns it is difficult to find lamb carcasses that can be cultured before autolysis has occurred. Few lamb carcasses have been examined or cultured after a die-off. An effective method is needed to detect sick lambs and locate carcasses in the field.

The health status of a bighorn lamb can be determined by interpreting the behavior of its dam within a social context. Bighorn sheep are a social species. They have predictable behavior patterns. Ewes with newborn lambs join other ewe-lamb pairs a few days after lambing (Geist

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1971). Lambs readily form bonds with other lambs, playing and feeding together within the nursery group. Ewes with lambs remain in groups throughout the summer. Akenson and Akenson (1992) located lamb carcasses by observing agitated behaviors of bighorn ewes whose lambs had recently died. Ewes have been observed staying in the vicinity of their dead lambs for up to 3 days (Geist 1971, Akenson and Akenson 1992). As a result of the strong social bonds between a ewe and its lamb and among ewes, the behavior of a ewe can be interpreted to indicate that its lamb may be weakened or dead. This paper describes a technique for observing and interpreting ewe and lamb behavior within a social context to predict imminent lamb mortality or to find lamb carcasses within 24-hours of death.

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STUDY AREA AND METHODS

The Wenaha herd of Rocky Mountain bighorn sheep in northeastern Oregon experienced a die-off in 1996. The die-off was part of the widespread Hells Canyon die-off that started in late 1995. I monitored the Wenaha bighorn sheep in 1997 to assess summer lamb mortality during a *Pasteurella* vaccine trial (Cassirer et al. 1998). Twelve radio-collared ewes and their associated groups were located from the ground several times per week from May through mid July. Group composition, location, and lamb health were determined. The bighorn ewes used bunchgrass slopes and rims in and adjacent to the Wenaha-Toucannon Wilderness. Bighorn groups were widely dispersed along 25 km of river corridor. I used a 40 power spotting scope to monitor lambs up to 2.5 km away on the opposite side of a 370 m deep canyon.

Clinical symptoms of pneumonia, including coughing, nasal discharge, weakness, and head shaking, were documented. Individual lambs were watched for up to one hour to determine health status. When a ewe was observed standing or bedded alone, acting agitated, or vocalizing and travelling rapidly, the ewe was watched and vicinity scanned for evidence that a lamb was sick or dead. Searches for a dead lamb were conducted in the vicinity of the ewe. Dead lambs were collected, then necropsied at the Idaho Fish and Game Wildlife Health Lab. Nasal and pharyngeal swabs and tissues were cultured and *Pasteurella spp.* identified by DNA restriction enzyme assay (Jaworski et al. 1993) at University of Idaho Caine Veterinary Teaching Lab.

RESULTS

Fourteen lambs were observed with 32 ewes of the Wenaha herd. Median date of birth was May 26 (range May 18-June 3, n=14). Five lambs had died by July 16; all were under 7 weeks old. Three of the lamb carcasses were recovered within 24 hours of death. These lambs were 10, 19, and 47 days old. Two strains of *Pasteurella trehalosi* (also referred to as *Pasteurella haemolytica* biotype T) were cultured from lungs of the 3 bighorn lambs. Two lambs had the non-hemolytic biogroup 2b, while 1 lamb had the hemolytic biogroup 2.

The presence of clinical pneumonia symptoms did not consistently predict lamb mortality. Coughing was observed in several lambs, but some lambs coughed that did not die immediately, while other lambs died although coughing was not observed. Long distance observations made it difficult to see nasal secretions. Ward et al. (1992) described symptoms of bighorn lambs with inner ear irritations, exhibited by head tilting, ear drooping, ear scratching, and head shaking. Within 72 hours death from *Pasteurella* associated pneumonia was imminent for these captive lambs. Ear scratching and head shaking were observed in lambs and ewes, but it was unclear whether insects or inner ear irritations caused these responses.

The behavior of a bighorn ewe was more reliable for indicating the presence of a newly dead lamb than random searches or focusing on scavenger activity. All 3 recovered lamb carcasses were located based on behavioral cues exhibited by the dam. Each ewe exhibited several of these actions:

- The ewe was alone
- The ewe was agitated, scanned the area, and vocalized frequently
- The ewe travelled rapidly between the group and its dead lamb
- The ewe bedded near its dead lamb
- The ewe remained in the vicinity of the carcass when approached by a human

One ewe displayed several cues that indicated her lamb had died. The ewe and her 9-day old lamb had just joined a nursery group 1 km from the lambing area. A major thunderstorm occurred that afternoon. In the evening the agitated ewe ran between the lambing area and their location prior to the storm. A carcass could not be located through the spotting scope. In the morning the ewe was in the lambing area without her lamb. A ground search was fruitless and the ewe left the area. After more than 15 hours of known separation the ewe and lamb were reunited. They pair moved 2 km from the group and remained near a crevice in a cliff for 3 days before rejoining the nursery group.

The behavior of a ewe could also indicate that its lamb was sick. On 3 occasions different ewes from the Wenaha herd were observed leaving their group to stay with the sick lamb. Each ewe responded to its sick lamb with these behaviors:

- The ewe left the group to remain with its lamb
- The ewe nuzzled or pawed its lamb to urge it to stand, nurse, or travel
- The ewe vocalized and ran back and forth between the lamb and the group
- The ewe was aggressive (horn threat, teeth grinding) to human approach

One sick lamb was so weak that it remained bedded when captured by hand. As we searched for this lamb, its dam vocalized, ran toward us, isolated one person on a ledge with a horn threat, then when 2-5 m away, horn threatened 2 other people. We found the lamb 3 m from us. The lamb died while being carried out of the wilderness.

Lamb behavior that was inconsistent with typical lamb social patterns was also an indicator that the lamb was near death. These behaviors were observed from long distances. The health of lambs was most readily assessed when the bighorn group travelled or fed. Three critically ill lambs displayed the following behaviors (ordered by increasing severity of illness):

- The lamb lagged behind a travelling group
- The lamb stumbled or bedded when it followed the group
- The lamb remained bedded when the group moved away
- The lamb would not/could not move uphill
- The lamb could not be encouraged by its dam to follow the group
- The lamb oriented its body away from the group, then moved downhill and away from the group (2 lambs ended up in a brushy draw or riparian)
- The lamb bedded or stood motionless and was inattentive to the activities of the other bighorns
- One lamb stood with a bison-like posture: its back was rounded and its head was lowered.
- The lamb was alone after the bighorn group moved away
- The sick lamb was found dead within 16 hours of the last live observation on 2 occasions

Bighorn social groups provided additional cues to confirm that a lamb was critically ill. Under normal conditions ewes and lambs showed strong group cohesion. The following behaviors were observed when a sick lamb was present:

- Bighorns in the group directed their attention toward a lamb that was detached from the group
- The group moved toward the lamb
- The group moved away from the lamb
- A ewe was aggressive to a lamb

In one incident a ewe and lamb joined the sick lamb. This ewe and the dam of the sick lamb moved off when the dam could not encourage the lamb to follow. The healthy lamb remained with the 18 day-old sick lamb despite the healthy lamb's dam repeatedly encouraging it to follow. This ewe returned to the lambs and butted the sick lamb in the side 4 times. The dam of the sick lamb observed this interaction, but did not interfere. The 2 ewes and healthy lamb fed away from the sick lamb. The next morning the sick lamb was dead. Its dam was 250 m away. A necropsy revealed that this lamb had pneumonia, as well as a punctured rumen and bruises on both sides of the body (presumably from being butted, but possibly from a fall or being pawed).

DISCUSSION

The criteria described in this paper for recognizing the health status of lambs is based on a small sample of bighorn lambs that were observed sick or dead. Despite the small number of individuals, ewe behaviors observed in this study were consistent. Some were the same as ewe behaviors described in other bighorn populations (Geist 1971, Akenson and Akenson 1992). The behavioral responses of these ewes to their sick and dead lambs are likely ubiquitous among bighorn sheep.

Advantages. The use of bighorn behavior to locate lamb carcasses has several advantages over other methods. A ewe's behavior can indicate that a lamb has died and focus the search area so lamb carcasses can be recovered rapidly and in greater numbers. The dam of the dead lamb can be identified by its agitated behavior. In comparison, routinely scanning an area used by bighorn sheep to find carcasses is inefficient. Carcasses located from scavenger activity are usually not intact for post-mortem examinations and too decayed for bacteriology and virology culture. Lamb mortality studies requiring radio-instrumentation of lambs are expensive, can cause significant disturbance in lambing areas, and are logistically not possible in many areas. Using bighorn sheep behavior to indicate lamb mortality does not require live animal handling, is inexpensive, unobtrusive, and is effective for long distance observations. Since imminent mortality can be predicted by bighorn behavior, intensive follow-up monitoring results in less contaminated carcasses than those collected using other methods. Although clinical symptoms of pneumonia in free ranging bighorn sheep are difficult to detect while observing bighorn behavior from long distances, the presence of pneumonia symptoms does not necessarily lead to imminent lamb mortality.

Limitations. There are several limitations of this technique. It requires good vantage points for observing bighorn sheep. Each group must be observed daily to maximize recovery of uncontaminated carcasses. If a ewe and its sick or dead lamb are segregated from other sheep they are more difficult to locate. There is a danger to humans approaching an aggressive ewe to collect a dead lamb. Since observations of ewes with dead lambs have been limited, it is not known whether ewes respond in the same manner to lambs that died from predation or other non-disease causes of mortality.

There were several interesting results from monitoring summer lamb mortality in the Wenaha herd. Two strains of *Pasteurella trehalosi* were isolated from lungs of the bighorn lambs, biogroup 2b and biogroup 2. Both of these strains were found in bighorns sampled during the Hells Canyon die-off in 1995-1996. Biogroup 2b, a non-hemolytic strain was identified in 71% of bighorn sheep and biogroup 2, a hemolytic strain was cultured from 5% of bighorn sheep that were sampled during the Hells Canyon die-off (Cassirer et al. 1996). *Pasteurella trehalosi* biogroup 2 was implicated in a bighorn sheep die-off in central Idaho in 1989-1992 (D. Hunter, Idaho State Wildlife Veterinarian, lab report 7/9/97). Foreyt (1990) found that post die-off mortality in captive bighorn lambs did not occur until after lambs were 6-11 weeks old since lambs were apparently protected for several weeks by passive immunity from colostrum. In the Wenaha herd, mortality from pneumonia occurred in lambs under 7 weeks old indicating that colostral immunity may not function adequately. Sams et al. (1996) found that transfer of passive immunity through colostrum absorption was compromised in an overpopulated and malnourished herd of white-tailed deer (*Odocoileus virginianus*). Perhaps the multiple year summer lamb mortality that occurs following a *Pasteurella* die-off is triggered by interference in colostrum absorption by lambs of die-off survivors.

CONCLUSION

Sick lambs and lamb carcasses were located during a study of lamb mortality by observing and interpreting bighorn ewe and lamb behaviors. Ewes and lambs displayed distinctive behaviors when a lamb died or was critically ill. When I recognized these behavioral cues I was able to identify sick lambs that would die within 24 hours, to locate lamb carcasses less than 24 hours after death, to identify a ewe whose lamb had recently died, and know where to search for the carcass. A bighorn ewe's behavior was the most reliable indicator that its lamb was critically ill or dead. The ewe's behavior alerted me to intensively watch the lambs for signs of illness. Critically ill lambs should be monitored for 24 hours to document mortality and recover carcasses immediately after death. The localized nature of a ewe's activities identified the site of the lamb carcass or sick lamb. The bighorn lamb's behavior was the best indicator of the lamb's health. Lamb health was most readily assessed when the group was travelling, since a sick lamb lagged behind the group. These techniques were very effective for long distance assessment of the health status of individual lambs. Since carcasses could be located and recovered quickly by using this method, all 3 carcasses collected were intact and could be cultured for bacteria and viruses. Strains of *Pasteurella trehalosi* were isolated from the lungs of all 3 lamb carcasses.

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EVALUATION OF EWE VACCINATION AS A TOOL FOR INCREASING BIGHORN (OVIS CANADENSIS) LAMB SURVIVAL FOLLOWING PASTEURELLOSIS EPIDEMICS

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Abstract: Successful restoration and management of bighorn sheep herds has been limited by periodic pneumonia-related outbreaks. These outbreaks cause extensive all-age mortality, followed by several years of low lamb survival. This low lamb survival is presumably due to transfer of pathogenic strains of Pasteurella spp. from ewes to lambs.

We conducted a field experiment to evaluate whether treatment of free-ranging pregnant, bighorn ewes with a combination of an experimental sheep Pasteurella vaccine (Miller et al. 1997) and a commercially-available bovine Pasteurella vaccine (PRESPONSE®H-M, Fort Dodge Laboratories, Inc.) would increase lamb survival following a pneumonia outbreak. We assumed that pasteurellosis was the dominant source of lamb mortality in each study herd, that vaccines would enhance colostral antibody secretion in treated ewes, and that peak exposure of lambs to pasteurellosis occurred before colostral immunity completely waned.

Thirty-six bighorn ewes (12 ewes/herd) from 3 district herds in or near Hells Canyon affected by a pasteurellosis epidemic in 1995 were included in our experiment. Survival of lambs in 1996 was low in all 3 herds, with November lamb: ewe ratios of $\leq$7:100. In March 1997, 6 randomly-selected ewes in each herd were captured, radio collared, and injected with both vaccines; 6 others were captured, radio collared, and injected with 0.9% saline solution as controls. In addition to our field study, we concurrently evaluated vaccine effects on survival of lambs born to captive ewes (n=7) removed from Hells Canyon during the 1995 epidemic. Lambs were observed at least weekly, and usually more frequently. Lambs were considered to have survived if they were alive in October 1997, approximately 6 months after birth. Free-ranging lamb survival differed among herds (range:22% - 100%), but survival among lambs born to vaccinated and unvaccinated ewes did not differ within herds. No captive lambs survived. In light of our findings, we reexamine our a priori assumptions to assess why vaccination failed to increase lamb survival in these study populations.

Submitted to a refereed journal for publication.

Non-natives
Predation

PHENOTYPE EVALUATION OF FREE-RANGING EUROPEAN MOUFLON (OVIS ORIENTALIS MUSIMON) ON KAHUKU RANCH, SOUTH POINT HAWAII

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Abstract: Are the free-ranging European mouflon (Ovis orientalis musimon) on the Kahuku Ranch "true" mouflon? Field surveys conducted during October 1997 examined this question based on phenotype conformation. Five-hundred-thirty four live mouflon were examined in the field and 17 hunter harvested rams were measured and photographed. The mouflon on Kahuku Ranch were determined to be phenotypically true, exhibiting typical or classical characteristics attributed to the species Ovis orientalis musimon.

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ARGALI AND BLUE SHEEP ON THE TIBETAN PLATEAU: STATUS UPDATE

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Abstract: Surveys we conducted from 1986 through 1997 in Qinghai Province (roughly the northern half of the Tibetan plateau) form the basis of our understanding of the conservation status for 2 species of wild caprin, argali (*Ovis ammon*) and blue sheep (*Pseudois nayaur*). Blue sheep are relatively common and wide-spread, and although the subject of some unregulated hunting, are not in immediate danger. Argali are considerably more patchily distributed, subject to greater mortality pressure, and exist in lower numbers where present. Still, at least locally, argali can support limited trophy hunting where such an activity provides an incentive to more active conservation. National parks -- as North Americans conceive them -- are absent in China, and "nature reserves", although encompassing large areas of the Plateau, cannot be assumed to effectively protect wild fauna. Because of the vast areas and general inaccessibility of the Plateau, as well as the limited financial resources available to Chinese managers and researchers, the future of these species resides largely in the hands of those living near them. As market forces increasingly enter previously remote areas, both species are vulnerable to non-local Chinese who have little incentive to act responsibly. Fortunately, most local pastoralists posses positive attitudes toward wildlife conservation, but even they often will require specific incentive programs to help them assure these species' future.

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COMPARING METHODS TO DETERMINE DISTRIBUTION AND MOVEMENT PATTERNS OF FOREST-DWELLING MOUNTAIN GOATS

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Abstract: We compared direct and indirect methods of observation to record the presence of mountain goats (*Oreamnos americanus*) along Pinto Creek, Alberta. Observation methods consisted of visual sightings of goats, the use of remote cameras, and locating goat sign (i.e., hair, tracks, and pellets) within belt transects and plots along the top of 29 discontinuous cliffs within the study area from February to October 1997. Belt transects were the most reliable single method of recording presence of goats on cliffs during winter and summer 1997. Belt transects alone, however, were limited to recording presence-absence data. The other methods are required if data on population structure, individuals, behaviour, daily activity, or intensity of use are needed.
Key Words: mountain goat, (*Oreamnos americanus*), wildlife inventory, remote cameras, activity indices.

INTRODUCTION

Biologists monitor movements and distributions of ungulates by direct and indirect observations. In open areas, where visibility is good, aerial and ground surveys enable biologists to census populations and record behaviour and habitat use (e.g., Bowden and Kufeld 1995, Varley 1994, Côté 1996, Romeo and Lovari 1996). Where visibility is poor, biologists collect data on movements, habitat use, and activity patterns with very high frequency (VHF) transmitters (e.g., Singer and Doherty 1985, Haynes 1994, Fritzen et al. 1995, Warren et al. 1996) or Global Positioning System (GPS) technology (e.g., Moen et al. 1996, Biggs et al. 1997, Poole and Heard 1998). Locating sign (i.e., tracks, pellets, hair) within plots or along transects has been used to monitor., Neff 1968, Mooty and Karns 1984, the presence of ungulates in a variety of habitats (e.g Loft and Kie 1988, Poole and Fear 1998). Jacobson et al. (1997), censused white-tailed deer (*Odocoileus virginianus)* with infrared-triggered cameras.

The Pinto Creek mountain goat herd is atypical of goat populations because of its year-round use of forests. Standardised methods for monitoring movements and habitat use of goats in forests are not well developed and methods for studying goats in open areas may not be suitable for forest-dwelling populations where visibility is low. Penner and Jalkotzy (1982) observed goats most often on the cliffs along Pinto Creek and less often in the forests. Pellet-group counts revealed that use of forests by goats in the Pinto Creek Goat Reserve was greater and more widespread than expected from direct observations alone (Niederleitner 1994). Those data

data illustrate the potential bias associated with direct observation alone; goats in forests are not easily observed, therefore, use of forest is underrepresented.

We compared the seasonal distribution, movements, and use of forests by mountain goats along Pinto Creek using 4 methods during winter and summer: visual observations, remote cameras, and observation of goat sign (i.e., tracks, pellets, hair) within belt transects and within plots. We then determined the best combinations of methods to obtain the most comprehensive pattern of distribution of mountain goats.

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Study area

STUDY AREA

The study area, which encompasses the lower Pinto Creek valley, lies on the eastern slopes of the Rocky Mountain Foothills and is located between 53°49'N and 53°43'N and 117°52'W and 117°47'W (Fig. 1). This area is approximately 50 km northwest of Hinton, Alberta, and is separated from the Rocky Mountain ranges by at least 40 km of coniferous forest.

Pinto Creek cuts through several high, rounded hills, composed of Mesozoic and Paleozoic sedimentary rock (Strong 1992). Stream erosion has formed a steep-sided canyon along parts of the valley. Habitat used by goats in the study area includes a series of discontinuous cliffs along the slopes of Pinto Creek and the lower reaches of Hightower and Wroe Creeks (Fig. 1). Penner and Jalkotzy (1982) identified 34 discrete cliffs along Pinto Creek and its tributaries; 29 of these cliffs are located within our study area (Fig. 1).

Cliffs generally consist of 4 vegetation zones: riparian, talus, cliff-face, and above-cliff. Located at the bottom of most cliffs is a narrow riparian zone adjacent to the creek. Vegetation within this zone includes aspen seedlings (*Populus tremuloides*), willow (*Salix spp.*), and occasional mature white spruce (*Picea glauca*). The talus zone is predominantly loose sand with patches of aspen seedlings, bluejoint (*Calamagrostis canadensis*), hairy wild rye (*Elymus innovatus*), and common juniper (*Juniperus communis*). On some cliffs, the riparian and talus zones are absent and the cliff-face zone ends abruptly at water's edge. The cliff-face zone consists of loose sandstone and rocky outcrops used as escape terrain by goats. The vegetated portions of the cliff-face zone include bearberry (*Arctostaphylos uva-ursi*), common juniper, bluejoint, and fescues (*Festuca* sp.). Small clumps of lodgepole pine (*Pinus contorta*) or aspen grow within the cliff-face zone of some cliffs where the soil is stable. We considered the top edge of the cliff-face zone to end where loose sandstone meets firm, stable soil. Individual cliffs range in size from 30 m to 420 m in length and from 18 m to 90 m in vertical height. We considered the above-cliff zone to begin at the cliff edge and extend 20 m behind the cliff. This zone is generally forested with an overstory dominated by lodgepole pine and aspen. The groundcover within this zone is predominately graminoids (bluejoint and hairy wild rye) and the shrub understory is dominated by buffalo-berry (*Shepherdia canadensis*), wolf-willow (*Elaeagnus commutata*), and aspen seedlings.

The forested plateau above the cliffs is dominated by lodgepole pine and white spruce, with minor components of trembling aspen and balsam poplar (*Populus balsamifera balsamifera*). Labrador tea (*Ledum groenlandicum*) and mosses, particularly red-stemmed feathermoss (*Pleurozium schreberi*), make up the understory (Beckingham et al. 1996). Black spruce (*Picea mariana*) is a common species on poorly drained areas. Along the steep valley breaks, aspen is abundant at cliff edges and in the steep gullies between cliffs. Buffalo-berry, wolf-willow, wild rose (*Rosa acicularus*), willow, bearberry, wild vetch (*Vicia americana*), and various graminoids are common understory plants of aspen stands. Mixedwood forests on floodplains contain white spruce, aspen, balsam poplar, and paper birch (*Beltula papyrifera*). Total relief varies less than 110 m (1110 -1220 m elevation) along the gently-rolling forested plateau behind the cliffs. Macroclimatic conditions of this area are characterised by cold and dry winters and cool and moist summers (Beckingham et al. 1996). The mean annual precipitation is 540 mm with maximum precipitation occurring in July and the majority of winter precipitation falling as snow (Beckingham et al. 1996). Mean seasonal temperatures range from -13 to +17°C, where February is the coolest month and July the warmest. During winter, this area is often influenced by cold Arctic air masses and also moderated by Chinook winds (Beckingham et al. 1996). Within the study area, topographic features largely influence microclimate. Windswept cliffs are typically snow-free during most of winter and south-facing cliffs experience more rapid snow-melt than north-facing cliffs.

METHODS

We used direct and indirect observation methods to monitor the distribution of mountain goats along Pinto Creek. Direct observations were visual sightings of goats on cliffs within the study area. Indirect observations were remote cameras and the location of goat sign (i.e., tracks, pellets, hair) within belt transects and plots along the top of cliffs. We used all observation methods, except plots, during each sampling interval from February 1997 through October 1997. Plots were also used from May 1997 through October 1997. During winter (Feb through Mar), sampling intervals were 3 to 5 days with 10 to 14 days between intervals. Sampling intervals were 10 days in summer (May through Oct) with 4 days between intervals. Additional visual observations of cliffs were made while conducting monthly population surveys and when collecting vegetation data.

DIRECT OBSERVATION METHODS

Visual observations. We scanned each cliff using binoculars (8X or 10X) and a 15-45X spotting scope (Bushnell Spacemaster, Bushnell Sports Optics Worldwide, Richmond Hill, Ont., Canada). We observed some cliffs while walking along trails at the top of a cliff; other cliffs were observed from trail locations directly opposite a cliff. Location, time, age and sex class of goats,

goats, behaviour of the goats, cliff vegetation zone, and weather conditions were recorded for each visual observation. We identified individual goats as kids (young of year), yearlings (1-year-old), 2-year-olds, adult females (> 2 years old), adult males (> 2 years old) or unclassified adult based on horn morphology, body size, and urination posture (Chadwick 1973, Smith 1988).

INDIRECT OBSERVATION METHODS

Remote Cameras.— We used Trailmaster (TM1500) active-infrared remote camera systems (Model TM1500, Goodson and Associates, Inc., Lenexa, KS) to record the presence of goats. Each camera system consisted of a sending and receiving unit, and a 35-mm camera. We positioned the camera systems on goat trails along the top edge of selected cliffs within the above-cliff zone. We selected cliffs where we consistently observed goats as well as cliffs at the periphery of the study area. We mounted the sending and receiving units on trees 0.5 to 1 m above the ground and on opposite sides of goat trails such that the infrared beam crossed the goat trail. The distance between the sending and receiving units was 3 to 5 m. We mounted the cameras on trees along goat trails 5 to 8 m from the infrared beam. We wrapped the cable connecting the sending unit to the camera with tinfoil to prevent damage by rodents and birds. During winter 1997, we placed an individual camera unit on each of 6 cliffs. During summer 1997, cameras were placed on 4 additional cliffs. We enabled the flash and set the cameras to be active 24 hours per day throughout each sampling interval. We used 400 ASA, 36-exposure colour print film. We set the camera delay on the Trailmaster unit at 30 seconds to ensure that cameras did not take a picture when there were multiple events within 30 seconds. We changed camera batteries (2 AA batteries) at the beginning of every sampling interval to ensure adequate battery power for the duration of the interval. We programmed the cameras to date and time stamp each photo. Printed photographs from exposed film were used to determine the number, age class and sex of goats present.

Belt Transects.— We established a 5-m wide belt transect along the top edge of all cliffs within the above-cliff zone. The length of transects depended on the distance along the top of each cliff: distances ranged from 30 to 420 m. Transects were centred on the main trail used by goats at the top of each cliff. We selected the main trail based on the relative amount of accumulated goat sign and relative degree of erosion. We marked the main trail on each cliff with flagging tape. During each sampling interval, observers walked along the trail at the top of each cliff and searched for new goat sign within the belt transect. Goat pellets, hair, or tracks were recorded as present or absent and then all sign was eliminated from the belt transect.

Plots.— Permanent plots were established within the belt transect along the top of all cliffs. We chose the location of plots within the belt transect by first stratifying the area along the main goat trail into high or low use based on accumulated goat pellets. On each cliff, we placed 5, 4 x 2 m plots in areas of high pellet accumulation. We removed all pellets, tracks, and hair from each plot on the date the plots were established. During each sampling interval, we recorded the number of goat-pellet groups, number of track sets, and presence of goat hair found within each plot. We raked all plots to remove goat sign after data were recorded.

DATA ANALYSIS

We analysed data only from those cliffs where all methods were used concurrently. In order to compare results among methods, we created a dummy variable called "goats detected". This variable indicated if goats were recorded as present or absent on a cliff during a sampling interval. We determined values for goats detected by examining the results from all methods for each sampling interval. If the presence of goats was recorded by any 1 method during the sampling interval, then goats detected = 1. If the presence of goats was not recorded by any method, then goats detected = 0. To compare the detection rates among methods, we compared the result of each method (either goats present or absent) to goats detected for each sampling interval. If the result from the individual method matched goats detected, than a value of "1" (match) was assigned; if the result did not match, a value of "0" (no match) was assigned. We did this for each individual method and combinations of methods (see example in Table 1). We determined the proportion of matches for all methods on each cliff. We combined the results from all cliffs to determine the mean proportion and standard error (SE) of matches for all methods.

We then used an arcsine square-root transformation (Zar 1984) to normalise mean proportions before conducting statistical analyses. To compare results for those methods used during both winter and summer, we conducted a 2-way analysis of variance (ANOVA; Zar 1984) with season and method as the independent variables and proportion of matches as the dependent variable. We used 2 seasons (winter and summer) and 6 methods (visual, belt, camera, visual-belt, visual-camera, and camera-belt). We also used a 2-way ANOVA to compare indicators of goat presence within belt transects by season. Season and type of sign were independent variables and proportion of times each type of sign was recorded was the dependent variable. We used 3 types of sign: tracks, hair, and pellets. We used 1-way ANOVA to test the null hypothesis that all types of sign (i.e., hair, tracks, pellets) recorded within belt transects indicated the presence of goats equally. We used 1-way ANOVA to test the null hypothesis that the proportion of matches between the results of individual methods and goats detected was equal among observation methods. We used Scheffé's test (Zar 1984) to examine multiple comparisons among observation methods and types of sign. All statistical analyses were performed using STATISTICA (StatSoft Inc. 1997).

RESULTS

The proportion of matches with goats detected did not vary between seasons ($F_{1,84} = 0.01$, $P = 0.909$) and there was no significant interaction between season and type of method ($F_{5,84} = 0.67$, $P = 0.647$). The proportion of matches with goats detected was significantly different among methods ($F_{5,84} = 12.33$, $P < 0.001$). We analysed the data from winter and summer separately because during winter 1997 we used and compared 3 methods and during summer 1997 we used 1 additional method.

In winter 1997, the mean proportion of matches with goats detected varied from 0.47 ± 0.14 to 0.89 ± 0.07 for single methods and 0.72 ± 0.13 to 0.95 ± 0.06 for combinations of 2 methods

(Fig. 2). Belt transects had the greatest proportion of matches with goats detected. The result for belt transects, however, was not significantly different from other single methods ($F_{2,15}$ = 2.40, P = 0.124, Fig. 2). The combined methods of belt transect-visual and belt transect-camera had the greatest proportion of matches with goats detected, but were not significantly different from visual-camera ($F_{2,15}$ = 1.73, P = 0.211, Fig. 2). There was no significant difference in the proportion of matches with goats detected when only the belt transect method was used and when belt transect was paired with any 1 other type of observation method ($F_{2,15}$ = 0.28, P = 0.761).

In summer 1997, the proportion of matches with goats detected varied among single methods ($F_{3,36}$ = 8.87, P < 0.001). Proportions of matches for belt transects were greater than visual, camera, and plot methods (Fig. 3). The mean proportion of matches with goats detected varied among combinations of 2 methods ($F_{5,54}$ = 8.05, P < 0.001). There was a significant difference between some combinations that included belt transects and those without. Visual-belt was greater than visual-plot (P = 0.002; Fig. 3), and belt-camera was greater than visual-camera (P = 0.001; Fig. 3) and visual-plot (P < 0.001; Fig. 3). We did not find a significant difference among the proportion of matches for combinations of 3 methods ($F_{3,36}$ = 1.96, P = 0.138, Fig. 3). We did not find a significant difference between the proportion of matches with goats detected using belt transect alone and when belt transect was combined with 1 additional method ($F_{3,36}$= 1.53, P < 0.223). We did find a greater proportion of matches with goats detected when 2 methods were added to belt transect ($F_{3,36}$ = 3.47, P = 0.026) as compared to belt transect alone. The proportion of matches for the combinations of belt-visual-camera (P = 0.049) and belt-camera-plot (P = 0.049) were greater than for belt alone.

When we combined the results for winter and summer, 5% of observations of goats were detected by remote cameras alone while being missed by all other methods. During July 1997, we disabled the flash on 3 cameras that were located on frequently used cliffs and used 1000 ASA film. All 3 cameras recorded the presence of goats during the day and we obtained 1 photo of a goat during the night. We replaced the film in the 3 cameras with 400 ASA and enabled the flash. Subsequent photographs of goats were recorded during the day and night when the flash was activated. Although inconclusive, we believe that goats did not avoid the camera area when the flash was activated.

COMPARISON OF TYPES OF GOAT SIGN RECORDED WITHIN BELT TRANSECTS

Season affected the proportion of times each type of sign (i.e., hair, tracks, pellets) was detected within belt transects ($F_{1,42}$ = 8.47, P = 0.006). Independent of season, we found an overall difference among the proportion of times each type of sign was detected ($F_{2,42}$ = 14.22, P < 0.001). There was no interaction, however, between season and type of sign ($F_{2,42}$ = 2.56, P = 0.089). During winter, the mean proportion (± SE) of times tracks were recorded within belt transects (0.72 ± 0.13) was greater than hair (0.04 ± 0.04, P = 0.003), but not different than pellets (0.46 ± 0.15, P = 0.292). There was no significant difference in the proportion of times hair and pellets were observed (P = 0.057). Similar to winter results, the proportion of times tracks were recorded during summer (0.88 ± 0.04) was greater than hair (0.55 ± 0.08, P = 0.027) but not different from pellets (0.63 ± 0.11, $P = 0.080$). There was no significant difference between the proportion of times pellets and hair were detected during summer ($P = 0.872$).

DISCUSSION

Belt transects were the most effective method for monitoring the presence of mountain goats in forests. We believe belt transects were more effective than other indirect methods because they covered a large area over a relatively long time. In contrast, plots and remote cameras collected data over a small area and at specific locations, while direct visual observations were sampled over a short time and the view of parts of cliffs was frequently obstructed. There is a level of dependence between goats detected and each individual method result because of the way our "goat detected" variable was calculated. By definition there is a high correlation between the best method (i.e., belt transect in most cases) and "goats detected". In summer belt correctly predicted "goats detected" 90% of the sampling intervals (range 60 - 100%); in winter belt transects correctly predicted "goats detected" 90% of the sampling intervals (range 67 - 100%). Despite using a very conservative post-hoc comparison (Scheffé's test), this dependency may still be influencing the significance of belt transect method. Therefore, the most conservative way to view this analysis, is as a comparison of each method to the performance of belt transects. We believe that this dependency had little effect on comparisons of multiple methods.

Although belt transects were inexpensive to establish and maintain, they were the most time consuming and did not always detect the presence of goats on cliffs. One reason for this error may be observer error. Robinette et al. (1974) and Neff (1968) reported that observers occasionally overlooked goat sign on belt transects, particularly on those greater than 1000 ft (256 m) long. Observer error also may have been affected by vegetation cover within the belt transect. Unlike plots that were placed in areas with little vegetation, belt transects encompassed many areas of dense understory, thus reducing the ability of observers to see goat pellets and tracks. Belt transects did not provide detailed information as to population size and structure, behaviour, or daily activity.

The proportion of times that goat tracks were recorded within belt transects was greater than for hair during winter and summer. Unlike during late spring and early summer, goats do not shed large amounts of hair during winter. During winter, goat hair is shed in small amounts that are difficult to observe (D.G. Harrison, personal observation). We believe this explains why hair was observed less frequently than tracks during winter. Although goats shed large, conspicuous amounts of hair in summer, the period of shedding is relatively short (2 months) and this may explain why tracks were observed more often than hair within belt transects. Because tracks and pellets occur during all seasons, these 2 types of sign are more consistently deposited and observed within belt transects.

The reliability of plots and remote cameras was limited by their number and location. It is possible that goats were present within a belt transect but not at specific plot or camera stations. Adding more plots or camera stations along cliffs, especially large cliffs, may have increased the reliability of those methods. Plots and cameras, however, represent sub-samples of the belt transect. As more plots or cameras are added to a cliff, the sub-sample becomes more representative of a belt transect.

The ability of cameras alone to detect the presence of goats was not substantial and we concluded that remote cameras did not contribute significantly to our ability to record the presence or absence of goats. However, remote cameras provided information about population size and structure and behaviour of individual goats (e.g., bedding, feeding, nursing).

Data from cameras also showed that goats were active throughout the day and night. Although we had few problems with cameras during summer, cameras were difficult to maintain during winter. During prolonged cold temperatures ($\leq$ -20°C), the response time of the camera increased by up to 15 seconds (D.G. Harrison, personal observation). As a result, goats may have triggered the camera, but were out of the camera field of view before a picture was taken; the result was pictures with no animals in them. Bull et al. (1992) had similar problems with remote cameras during winter in Oregon. Perhaps the greatest restriction to using remote cameras during winter was maintaining battery power. During winter, camera batteries lasted a maximum of 10 days as compared to 25 days during summer. Consequently, the length of our sampling interval was based on the life of camera batteries. To alleviate these problems, we recommend that during winter a larger, external battery be used.

The advantage of visual observations is that they allow for the collection of population, behaviour, and habitat use data. A number of factors, however, may limit the reliability of this method. Probably the most limiting factor in our study was the obstruction of view of cliffs by vegetation and topography. Penner and Jalkotzy (1982) also reported difficulty observing cliffs along Pinto Creek because of vegetation and topography. Occasionally, weather conditions, such as heavy rain and snow, also obscured the view of cliffs. Unlike indirect-observation methods, visual observations were not continuous over the sampling interval but rather were limited to daylight hours and were used only on 2 or 3 days during the sampling interval. It is likely that the presence of goats was not recorded using the visual method because the goats were present at night when cliffs were not being observed. Observer presence also may have affected the reliability of this method. Goats may have been aware of observers and moved away before the goats presence could be observed.

The methods that we compared provided evidence that goats were present at particular cliffs. These methods, however, did not conclusively show that goats were not present at a particular cliff. The indirect observation methods monitored only the top portion of cliffs and visual observations of some portions of cliffs were impaired by vegetation, topography, and weather conditions. Consequently, goats may have been present on those cliff areas that we did not monitor. A definitive test of these methods would be to radiocollar all goats within the study area and compare radio-locations to each individual method or saturate cliffs with remote cameras.

We have discussed 4 methods that are useful for recording the presence of goats in forests. The methods we compared have the ability to record animal presence in specific habitat types (e.g., along the top of cliffs) over time. More traditional methods for recording animal movements and habitat use, such as radio telemetry, often do not provide the level of precision that is sometimes required. For example, VHF radio telemetry indicates the general area in which an animal is located. For a precise location, however, visual confirmation is required. For those species that are susceptible to disturbance by humans or aircraft, such as mountain goats (Côté 1996), close approaches by humans may disrupt normal daily activities and movement patterns. Very high frequency radio telemetry is generally limited to daylight hours and collared animals may move significant distances and into other habitats between location fixes. Global Positioning System radio collars alleviate the problem of observer presence and some larger collars can continuously record and store animal locations over a 24-hr period. Both VHF and GPS radio telemetry will provide information as to the location of collared individuals. These methods, however, do not provide any information about the presence of other uncollared animals found with collared individuals. Indirect observation methods (e.g., belt transects, plots, and remote cameras) are non-intrusive and can continuously record animal presence. Additionally, some of these methods can provide information about groups of animals and individual behaviours.

MANAGEMENT RECOMMENDATIONS

Where more conventional methods such as radio collars and aerial surveys are not practical, the use of belt transects can provide useful information on mountain goat movements and distribution in a canyon habitat. We recommend searching for more than 1 type of goat sign to reduce error associated with the lack of persistence of some types of sign and to maximise the probability of detecting the presence of goats based on the presence of sign. Although remote cameras provide data on population structure, the use of cameras did not appreciably increase our ability to detect the presence of goats. Therefore, we believe that goat presence data collected with belt transects, plots, and visual observations adequately describes the distribution and movements of goats within the Pinto Creek study area.

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Table 1. An example of how results from direct and indirect observation methods were combined for cliff 9, 18 February 1997 to 30 March 1997. A count of 1 indicates presence of goats and 0 indicates absence (see text).

	Observation method result				Match between observation method result and goats detected					
Monitoring session	Visual	Belt	Camera	Goats detected	Visual	Belt	Camera	Visual-belt	Visual-camera	Belt-camera
1	0	0	0	0	1	1	1	1	1	1
2	1	0	0	1	1	0	0	1	1	0
3	1	1	1	1	1	1	1	1	1	1

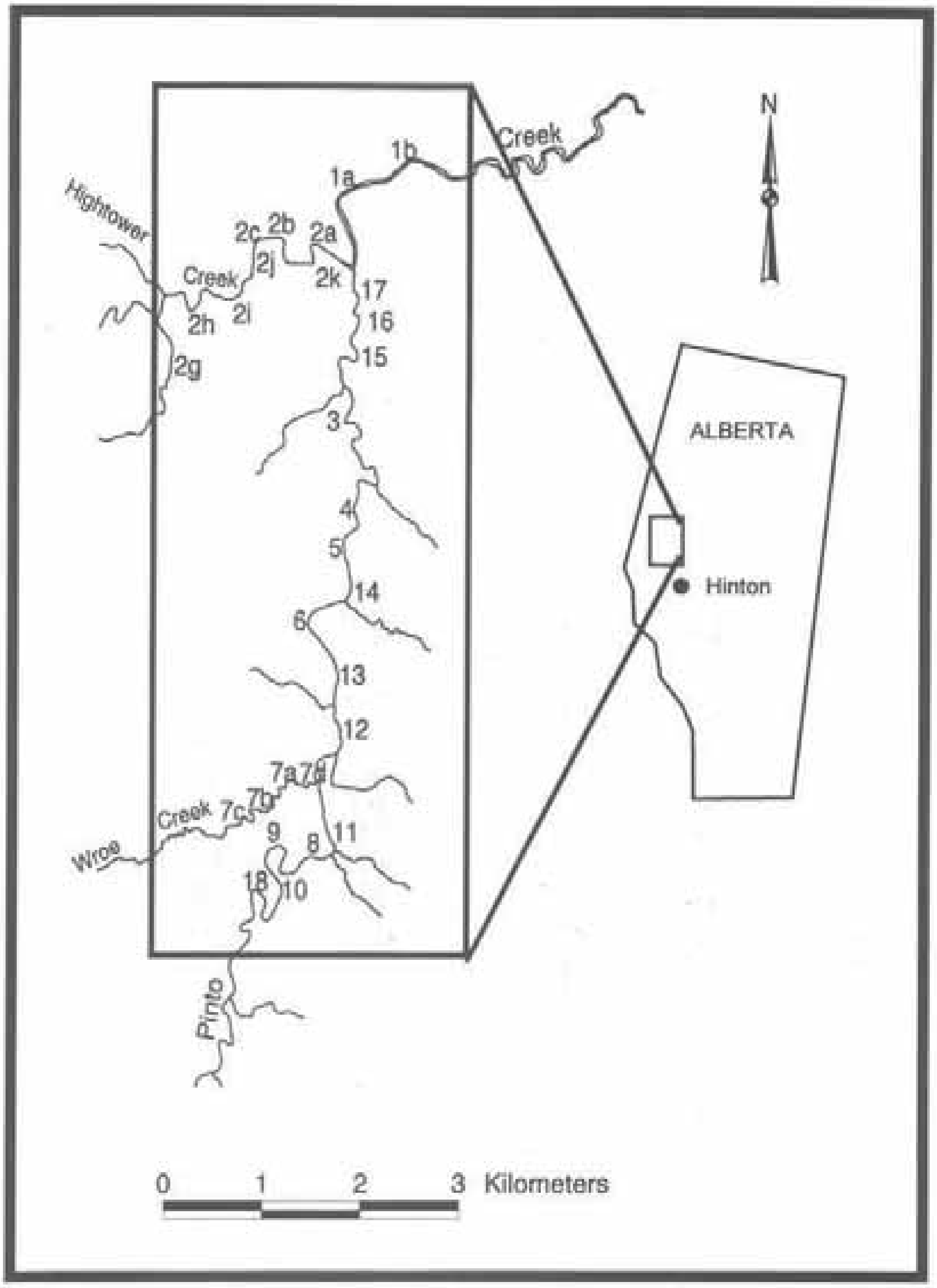


Figure 1. Locations of numbered cliffs (following Penner and Jalkowsky 1982) within the Pinto Creek study area. The inset box shows the location of the study area within Alberta, Canada.

Figure 2. Mean proportion of matches with goats detected for each observation method on 6 cliffs during winter 1997 at Pinto Creek, Alberta. Error bars indicate 1 SE.

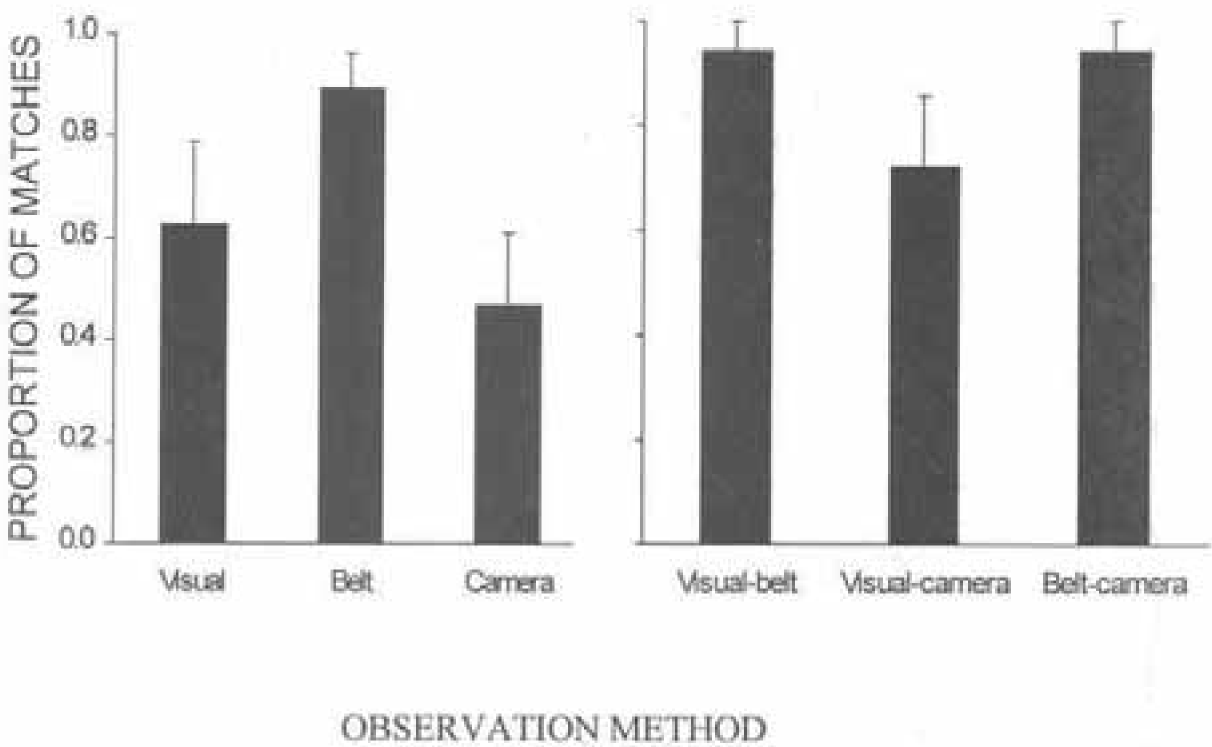
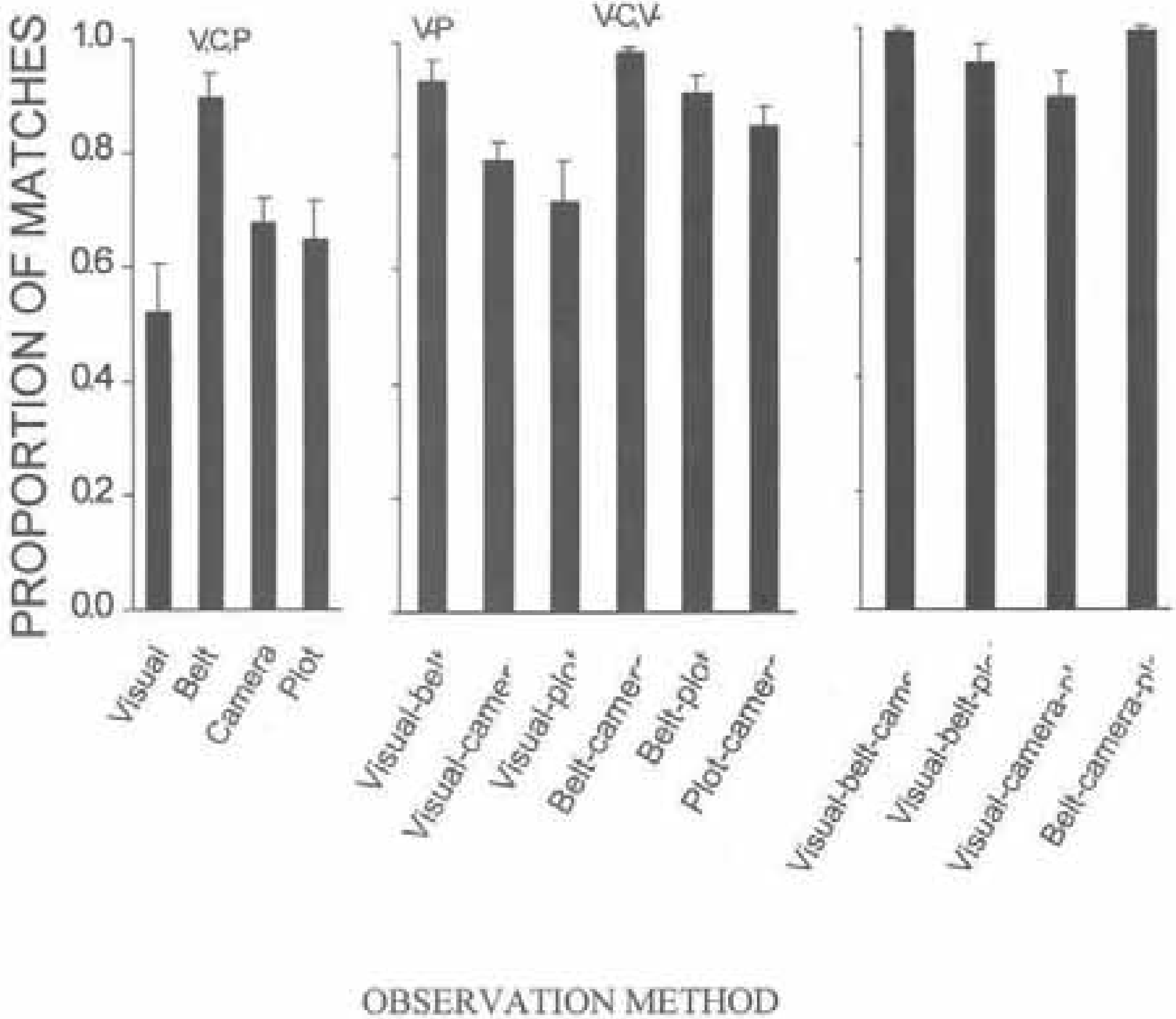


Figure 3. Mean proportion of matches with goats detected for each observation method on 10 cliffs during summer 1997 at Pinto Creek, Alberta. The abbreviations above the bars indicate significant differences between the observation method indicated at the bottom of the bar and those methods abbreviated above the bar where V is visual, C is camera, and P is plot. Error bars indicate 1 SE.



HIGH PREDATOR DENSITIES IN YELLOWSTONE NATIONAL PARK MAY LIMIT RECOVERY OF BIGHORN SHEEP POPULATIONS FROM THE 1981 *CHLAMYDIAL* - CAUSED DIE OFF

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Abstract: Seventeen years have passed since bighorn sheep (*Ovis canadensis canadenesis*) in Yellowstone National Park (YNP) experienced a massive *Chlamydial*-caused die-off. Currently, no sign of *Chlamydia* or pneumonia is evident in the population, thus other factors are considered to be limiting the population. Populations directly outside YNP have also declined, suggesting the problem is not isolated to the Park. A suspected direct causal relationship between increasing elk (*Cervus elaphus*) and a decline in bighorn sheep has not been proven. The winter of 1996-1997 was one of the most severe on record, yet mortality was not abnormally high for bighorn sheep. The majority of lamb mortality occurred in early summer, except for a band on Mount Washburn that experienced no mortality until arrival on the winter range in October. Further evidence of predation was found in populations that remained close to the northern winter range during the summer. Large numbers of elk wintering along the northern boundary may provide a source of carrion for high densities of coyotes *(Canis latrans)* and golden eagles (*Aquila chrysaitos*) in the winter, and serve as a prey base for lions (*Puma concolor*). These predators may switch to bighorn sheep in the summer.

INTRODUCTION

Bighorn sheep (*Ovis canadensis canadensis*) populations on the northern winter range of Yellowstone National Park (YNP) have ranged from a high count of 487 in 1981 to a low of 134 in 1998 (Meagher et al 1992, Caslick 1993, Lemke 1998, Unpublished Report, (Montana Fish, Wildlife and Parks, MFWP). Extensive aerial surveys (both fixed wing and helicopter) have been conducted almost every year since 1958 (Barmore 1980, Caslick 1993, Lemke 1996, Unpublished report, MFWP). Prior to 1958, surveys were conducted in conjunction with other activities, and are only useful for rough estimates of the population. The largest population of wintering sheep are located on the Everts winter range (EWR), comprised of approximately 480 ha at 1500-2000 m in elevation (Keating et al. 1985).

During the winter of 1981-1982, an outbreak of infectious keratoconjunctivitis resulted in the mortality of approximately 60% of the total northern range population and up to 80% of the EWR population (Keating 1982, Meagher 1982, Legg 1996, Meagher et al. 1992, Caslick 1993). Seventeen years later the population has not shown significant signs of recovery and may be decreasing. In addition to declines on the EWR, populations to the north and east have also declined. Recent studies found that human disturbance, poaching, inbreeding suppression, disease, and interspecific competition were unlikely to be important in limiting populations north of the EWR (Irby et al. 1986, 1989, Legg 1996). Predation and weather are 2 factors that have not been fully examined (Legg et al. 1996).

In response to the unknown factors limiting bighorn sheep population recovery on the EWR and a proposed resiting of the Gardiner-Mammoth highway, a behavioral observation study was begun in order to evaluate the potential impacts of the road realignment. This study focused on the impacts of human related stress on the bighorn sheep population. Our data on movements and mortality patterns allowed us to make a preliminary assessment of the role of predation in this population.

ACKNOWLEDGEMENTS

This study was funded by the Federal Highways Department of Transportation in conjunction with the National Park Service (NPS) and Montana State University (MSU) in Bozeman. Montana Fish, Wildlife and Parks (MFWP), the Biological Research Division (BRD), the Mountain Research Center, and the Northern Yellowstone Cooperative Wildlife Working Group provided additional support. Roger Stradley of Gallatin Flying Service provided a wealth of knowledge about bighorn distributions in YNP and conducted amazing flights during migrations. Tom Roffe of the National Wildlife Federation (NWF) and Kerry Gunther of the NPS collared two additional sheep in the fall. Dan Tyers of the USFS in Gardiner assisted with captures and organized housing and volunteers. Keith Aune, Tom Lemke, Neil Anderson and David Worley assisted with laboratory work and offered many useful suggestions. We were lucky to have the support of Emily Cayer, Triss Hoffman, Payam Ostovar, Tobias Swank, Marett Taylor and Amy Zimmerman, who hiked over 6,500 km during 15 months of fieldwork. Many people in Yellowstone park provided assistance: Mark Biel, Jim Caslick, Stu Coleman, Eric Compass, Wendy Clark, Robert Furhman, Mike Heiner, Gregg Kurz, Terry McEneaney, and Mary Meagher.

METHODS

Fourteen ewes and 4 young rams (1-3 year olds) were radio collared, using helicopter net guns and drug immobilization from the ground (Andryk et al. 1983, Bates et al. 1985, Kock et al. 1987, Heimer et al. 1990). Serology, virology and bacteriology tests were performed on samples collected during the capture process. Collared animals were used to track bighorn sheep groups on their migration from winter to summer ranges and also as focal animals for behavioral observations. Focal animals were located daily during the winter and several times a week during the summer on random days and times. Individual and group behavior data were recorded, including information on group size, composition, distance moved, spread of the group, distance to other species, habitat features and distance to human activity. All locations were plotted into a geographic information system (GIS) and used to evaluate potential impacts of proposed road corridors. Monthly fecal samples were collected from known individuals for a period of 1 year. These samples are being analyzed for lungworm and cortisol levels.

In order to increase our sample size to approximately 50% of the females and 23% of the males, other individuals were sampled by using identifiable, unique physical features. Using these methods, a total of over 400 fecal samples were collected during the period of 1 year.

RESULTS

The level of habituation and accessibility of the EWR bighorn sheep allowed us to get an accurate population estimate of 60 individuals. In the winter of 1996-1997 we estimated 32 adult females, 2 yearling females, 20 adult males, and 6 yearling males associated with the EWR. Our monitoring of summer migration revealed 3 bands of ewes from the EWR with separate lambing sites. Migrations varied from partial short distance movements (5 km or less) to long distance movements (45 km). Rams were found to move into the Gallatin Range or remain near the EWR for the summer.

Our serology, bacteriology and virology lab results were negative for all captured animals. However, we did see some sick lambs in populations that remained around the EWR during the summer months. The other stress related factors we observed near the EWR were helicopter flights and the presence and activity of predators. Since the Yellowstone sheep are very habituated to humans, most recreational activity does not seem to disturb daily behavior. An exception to this would be during the first couple months of lambing when ewes are extremely skittish and will not tolerate human presence to the same degree as other times of the year.

Helicopter flights occur primarily between June and September around the EWR due to topography and the heliports in Gardiner and Mammoth. We totaled the number of contract flights out of the Mammoth heliport during 1995 and 1997 and found 170 and 175 flights, respectively. During the winter of 1997-98 an increase in flight activity occurred during the winter months, primarily related to research within Yellowstone National Park. On several occasions flights over the EWR caused sheep to abandon open wind blown slopes at lower elevations and move up into steep terrain for up to 10 days.

Lamb mortality in 1997 occurred during the early months of summer in most populations. By the end of August the semi-migratory bands had no lamb survival, while the migratory band that moved to Mount Washburn still had lambs. When the Washburn band returned to the winter range in the fall they immediately lost two more lambs. This was consistent with the hypothesis that predation was severely impacting lamb survival in all populations associated with the EWR (6 lambs/100 ewes, fall 1997).

We conducted coyote howling surveys to determine rough pack densities around the winter range and found approximately four packs of 2-3 individuals in the EWR area. Behavioral observations recorded numerous coyote sightings on the winter range and only 2 on Mount Washburn. In addition, we observed 1 attempted predation by a golden eagle, 4 attempts by packs of coyotes, 1 attempt by a lion and 2 documented kills of adult ewes by lions. A lion study that began during the winter of 1998 found an adult lion with 2 kittens frequenting an area near the EWR. The density of predators near the EWR can be explained by the numbers of elk (1998 estimate11,736 Mack pers. commun., NPS) which may serve as both a prey base and carrion supply.

DISCUSSION

The EWR is located within 2 km of the northern boundary of YNP. Elk hunting and harassment on agricultural lands directly north of the park may cause elk to pool unnaturally along the boundary in the winter (Houston 1982, Keating 1985). This may directly impact the bighorn population through interspecific competition with elk (Woolf 1968, Oldenmeyer et al. 1971, Constan 1972, Barmore 1980, Kasworm et al. 1984, Picton 1984, Keating 1985, Singer 1991). After the *Chlamydia* epizootic, Keating (1982) proposed three hypotheses to explain the level of interspecific competition between elk and bighorn sheep. 1. The bighorn sheep population would recover rapidly to 150-200 individuals after several years (indicating minimal interspecific competition). 2. The population would grow but stabilize at a lower median level (indicating that sheep-elk interactions may occur to some degree). 3. The population would remain around 60 individuals similar to the pre-elk reduction program. (indicating elk numbers have a negative influence on bighorn sheep populations). Keating's third hypothesis is very similar to what has occurred in the population. Kasworm et al. (1984) and Singer and Norland (1991) also found that elk and bighorns had the greatest degree of winter diet overlap among ungulates in north central Montana and Yellowstone National Park, which might suggest interspecific competition.

The large numbers of elk on the EWR may result in interspecific competition, especially during severe winter conditions (Buechner 1960, Oldenmeyer et al. 1971, Barmore 1980). However, direct forage competition may be too simplistic to explain the interactions between elk and bighorn sheep. A sheep faced with starvation can decrease this risk by increasing either the amount of food obtained or the protein content in the vegetation consumed. The increased risks taken to obtain food can increase the probability of predation (McNamara and Houston 1987). Sinclair (1985) examined the relationships of nine species of herbivores in the Serengeti and determined that predation played as important a role in structuring the community as interspecific competition. Migratory ungulates may be less likely to be regulated by predators than resident populations. Simulations run by Fryxell et al. (1988) found that predators could regulate resident herbivores at low population densities. This could explain the disparity between lamb survival in the different bands of bighorn sheep that winter on the EWR.

The large numbers of elk and winter carcasses on the EWR may also result in high predator densities that may be more limiting and detrimental to bighorn sheep on the EWR than interspecific competition. While population trends of predators are not well known, there is evidence that many predators such as golden eagles (*Aquila chrysaitos*), coyotes (*Canis latrans*) and lions (*Puma concolor*) have increased in the northern Yellowstone ecosystem during the past 10 years (Legg et al. 1996, Murphy 1998, Stradley Pers. Commun.). Further supporting the hypothesis that predation is limiting the recovery of this population is the decline of bighorn sheep outside YNP where interspecific competition with elk is lower. Legg (1996) and Murphy (1998) found instances of lion predation on bighorn sheep both in and out of the park. Recent studies have recorded selective predation by lions on bighorn sheep in British Columbia, California, and Alberta (Harrison et al. 1988, Wehausen 1996, Ross et al. 1997). The documentation of lion kills may be biased towards adult sheep since lambs can be rapidly consumed and are therefore difficult to confirm. An intensive study on lion-bighorn interactions revealed that lions were selecting lambs over adult bighorn sheep (Ross et al. 1997). Unfortunately their study utilized lambs collared in August, leaving many questions about mortality in the first two months after parturition. Scotton (1998 in press) and Haas (1988) marked lambs within several days of birth and attributed the majority of lamb mortality to coyote predation within the first few weeks of life.

There is a possibility that the EWR population of sheep exist in a multi-equilibrium system. The fact that the population remained over 150 individuals for more than ten years and now seems stuck in a "predator pit" at around sixty individuals (Seip 1992) is typical of a multi-equilibrium system (Dublin et al. 1990) (Fig 1). An increase in alternate prey (in this case elk) can increase predation by the resultant numerical increase of predators in the system. This has been described with expanding moose (*Alces alces*) populations and the subsequent decline of woodland caribou (*Rangifer tarandus*) due to wolf predation (*Canis lupus*) (Bergerud and Elliot 1986, Seip 1992). In a similar case the increase of wood bison (*Bison bison athabascae*) in the Mackenzie Bison Sanctuary may have exacerbated predation on moose (Gates and Larter 1990).

CONCLUSION

It is obvious that we have not answered whether interspecific competition or predation may regulate the population of bighorn sheep on the EWR. We hope that our final field season and analysis of cortisol and behavioral observations will reveal factors related to the inability of the population to recover from the epizootic. If bighorn sheep are experiencing a "predator pit" than one would expect the situation to remain unchanged until the system experiences a large perturbation. This could be an epidemic in the coyote population, a decline in the elk population or some other unknown factor. It is clear that if the poor lamb recruitment trend continues there will be cause for concern. Managers need to keep in mind the potential accumulation of detrimental factors impacting the population of bighorn sheep on the EWR.

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DENSITY EFFECTS ON POPULATIONS

MATING IN BIGHORN SHEEP: FREQUENT MALE REPRODUCTION VIA A HIGH-RISK "UNCONVENTIONAL" TACTIC[1]

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Abstract: Rocky Mountain bighorn rams use three distinct tactics in competition for mates. Two tactics (tending and blocking) feature defense and cooperative breedings over a relatively prolonged consort period (up to 3 days). In the coursing tactic, subordinate rams fight dominants for temporary copulatory access (lasting seconds) with defended ewes. By combining population-wide genetic (microsatellite) exclusion of paternity, behavioral data and a model of bighorn reproductive competition, we estimated that coursing rams fathered 44% of 142 lambs assigned paternity in two natural populations. In one population, the probability of successful defense against coursing was lowest among rams that had many female consorts and held highest dominance rank. Even so, per-capita annual male reproductive success was positively associated with social rank in both herds when measured in terms of fall conceptions. The proportion of coursing versus defending ram breedings in each population (0.36 and 0.39) was similar to the corresponding fraction of lambs (0.43 and 0.47) fathered by coursing rams, suggesting that sperm competition approximated a fair lottery. Male traits important in gaining social status and obtaining cooperative consorts with ewes were different and potentially in conflict with those needed to defend against (and practice) coursing. Although the concussive weapons (horns) of rams are less dangerous than, for example, the piercing weapons of other bovids, injury from falls and horn blows during coursing brawls may cause death, handicap future mating competition or increase the risk of predation. Coursing is a rare example of an unconventional alternative mating tactic that is high-gain and high-risk. The high-gain, high-risk nature of coursing has likely had important ripple effects on many features of the bighorn life history including male survivorship and demography, mating system generated genetic bottlenecks and the evolutionary processes associated with small effective population size.

[1]Full paper published in Behavioral Ecology and Sociobiology 41:33-48,(1997).

POPULATION DYNAMICS OF BIGHORN SHEEP ON THE BEARTOOTH WILDLIFE MANAGEMENT AREA, MONTANA

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Abstract: A study of reintroduced Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) was conducted on the Beartooth Wildlife Management Area in west-central Montana between 1995 and 1998. Research included investigation of post-dieoff population dynamics and evaluation of a sheep augmentation program. Data were collected on sheep distribution and habitat use, reproduction and lamb recruitment, lamb and adult mortality, and general health. Particular emphasis was placed on assessing the role of mountain lion (*Felis concolor*) predation on adult sheep. Transplanted sheep (n = 39) were closely monitored to determine the effectiveness of herd augmentation. Results suggest that late summer lamb mortality and annual adult losses were responsible for a declining sheep population. Augmentation had no influence on herd productivity due to excessive loss of relocated sheep and limited annual reproduction. As a study in progress, statistical analyses have yet to be completed and conclusions are limited.

INTRODUCTION

The decline in distribution and abundance of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) over the past century is well documented and has been attributed to a host of factors including overharvesting, loss of habitat, competition with domestic livestock, and disease (Buechner 1960). During their ascent of the Missouri River in 1805, Lewis and Clark noted bighorn sheep in many areas (Coues 1965) from which they were subsequently extirpated by the early 1900's (Couey and Schallenberger 1971). One such population, which historically inhabited the Gates of the Mountains area between Helena and Great Falls, Montana, was extirpated by 1935 as a result of overhunting and disease (Hilger 1989). Between 1971 and 1975, the State of Montana relocated a total of 113 sheep from the Sun River to the Beartooth Wildlife Management Area (BWMA) located adjacent to the Gates of the Mountains area and re-established a viable bighorn population (Rognrud 1983). Annual censuses conducted by the Montana Department of Fish, Wildlife and Parks (MDFWP) indicated a rapidly growing sheep population which approached 300 individuals by 1983, and a permit-only hunting season for 3/4 + curl rams was established in 1979 and continued through 1992. The population expanded its distribution beyond the release site and established seasonal migrations. A disease-mediated dieoff in 1984 decimated the herd and left only 51 survivors. Post-dieoff censuses between 1985 and 1994 indicated that the population had stabilized at approximately 70 individuals.

In an effort to stimulate population growth, MDFWP conducted an augmentation program in which sheep from Plains, MT (n=19) and Rock Creek, MT (n=20) were relocated to the BWMA in March 1995 and March 1996, respectively. I refer to the relocated sheep as "transplants" and to sheep previously inhabiting the BWMA as "natives" in this paper. Simultaneous with the augmentation program, a research project was initiated to investigate population dynamics of the BWMA sheep herd and to evaluate the effectiveness of herd augmentation. Specific study objectives included 1) documenting sheep distribution and habitat use, 2) quantifying and qualifying sheep reproduction, recruitment, and mortality, 3) evaluating general herd health and nutrition, and 4) monitoring transplant fates and reproductive success.

I wish to acknowledge MDFWP and Montana State University-Department of Biology for providing financial support. I thank Keith Aune and Dr. David Worley for laboratory assistance and Bob Michaelson and Terry Antonich for field assistance. Finally, I express sincere gratitude to mountain pilot extraordinaire Jim Lowe and houndsmen Gary and Scott Lankford.

STUDY AREA

The Beartooth Wildlife Management Area (BWMA) is located at the northern end of the Big Belt Mountains approximately 40 km. north of Helena, Montana (Figure 1). Purchased by the State of Montana in 1970 as elk winter range, the BWMA encompasses approximately 1,300 hectares and is annually closed from December 1 through May 15 to minimize disturbance of ungulates on winter range. Boundaries include the Missouri River and Holter Lake to the west, the Gates of the Mountains Wilderness Area to the south, and large private cattle ranches to the north and east (Figure 1). Elevations range from approximately 1100 meters along the western boundary to over 2400 meters at the southeastern corner.

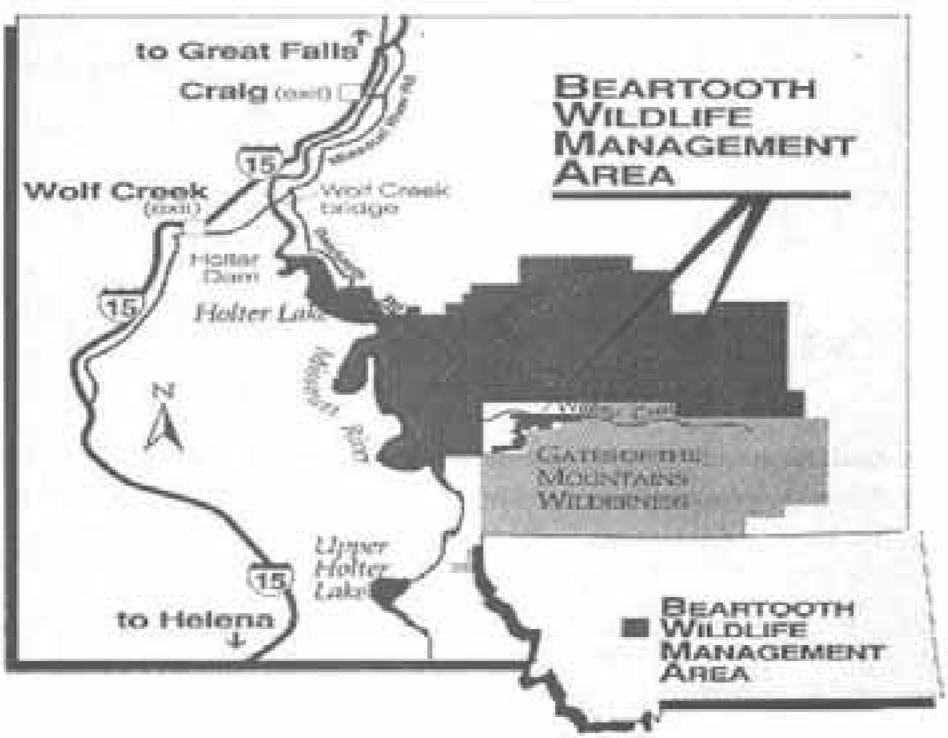

Figure 1. Study area location map

Physiographic zones within the study area include 1) large flat plateaus and "bars" at lower elevations along the Missouri River with bunchgrass meadow (*Agropyron spicatum* and *Festuca idahoensis*) and Ponderosa pine parkland (*Pinus ponderosa* and *Agropyron spicatum*) communities, 2) rolling hills and rocky reefs at mid-elevations near the center of the study area with bunchgrass meadows and douglas fir (*Pseudotsuga menziesii*) communities, and 3) steep mountainous terrain at higher elevations along the southern edge of the study area with stands of douglas fir and aspen (*Populus tremuloides*) and extensive talus slopes and rock cliffs. A wildfire in 1990 burned 80% of the BWMA including much of the area currently occupied by bighorn sheep.

The general climate of the study area can be described as semi-arid with relatively hot, wet summers and cold, dry winters. Figure 2 presents monthly precipitation totals for the 3 year study period compared to the 30 year mean. Climatological data was obtained from the Holter Dam weather station located approximately 7 km northwest of the study area at an elevation of 1100 meters. Summer precipitation (May through September) accounts for 68% (21 cm) of the total annual precipitation. Figure 2 indicates 1994 and 1996 were particularly dry summers (50% of normal) and 1996 was a particularly wet summer (148% of normal). Southwesterly chinook winds are an important local climatic factor, moderating winter temperature extremes and keeping slopes with southerly aspects relatively snowfree throughout the winter.

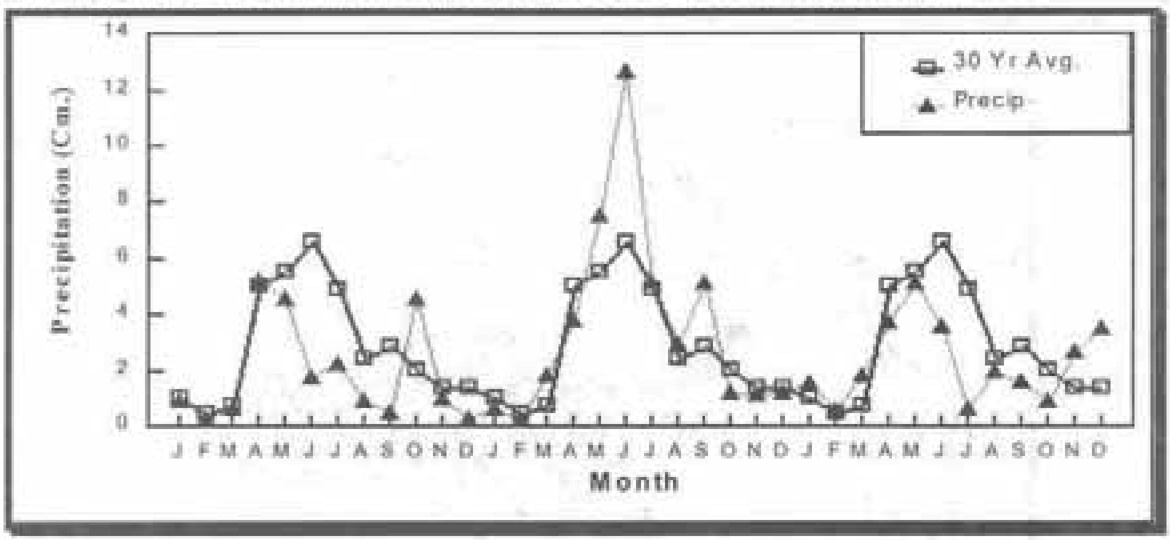

Figure 2. Monthly precipitation for January 1994 through December 1996 compared to the 30-year mean.

METHODS

Bighorn sheep (n=39) were captured via netgun by Helicopter Wildlife Management, Inc. and relocated to the BWMA. Samples (blood, nasal/pharyngeal swabs, and pellets) were obtained from each individual for health-related analyses by the MDFWP Research Laboratory and the Montana Department of Livestock Diagnostic Laboratory. All sheep were marked with numbered eartags and either a radiocollar (n=17) or an individually identifiable neckband (n=22). Mountain lions (*Felis concolor*) occupying bighorn sheep habitat were tracked and treed by trained hounds, immobilized, and fitted with radiocollars. Relocations of marked sheep and mountain lions were obtained via daily ground observations and 28 flights. Ground sightings and radio relocations utilized a Telonics receiver with a hand-held H-antenna, 8 x 42 binoculars, and a 40X spotting scope. Aerial relocations were made from a Piper Super Cub with a retractable, bottom-mounted, 3-element Yagi antenna. Relocation data were utilized to estimate sheep population size, to determine sheep dispersal and survival, and to evaluate sheep and lion distribution, habitat use, core ranges/territories. A modified Lincoln-Peterson estimator (Lancia et al. 1994) was utilized for estimating population size. The program CALHOME (Kie. Et al. 1994) was utilized to identify distribution and home range characteristics via the minimum convex polygon and harmonic mean methods. Lambing grounds were identified and monitored daily during lambing season to assess production and neonatal mortality. Sheep mortalities and lion kill sites were investigated to determine location, time, and cause of death. When possible, sheep carcasses were necropsied at the MDFWP Research Laboratory in Bozeman and samples submitted to the State of Montana Department of Livestock Diagnostic Laboratory for histological analyses.

Sheep pellet samples were collected from known individuals on a year-round basis and were obtained within 15 minutes of deposition to minimize potential contamination. Pellet samples were analyzed for lungworm via the modified Baermann technique (Beane and Hobbs 1983) and for fecal nitrogen via the Kjeldahl method (Horowitz 1980) performed at the Montana State University-Plant and Soils Analytical Laboratory.

Coyote (*Canis latrans*) and mountain lion scats were collected over the course of the study to augment predation analysis. Scats were airdried and washed and contents identified following Moore et. al (1974).

RESULTS

Sheep

1) Population size

Sheep population estimates were based upon MDFWP censuses for pre-augmentation years (1988-1994) and both census and sheep relocation data for post-augmentation years (1995-1998). MDFWP census results indicate a significant decrease following the fire in 1990, a relatively stable population between 1991 and 1995, and a decline in 1996 and 1997 (Table 1). Lincoln-Peterson estimates based upon relocation data also indicate a declining population during the study period, with the number of reproductive age ewes declining despite the addition of 29 transplant ewes.

	Total Population		Mature Ewes	
Year	MDFWP[1]	Relocation[2]	MDFWP[1]	Relocation[2]
1988	87	NA	53	NA
1989	84	NA	62	NA
1990	98	NA	69	NA
1991	56	NA	48	NA
1993	54	NA	33	NA
1995	45	69	41	54
1996	30	66	25	49
1997	20	40	10	27
1998	24	44	12	32

Table 1. Estimates of total population size and number of mature ewes based upon annual MDFWP census results[1] and Lincoln-Peterson estimates[2].

2) Distribution and habitat use

Sheep distribution was determined via construction of a 100% minimum convex polygon (MCP) utilizing all relocations excepting those associated with dispersal events. The 100% MCP indicates that total sheep habitat encompasses approximately 66 hectares and is limited to the western third of the BWMA (Figure 3). The polygon was modified to eliminate water from area calculations. Specific sheep activity areas were identified via the harmonic mean method. The 90% harmonic mean (Figure 4) reveals that the BWMA sheep population is comprised of 2 subgroups which occupy distinct portions of the study area (a northern and southern range). An 80% harmonic mean was utilized to more precisely delimit habitat use and identified 3 core activity areas within the southern subgroup range and 2 core areas within the northern subgroup range (Figure 4). These core areas are similar in that all are 1) located within lower elevations of the BWMA (<1550 m.), 2) associated with patches of escape terrain, and 3) utilized by sheep during all seasons. Although representing 80% of sheep use, these core areas encompass a total area of 12 and 8 hectares for the northern and southern subgroups, respectively. The BWMA bighorn sheep population is non-migratory and all core areas were occupied throughout the year. Several unmarked native rams (n=5) did migrate to unidentified summer range(s) outside the study area.

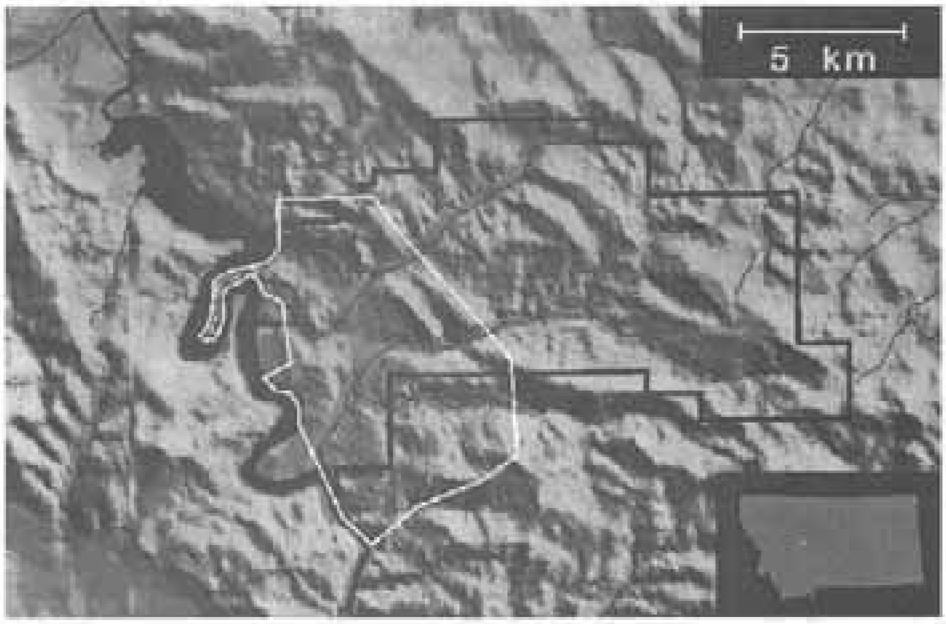

Figure 3. BWMA boundary (black line) and 100% MCP of sheep relocations (white line).

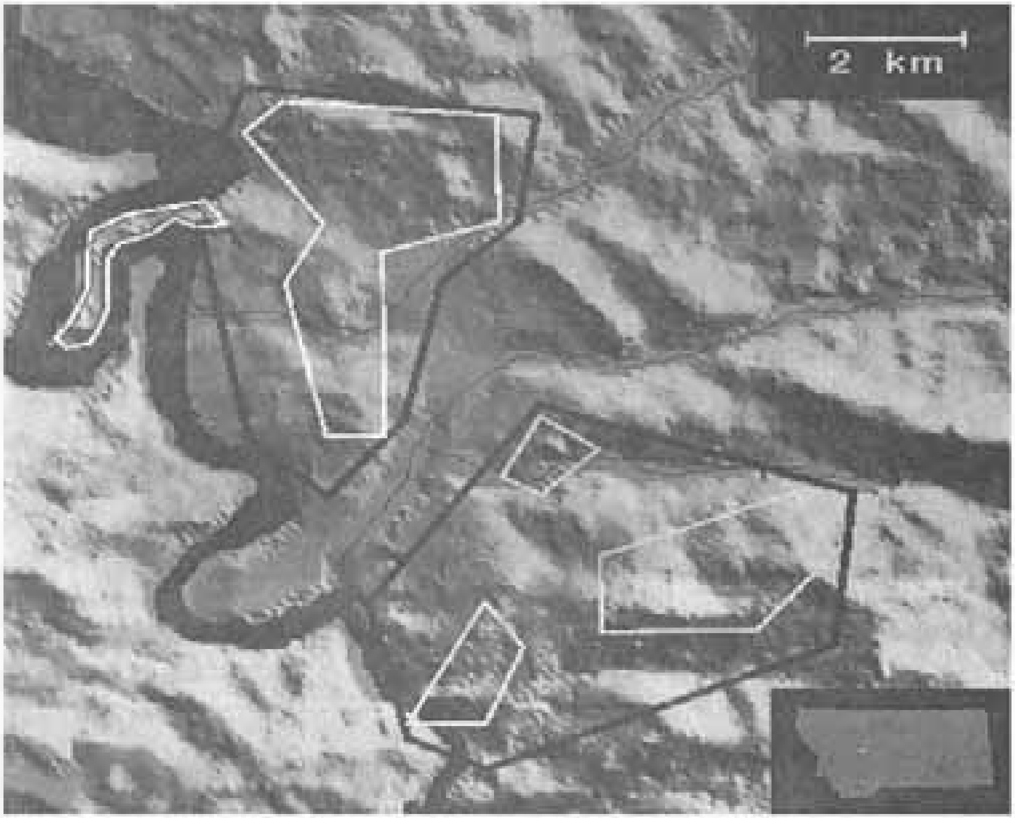

Figure 4. 90% (black lines) and 80% (white lines) harmonic means of sheep relocations.

2) Reproduction

Lambing peaked during the last week of May and extended into mid-June. In 1996, the transplant group released onto the BWMA in March 1996 lambed 3 weeks earlier than the native ewes. Lambing was generally synchronous between transplant and native ewes in 1997. Ewe production varied among years (Figure 5) with the highest production in 1996 (n=19) and lower production in 1995 (n=14) and 1997 (n=11).

Lamb survival patterns were similar for all 3 years, with most losses occurring between August 1 and September 15 (Figure 5). Little mortality occurred after this period and lambs surviving to October 1 were generally recruited into the population. Annual recruitment varied between 6 and 8 lambs and did not appear to be correlated with absolute lamb production. Lamb:ewe ratios never exceeded 40 lambs per 100 ewes, and spring ratios varied from 10 to 26 lambs per 100 ewes.

Lamb mortalities were difficult to locate and of 4 known mortalities, 2 were due to predation and 2 to disease. Both predation events occurred in 1997 while sheep were on lambing grounds and predator species could not be determined in either case. Coyotes (*Canis latrans*) are relatively common on the BWMA, yet no coyote-sheep interactions were observed over the course of the study and ewes with lambs were not overly concerned by the presence of coyotes. Golden eagles (*Aquila chrysaetos*) are extremely abundant but despite daily occurrences of eagles flying over/perching near lambs, no eagle-sheep encounters were observed and ewes were oblivious

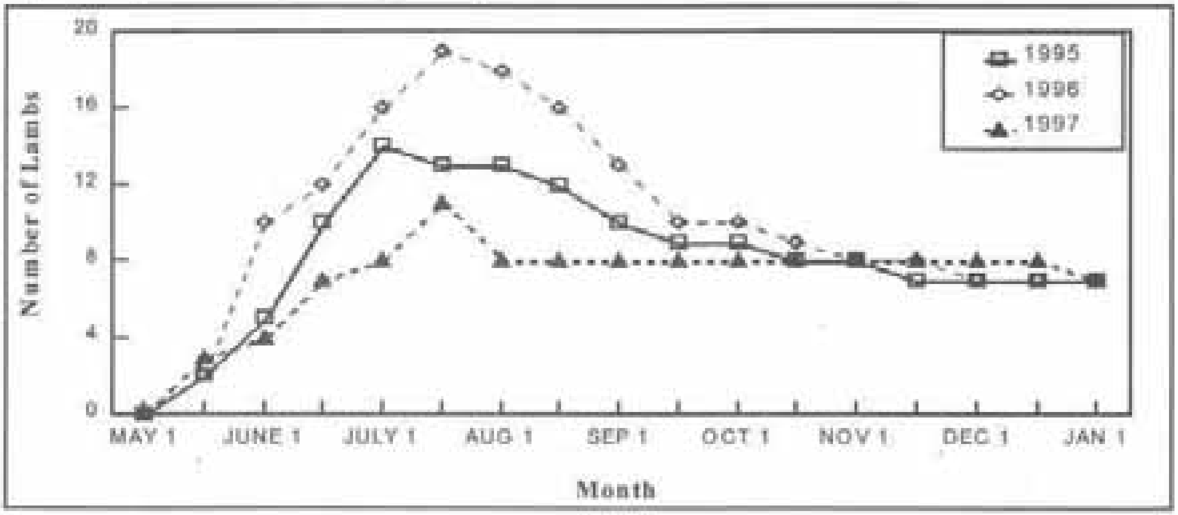

Figure 5. Lamb production and survival for the study period.

to their presence. Two disease-related lamb mortalities were discovered in July and August of 1996, 1 of which was necropsied and diagnosed as pneumonia (see necropsy results). These 2 mortalities were coincident with 1) observations of severe coughing among lambs and ewes and 2) the disappearance of numerous other lambs.

3) Adult sheep losses

Losses of marked sheep resulted from dispersal, mortality, and disappearances. Table 2 summarizes the fates of the 39 transplanted sheep. Only a third are currently alive on the BWMA, with dispersal and mortality accounting for 76% of the losses. While "random" dispersal did occur, most dispersers swam across the Missouri River and joined a small sheep herd on the opposite side. Fates of all marked sheep regardless of dispersal status are also presented in Table 2. Approximately 50% of the transplants are alive, 31% are dead (21% predation and 10% disease), and 19% have disappeared. Of 17 radiocollared sheep, 41% (n=7) are alive, 48% (n=8) were killed by mountain lions, and 12% (n=2) died from disease.

Fate	Number of sheep[1]	Number of sheep[2]
Alive	14 (on BWMA)	19
Dispersed	12	NA
Predation Mortality	4	8
Disease Mortality	3	4
Unknown	6	8

Table 2. Fates of transplanted sheep including dispersal[1] and without regard to dispersal[2]

4) Health

Results of serological tests, nasal and pharyngeal cultures, and Baermann and Lane analyses indicated that sheep transplanted to the BWMA in 1996 carried various gastrointestinal parasites and lungworm. While none of these individuals tested positive for *Pasteurella* spp., several other sheep obtained during the same capture operation did test positive. All sheep appeared to be in good health at the time of capture and there were no incidents of capture myopathy.

Two sheep carcasses (1 lamb and 1 ewe) were discovered in summer 1996 in a condition which permitted necropsy and both were diagnosed as pneumonia-related mortalities. Table 3 summarizes necropsy results for these individuals as well as previous necropsies of BWMA sheep. In all cases the diagnosis was pneumonia, individuals were in poor to fair nutritional condition with low lungworm loads, and mortalities occurred in late summer/early fall.

Another transplant ewe and lamb were discovered in late July 1996, but their condition prohibited necropsy. The ewe had dispersed from the BWMA and died in a domestic sheep pasture with no evidence of predation, trauma, or injury. The lamb died under circumstances similar to the necropsied lamb and had no visible trauma or injury. Additionally, we monitored 2 ewes during fall and winter of 1996 that were in extremely poor health. Both ewes were coughing with nasal discharge and rough pelage when last observed in late November and neither was observed again despite extensive searches.

Date	Age/Sex	Lungworm	Nutrition	Isolates	Diagnosis
09/20/84	3 Yr. ram	Few	Poor	P. hemolytica, E.coli	Pasteurellosis
09/25/84	5 Yr. ram	Many	Poor	P. multocida, E. coli	Verminous pneumonia
07/24/91	lamb	None	Fair	Streptococcus spp.	Streptococcal pneumonia
07/31/96	lamb	None	Fair	NA	Unspecified pneumonia
10/22/96	5 Yr. ewe	Few	Poor	Streptococcus spp.	Streptococcal pneumonia

Table 3. Necropsy results for sheep found within the study area

Results of Baermann analyses indicated that 97% of the adult pellet samples contained lungworm larvae. Mean monthly larval counts (expressed as larvae per gram-LPG) were relatively high and exceeded 100 LPG during several months with individual samples approaching 550 LPG (Figure 6). Lamb samples were negative for lungworm until August, at which time low shedding rates (~10 LPG) were observed.

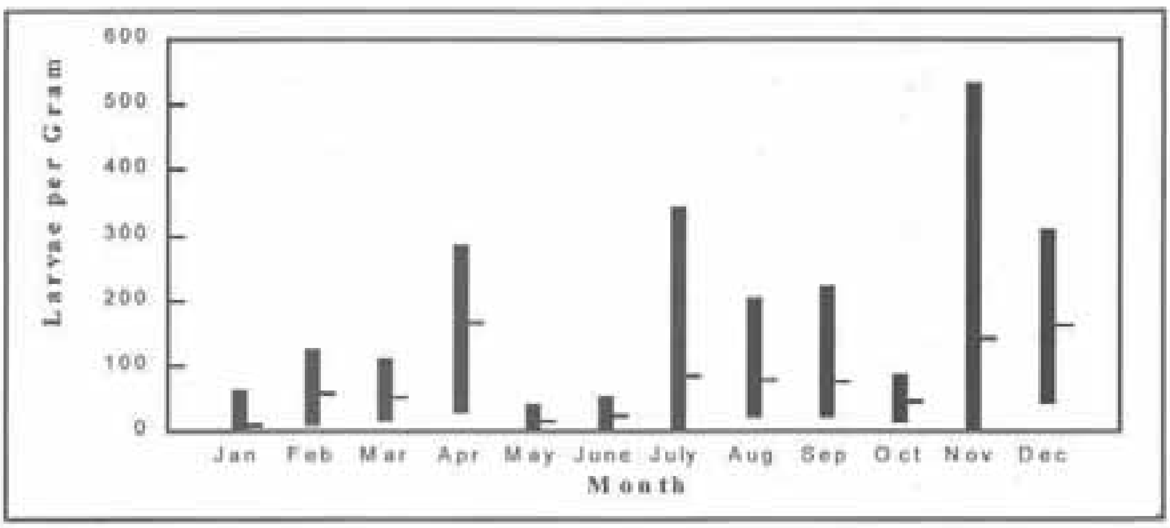

Figure 6. Baermann results on adult pellet samples with monthly ranges (horizontal bars) and means (vertical bars).

Kjeldahl results for adult sheep samples revealed a typical seasonal pattern of fecal nitrogen levels (Figure 7). Fecal nitrogen declined rapidly from June to October 1996, at which time they leveled off at approximately 1.3% TKN and remained at that level until April 1997. Nitrogen levels increased in May 1997 and then started to slowly decline during the summer months.

Lamb samples also revealed a seasonal trend, although lamb fecal nitrogen levels were generally higher than adult levels during late summer and fall months.

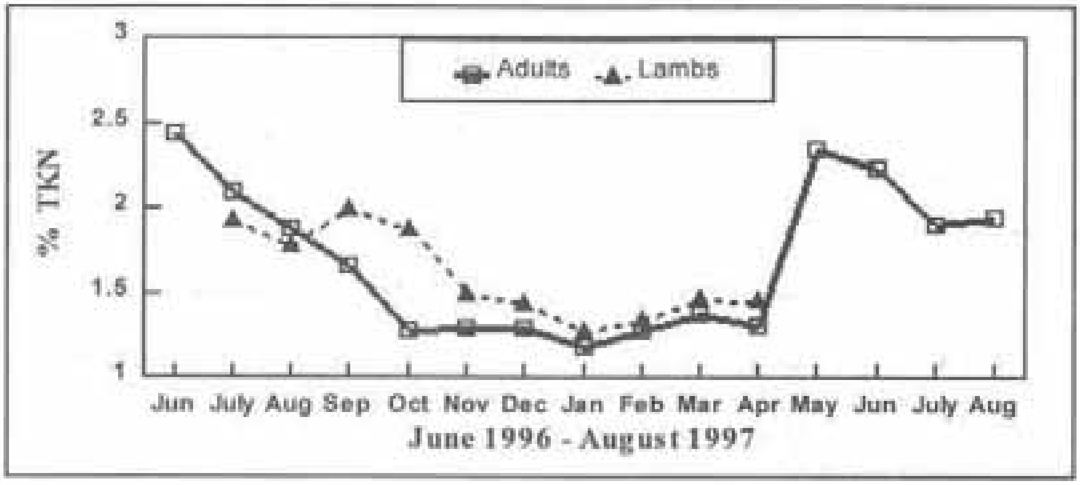

Figure 7. Monthly Kjeldahl results for adults and lambs

5) Transplant ewe productivity

Timing of the transplant events was such that ewes were bred in their indigenous habitats (Plains, MT and Rock Creek, MT) and lambed on the BWMA during 1995 and 1996. Although lambing was not monitored in 1995, data indicate that transplant ewe production varied considerably in 1996 and 1997. In 1996, 38% of the 1995 ewes and 78% of the 1996 ewes produced lambs. Proportions were reversed in 1997, with 73% of 1995 ewes and 25% of 1996 ewes producing lambs. Over this 2-year period, the 29 transplanted ewes produced total of 16 lambs on the BWMA (9 in 1996 and 7 in 1997). Data will be collected during the 1998 lambing season to augment productivity analyses.

Lions

1) Distribution and habitat use

A total of 8 mountain lions were captured and radiocollared. Mountain lions were widely distributed throughout the BWMA and principally utilized Douglas fir and ponderosa pine habitats. Relocation data and kill site analyses indicated that they relied on both vegetative cover and topographic complexity (i.e. rocky reefs and steep terrain) for traveling and stalking prey. Backtracking revealed that mountain lions were not averse to crossing large open meadows and on several occasions individuals were tracked for > 2 km. through open habitats.

Mountain lion territories significantly overlapped with occupied sheep range (Figure 8), largely due to a female territory which encompassed 4 of the 5 sheep core areas. Elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) winter on the BWMA and migrate to higher elevation summer ranges. Mountain lions tended to follow seasonal ungulate migrations and were therefore seasonal occupants of bighorn sheep range. Drawn by winter ungulate concentrations on the BWMA during winter months, individual mountain lion territories overlapped and it was not uncommon for several different lions, including adult males, to travel through the same drainage during a single week. As a result of mountain lion concentrations and reduced territoriality, we identified 12 different lions that spent time in occupied sheep habitat.

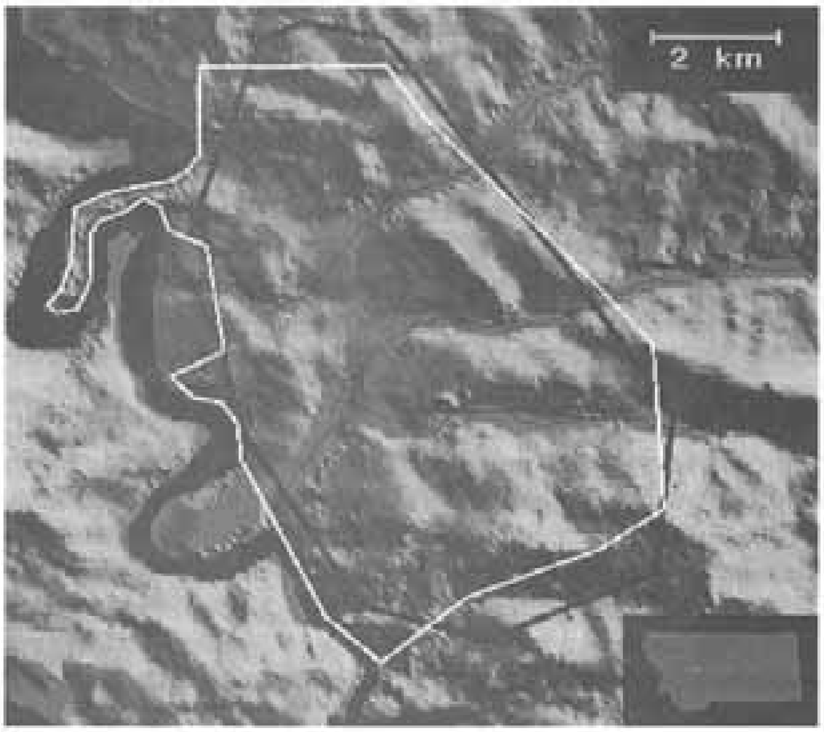

Figure 8. 100% MCP's of mountain lion F1 (black line) and bighorn sheep (white line).

2) Diet

Evaluation of 33 mountain lions kill sites within occupied sheep range indicated that deer accounted for nearly 80% of the prey base. Bighorn sheep (18%) and elk (2%) represented lesser components of mountain lion diets. Deer kills were found in all seasons while sheep kills were generally limited to spring (March and April) and early winter (November and December) periods. All sheep kill sites were located either in riparian corridors or adjacent to escape terrain. A total of 10 sheep kills (8 transplants and 2 natives) were discovered during this study when including dispersers.

Large ungulates remains were found in 100% of mountain lion scats analyzed (n=23). Sheep hair was identified in 22% of the scats (n=5), however this number may be biased due to the collection of scats at sheep kill sites. Coyote scats (n=153) were also analyzed and sheep hair was identified in 11% of the samples. Sheep hair was primarily found in coyote scats collected during winter months, and of scats collected between the months of May and November, only 3 contained sheep hair.

DISCUSSION

1) Sheep distribution and habitat use

Bighorn sheep on the BWMA are limited in distribution to small, widely dispersed core areas of low elevation, winter range-type habitats. Core area locations are largely determined by the presence of escape terrain. Sheep on the BWMA are skittish, unapproachable, and easily disturbed, a behavior likely due to 13 years of hunting pressure on the BWMA as well as hunting in the indigenous habitats of transplanted sheep (Geist 1971). The result is that sheep are frequently disturbed and subsequently flee over relatively long distances to the nearest escape terrain. Such flight often necessitates travel through "vulnerable" terrain, including riparian corridors, which increases the risk of mountain lion predation. Several kill sites were located in riparian communities. This behavioral response also represents a potential stressor, requiring expenditure of significant energy which may affect sheep health and reproductive fitness (Geist 1979)

Precipitation is critically important to promoting plant growth in semiarid habitats (Sinclair 1977) and production of quality forage is highly correlated with precipitation during the growing season (Smoliak 1986). Herbivore populations are strongly limited by their food supply and particularly by the relative quality of available forage rather than absolute abundance (Schwartz and Hobbs 1985). Many bighorn sheep populations in the Rocky Mountain region have established seasonal migrations as a behavioral response to external environmental cues, including forage availability (Geist 1971). Sheep relocated to the BWMA in the early 1970's established a seasonal altitudinal migration, an atypical characteristic of reintroduced herds (Geist 1971) which might have been due to the migratory traditions of the Sun River source herd (Erickson 1972, Frisina 1974). Seasonal migrations ceased subsequent to the 1984 die-off with the exception of a small ram group. The low elevation, non-migrational BWMA population is largely dependent upon summer precipitation which determines the temporal availability of quality forage.

2) Reproduction

Lamb production and survival on the BWMA appears to be correlated with summer precipitation and associated forage quality. The nutritional status of individual ewes, based upon the availability of quality forage, dictates the reproductive component of sheep population dynamics and appears to be critical to the BWMA sheep population. Ewe production in domestic sheep has been demonstrated to be correlated with nutritional status, particularly the periods immediately preceding conception and birth (Edey 1970). Production was low over all 3 years and ranged between a maximum of 19 lambs in 1996 (following a particularly wet summer) and a minimum of 11 lambs in 1997 (following a particularly dry summer). The observed annual variability in lamb production was likely a function of the ewes' ability to obtain adequate energy reserves necessary for viable estrus and ovulation and to support fetal growth (Gunn 1983). A significant decrease in the 1997 lamb crop also occurred on a domestic sheep ranch adjacent to the study area which experienced a 30% decline in lamb production despite supplemental feeding during winter months. The rancher attributed low productivity to the lack of precipitation and associated forage quality in summer 1996 (S. Blackman, pers. comm.). The data indicate that only 35% of all BWMA ewes produce lambs in a given year, and transplant ewe production patterns are suggestive of an alternate year reproduction which is common among "low quality" herds (Heimer 1978). Results of Kjeldahl analysis support a nutritional stress hypothesis as fecal nitrogen levels decreased rapidly during the dry summer of 1996 and likely prevented ewes from attaining body condition necessary for successful reproduction in 1997.

Lamb survival was low in all 3 years and data indicate high rates of late summer mortality. Lamb survival and recruitment is critical to bighorn population dynamics (Geist 1971) and lamb mortality has been subject to numerous investigations (Woodard et al. 1974, Spraker and Hibler 1977, Festa-Bianchet and Samson 1984, Douglas and Leslie 1986, Akenson and Akenson 1992). Studies have generally concluded that lamb mortality was due to either predation (Hass 1986, Scotton, pers. comm.) or disease (Marsh 1938, Woodard et al. 1974, Spraker and Hibler 1977, DeForge et al. 1982, Cook et al. 1990). Coyotes and golden eagles have both been implicated in populations with high rates of lamb predation (Hass 1986, Scotton, pers. comm.), which are often characterized by significant neonatal/early summer losses (Hass 1986). These studies noted regular predator-sheep interactions and observed specific ewe behavioral responses to the presence of predators. Two cases of lamb predation during this study occurred as sheep departed lambing grounds in early July 1997, which is similar to the findings of Akenson and Akenson (1992). No other known predation events/attempts were observed during this study, and ewes with lambs did not exhibit any behavioral responses when coyotes or eagles were present.

Results of scat analysis suggests that lamb predation is limited. The absence of sheep hair in coyote scats collected between May and November indicates that lambs are not a significant prey item. The majority of coyote scats having sheep hair were collected during winter months, corresponding to the peak of lion predation upon adult sheep and therefore possibly representing scavenging by coyotes. Mountain lions, whose presence on the BWMA is limited during summer months, did not prey upon lambs.

Pneumonia is often the proximate cause of disease-mediated lamb mortality and suggested ultimate causes have included loss of winter range (Woodard et al. 1974), lungworm loads (Festa-Bianchet and Samson 1984), temperature (DeForge and Scott 1982), precipitation (Douglas and Leslie 1986) and nutritional stress (Akenson and Akenson 1992). Losses resulting from disease-mediated lamb mortality typically occur in late summer and early fall (Akenson and Akenson 1992) and such timing is thought to be associated with weaning (Dr. Mike Miller, pers. comm.). Studies have also noted high rates of lamb mortality in years subsequent to a die-off event (Ryder et al. 1994). Evidence suggests that lamb mortality on the BWMA is disease-related. The majority of lamb losses (77%) occurred between late July and September 15. Two lambs that died of pneumonia were discovered in late July and early August 1996 and coincided with coughing in ewe-lamb groups. No lamb-predator interactions were observed after ewe/lamb groups departed lambing grounds. Necropsy results indicate the presence of pneumonia-inducing pathogens in this population. Sources of such pathogens could include a long-term residual effect of the 1984 die-off, *Pasteurella* spp. carried by transplanted sheep, known contact with domestic sheep and goats, and seasonal migrations of native rams.

Potential stressors resulting in lamb susceptibility to pathogens include inadequate nutrition and lungworm burdens. Lamb survival may be correlated with precipitation levels during their first summer, with 73 % survival during the wettest summer (1997) and 42% survival in the driest summer (1996). Forage quality mediated through summer precipitation affects lamb survival through both maternal nutritional status and lamb physiological condition. Low quality forage in dry years likely results in reduced lamb vigor and development and inadequate ewe milk production (quantity and quality) which results in earlier weaning and increased lamb reliance on poor quality forage. The initial appearance of lungworms in lambs in August could augment nutritionally-induced physiological stress. Several surviving lambs were relatively small as yearlings which is indicative of inadequate nutrition levels during development and which may result in reduced survivorship and lifetime reproductive potential (Gunn 1983). The production and survival rates of BWMA lambs results in very low annual recruitment levels which are inadequate for a growing or stable population (Lawson and Johnson 1982).

3) Adult mortality

Adult mortalities were associated with mountain lion predation and disease. Predation represented a significant source of mortality relative to the small sheep population (10 sheep). Other studies have found sheep to be an important dietary component for mountain lions (Williams 1992, Ross et. al 1996). Mountain lions were generally winter occupants of sheep range and sheep predation can be characterized as seasonal and opportunistic. The timing of sheep kills indicates that sheep are seasonally utilized as a supplemental dietary item while elk and deer migrations are in progress and preferred prey is unreliable. Locations of sheep kill sites suggest sheep were taken opportunistically while crossing riparian areas. Topographic features representing sheep escape terrain were also utilized by mountain lions. The use of similar landscape features by both species resulted in significant spatial overlap and increased sheep vulnerability.

Disease-related mortality of adult sheep was also seasonal, occurring in late summer and early winter months. This timing suggests that nutritional deficiencies play a role in increasing susceptibility to pathogens and the resultant pneumonia. Mortalities followed a particularly dry summer during which fecal nitrogen levels declined sharply, a factor which suggests that sheep relied on low quality forage. A necropsied ewe had a full rumen yet was in poor nutritional condition in October 1996. Bone marrow evaluation on all mortalities indicated sheep were in good nutritional status and suggests a relatively short-term decline in health as would be expected with pneumonia. Lungworm loads likely represented an additional stressor for sheep of poor nutritional status. Physiological stress resulting from poor quality forage and lungworm burdens, in the presence of *Pasteurella* spp. and other pathogens, was likely the proximate cause of these mortalities.

4) Augmentation

The primary goal of the bighorn sheep augmentation program was to stimulate population growth by increasing the herd's reproductive potential (annual lamb production). Augmentation was unsuccessful in attaining this goal due to high rates of transplant dispersal and mortality and limited transplant ewe production. Disease-mediated mortalities and predation have accounted for the loss of 32% of the transplants. Of the 39 sheep relocated in 1995 and 1996, only 38% (11 ewes and 4 rams) are currently alive on the BWMA and in 3 years transplant ewes have produced a total 16 lambs. Not only has augmentation not improved herd reproductive rates, but population estimates indicate a 20% *decline* subsequent to augmentation. This decline is attributable to a low herd productivity, limited lamb survival, and relatively high rates of adult mortality

SUMMARY

Disease-mediated dieoffs are relatively common in bighorn sheep populations, often reducing herds by >70% and expressing residual effects for several years. When reduced to low numbers, the ability of such herds to recover and attain pre-dieoff densities depends largely upon a variety of stochastic factors. Relatively small changes in annual reproduction and survival rates can dramatically influence population dynamics and determine the ultimate fate of such populations. The BWMA bighorn sheep population, reduced to approximately 50 individuals in 1984, is currently regulated primarily by limited reproduction and recruitment and secondarily by annual adult mortality. This low elevation, non-migrational population is constrained to "winter-range" type habitat throughout the year and access to quality forage during summer months is largely determined by summer precipitation levels. Nutritional stress resulting from low quality summer forage is likely the proximate cause late summer/fall mortality of lambs and adults. While winter is considered *the* critical season for bighorn sheep inhabiting the Northern Rockies, it appears that summer is the critical period for non-migrational populations limited to low elevation ranges.

Mountain lion predation accounted for significant transplant mortality and plays a significant role in the current sheep population dynamics. Results suggest that escape terrain may not provide adequate protection from predation in environments where mountain lions represent the primary predators. Given expanding mountain lion populations in the Rocky Mountain region, it may be necessary to re-evaluate "escape terrain" and sheep-predator dynamics in ecological settings similar to the BWMA.

Augmentation programs are utilized by many states and provinces as a management tool to increase productivity of bighorn sheep populations. Although relatively expensive, augmentation projects are often not evaluated with respect to the fate of relocated individuals and their ultimate effectiveness in improving population dynamics. The BWMA augmentation program was not successful in stimulating population growth. Transplant losses due to dispersal (31%) and mortality (33%), in conjunction with limited lamb production, prohibited population growth. Additionally, transmission of pathogens between transplants and natives may have resulted in adult mortalities and a declining post-augmentation population. Results suggest that prior to conducting transplant operations, managers should evaluate 1) the specific factors influencing population dynamics and 2) transplant health.

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BIGHORN SHEEP POPULATION DYNAMICS ON THE BEARTOOTH WILDLIFE MANAGEMENT AREA, MONTANA

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Abstract: The dilemma of bighorn sheep dieoffs has plagued wildlife biologists and managers for decades. Many states have established augmentation programs in an effort to counteract such dieoffs and maintain viable sheep populations. I studied the population dynamics of a reintroduced bighorn sheep herd on the Beartooth Wildlife Management Area (BWMA) in west-central Montana. After a decade rapid growth, this herd experienced a major disease-mediated dieoff in 1984 and has subsequently been unable to recover to pre-dieoff densities. Primary study objectives included evaluation of sheep reproduction and mortality, habitat use, and disease. Particular emphasis was placed on determining the role of predation in sheep population dynamics. Additionally, transplanted individuals were monitored to evaluate the effectiveness of two augmentation projects (N=39 sheep). Results from this study will provide insight into the post-dieoff population dynamics of small sheep herds and improve our understanding of augmentations and the degree to which they actually assist in population recovery.

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LESSONS LEARNED FROM RATES OF INCREASE IN BIGHORN HERDS

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Abstract: Bighorn herds have the potential to double their numbers in approximately three years. Theoretical and actual cases are provided in this paper. For 100 bighorns it was found the optimum ratio for herd maintenance at a 1:1 sex ratio was approximately 20 lambs: 40 ewes (1+ yrs) of which no more than 30 ewes (2+ yrs) were required to optimize production. The implications of these ratios for managing nursery herds are discussed.

DISCUSSION

Rocky Mountain Bighorns are a density dependent species relegated by predators and deep snow to islands of unique habitats of rocky escarpments adjacent to grassy pastures, which in winter are exposed to wind and/or sun. These"islands" are quickly overpopulated by a species that has the potential to double approximately every three years (Buechner 1960). Bighorns throughout their ranges have at one time or another followed most of the suites of population curves and age pyramids found in most ecology texts, e.g.,Odum (1971).Wildlife managers should be able to recognize where their bighorn herds fit in these population configurations and as managers should take appropriate measures in regulating herd numbers.

The capability of bighorns to increase at a rapid rate was demonstrated by Beuchner (1960) using Leopold's (1933) life tables and examples from bighorn populations from Wildhorse Island, Tarryall and Fort Peck. For example, the annual rate of increase at Wildhorse from 1947 to 1954 was 30% and is almost identical to the "no mortality" table from Leopold.

Recently, we observed a similar rapid increase (26% per annum) in a bighorn nursery herd that was colonizing a coal mine site that was undergoing reclamation at Minalta Coal Ltd. Gregg River Mine (GRM) near Hinton, Alberta (Table 1). The mine site is immediately adjacent to a largely reclaimed mine site leased by Cardinal River Coals Ltd.(CRC) that presently harbors a large bighorn herd that has stabilized around 400 animals. Aside from the rapid increase in the GRM herd, there were two other notable events. The first observation was that the GRM herd had a high lamb : ewe ratio (53:100) compared to the CRC herd (23:100) immediately to the south during the same year, 1996, indicating significant differences in density dependent responses by the two adjoining herds. The second observation was that the age structure of the GRM ewe and lamb herd corresponded closely to the Leopold "no mortality" table of 100 animals (Table 2), i.e., approximately 20 lambs:40 ewes (1+ yrs) and 30 ewes (2+ yrs).

Table 1. Rate of increase in a bighorn nursery herd during colonization of a reclaimed coal mine site at Gregg River Mines (GRM), Alberta 1993-1996.

YEAR	Lambs	Yearlings	Ewes	Total	
1993	12	11	17	40	annual rate of increase 26%
1996	23	15	35	73	

At this point, it is appropriate to note that the above age ratios of ewes to lambs was maintained in a population of bighorns that were kept at 100 animals at a 1:1 sex ratio through ewe harvests, transplants and ram hunts for six years (1975-1980) at Ram Mountain in west central Alberta (Jorgenson and Wishart 1986) see (Table 2). In other words, during that period the population was kept at the inflection point of its sigmoid curve, that is, young and productive and near its maximum potential rate of increase and with minimal losses to natural mortality such as old age. Thereafter, the herd was left to expand without ewe harvests and although the population doubled during the next ten years, the rate of increase (7% /annum) was far below the annual potential of 30% suggesting that indeed we had been managing the herd at or near its inflection point at 100 animals.

Table 2. Age composition of ewes with lambs in populations of 100 bighorns.

HERD	Lambs	Yrlgs	2 Yrs	Ad	Total	
Model	23	9	7	23 =	39 ewes (30 2+ewes)	Leopold (1933)
Wildhorse (1954)	18	7	5	27 =	39 ewes (32 2+ewes)	Woodgerd (1964)
Ram Mtn. (1975-80)	21	9	8	24 =	41 ewes (32 2+ewes)	Jorgenson and Wishart (1980)
GRM	23	8	(35)	=	43 ewes (35 2+ewes)	This study

In order to maintain the 20:40:40 ratio at Ram Mountain during the 1970's, it was necessary to remove approximately 18% of the ewes each year. Two notable events took place within the ewe herd under this harvest regimen. Firstly, some of the yearlings began to breed and, secondly, when adult ewes(2+yrs) exceeded 28 animals there was an abrupt decline in breeding by yearling ewes. In either case, lamb production and survival within the frame of 40 ewes was equally successful. Hence the conclusion, that a herd of 100 bighorns with a 1:1 sex ratio could be maintained by approximately 20 lambs:40 ewes (1+ yrs) and with no more than 30 ewes (2+yrs). In fact, this optimum age ratio of ewes and lambs on nursery ranges is basically independent of ram numbers, since the young rams leave the nursery ranges after a few years and remain segregated from the ewes except during the rut. By viewing a nursery herd that appears to support only 20 lambs implies that it requires no more than 40 ewes one year and older to maintain that production; the rams are simply a by-product (Jorgenson et al. 1993).

At the CRC mine during a bighorn nursery herd population rise of approximately 9% per year from 1985 to 1993, the population was being subjected to a ewe removal program that averaged 11% per year. In other words, the ewe removals were insufficient to prevent a population increase. This was due partly to new ranges being created by reclamation, however, by 1995 the nursery herd had peaked at 184 ewes (1+yrs) with 98 lambs followed by a drop to 51 lambs and 186 ewes the following year. As stated earlier , the adjoining herd that was expanding at the GRM site enjoyed a healthy lamb:ewe ratio of 53:100. Since the population peak at CRC, it has been recommended that the total ewe herd size be reduced and stabilized at 144 females and maintained at or near the inflection of the population curve. This will require an annual removal of 26 ewes or 18% of the ewe herd. A rancher would liken this approach to a cow/calf operation, except he would remove the annual calf increment. In either case, both management systems are dealing with "fenced" or "island" populations.

Once the Ram Mountain herd was allowed to expand with the cessation of ewe removals, a significant series of population self regulation events took place (Festa-Bianchet et al. 1995). Body mass of young ewes decreased (Figure 1) and corresponded to increased age at primiparity and decreased lamb production. Primarily, the young ewes stopped breeding; first the yearling ewes, followed by the 2 yr-olds, then the 3 yr-olds. The reduced contribution of lambs from young ewes was reflected in the declining percentage of lambs to adult ewes (3+ yrs) (Table 3 and Figure 2). In other words, the bottom of the age pyramid began to shrink. Although there were ewe and lamb age ratios approaching Leopold's "no mortality" table in some years during rise, the percentage of lambs/adult ewes (3+ yrs) was approximately 20% below Leopold and approximately 10% below the years of optimum production on Ram Mountain (Table 4).

Fig. 1. Ave. wt. gain of yrlg ewes

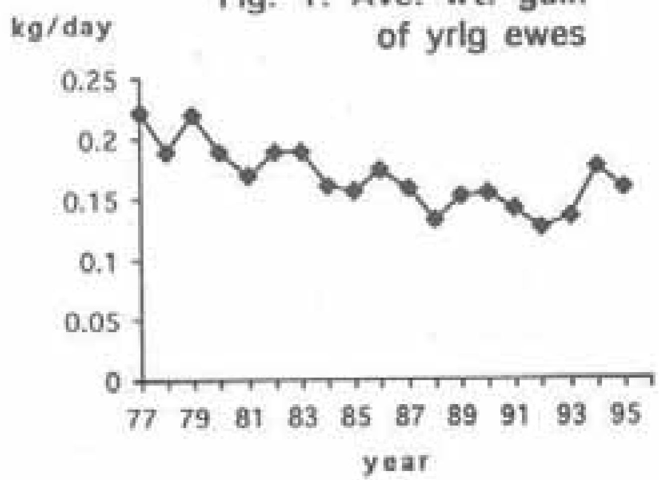


Table 3. Adult ewe (3+ yrs) : lamb ratios at Ram Mountain from 1975 to 1997 in response to ewe removals, followed by the rise and fall of the population during five year intervals without ewe removals.

YEARS	Adult Ewes (3+ yrs)	Lambs	Percent Lambs	Ave. Age of all Ewes
1975-82 (population control)	24	22	92	3.8
1983-87 (population rising)	43	35	81	4.4
1988-92 (population peaking)	70	47	67	5.1
1992-97 (population falling)	77	43	56	6.4

Figure 2. Diverging ewe/lamb numbers on Ram Mtn. 1975-1997.

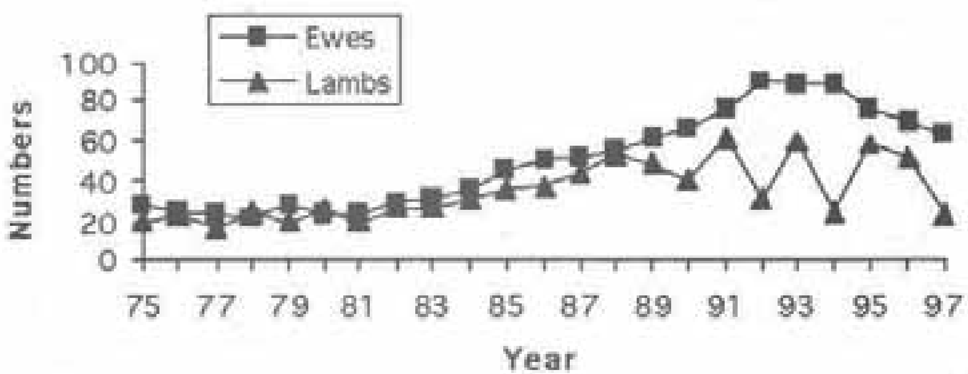


Table 4. Ewe and lamb age ratios at Ram Mountain (RM) in 1983 and in 1989 during a population rise that were approximately comparable to Leopold's (1933) "no mortality" life table.

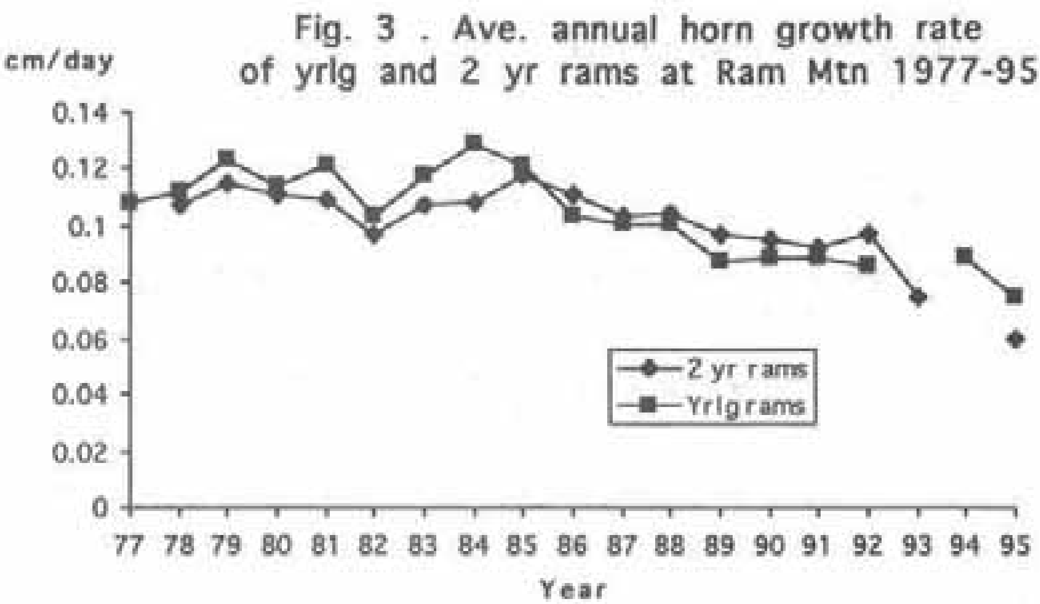
YEAR	Adult Ewes (3+ yrs)	Lambs	Percent Lambs	Yearling Ewes	2 yr Ewes	Total Ewes and Lambs
RM 1983	31	26	84	13	7	77
Leopold	30	30	100	12	9	81
RM 1989	61	48	79	24	11	144
Leopold	61	61	100	23	18	163

The early stages of overpopulation are not easily perceived in bighorn populations from lamb:ewe ratios without accurate knowledge of the age structure of the ewes to at least age three. In a field situation without ground counts and a lot of marked animals this precision of assessment is not attainable (Jorgenson 1992, Festa-Bianchet 1992). However, the later stages of overpopulation are quite apparent when ewe and lamb numbers begin to diverge as we observed at Ram Mountain and as we often see in our mountain Parks. In the late 1970's in southwestern Alberta we failed to perceive the consequences of this ewe/lamb divergence in our bighorn herds from aerial surveys until after a pneumonia die-off (Table 5). Although the die-off may not have been prevented, the losses may have been less severe (Onderka and Wishart 1984).

Table 5. Numbers of bighorns observed from winter aerial surveys north of Waterton Park to Crowsnest Pass, Alberta before and after a pneumonia die-off (1975-1984). *Note diverging ewe/lamb numbers from 1975 to 1979 before die-off, followed by continued low lamb production.

YEAR	Ewes	Lambs	Rams>1/2 curl	Rams >4/5curl	Total
1975	187	81	50	35	353
1979	248	77	44	29	389
1981/82			die-off		
1983	86	20	4	5	123
1984	108	19	21	3	159

One of the more conspicuous symptoms of overpopulation, aside from reduced body mass in young ewes, is reflected in reduced horn growth of young rams on the nursery ranges (Jorgenson et al. 1998). At Ram Mountain, horn size in yearling and 2 year-old rams decreased significantly as the nursery herd increased (Figure 3). This observation of poor initial horn growth in rams on an overstocked range in Banff National Park (BNP) was also noted by Shackleton (1973). He compared ram horn increments from BNP and a herd recovering from a die-off in Kootenay National Park (KNP). Rams from KNP had significantly greater horn lengths and diameters during their first four years of growth compared to BNP.



Horn increment measurements can be relatively easily obtained from rams harvested from various ranges and can provide a useful measure of population quality as predicted by Geist (1971). It is interesting to note that many record book rams are a result of nursery herds having accessed new or renewed ranges following die-offs, transplants, fires or reclamation. This has been particularly true in Alberta and Montana (Gilchrist 1992).

In summary, Rocky Mountain bighorns have a very high reproductive potential, possibly in response to short-term density fluctuations during their evolution (Festa- Bianchet and Jorgenson 1998). Certainly this capability has served the species well when they have invaded and heavily utilized newly formed food sources from fires or avalanches, thereby suppressing forest succession in their favor. In recent times the natural sources for range expansion have been largely replaced by introductions of sheep to new or former ranges or by sheep invading reclaimed mine sites. Bighorn managers should keep in mind that with this high reproductive potential, mountain sheep should be managed as though they are about to overpopulate an island. This can be achieved by removing the ewes, keeping in mind that a nursery herd requires no more than 30 ewes (2+ yrs) to produce 20 lambs. Overpopulation clues can be reflected in poor lamb crops, poor growth rates in young ewes and poor early incremental growth in ram horns.

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POPULATION OVERVIEWS

STATUS, HARVEST, AND CO-MANAGEMENT OF DALL'S SHEEP IN THE MACKENZIE MOUNTAINS, NORTHWEST TERRITORIES

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Abstract: the Mackenzie Mountains of the western Northwest Territories (NWT) cover an area of approximately 140,000 km^2 between the Mackenzie River and the Yukon-NWT border. The mountain range is uninhabited and has no roads, which make the Mackenzies one of North America's most pristine wilderness areas. Ten aerial and ground surveys to count and classify Dall's sheep (*Ovis dalli dalli*) have been done since 1966. We estimate that there are currently 14,000 to 26,000 sheep in the NWT portion of the Mackenzie Mountains. The Government of the NWT (GNWT) opened the Mackenzie Mountains to non-resident hunting in 1965 and Dall's sheep quickly became the principal trophy species sought by sport hunters. Non-residents must hunt with one of eight licenced outfitters, each of whom has the exclusive privilege of providing outfitting services in their designated zone. Licenced non-resident hunters are permitted to take one adult male sheep per year, with minimum ¾ curl horns during a season that lasts from 15 July to 31 October. From 1991 to 1996 an annual mean of 194 rams were harvested by non-residents. In 1997 the mean age and right horn length of harvested rams were 10.0 years and 89.9 cm, respectively; the average age of harvested rams has increased 1.5 years since 1980. Resident hunters generally take 10-20 rams per year. Subsistence harvest is unrestricted by season, numbers, age, or sex, but only 10-30 sheep are estimated to be taken annually. The current total annual harvest removes 0.8 to 1.6% of the population and appears to be sustainable. Some areas nearer communities receive heavier hunting pressure and local management concerns exits. Through the co-management process we have developed a program of ground surveys for sheep in four mountain blocks. Sahtu Dene and Metis land claim participants have been trained in data collection and are actively involved in obtaining needed data on sheep population dynamics.

Key words: Dall's sheep, *Ovis dalli*, Northwest Territories, Mackenzie Mountains, status, harvest, management, co-management

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INTRODUCTION

The Mackenzie Mountains straddle the Yukon-NWT border in northwestern Canada. The NWT portion of the range covers approximately 140,000 km^2 between the Mackenzie River on the east and the Yukon-NWT border on the west (Figure 1). Dall's sheep are the only species of mountain sheep that occur in the NWT and occupy the Mackenzie Mountains (Figure 2) and the more northerly Richardson Mountains west of the Mackenzie River delta. All mountain sheep populations in the NWT are native - no sheep have been transplanted to, from, or within either the Mackenzie or Richardson Mountains (Veitch 1998).

The Mackenzie Mountains are a system of irregular mountain masses resulting primarily from deformation and uplift (Simmons 1968). Since the Mackenzies are comprised primarily of limestone, dolomite, and shale they are easily eroded, which has produced unstable rubble slopes over large areas (Simmons 1982*a*) and many spectacular canyons, ravines, and rock outcrops. Along the Yukon-NWT border some peaks reach 2700 m and a few active glaciers occur, whereas along the eastern front range the topography is more gentle (1000-2000 m) and considerable high quality Dall's sheep summer range is provided on alpine meadows. The average frost-free season lasts only 70-75 days and total annual precipitation is between 25 and 30 cm (Simmons 1968).

The major large mammal species that occur across most of the mountain range are: Dall's sheep, woodland caribou (*Rangifer tarandus caribou*), moose (*Alces alces gigas*), grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and wolverine (*Gulo gulo*). Mountain goats (*Oreamnos americanus*) occupy high country in the southwest along the Yukon-NWT border and black bears (*U. americanus*) occur at very low density in the southern half of the range (Simmons 1968; Veitch and Popko 1997). During the 1997 hunting season a lone bull muskox (*Ovibos moschatus*) was reported at the northern end of the mountain range (Kelly Hougen, Arctic Red River Outfitters, personal communication). This is the only known occurrence of this species in the Mackenzies, but musk ox numbers and range are expanding east of the Mackenzie River (Veitch 1997). Reports of mule deer (*Odocoileus hemionus*) have been received in the Nahanni Butte area at the south end of the mountain range (Simmons 1968).

There are no active roads in the Mackenzie Mountains of the NWT. In 1943-44, the Canol Road (Figure 2) was constructed as part of a project to move oil from Norman Wells across the Mackenzie Mountains to Alaska. At the end of the project in 1945, the road was left to deteriorate over its 357 km length on the NWT side of the border (Fradkin 1977), such that now the Canol Heritage Trail in the NWT is considered one of the premier backcountry hikes in North America (Howe 1996). Plans are being developed to make the trail a territorial park (Downie 1997). On the Yukon side, the Canol Road has been maintained as a summer-use road. An all-season highway skirts the southeastern edge of the Mackenzies in the vicinity of the communities of Nahanni Butte and Fort Liard in the NWT, and another summer-use road reaches the Yukon-NWT border at the abandoned mining community of Tungsten west of Nahanni National Park (Figure 2).

Figure 1. Mackenzie Mountains, NWT.

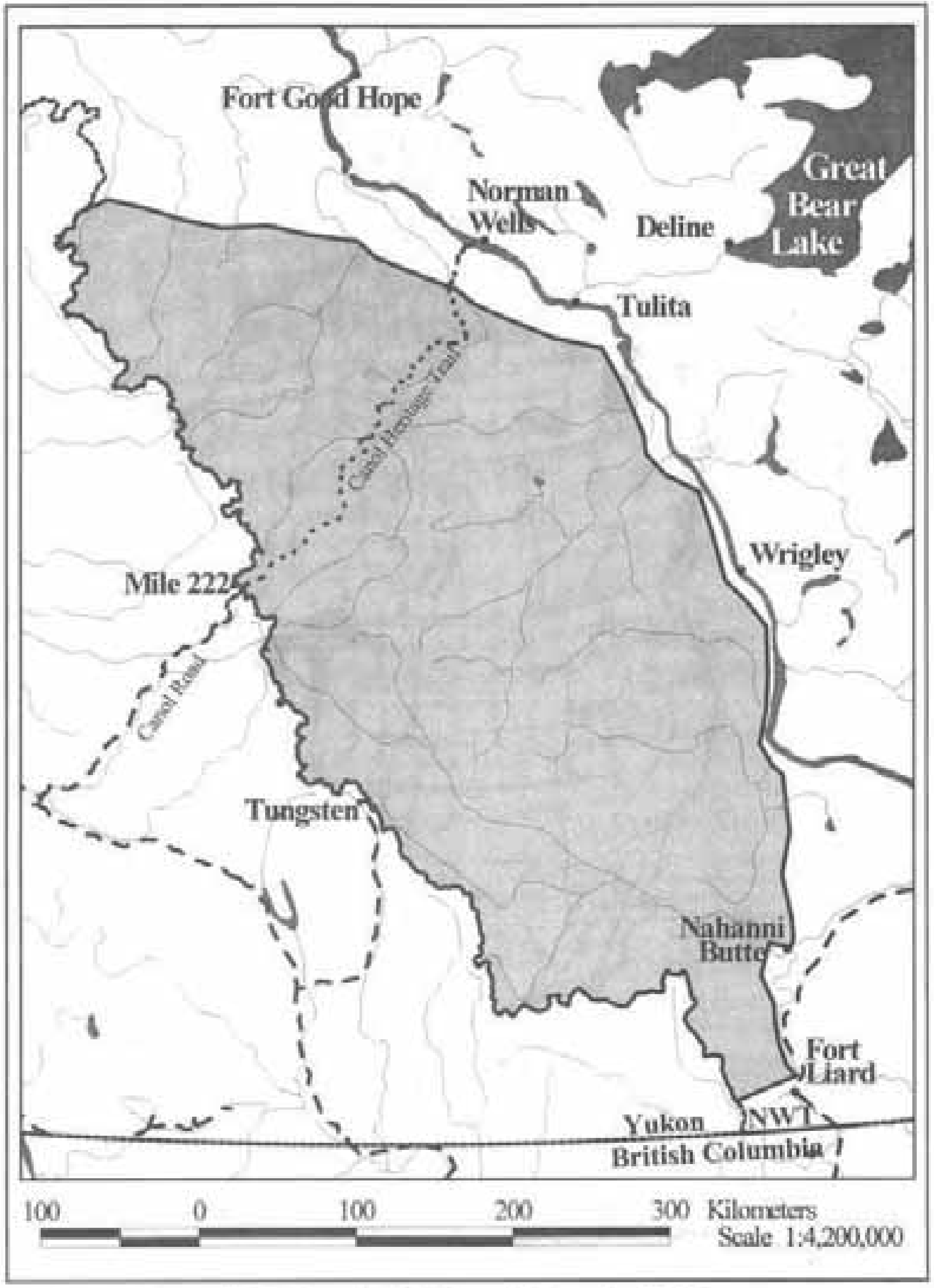

Figure 2. Range of Dall's sheep in the Mackenzie Mountains, NWT

Five communities along the Mackenzie River, with a combined population of 1913 (GNWT 1996; range 75 to 798), are located within 50 km of the Mackenzie Mountains in the NWT (Figure 2). In 1991, 63% of the residents of those communities identified themselves as aboriginal, primarily Dene and Metis (GNWT 1996).

With the closure of mines at Tungsten and Mile 222 on the Canol Road there are no ongoing industrial activities within the mountains. The primary human activities that occur in the mountains are hunting, fishing, hiking, sightseeing, and skiing. Snowmobiles and all-terrain vehicles are used along the eastern and western fringes of the mountain range gaining access via summer roads and rivers, and jet boats are used primarily by subsistence hunters to access the mountains through some of the larger rivers. No domestic sheep or goats are farmed anywhere within 50 km of the Mackenzie Mountains in the NWT, nor are there any plans to develop a domestic sheep or goat industry in the NWT (John Colford, Fish/Agriculture Coordinator, GNWT, personal communication).

POPULATION STATUS

No surveys have been done to estimate numbers of Dall's sheep across the entire Mackenzie Mountains; however, 10 aerial and ground surveys to count and classify sheep have been done within several study areas from the mid-1960's to 1997 (Table 1; Figure 3). We can use those to derive a crude population estimate.

We have surveyed 10,202 km^2 (7.3% of the mountain range) and estimated densities have ranged from 19 to 53 sheep per 100 km^2 (Table 1). The 1988 survey in E1-1 over a 4956 km^2 area included unusable to prime sheep habitats and resulted in an average density of 19 sheep per 100 km^2 (Latour 1992). Applying this density to the 140,000 km^2 total area of the Mackenzie Mountains in the NWT gives an estimate of 26,600 Dall's sheep.

Most surveys focus on areas of good sheep summer habitat. If we assume that about 25% of the Mackenzie Mountains is good summer habitat (cf. Simmons 1982*a*) then we can calculate another population estimate. The mean density of the 10 surveys on summer range is 39 ± 12 sheep per 100 km^2, which gives an estimate of 13,650 Dall's sheep on 35,000 km^2 of summer range.

Because of the assumptions and limitations of both these procedures we suggest there are between 14,000 and 26,00 sheep in the Mackenzie Mountains, NWT. We have no measure of population trend. In future, once LANDSAT Thematic Mapper digital satellite images for the Mackenzie Mountains have been classified, we will be able to refine our estimates of suitable sheep habitat. The combination of quantified habitat information with detailed population survey data will produce more accurate and precise estimates of Dall's sheep within the Mackenzie Mountains of the NWT.

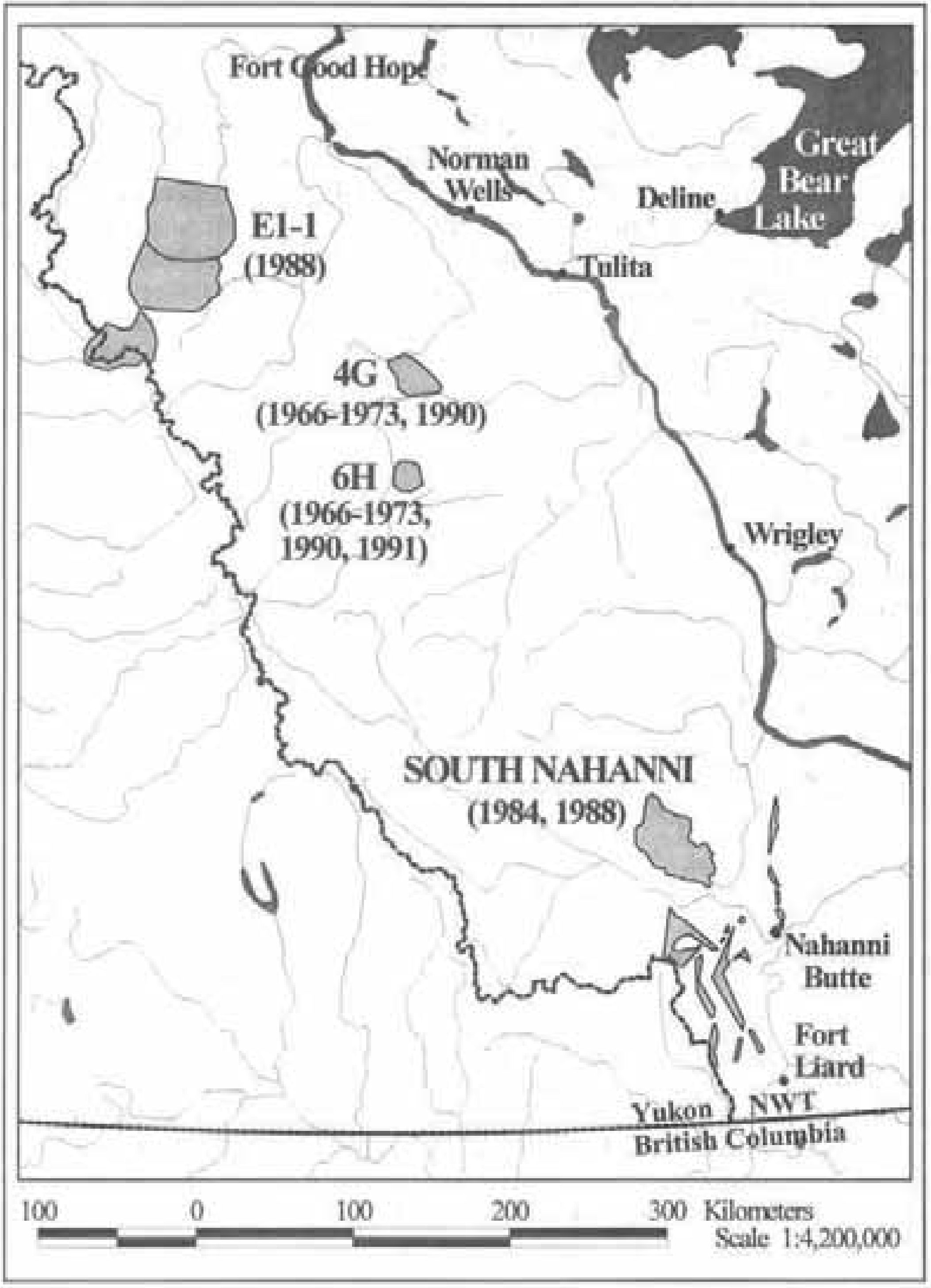

Figure 3. Dall's sheep study areas in the Mackenzie Mountains, NWT: 1966 - 1991.

Table 1. Dall's sheep surveys in the Mackenzie Mountains, Northwest Territories: 1966 to 1997.

Location	Year(s)	Month	Survey Type	Total Area (km^2)	Density ($sheep/km^2$)	Reference
Unit 4G	1966 to 1973	Feb & Jul	Fixed-wing	236	0.47	Simmons et al. 1984
Unit 6H	1966 to 1973	Feb & Jul	Fixed-wing	196	0.51	Simmons et al. 1984
South Nahanni	1984	Jun	Helicopter	1100	0.51	Ferguson et al. 1987
South Nahanni	1984 to 1988	Jun	Helicopter	2900	0.30	Case 1989
Zone E1-1	1988	Jun	Helicopter	4956	0.19	Latour 1992
Unit 4G	1990	Jun	Helicopter	236	0.25	Shank et al. 1993
Unit 6H	1990	Jun	Helicopter	196	0.43	Shank et al. 1993
Unit 6H	1991	Jun	Helicopter	196	0.41	Shank et al. 1993
Katherine Ck.	1997	Apr	Ground	423	0.31	R. Popko, unpubl. Data
Palmer Lake	1997	Sep	Ground	391	0.53	R. Popko, unpubl. Data

Our density estimates from our 10 aerial and ground surveys are comparable with aerial survey results for Dall's sheep from Alaska's Western Brooks Range (19-53 sheep/ 100 km^2 ; Hicks 1996), Gates of the Arctic National Park (29 sheep/ 100 km^2 ; Hicks 1996), Wrangell-St. Elias National Park (41-43 sheep/100 km^2; Strickland et al. 1992), and Kenai National Wildlife Refuge (64 sheep/ 100 km^2; Strickland 1994), and from the Richardson Mountains of the northern Yukon and NWT (29 sheep/ 100 km^2 ; Barichello et al. 1987).

HARVEST

Regulations

There are four classes of big game hunting licences in the NWT (GNWT 1998):

1) General - holders are not restricted by season, by number of animals they may take, or by age/sex classes. These are primarily aboriginal people, but some long-term non-aboriginal residents also have these licences. This is the subsistence harvest.

2) Resident - Canadian citizens or landed immigrants to Canada that have resided in the NWT for at least 2 consecutive years before applying for a licence;

3) Non-resident - those who have not lived in the NWT for at least 2 consecutive years before applying for a licence, and who are either Canadian citizens or landed immigrants to Canada;

4) Non-resident Alien - those who are not either Canadian citizens or landed immigrants to Canada.

The Mackenzie Mountains were first opened to non-residents and non-resident aliens for hunting big game in 1965 (Simmons 1968). Applicants for resident, non-resident, and non-resident alien hunting licences must be at least 16-years-old when they apply. Non-resident and non-resident alien hunters must use the services of a licensed outfitter, and must be accompanied by a licensed guide during their hunt. Outfitter and guide licences are issued by the GNWT. There are eight licensed outfitters for Dall's sheep in the Mackenzie Mountains and each has the exclusive privilege to provide outfitting services within their zone (Figure 4). Resident hunters do not require the services of either an outfitter or guide.

The season for Dall's sheep for resident, non-resident, and non-resident alien hunters lasts from 15 July to 31 October and each tag holder is allowed to take one adult male Dall's sheep with minimum ¾ curl horns per year. General hunting licence holders are not restricted in numbers of sheep they may take, by season, or by age or sex class. There is no quota for the total number of sheep that can be taken annually by outfitted hunters or by residents. Hunting by non-residents, non-resident aliens, and residents is not permitted within Nahanni National Park (Figure 5), but aboriginal general hunting licence holders have the right to harvest in the park for subsistence purposes (S. Catto, Director of Warden Services, Nahanni National Park, personal communication).

Harvest data from non-resident and non-resident alien hunters has been collected since 1965 (Latour and MacLean 1994; Veitch and Popko 1996*a*, 1997). Since 1996, as a condition of their licence, outfitters are required to submit a report to the GNWT for every client for whom they provide outfitting services whether the client harvests or not. Resident hunters receive a mailed questionnaire from the GNWT at the end of each hunting season; letters and duplicate forms are sent to non-respondents at 6 and 12 weeks after the initial mailing. In the past, subsistence harvest has been estimated by GNWT officers in communities along the Mackenzie River valley. Currently, detailed 5-year harvest studies to document total subsistence harvest of all big and small game are being done in the Sahtu and Gwich'in land claim settlement areas (Figure 5). Completion of these studies will refine our subsistence harvest data.

Hunting Pressure

Non-residents and non-resident aliens purchased an annual mean of 363 Mackenzie Mountain big game hunting licenses from 1991 to 1997 (Table 2). Dall's sheep have continued to be the most sought after trophy by sport hunters since the inception of hunting in 1965 (Table 2). In

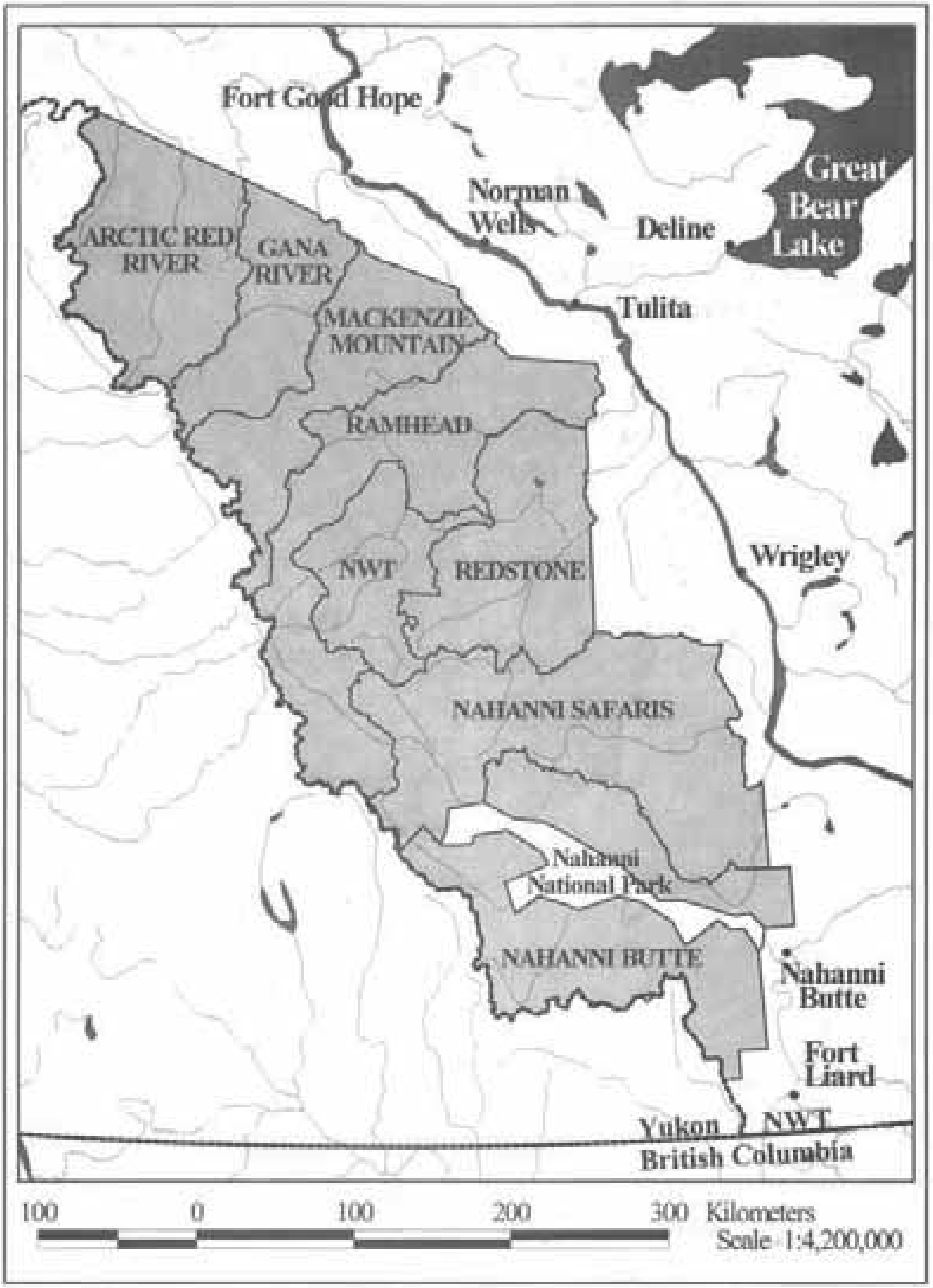

Figure 4. Outfitter zones For non-resident and non-resident alien Dall's sheep hunting, Mackenzie Mountians, NWT.

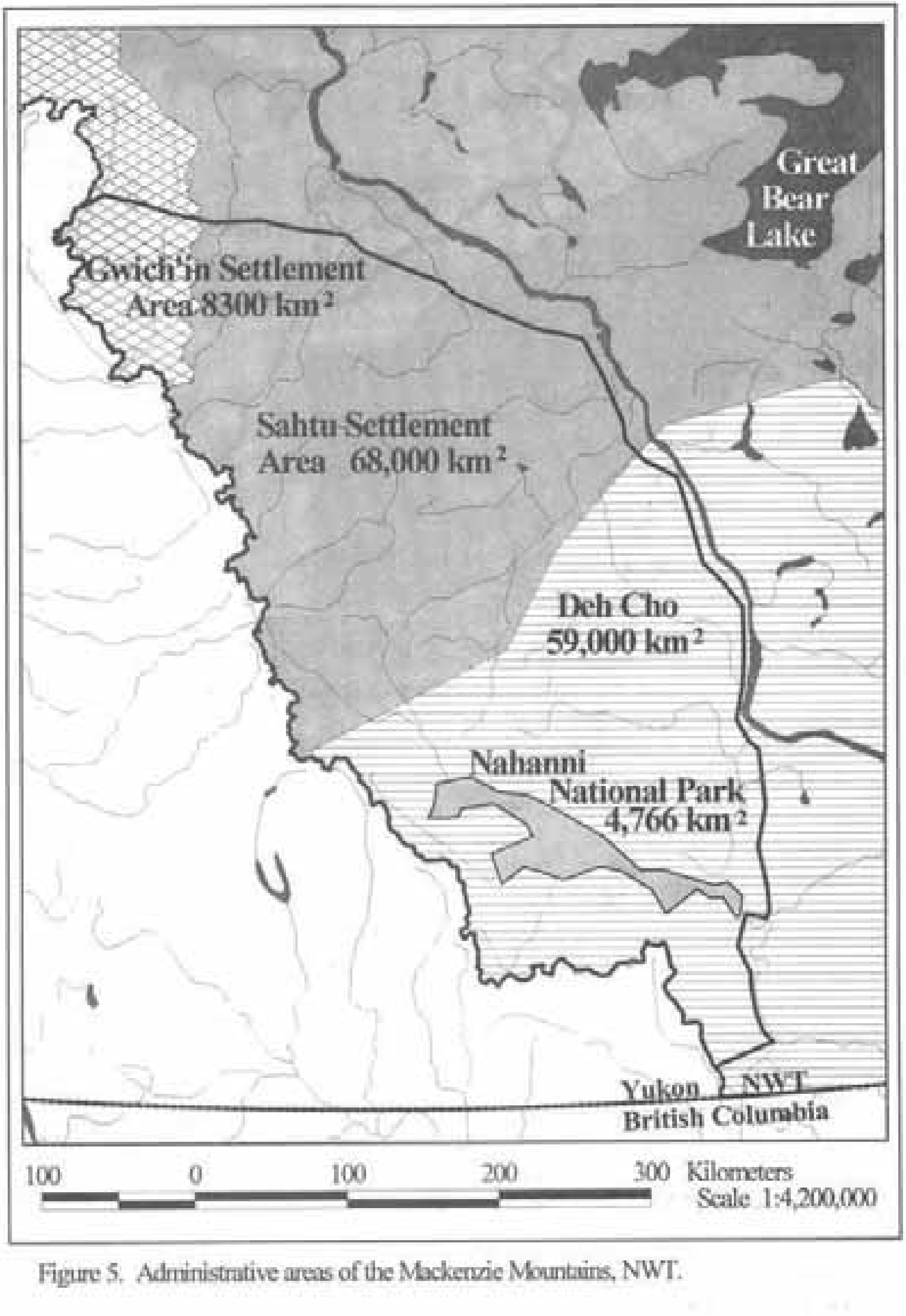

Figure 5. Administrative areas of the Mackenzie Mountains, NWT.

1996, tags to hunt Dall's sheep were purchased by 65% ($n = 252$) of 387 non-resident and non-resident alien licence holders (Veitch and Popko 1997). At least 230 (91%) of those spent some time sheep hunting and they harvested 201 rams for an 87% success rate. The average length of a guided sheep hunt in 1996 was 5.0 $\pm$ 3.0 days (range 1 to 13 days).

Table 2. Outfitted non-resident and non-resident alien hunter harvests in the Mackenzie Mountains, Northwest Territories: 1991-1997

Year	Licenced Hunters	Dall's Sheep Harvest	Woodland Caribou Harvest	Moose Harvest
1991	354	170	175	40
1992	364	203	142	32
1993	382	191	189	56
1994	355	195	164	46
1995	344	190	180	49
1996	387	201	172	47
1997	352	209	168	44
Mean	363	194	170	45

Over the last seven years the average annual harvest by outfitted hunters was 194 rams (Table 1). The consistency in annual harvest (range 170 to 209) is maintained primarily by the logistical constraints imposed in the number of hunters outfitters can get into the field (K. Hougen, personal communication). It is this limitation that has made the imposition of quotas on outfitters unnecessary. Due to the exclusive licence given to outfitters for provision of outfitting services within their zones, each outfitter is responsible for management of his area to ensure that hunting activity is spread out and localized overharvest does not occur.

From 1982 to 1992 an average of 26 resident hunters per year hunted Dall's sheep in the Mackenzie Mountains and they harvested a mean of 13 $\pm$ 7.6 (SD; range 1-29) rams (Table 2). Sixty-four rresident licence holders bought sheep tags in 1996, 32 hunted sheep, and 7 (22%) harvested rams (A. Veitch, unpublished data).

Because of the relative inaccessibility of the mountains without the use of aircraft, Dall's sheep hunting is not a common activity among subsistence harvesters in the NWT. The annual harvest is estimated to be 10 to 30 animals (Case 1990), of which no more than 5 are taken within Nahanni National Park (S. Catto, personal communication). The subsistence harvest includes an unknown number of adult females and juveniles in addition to adult males. Subsistence harvest tends to be concentrated near lakes and navigable rivers along the eastern front range. It does not appear that locations or numbers of sheep taken by subsistence harvesters have changed appreciably since the mid-1960's. For the 1964-65 and 1965-66 hunting seasons 12 and 4 sheep were taken, respectively (Simmons 1968); hunters did 88% of the harvest from Tulita, with the remainder by hunters from Nahanni Butte.

Characteristics of Harvested Rams

Since 1965 a minimum of 3192 rams has been harvested by non-resident and non-resident alien hunters in the Mackenzie Mountains (Table 3). The majority of these have been aged and measured by government biologists, technicians, and officers when hunters had a legal identification plug inserted in the horns and paperwork was done for export. Age was determined from counts of horn annuli (1965-1997) and by counts of cementum annuli from incisors extracted from the lower jaw 1981-1988 (Latour and MacLean 1994). Ages determined by horn annuli did not differ from age determined by cementum annuli, so age is now determined from horn annuli alone. Total contour length (outer circumference) of both horns was measured using a cloth tape placed at the front and base of the horn and run along the top edge of the horn back to the tip. No significant difference has been found between the average length of the left and right horns (Latour and MacLean 1994; Veitch and Popko 1996, 1997).

The average length of horns has remained consistent while the average age has increased from a mean of 8.5 between 1981 and 1985 to 10.0 in 1997 (Table 4). Outfitters now encourage their hunters and guides to seek out older rams as opposed to just those with the longest horns (K. Hougen, personal communication), which helps explain the marked increase in the average age of harvested rams. However, studies in the Yukon have shown that 'cohort pulses' where large

Table 3. Resident hunter statistics for Dall's sheep, Mackenzie Mountains, Northwest Territories, 1982-1992 (source: Government of the Northwest Territories 1994).

Year	Number That Hunted	Harvest	Success Rate
1982	28	16	57
1983	53	29	55
1984	24	11	46
1985	30	13	43
1986	22	7	32
1987	26	14	54
1988	26	10	38
1989	34	20	59
1990	10	10	100

numbers of male lambs survive to recruitment during some remarkably good years also have a dramatic effect on changes in average age of harvested rams (Carey and Dehn **this volume**). Older animals are also more likely to have the horn tips broken, or broomed, which could explain the consistency in horn length in spite of the increase in average age.

Table 4. Numbers, mean age (yr), and horn measurements (cm) of Dall's sheep rams harvested in the Mackenzie Mountains, Northwest Territories by non-resident and non-resident alien hunters, 1965 to 1997.

Period/Year	Harvest	Mean Age	Mean Horn Length
1967-68	168	8.4	86.4
1981-1985	638	8.5	91.0
1986-1990	905	9.4	90.0
1991-1995	949	9.7	88.5
1996	201	9.5	88.8
1997	209	10.0	89.9

The NWT is the last jurisdiction where Dall's sheep are taken under a ¾ curl rule (W. Heimer, Fairbanks, AK, personal communication; J. Carey, Sheep and Goat Biologist, Yukon Territorial Government, personal communication). Most rams in the Mackenzie and Richardson Mountains become legal for harvest at 5 or 6 years and attain full curl at 7 years (Barichello et al. 1987, Latour and MacLean 1994). The age distribution of harvested rams indicates that at least 85% of the rams taken each year are full curl (Latour and MacLean 1994, Veitch unpublished data). There does not appear to be any necessity to change the current ¾ curl rule for resident or non-resident and non-resident alien harvest.

Total Harvest

We estimate that the current total annual harvest of Dall's sheep in the Mackenzie Mountains is 210 to 260, of which at least 95% are ≥ ¾ curl rams. Assuming a total population of 14,000 to 26,000 sheep, this harvest removes 0.8% to 1.6% of the total population annually. This harvest rate appears sustainable, although some areas near communities receive relatively heavier hunting pressure and there may be some valid local management concerns. Latour and MacLean (1994) estimated that only 20% of the available full curl rams in study area E1-1 were harvested in 1988 and suggested the harvest level from 1979 to 1990 was "probably optimal for maintaining maximum productivity of sheep in the Mackenzie Mountains" (p. 35). This situation does not appear to have changed over the last seven years.

The Yukon Territorial Government (YTG) suggests harvest should be limited to ≤2% of the total population where the management goal is to increase a thinhorn sheep population (YTG 1996). The YTG also assumes that average annual mortality of full curl rams fully involved in the rut is about 50%, therefore, a harvest that focuses on older rams should be at least partially compensatory by taking animals that likely would not survive the winter (YTG 1996). The average age of rams harvested by non-resident and non-resident alien hunters in the Mackenzie Mountains is strongly biased towards older animals, so it is likely that this harvest is also largely compensatory.

CO-MANAGEMENT

Agencies Involved in Co-management

Responsibility for wildlife and other resource management within the Mackenzie Mountains is shared by the governments of Canada and the NWT, and by a variety of agencies set up under settled land claim agreements (Figure 2). The federal government is responsible for administration of Nahanni National Park (4766 km^2) in the southern end of the mountains while 56% of the remaining area is primarily under supervision of land claims. The Sahtu Dene and Metis Settlement Area (Government of Canada 1993) covers about 68,000 km^2 of the mountain range and the Gwich'in Settlement Area (Government of Canada 1992) covers 8,300 km^2. Within these settled land claim areas Renewable Resources Boards are the main instruments for co-management of forestry, fish, and wildlife while Land and Water Boards regulate land and water use. These and other boards set up under the land claims (e.g., Land Use Planning Boards and Environmental Impact Review Boards) feature representation from both the governments of Canada and the NWT with aboriginal participants in the agreements. The remaining 59,000 km^2 are within the Deh Cho Region where there is no land claim settlement and the governments of Canada and NWT maintain primary responsibility for resource management.

The Gwich'in and Sahtu Renewable Resources Boards have the following responsibilities regarding wildlife (Government of Canada 1992, 1993):

- Establish policies and propose regulations for wildlife harvest
- Approve wildlife management plans
- Change or remove selected special harvesting areas of participants of the land claims
- Permit or restrict commercial activity regarding wildlife
- Conduct research with other agencies or independently
- Carry out 5-year subsistence harvest studies (hunting, fishing, and trapping) with participants of the land claims. These studies quantify community minimum needs levels for every species harvested by each participating community
- Approve regulations proposed by the government

The Renewable Resources Boards each have six appointed members and a chairperson – three members are appointed to represent the governments of Canada and the NWT, and three to represent participants of the land claims.

Each community within the settled land claim areas also has a Renewable Resources Council that works with the Renewable Resources Boards and government departments to manage renewable resources. These councils have up to seven elected or appointed members whose primary responsibility is to encourage local involvement in wildlife conservation, harvest, research, and management issues. The Renewable Resources Councils within the Sahtu and Gwich'in Settlement Areas have the following responsibilities regarding wildlife (Government of Canada 1992, 1993):

- Manage the harvest rights for the community (methods, seasons, locations – within the law)
- Allocate community subsistence harvest needs levels among their members and allocate harvesting rights in national parks or protected areas among individual harvesters
- Advise the Renewable Resources Boards and government about issues of local concern
- Participate in collecting data about wildlife and wildlife habitat, including harvest

The fundamental feature of the co-management process is that it brings together government researchers and managers with the participants of the settled land claims to collectively develop recommendations and plans for management actions (Bailey et al. 1995). In co-management we seek consensus on management issues and actions, and the active involvement of participants in the land claim in any wildlife research and management that occurs within their settlement areas.

Population Monitoring 1997-98

Over the last three decades, due to the relatively low priority given to Dall's sheep by the GNWT, most management efforts for Dall's sheep in the Mackenzie Mountains have been passive (Poole and Graf 1985) and devoted to maintaining accurate harvest databases from the non-resident, non-resident alien, and resident harvests (Latour and MacLean 1994; Veitch and Popko 1996*a*; Veitch and Popko 1997). This has been periodically supplemented by aerial and ground surveys by Simmons (1967, 1969, 1970, 1982*a*, *b*), Simmons et al. (1984), Latour (1992), Shank et al. (1993), and Veitch and Popko (1996*b*).

Considerable effort was made by government biologists and officers each year to age and measure all horns from rams taken by non-resident and non-resident alien hunters on the premise that changes in sheep population numbers would be reflected in changes in the average age or horn length (Latour and MacLean 1994). However, recent work by sheep researchers in the Yukon has clearly shown the inability to detect underlying changes in population numbers from simply monitoring the average age of harvested animals on an annual basis (Carey and Dehn 1998).

Given this new information, the increased profile that outfitted sport hunting was receiving in the NWT, and greater access to secure funding by creation of the Sahtu Renewable Resources Board (SRRB) - we decided that a more active sheep management program was necessary. Over the course of the summer and fall of 1997 a joint project of the GNWT and the SRRB was established. We began ground-based Dall's sheep studies in three mountain blocks within the Sahtu portion of the north Mackenzie Mountains (Figure 6) chosen in consultation with the

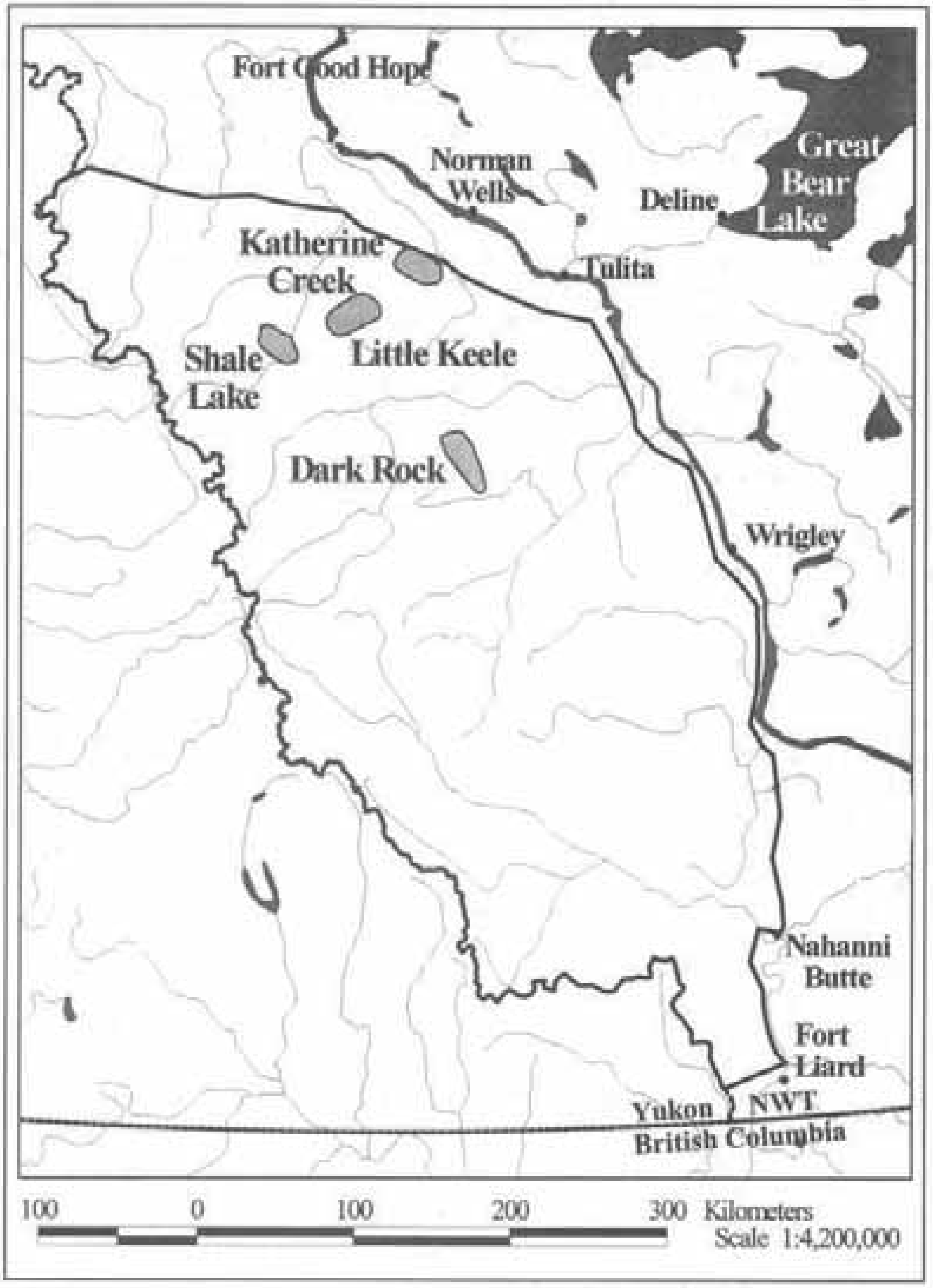

Figure 6. Dall' sheep study areas in the Mackenzie Mountains, NWT: 1998.

Renewable Resource Councils in Tulita, Norman Wells, and Fort Good Hope. These blocks complement an existing ground-based sheep study (1994 to present) at Katherine Creek (Veitch and Popko 1996*b*). The mean size of the study areas is 483 km^2 (range 391-599 km^2).

The primary objective of this project is to collect harvest data from each of the blocks and to collect information on numbers of sheep, productivity, recruitment, adult sex ratios, and the proportion of rams that are legally harvestable. We chose the ground-based approach instead of aerial survey because helicopter surveys have been shown to cause significant disturbance to sheep (Bleich et al. 1990, 1994), are expensive, inherently dangerous (Heimer 1994), and inaccurate when observers do not have extensive experience in an area (Shank et al. 1993). Harvest data will also be collected from each of the four study blocks.

In addition to providing needed data on the internal population dynamics of sheep within the study blocks, a complementary goal of the project has been to fully involve Sahtu Dene and Metis participants of the land claim in the communities of Norman Wells, Tulita, and Fort Good Hope. Therefore, the project has involved training for aboriginal residents of these communities in research logistics and methods, which was done during two training sessions with each two-member community team in the summer and fall of 1997. In June 1998 we plan to have crews in all four study areas simultaneously to allow meaningful comparisons among areas.

We hope that the studies established within the Sahtu Settlement Area will lead to additional ground-based sheep study areas in the Deh Cho region and Gwich'in Settlement Area. This would provide a clearer picture of the status and trend of sheep populations in the Mackenzie Mountain, more accurately define the role of harvest, involve more aboriginal people in data collection and population monitoring, and raise the profile of Dall's sheep within and outside the NWT.

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HISTORY AND CURRENT STATUS OF BIGHORN SHEEP IN NORTHEAST MONTANA

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Abstract: For thousands of years Audubon bighorn sheep (*Ovis canadensis auduboni*) inhabited the badlands, breaks and isolated mountain ranges of eastern Montana. In 1916 the last known Audubon sheep was killed in the Missouri River Breaks (MRB) near Seven Blackfoot Creek. In 1947 an attempt was made to reestablish bighorns in the MRB when 16 Rocky Mountain bighorn sheep (*O. c. canadensis*) were released in Garfield County. This reintroduction attempt initially appeared successful, but by 1956 the population had started to decline and by 1963 all of the sheep had died. There are currently 4 bighorn sheep populations in northeast Montana. Three of these populations occur in the MRB while the third is in the Little Rocky Mountains south of Malta. The sheep population in the Little Rocky Mountains, Hunting District (HD) 620 is the result of a 1972 transplant when 43 sheep were released near Saddle Butte. In 1982 a hunting season was established for this population. Since 1982 42 rams, having an average age of 4 ½, have been harvested. In December 1996, 87 sheep were observed during an aerial bighorn sheep survey in the Little Rocky Mountains. Two bighorn sheep populations are found in the MRB south of Malta in the Charles M. Russell National Wildlife Refuge. These populations are the product of a 1980 transplant when 28 bighorns were released near Brandon Butte. A hunting season was established in 1987 and both populations occur in HD 622. Since 1987 51 rams have been harvested in HD 622. The average age of harvested rams was 6 ½. One hundred and twenty eight sheep were observed during an aerial survey of these populations in December 1996. The fourth, and largest, bighorn sheep population is located in the Missouri River Breaks south of Chinook. This population is the result of transplants occurring from 1958 to 1961 in Two Calf Creek and a 1980 transplant in the Chimney Bend area. These sheep subsequently pioneered into the MRB along both sides of the Missouri River. Hunting seasons for this population were established in 1987 and in 1996 the area was split into 2 HDs. HD 482 lies to the south of the Missouri River, while HD 680 lies to the north. In the spring of 1996, 483 bighorns were counted during aerial surveys of both HDs. Since 1987, the average age of harvested rams has been 6 ½. Currently all 4 bighorn sheep populations in northeast Montana appears to be either stable or increasing. In April 1998, Montana Fish Wildlife & Parks (FWP) initiated a research project in conjunction with Montana State University to study bighorn sheep in HD 680. The objectives of the study include: 1) establish a standardized population estimation procedure; 2) determine movement and habitat use patterns; 3) test the efficiency of a bighorn sheep habitat suitability model and determine how much potential range in HD 680 is occupied; and 4) assess mortality, disease, predation, and other limiting factors in this population.

HISTORY

The first documented record of bighorn sheep in Montana occurred on April 29, 1805, by Joseph Fields of the Lewis and Clark expedition (Thwaits 1904-5). Although few people consider northeast Montana as bighorn sheep country, the sheep observed by Mr. Fields were along the Missouri River near the present day town of Culbertson. Further down the Missouri River Clark noted "great herds of the horned animals, one of which I killed." Bighorn sheep were still abundant in the mid-1800s, a fact noted by passengers aboard steamboats traveling up and down the Missouri River.

The bighorn sheep observed by early explorers were Audubon bighorn sheep, a race distinct from the Rocky Mountain bighorn native to the mountains of western Montana. Unfortunately, by the late 1800s Audubon bighorn sheep were nearly extinct and the last known Audubon bighorn was killed in 1916 near Seven Blackfoot Creek in the MRB (Walcheck 1980). Competition with livestock, habitat loss, disease, and unregulated hunting all contributed to their extirpation.

The first attempt to reintroduce bighorn sheep back into the MRB occurred in 1947 when 16 Rocky Mountain bighorns from Colorado were released near Billy Creek in northern Garfield County. This population initially grew quickly, but began to decline in 1956 and by 1963 it had completed disappeared. Biologists believe that these sheep died off from a number of reasons including competition for forage, disease, crossbreeding with domestic sheep and social intolerance towards domestic sheep (Eichhorn and Watts 1972).

CURRENT STATUS

There are currently 4 populations of bighorn sheep in northeast Montana. Three of these populations are located in the MRB, while the fourth population inhabits the Little Rocky Mountains. All of these bighorn populations are the result of transplants of Rocky Mountain bighorn sheep captured along the east front of the Rocky Mountains near Augusta, Montana.

Little Rocky Mountains - HD 620

The Little Rockies are a small isolated mountain range in south Phillips County. Although these mountains are heavily wooded, scattered meadows and rocky outcrops provide habitat for bighorn sheep. Most of the sheep habitat is on land administered by the Bureau of Land Management (BLM); however, some sheep also use private land within the Zortman/Landusky Gold Mine.

Forty-one bighorn sheep were transplanted into the Little Rockies in 1972. Since 1981 this population has remained relatively stable although there has been some year to year variation in survey data due to variables affecting sightablity. Since 1994 a helicopter has been used to conduct this survey. Prior to this time most surveys were conducted using a fixed-wing aircraft or by ground crews.

In most years 40 - 65 bighorns are counted during aerial surveys (Table 1). However, in December 1996, eighty-seven sheep were located. Survey conditions were excellent at the time of this census and sheep were concentrated on their winter range due to deep snow conditions on other parts of their range. Sheep were very dispersed during the winter of 1997-98 and, as a result, only 46 animals were located. Many of these animals were observed in wooded areas making classification difficult and sometimes impossible.

Table 1. Survey data for Hunting District 620 (1991-98).

Date	Rams				Ewes	Lambs	Unc	Total
	<½	½-3/4	>3/4	Tot.				
3/91	4	0	1	5	23	9	0	46
8/94	2	3	1	6	40	17	0	63
8/95	0	0	0	0	26	9	0	35
3/96	6	4	0	10	21	10	25	66
12/96	15	1	0	16	44	23	4	87
1/98	8	2	0	10	11	9	16	46

Unc = unclassified sheep

Although good lamb production is typically observed in this population, ram numbers are low. Poaching is suspected as being the primary cause of low ram numbers and last year 3 residents of the Fort Belknap Indian Reservation, were cited for illegally harvesting antelope, deer, elk and bighorn sheep outside of the Reservation (Chris Wright, pers. commun.).

A hunting season was established in 1982 with a quota of 2 either-sex bighorn sheep licenses. Either-sex licenses were increased to 3 in 1987 and 5 in 1988. In 1994 the either-sex license quota was reduced to 2 due to the low numbers of rams in the population.

Since 1982 hunters have taken 42 rams. These 42 rams had an average age of 4 ½ and ages ranged from 2 ½ to 9 ½ years old. The average base circumference for the largest horn of harvested rams was 13.6 inches and ranged from 10.0 to 16.5 inches. The average length of the longest horn was 27.3 and lengths ranged from 18.6 to 34 inches.

MISSOUR RIVER BREAKS - HD 622

Twenty-eight bighorns were transplanted into the Mickey-Brandon Buttes in 1980. Some of these sheep soon split off and moved into the Iron Stake Ridge vicinity, approximately 15 miles to the northeast. Bighorn sheep habitat is very marginal between these two areas and, although there may be some interchange of rams, these are basically 2 distinct sheep populations. Since both sheep populations occur within the Charles M. Russell National Wildlife Refuge, FWP cooperates with the Fish and Wildlife Service in managing these sheep.

Prior to 1994 surveys of this HD were conducted by ground crews, sometimes in conjunction with a fixed-wing aircraft. Since 1994 a helicopter has been used to conduct sheep surveys. Typically around 120 sheep are observed during annual surveys (Table 2) and year to year variations are primarily due to sightability.

Table 2. Survey Data for Hunting District 622 (1990-98).

Date	Rams				Ewes	Lambs	Unc	Total
	<½	½-3/4	>3/4	Tot.				
12/90	15	14	7	36	49	28	6	119
12/91	18	5	4	27	42	9	1	79
12/92	17	9	5	31	38	8	7	84
12/93	13	7	7	27	46	18	0	91
8/94	5	5	20	30	66	27	0	123
8/95	7	8	8	23	55	28	12	118
12/96	27	9	16	52	46	26	4	128
1/98	19	10	11	40	46	18	0	104

Unc = unclassified sheep, most of these sheep are probably ewes and yearling (1/4 curl) rams.

A bighorn sheep hunting season was established for HD 622 in 1987 with 2 either-sex licenses available. In 1988 the either-sex quota was raised to 5 where it has remained, except for a one-year increase to 7 in 1996. Five adult ewe permits were also issued in 1996 and 3 in 1997.

Since 1987 51 rams and 9 ewes have been harvested. Ages of harvested rams range from 3 ½ to 9 ½ years and average 6 ½. The average base circumference of the largest horn for harvested rams is 15.6 and range from 14.0 to 16.7 inches. The average length of the longest horn for rams is 35.7 inches and ranges from 30.5 to 40.5 inches.

MISSOURI RIVER BREAKS - HD 680 & 482

These river breaks encompass approximately 40 river miles between the Judith Landing (State Highway 236) downstream to the Fred Robinson Bridge (State Highway 191). Most sheep are found within 5 miles north or south of the Missouri River. The varied topography of these breaks supports a complex mosaic of vegetation and habitat types. Benchlands, ridgetops, coulee bottoms and steep south-facing slopes are dominated primarily by sagebrush-grasslands. The sideslopes of drainages have scattered stands of juniper and Douglas fir. The majority of sheep habitat is managed by the BLM although some sheep habitat also occurs on private land.

Between 1958 and 1961, 43 bighorns were released near Two Calf Creek in north Fergus County. A hunting season was established in 1969 and by 1971 the population had grown to 90 animals. However, the herd experienced high winter mortality during the winter of 1971-72 and for the next 8 years the population was static at 20 to 30 animals. In 1980, 28 bighorns were released in the Chimney Bend area in north Fergus County. These sheep subsequently merged with the Two Calf population and pioneered into the Breaks along both sides of the river. By 1986, a total of 63 sheep were counted during a fixed wing survey of this area. Another fixed-wing survey was conducted in 1992. During this survey, a total of 281 sheep were observed, including 64 rams of which 29 were 3/4 curl or larger. Helicopter surveys were conducted in 1995 and 1997. The 1995 survey revealed a total of 462 sheep including 84 3/4 curl or larger rams and 50 lambs/100 ewes. A total of 483 sheep were observed in 1997 including 69 rams that were 3/4 curl or larger and 44 lambs/100 ewes. This population obviously was growing in size and distribution, although survey effort and efficiency also increased over time.

Hunting seasons were established in 1987 and 2 either-sex licenses were issued for HD 680, which included the sheep range north and south of the Missouri River. From 1988-93, 5 either sex licenses were issued each year. The license quota was increased to 6 in 1994 and 15 in 1995. In 1996, HD 680 was divided into HD 482 south of the Missouri River and HD 680 north of the Missouri River. In 1996 and 1997 there were a total of 23 either-sex licenses and 18 ewe licenses issued each year for both HDs.

During these 11 hunting seasons, only 1 of 99 either sex permit holders was unsuccessful in harvesting a ram. The 98 rams that were harvested had an average age of 6 ½ years and ranged from 3 ½ to 10 ½. The average base circumference of the largest horn for these rams was 15.7 inches. Base circumferences ranged from 14.1 to 18.3 inches. The average length of the longest horn for these rams was 37.4 inches and lengths ranged from 32.6 to 44.2 inches.

HD 680 RESEARCH PROJECT

In early April 1998 FWP initiated a 3-year research project to study the sheep population in HD 680. Thirty bighorn sheep, 20 ewes and 10 rams, were radio-collared using helicopter net gun techniques. Radio collars were put on individuals from 10 different sheep bands throughout their distribution on the north side of the Missouri River. All collars were color coded for individual recognition. Microchips were injected under the skin of rams for additional identification and enforcement purposes. Blood samples were taken from all 30 sheep for standard disease and parasite tests.

The objectives of the study include 1) establish a standardized population estimation procedure; 2) determine movement and habitat use patterns; 3) test the efficiency of a bighorn sheep habitat suitability model and determine how much potential range in HD 680 is occupied; and 4) assess mortality, disease, predation, and other limiting factors in this population.

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TO BE UNLIMITED OR NOT, THAT IS THE QUESTION

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Abstract: Montana fills an interesting and somewhat contradictory role in the world of sheep management and sheep hunting opportunity. On the one hand we produce some of the largest Rocky Mountain bighorn sheep in North America in very restrictive limited entry hunting districts. At the same time we provide the most liberal hunting opportunities with our "unlimited" season hunting districts. Montana has 29 limited entry hunting districts and 5 "unlimited" hunting districts. The "unlimited" hunting districts are all located in southwest and southcentral Montana, north and east of Yellowstone National Park.

In our limited entry hunting districts the permits are generally either sex licenses. If successful in the draw, a hunter cannot apply for another Montana sheep license for seven years. All "unlimited" hunting districts have the following in common: unlimited number of hunters can participate, hunters must obtain the license through the drawing, i.e. must choose between obtaining an "unlimited" license or applying for a limited license; the license allows only harvest of a legal ram and; upon successfully harvesting a ram, the hunter cannot apply for a sheep license (limited or "unlimited") for seven years. There are three different versions of unlimited seasons in Montana: 1) runs until the quota of legal rams is harvested, usually 1-3; 2) has a set season length, usually 6 days, with a restrictive legal ram quota, usually 1; and 3) has a set season length, usually 6 days, with no quota on legal ram harvest.

Here, I focus on unlimited Hunting District 301. Changes began to occur in both the hunting district boundary and regulations in 1976, the first year transportation permits were required. Sheep Hunting District 301 was unchanged in boundary, season structure and quota during the 13 year period 1978-1990. From 1978 through 1990, the quota was 5 with two exceptions when the quota was 4, 1984 and 1985. The quota was exceeded 9 years out of this 13 year period and the season length ranged from 4 to 67 days. In 1991, the season changed to a 6 day season with no quota and for the first time hunters had to choose to apply for either a limited entry hunting district or unlimited entry hunting district during the permit application period. In short, Montana fully recognized the importance and significance of the unlimited season hunt relative to restrictive entry trophy sheep management districts.

In the 1990's, the "unlimited" season has become more popular. There was a 28 percent increase in number of hunters comparing the two 7 year periods, 1984-90 and 1991-97. In comparing the same time periods, there was no change in the percent success rate, median age of rams or the percent of rams 6.5 years and older in the harvest, 8.8 percent, 5.5 years and 46 percent, respectively.

Future changes are likely to be driven by hunter numbers and hunter congestion, rather than by a biological problem such as harvest rate or age structure. One is to simply go to limited entry hunts. The other is to try to implement a change which keeps the tone and tenor of the unlimited concept but does limit hunters to receiving a permit during only one out of three years. The pros and cons of these two management options will be discussed.

AGAINST THE GRAIN

CONSIDERATION OF A BIOLOGICAL APPROACH TO MANAGEMENT OF SUBSISTENCE SHEEP HUNTING THROUGH ADJUSTMENT OF BAG LIMIT

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[Author's note: This paper was originally accepted for the Council's 1994 symposium, but the Alaska Department of Fish and Game (for which I worked at the time) insisted on "pulling the paper" because it had placed a moratorium on subsistence-related papers which might be interpretable as critical of subsistence. I failed to grasp how discussing a sheep management situation with professional colleagues in Cranbrook B.C. could threaten Alaskan management policy. I considered it a positive effort to gather input from other specialists in the field. Nevertheless, I was prohibited from formal presentation of the paper. In an effort to satisfy the politically nervous in Alaska, and still gather input from participants at the Council Symposium, I presented the content of the paper as my personal opinion during a suspension of the symposium program. No formal paper had been given and none was published. When I returned, the circumstances surrounding our informal discussion (including the "brown bag incident") were investigated, and my compromise ruled sufficiently unacceptable that I was threatened with termination in an official reprimand. Aside from this personnel matter, there was no negative fallout from our informal discussion at the symposium. Having already received the "glory" for presenting this paper, and because its prediction that management which set aside biological limitations to satisfy social demands would be problematic has been validated, it is now appropriate to publish this account. I shall first present the paper as drafted in 1994, and then offer an update on the consequences as an appendix. WH]

Abstract: Both state and federal laws provide priority for subsistence harvest of Dall sheep (*Ovis dalli dalli*) in Alaska, and both laws mandate exclusion of other competing non-subsistence uses (e.g. nonresident guided hunting) when the harvestable surplus from Dall sheep populations cannot provide reasonable opportunity for identified subsistence users to attain past levels of subsistence harvest. Interpretation of these subsistence laws through litigation so politicized subsistence management of Dall sheep that biology became a minor consideration. Present liberal subsistence seasons and bag limits are based on aboriginal traditions (specifically ewe harvests) rather than the biological capacities of Dall sheep to support harvest, and may threaten sheep populations subject to subsistence harvest. By limiting subsistence sheep harvest to the biologically sustainable surplus, mature rams, management could be greatly simplified, and the longer-term stability of subsistence-impacted sheep populations enhanced. At the same time, the social and broader legal impacts of subsistence sheep harvest management would be lessened. Calculations suggest the biomass of sheep harvested would not decrease, but subsistence sheep hunters would have to adjust harvest patterns through increased effort.

INTRODUCTION

Development of a legally-mandated priority for subsistence use of fish and wildlife in Alaska followed discovery of the Prudhoe Bay oil fields (Heimer 1978a, 1980, 1982, 1986). Subsistence hunting for Dall sheep was formally institutionalized in state harvest regulations in 1980. At that time, the following conditions existed:

The number of subsistence hunters was relatively small, limited to recognized users in small communities inaccessible by surface transportation.

Subsistence harvest of Dall sheep was limited to areas where sheep were abundant.

It was assumed that subsistence sheep hunting had been traditionally practiced over the long term without detrimental effects to sheep populations.
Little was known about the magnitude, distribution, or composition of subsistence sheep harvests, and it was assumed that "legalizing" the practice through issuing permits for permissive use would provide data upon which future subsistence management programs for sheep could be built.

Because of these circumstances and the state's lack of prior experience in managing for legally mandated subsistence sheep harvests, the population biology of Dall sheep was not a major factor in deciding how to provide for subsistence use. That is, management of Dall sheep for traditional subsistence uses was an untested experimental enterprise (see appendix for details).

METHODS

Immediately Relevant History

Based on these assumptions, the State of Alaska established liberal regulations unprecedented in modern sheep management. These regulations were specifically designed to allow the state to implement its subsistence priority law as interpreted by the courts. This law prescribed priority for subsistence users, and defined subsistence as customary and traditional use (of sheep in this case) primarily for personal use or family consumption. Beginning October 1, 1980, the subsistence sheep seasons ran for seven months (Through April 30). The bag limit was three sheep of any age or sex. Requirements for participation included an Alaska hunting license and an "on demand" subsistence registration permit issued at a village in the harvest area. The first subsistence permits were issued in the coastal village of Kaktovik, which is near the remote northeast corner of the Brooks Range. The use of aircraft for transportation to the hunt area, harvest, or transportation of meat or gear from the area was prohibited. Mandatory (but voluntary) harvest reporting was a condition of receiving the permit to participate.

One goal of this program was documentation of sheep subsistence use in the village of Kaktovik, a community which had maintained a tradition of unregulated winter harvest of both sexes of Dall sheep in modern times despite restrictive, conservation-based regulations dating from 1926 (see Heimer, this symposium). The Alaska Department of Fish and Game (ADF&G) needed to know the magnitude, sex and age composition, location, and chronology of the harvest to implement the state's subsistence law (see appendix). In addition, the Department's Division of Subsistence was interested in other questions of social, political and cultural significance associated with subsistence uses of sheep.

Still, the main thrust of the subsistence management program was provision for subsistence use of Dall sheep consistent with state and federal subsistence laws. Both laws recognize subsistence as the highest priority consumptive use and require that other uses be restricted as necessary to protect reasonable opportunity for subsistence users. According to state law, if a sheep population is unable to provide reasonable opportunity for all users to meet their defined needs, use by guided nonresident hunters must be eliminated first. Should this not make enough sheep available for subsistence uses, non-local Alaskans without a history of past use of the affected population would also be excluded. If further restrictions are necessary, local users are to receive priority based on dependence and past use. Only when the population can no longer support any harvest would subsistence uses be curtailed. Implementing the federal preference was less specific than the state's procedure, providing for a "rural" (undefined in federal law) priority with selection among rural users by the same criteria as the state law. As long as a harvestable surplus exists, both state and federal laws mandate allocation of the surplus for subsistence uses.

The biological consequences of this priority among consumptive uses of Dall sheep, especially when coupled with liberal harvest regimes which may not have been biologically sustainable, were not major considerations when subsistence hunting for sheep was first institutionalized. As stated above, there were relatively few qualifying subsistence sheep hunters in relation to the perceived abundance of sheep in the specific areas where sheep subsistence hunts were to take place. Also, there was but one set of subsistence regulations at that time because the federal government had not yet pre-empted state regulations to provide for rural preference on federal lands (Heimer 1993a, b, c).

Ancillary History

Subsistence harvest programs: In an effort to comply with federal interpretation of the federal Alaska National Interest Lands Conservation Act (ANILCA) subsistence provision (Title VIII), Alaska initially attempted to limit subsistence use to "rural residents." This was not simple because there is no definition of "rural residents" in the federal law.

Alaska's first effort to conform to the federal ANILCA interpretation was to define rural residents through administrative action, i.e. through state regulations. A court challenge of this approach resulted in the Alaska Supreme Court ruling that administrative linkage of rural residence and preference was illegal (see Heimer 1986 for a discussion of the Madison case). Faced with being federally designated as "out of compliance with ANILCA," the Alaska legislature amended its existing subsistence law to define subsistence users according to the federal law (which included residence location as an identifying criterion). This residence criterion was subsequently challenged in court by a citizen named McDowell, and found to be inconsistent with the Alaska Constitution (Holland 1989). By extension from the McDowell case, all Alaskan residents were defined as subsistence users under the Alaska Constitution. This increased the number of potential subsistence hunters tremendously.

RESULTS AND DISCUSSION

In the intervening years (between 1980 and the McDowell ruling in 1989), subsistence hunting had proliferated far beyond the experimental Kaktovik program (see appendix). Unfortunately, these efforts to gather subsistence use data failed; few villagers participated in the "mandatory but voluntary" harvest reporting system. Consequently, harvest size and locations remained undocumented and harvest could not be associated with population trend. There was no reason to believe the limited information gathered from the Northeastern Brooks Range was reliable or applicable to other sheep subsistence scenarios. At the end of the proliferation cycle, the Dall sheep subsistence season ran for seven months with a three-sheep bag limit throughout the Northeast, Southeast, Central and Western portions of the Brooks Range. In the Western Brooks Range subsistence hunting was limited to local residents by specific state regulations. The season was open to any Alaskan in both the Eastern and Central portions of the Brooks Range where a typically liberal season had been unintentionally created in areas readily accessible from the oil pipeline haul road (the Dalton Highway). Once state-recognized subsistence hunters discovered they could reach these sheep from the Dalton Highway, the season adjacent to the road was closed.

In addition, subsistence seasons had been defined for readily accessible sheep populations on state lands adjacent to the Wrangell Mountains as well as within Wrangell St.-Elias National Park and Park preserve. Following the McDowell decision in 1989, any Alaskan with a hunting license and free harvest ticket could hunt sheep populations covered by state regulations. This included state lands, federal wildlife refuges, and national Park Preserves. Except in the Brooks Range, these seasons were limited to 42 days (the traditional Aug. 10-Sept. 20 fall hunt period for what is now recognized as non-subsistence hunting). The subsistence bag limit for the sheep-poor Western Brooks Range and the south and west portion of the Wrangell Mountains was one sheep.

Management Justifications for Harvesting Ewes

Population control: These liberal seasons, bag limits, numbers of potential hunters, and relatively easy access to sheep populations raised the possibility that subsistence harvest of Dall ewes would result in population declines caused by decreased population productivity and growth (Heimer 1978b). In practice this had already been purposefully implemented in Alaska (Nichols 1978) and for bighorn sheep (see Jorgensen et al. 1993 for a summary paper). Throughout the managed bighorn herds of North America, harvest of ewes is not uncommon. However, it should be emphasized that wherever this management practice is employed, the stated objective is limiting population growth or decreasing sheep numbers. Bighorn sheep living in temperate climates where natural predators are greatly reduced or absent encounter insufficient environmental resistance to keep them in equilibrium with their food supply necessitating population stabilization or periodic reduction by ewe hunting or transplant (Jorgensen et al. 1993).

Disease control: An additional factor which dictates maintaining bighorn populations at low densities is their history of population-decimating disease epidemics resulting from contact with domestic livestock (Heimer et al. 1992). Even if food is sufficient to maintain dense bighorn populations, most managers prefer to hold them at lower densities in efforts to prevent disease-related mass mortality.

I have argued this is not the case for Dall sheep in intact ecosystems (Heimer 1992). Dall sheep in undisturbed Alaskan environments do not face the problems common to bighorn populations; disease-related die-offs are unknown in Alaskan Dall sheep (Heimer et al. 1992). Natural predators exist at pristine levels. Consequently, Alaskan sheep populations have been reduced by hunting associated with ewe harvests in both historic and modern times.

Historic accounts of subsistence harvest decimating Dall sheep populations

It is impossible to know with certainty what happened in the unrecorded past. However, Campbell (1974) suggested aboriginal overharvest resulted in the reported paucity of Dall sheep throughout the Brooks Range early in this century. He proposed a similar explanation for extirpation of muskoxen (another "extreme k-selected" species) in Alaska. Similarly, Pruitt (1966) wrote that old hunters reported having hunted Dall sheep in the Lisburne Hills and Cape Thompson cliffs at the extreme Western Brooks Range limit of sheep distribution. Also, Bailey and Hendee (1926) recorded occurrences of Dall sheep at Cape Lisburne and Cape Beaufort. Dall sheep are not known to occur in these areas at the present time. If Campbell (1974) were correct in his hypothesis, it would be reasonable to conclude that subsistence sheep harvests, even using the comparatively primitive transportation and hunting technologies of the early 20^{th} century, contributed to local extirpation of sheep in these areas.

Modern Alaskan examples of population declines associated with ewe hunting

Alaskan experience with ewe harvests on the Kenai Peninsula (Nichols 1978) indicates harvest of Dall ewes will lower the absolute productivity of Dall sheep populations and reduce population size. In that experimental population reduction, ewe hunting of an isolated ewe population on the Kenai Peninsula resulted in the planned population decline, but all of the missing ewe sheep could not be accounted for by reported human harvest. It is presumed the missing ewes were either killed by hunters who did not report their harvest (Heimer 1978a) or had abandoned their range as a result of disturbance (Nichols 1978). Population decimation by natural predators in this instance was not considered a rational explanation. Few large predators (wolves) were present on the Kenai Peninsula at that time, and aerial counts before and after the hunt showed the planned population decline took place during the hunting season.

An unplanned example of ewe overharvest took place in the Tok Management area of the eastern Alaska Range during the late 1970s. In this instance, a band of 20 ewes was reduced to two ewes in the course of one afternoon's hunting by a large party of moose hunters with permits to take ewe sheep (R. A. Matthews, ewe hunt participant, Tok pers. commun.). Recovery of this ewe band has not been documented. Ewe harvests were curtailed in this area 19 years ago.

Alaska Department of Fish and Game managers have also justified ewe-driven population reductions and alleged population and hunter benefits resulting from limited ewe harvests in the Chugach Mountains (Bos 1996). These claimed benefits were chronologically impossible to attribute to ewe population reductions. Nevertheless, this ADF&G testimony to the Alaska Board of Game serves to document the population reduction rationale which has underlain every ewe harvest ever proposed by ADF&G.

An ongoing limited permit hunt for ewes on Round Mountain, Kenai Peninsula was also justified as a necessary population reduction because of lower lambs:100 ewes ratios on this mountain compared with the surrounding area. This examples further demonstrates the ADF&G position that even very limited harvests of ewes are expected to reduce population densities.

These examples show the purposeful harvest of ewe sheep in modern times has been judged to reduce sheep populations even under harvest conditions which were greatly more restrictive than the ewe harvest regulations associated with subsistence hunting in the in the Brooks Range. These modern examples also show that the principle justification for planned harvesting of ewe sheep is to cause a decrease in population size. It appears that Assumption #3 (above) is inconsistent with this thinking.

The Western Brooks Range: a case study/example

A situation *analogous* to ewe overharvest has been developing in the Western Brooks Range since 1990. In contrast to other ADF&G managers, Western Brooks Range managers maintain it is unlikely this decline involved relatively modest subsistence harvest of ewe sheep. In the Baird Mountains, populations of ewes, yearlings, and young rams counted from aircraft declined dramatically in 1990. I suggest this population is *analogous* to a decline caused by overharvest because a serious population decline required immediate management action (curtailing ewe harvests) to protect the resource.

According to Ayers (1996), the average annual harvest for the five years preceding the decline was 15 ewes per year from a population averaging 466 "ewes." "Ewes" are sheep which look like ewes from survey aircraft (ewes, yearlings, and young rams). This reported mean ewe harvest calculates to a minimum (because of non-ewe sheep among the 466 "ewe" sheep used for the calculation) three percent mortality due to subsistence harvest. If this mortality is additive, it would approximately double the measured natural ewe mortality in Dall sheep populations where ewe hunting is prohibited (Watson and Heimer 1984).

Nevertheless, unfavorable weather is listed as a more likely cause of the decline (J. Dau, Alaska Dep. Fish and Game area biologist, Kotzebue pers. commun). Regardless of the proximal cause, the population decline is still analogous in a management sense. The population of "ewe" sheep had declined to the point it was clear a harvestable surplus of ewes no longer existed. Management action to reduce ewe mortality was clearly necessary.

Still, mature rams continued to be a biological surplus. Harsh weather may virtually eliminate lamb production in any given year, or sequence of years, without severely affecting the survival of adults in their prime (Watson and Heimer 1984). Experience (Heimer 1990) shows mature rams are indeed, a sustainable biological surplus because one ram will breed many ewes. Survey data (Ayers 1995) show the availability of mature rams in the Western Brooks Range had not decreased when "ewe" numbers crashed. Hence, there was a biological surplus of mature rams, just not one of ewes. Ram harvest was biologically permissible, but ewe harvest was not.

In the judgment of managers on the scene, it was unlikely subsistence users would understand why guided or non-local resident ram harvests (viewed unfavorably as "trophy hunting" by local residents) could continue while local residents could not harvest ewes for food (J. Dau, Alaska Dep. Fish and Game pers. commun.). As a result of this judgment by managers in the field, all hunting was curtailed even though a biological surplus of mature rams remained clearly available. In this case, biological and legal management considerations were secondary to local political realities which had their basis in the cultural relevance of subsistence harvest practices and the ADF&G need for harmonious relationships with local residents.

As a result, subsistence hunters (as well as non-subsistence hunters) were deprived of using the relatively abundant biological surplus of mature rams. When, if ever, the population recovers and ewe harvests are restored, and a future decline eventually occurs (whatever its cause), this cycle is likely to be repeated unless a differing view of subsistence sheep hunting management develops. Management is, however, more than biology, and other factors should also be considered.

Legal concerns

The Alaska Constitution (Article 8) establishes the policy of the state with respect to natural resources as, encouraging the "development of its resources by making them available for maximum use consistent with public interest." Title 16 of the Alaska Statutes implements this policy by establishing the Alaska Department of Fish and Game through the duties and powers of the Commissioner of Fish and Game. Duties of the commissioner include management, protection, maintenance, and enhancement of the fish game in the interest of THE ECONOMY and GENERAL WELL BEING of the state (emphasis added).

"In the interest of the economy:" Here I shall offer some projections which are so simple they may be considered inappropriate in rigorous economic terms. Still, I offer them as illustrative of potential economic costs associated with socially based decisions relating to the subsistence priority.

Based solely on 1983's hunter expenditures, the non-subsistence sheep harvest of about 1,000 rams grossed about $7 million dollars in Alaska (Watson 1990). Hence, the simple average expenditure (not necessarily the worth) for each ram harvested in 1983 was $7,000. Estimates published in 1994 placed the dollar value of non-subsistence ram hunting at about $12 million (McCollum and Miller 1994) for the harvest of about 900 rams (an average of $13,000 per ram taken). Arbitrarily deriving an economic estimate of ram harvest worth by averaging these two data points (separated by 10 years, and with the 1983 figure being only expenditures while the 1993 data estimated value) gives a rough cash worth of $10,000 per ram. Applying this per-ram worth to foregone harvest from the Western Brooks Range is revealing.

When both subsistence and non-subsistence hunts were offered in the Western Brooks Range, the average non-subsistence ram harvest was 30 rams per year. Simple multiplication (30 rams times $10,000 per ram) projects a potential loss of $300,000 per year in economic benefit to the Alaskan economy if the ram season were closed unnecessarily. Unnecessary closure is a rational possibility considering ram stocks were not depleted when the population of sheep which look like ewes from an airplane declined by 44 percent, and the fact it takes at least five years for a young ram which looks like a ewe from an airplane to reach harvestable maturity in the Brooks Range. If ram hunting were unnecessarily closed for 5 years the potential loss would have come to five times $300,000 or $1.5 million dollars.

With non-subsistence use excluded from the area, and with the sheep population at half of what it formerly was, the potential economic loss to the state from not harvesting 15 rams would calculate at $150,000 annually using this simplistic model. Again, I use these projections to illustrate the fact that values other than the cash costs of subsistence foods are attached to Alaska's wildlife. Similarly, I speak of these economic losses as "potential" because it is possible that hunters who would have hunted in the Western Brooks Range could have hunted elsewhere. However, the statewide declines in Dall sheep populations, resulting in a significant downward trend in Dall ram harvests increasingly limit this possibility. It might inform decision makers if they balance the economic loss associated with total closure against the calculated cash value of subsistence foods produced by the same populations.

"n the interest of general well-being:" While expenditure values may define the more-or-less direct contribution to the economy of the state, they are not considered adequate measures of value. Contingent valuation methods are better suited to defining value (Watson 1990).

Watson's estimates of net benefit to non-subsistence sheep hunters using contingent valuation methodology ranged from $30 million for one year's hunting opportunity ($30,000 per ram harvested) to about $28 billion for all future opportunities in Alaska (for just the 2,800 hunters surveyed in 1983). If, as Watson supposed, this high dollar value ($28 billion) represents a "cash expression" of the emotional/spiritual attachment non-subsistence sheep hunters have to Dall sheep hunting opportunity, these sums may represent a measure of the importance of sheep hunting opportunity to the "general well-being" of non-subsistence sheep hunters. The "general well-being" of subsistence hunters has not been estimated. Economic benefits of subsistence hunting are typically expressed as food replacement costs.

The question of whether maintaining subsistence hunting opportunities which are basically inimical to conservation serves the "general well-being" of the state should be considered. How should the feeling of local well-being (which ADF&G says derives from the assurance of potential future subsistence uses to subsistence hunters) be balanced against the measured value of general well-being for non-subsistence hunters?

State and Federal Subsistence Laws: In spite of the economic consequences, both state and federal subsistence laws (passed prior to development of wildlife economic valuation) mandate a priority for subsistence uses. The state law was passed in an effort to pre-empt the federal subsistence preference in ANILCA; the federal law resulted from an anti-pipeline alliance between preservationist and Alaska Native interest advocates (Heimer 1982).

Both laws define a procedure for providing subsistence preference: impacted populations must be identified, the harvestable surplus from these populations determined, and the subsistence need defined. Once the harvestable surplus and subsistence need are known, subsistence need is to be subtracted from harvestable surplus. If any of the harvestable surplus remains, or if subsistence users do not take all the harvestable surplus, the remaining animals are to be allocated to non-subsistence users. This process was followed by the state when sheep were relatively abundant in the Western Brooks Range, but not after the weather-related population decline. That is, these laws were set aside by local managers for social reasons. Few observers noticed.

Summary of the present situation and recent history

The biology of Dall sheep and common management practices coupled with recorded and anecdotal histories of ewe harvests strongly suggest the harvest of ewes should not be considered biologically sustainable under normal conditions in Alaska. Subsistence management of Dall sheep is based on allowing ewe harvests because they were historic aboriginal practices. A case study of subsistence sheep management attending a major population reduction suggests that managing on the basis of human cultural bias is inconsistent with provisions of the Alaska Constitution. Failure to allocate the harvestable surplus of mature rams in the Western Brooks Range served neither the economy or general well-being of the state, and was a violation of both state and federal subsistence laws. Unproductive results such as these, should drive the search for a viable alternative.

AN ALTERNATIVE FOR CONSIDERATION

The biological side of the management equation seems adequately understood for management of consumptive uses. Demonstration that higher lamb production, greater ram survival and ultimately increased ram harvests occur under a management program designed to stay within the constraints of Dall sheep behavioral ecology (Heimer and Watson 1990) indicated Heimer's (1988) working hypothesis of Dall sheep hunting management predicts correctly. Management failures have come on the human side of the equation. Hence, I suggest that managing within the biological constraints imposed by Dall sheep biology, and meeting human needs and desires within these constraints would mitigate problems such as those detailed in the Western Brooks Range case study (see appendix). If the bag limits for subsistence management of Dall sheep were limited to mature rams (the known biological surplus from sheep populations), problems would be greatly reduced, if not eliminated.

Biological Considerations

Several components of the cumulative data base relating to mountain sheep in general, and Dall sheep in particular, indicate the harvestable surplus produced by Dall sheep populations in intact ecosystems (those with unmanaged predator populations and without exotic diseases) is limited to mature rams. Faced with relatively high environmental resistance, Dall sheep populations typically show slow rates of increase. They are "k-selected" in the extreme. Dall sheep adaptations to their environment do not include multiple births, no matter how good their food. Neither do Dall sheep adaptation options include early ovulation by females as a result of superior nutrition. Apparently, all Dall ewes ovulate in the wild (as do their well-fed zoo counterparts) at the age of 18 months, regardless of sheep densities (Heimer and Watson 1986a). Still, Dall ewes don't normally reproduce until the age or three of four years (Heimer and Watson 1986a), and rams are not consistently involved in reproduction until social dominance is achieved (Geist 1971). For most Dall rams this requires eight years, but in the Brooks Range, ten years is the norm (Heimer and Smith 1975). Rams which are not socially dominant are spared the mortality costs of rutting, and survive at high rates (Heimer and Watson 1986b). Heimer and Watson (1990) demonstrated that sustainable harvests from Dall sheep populations are practically and efficiently maximized by limiting harvest to (i.e. defining the biological surplus as) mature rams. Hence, a biologically sustainable subsistence harvest program would logically limit harvest to mature rams.

Social Considerations

Management of subsistence harvests on the basis of biological capacity appears to be politically impractical at this time. This is because subsistence use of wildlife has evolved a meaning which is much broader than simple sustenance. If harvest of sheep for food were the main consideration, limiting subsistence harvest to mature rams would not pose a significant problem. Mature Dall rams are typically 1.5 to two times as large as mature ewes. Consequently, biomass needs of subsistence users could be supplied by significantly fewer rams than ewes. Using estimates of sheep biomass harvested by subsistence hunters from Kaktovik Village suggested mature rams were sufficiently abundant in the Kaktovik subsistence harvest area to more than satisfy the estimated need in the village and still leave enough mature rams to more than match past non-subsistence ram harvests.

However, hunting selectively for mature rams would require subsistence hunters to expend greater effort to harvest the equivalent biomass as mature rams. This decreased efficiency may not be culturally acceptable. Customary and traditional practices as they relate to maintenance of Alaska Native culture presently represent the political "high ground" in the subsistence debate. Common sense predicts that ancient harvest patterns were driven by economy of effort in obtaining food. If this were true, historic harvest traditions, which centered on ewe harvests, evolved because ewes were the most readily available sheep. Ewes would also have been slightly more abundant because of the natural tendency of sex ratios in Dall sheep to favor ewes in pristine conditions. Still, harvest of ewes could have continued indefinitely if at a low enough level (less than two percent of any band estimated by Heimer (1988)), or if rotated between several ewe populations, particularly given low yield harvest technologies. Campbell (1974) argued primitive technologies for Dall sheep were highly successful. Nevertheless, primitive harvest techniques were certainly less efficient than modern show machine (or aircraft) transport and flat-shooting rifles with telescopic sights.

Subsistence users are seemingly loath to forsake modern technology in gathering subsistence harvests, but cling tenaciously to the cultural values associated with harvesting wildlife for food. Consequently, there may be little hope of extracting subsistence sheep management from the over-exploitation/complete closure cycle predictable from the Western Brooks Range case study. Over the longer term, this cycle works against sustained subsistence use of Dall sheep populations by focusing on a harvest which does not appear biologically sustainable. If this is realized, it may be possible to eliminate the prospect of this cycle through changes in harvest selection by subsistence users.

Throughout the first 75 years of the 20th century, the dominant Western European culture was willing to coerce harvest selection among Alaska Native subsistence users in the name of conservation. However, as evidenced by the legal institutionalization of subsistence uses, those days have passed. The political and cultural mood of today appears to value human cultural diversity more highly than long-term wildlife conservation of the resources on which that diversity is based. This means the only hope for putting Dall sheep subsistence management on a biologically sustainable basis is a trade-off in cultural values within the Alaska Native community. If sustainable subsistence use is of sufficiently high value, Native societies where subsistence use of sheep is anticipated over the long term may find it adaptive (in the light of increased human population sizes and use of advanced harvest technologies) to consider restricting their harvests to those which are biologically sustainable. Even the tolerance of cultural diversity advocates (which favor subsistence uses of sheep as currently practiced) is likely to erode if the dire consequences illustrated by the weather-related events in the Western Brooks Range become associated with documented overharvest by subsistence users.

A Rather Encouraging Example

In 1992, the U.S. Fish and Wildlife Service (USFWS), acting in concert with the Interior Region of the Alaska Department of Fish and Game, took a biologically progressive step in adjusting the subsistence bag limit for Dall sheep in the Southeast Brooks Range. In this case, local residents (of Arctic Village) had complained that their subsistence hunting success was declining. They assigned this decline to sheep disturbance by non-subsistence hunters during the fall season (which effectively ended about a month before the opening of the subsistence season). Faced with this demand, the USFWS committed itself to a multifaceted approach to the problem.

First, the intensity of non-subsistence use was documented in cooperation with ADF&G. Results of this work suggested the level of non-subsistence harvest and its associated aircraft support were insufficient to produce the disturbance and redistribution of Dall sheep alleged by subsistence users.

Next, the USFWS flew intensive distribution and abundance surveys throughout the traditional subsistence use area where subsistence harvest success had allegedly declined. Surveys were also flown in the better sheep habitats adjacent to the subsistence use area. Data gathered on these surveys revealed Dall sheep were scarce in the core subsistence use area, but reasonably abundant in the adjacent better habitats.

Finally, USFWS and ADF&G biologists captured and radiomarked sheep in both the subsistence use area and the adjacent habitats. Subsequent relocations of these marked animals did not reveal movement into or out of the low-density subsistence use zone between the non-subsistence and subsistence seasons. That is, there were no data suggesting non-subsistence use affected subsistence harvest success in the area.

Nevertheless, the federal Subsistence Board (Heimer 1993a,b,c) responded to a request on the part of local residents to exclude all non-subsistence hunting from federal lands in the low-density subsistence use area (the Arctic Village Management Area). This was exactly what the local residents had requested. In this zone, only federally recognized subsistence users (Arctic Village residents and residents of tribally related villages with alleged histories of sheep use from this area) were allowed to hunt for Dall sheep during the "standard" seven-month season.

Most significantly, ADF&G and the USFWS jointly recommended an apparent bag limit reduction from three sheep of either six or any age to two rams.

> *[Author's note: Here it is important to note that while ADF&G and USFWS cooperated to effect a more biologically rational regulatory compromise than the three-sheep bag limit, both agencies failed to follow the legally mandated procedure for allocating resources where a subsistence preference is operative. Neither agency determined the harvestable surplus or the subsistence need prior to making subsistence use allocations restricting non-subsistence uses. Having failed to quantitatively define these parameters, it was impossible to subtract the "need" from the "surplus" to see how many sheep, if any, remained for allocation to non-subsistence uses. WH]*

Departure from the established "three-sheep" bag limit was not strictly based on agency recognition that "any ram" is part of the biological surplus (which has been demonstrably limited to mature rams where harvest pressure is high). Rationale for the "any ram" harvest was to allow subsistence users maximum selectivity and opportunity for success within a biologically conservative harvest regime. This rationale was based on projections (based on anecdotal accounts of past harvest from the Arctic Village Sheep Management Area) that the ram harvest would be biologically insignificant. The biomass arguments presented above were also a factor.

The USFWS bag limit recommendations were accepted by the Federal Subsistence Board, and became federal subsistence regulations. In the surrounding areas (where sheep were not so scarce) the three-sheep seven-month season was still available to these subsistence users, and non-subsistence harvests of full-curl rams during the fall season continued.

The affected rural residents are now (as of 1994) dissatisfied with this arrangement. They are currently pressing not only for expansion of the subsistence management area, but also for re-instituting ewe harvests and elimination of individual bag limits in order to increase efficiency of sheep harvests for Arctic Village. Allowing the better sheep hunters to take sheep (presumably in the most efficient manner) for the entire community would not only provide greater harvests, it would be consistent with historic aboriginal hunting, harvest, and sharing patterns.

> *[Author's note: After this paper was drafted in 1994, residents of Arctic Village were partially successful with proposals to the Federal Subsistence Board. The Arctic Village Sheep Management Area has been expanded to, and non-subsistence hunting excluded from, the higher density sheep populations on the upper east side of the East Fork of the Chandalar River. However, the bag limit has not been expanded from two rams to three sheep. Paradoxically, the result has been an actual lowering of the bag limit from three sheep to two rams in the expanded exclusive use subsistence area. Anecdotal accounts of subsistence effort and harvest from this exclusive use area suggest minimal use of Dall sheep by the federally-recognized users (F. Mauer USFWS, Fairbanks pers. commun.). WH]*

SUMMARY

Subsistence management of Dall sheep is still evolving, and thus far must be considered an experiment. To date, the experiment can not be considered a success. Little has been learned of subsistence harvest magnitude or distribution during the 14 years of subsistence harvest permit systems. As a result of this continuing dearth of knowledge and the closed-season example from the Western Brooks Range, an optimistic outlook for resolution of the resource-based problems discussed here is naïve.

Further skepticism is warranted by the apparent fact that in the Northeast Brooks Range, federally recognized subsistence users opted for a reduced bag limit (two rams instead of three sheep) in order to exclude biologically insignificant and sustainable ram harvest by non-subsistence users from an area which they use but little. That is, Arctic Village residents sacrificed their customary and traditional harvest patterns (which were earlier justified on economy of effort), and apparently accepted a more restrictive bag limit in order to exclude ram harvests by non-local residents.

> *[Author's note: Federal Subsistence Board Action in this case appears inconsistent with the Bureau of Indian Affairs solicitor's opinion that the Federal Subsistence Board cannot accept a proposal which is counter to subsistence (see appendix). WH]*

Descent into this management morass was not sudden. In fact, it has been nearly imperceptible. Failure to recognize this problem for so many years may account for some perceptions of this paper's content as alarmist or anti-subsistence. However, I think an actual and solvable problem exists, and that basing management on biological constraints before planning allocation of harvests to humans is the key to its solution.

At the outset, subsistence management for Dall sheep was limited enough that consideration of its biological impacts was secondary to its human, political, and experimental justifications. Focus on the human and political components of the system has led us into a complex legal maze which surely isn't the result envisioned by the well-meaning authors of the subsistence priority. The present situation may also be at variance with the state constitution and statutes dealing with natural resources.

Still, it may be possible to provide for subsistence use within a biological framework. If we accept (or test) the working management hypothesis for Dall sheep (that mature rams are the only harvestable surplus produced by mountain sheep populations in intact ecosystems) and provide for subsistence preference through increased opportunity for all hunters to take mature rams instead of excluding non-subsistence hunters for social reasons, the gloomy outlook for the future of sheep management for all uses could be much brighter. For these changes to occur, the adjustment will have to be voluntary, and on the part of the subsistence community. This presents managers with a formidable educational challenge.

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Appendix:

DETAILS AND FALLOUT FROM DALL SHEEP SUBSISTENCE MANAGEMENT IN THE WESTERN BROOKS RANGE, AUGUST 1998: "REAPING WHAT'S BEEN SOWN"

by Wayne E. Heimer

HISTORY

Both state and federal laws require several steps in providing subsistence preference.

First, the populations supporting subsistence use must be identified.

Second, calculation of the harvestable surplus from each population supporting subsistence use is required.

> Calculation of harvestable surplus requires specific knowledge of population size, recruitment to the population, and population mortality. These parameters are extremely difficult to measure. Determining them, in a major drainage or within a few discrete, impacted populations is incredibly expensive. Making these measurements over a large area is practically impossible, and the resulting projections are always arguable. Additionally, the determinants of harvestable surplus vary from year to year depending on environmental resistance components (weather, predation, and harvest by humans). Finally, calculation of sustainable harvest also assumes the habitat produces a predictably stable amount of food. For Dall sheep this may be a reasonable assumption. However, the lag time (9-10 years) between birth and maturity for Dall rams in the Brooks Range further complicates this calculation.

Third, both state and federal subsistence laws require knowledge of subsistence needs.

> Determining an accurate "need number" requires careful work because it is in the interest of local users to maximize this figure.
>
> Once the three prescribed data sets are in hand, the subsistence law's recipe for granting preference to recognized subsistence users require subtracting the *subsistence need* from the *harvestable surplus*. If any of the surplus remains, it is to be allocated to non-subsistence users. If local subsistence users don't want "outsiders" harvesting game in their area, it suits them to represent "subsistence need" as greater than it actually is. Hence, it seems risky business to simply ask rural residents how much they need.

Subsistence law procedure and "the Kaktovik program"

Identifying populations: When the state first provided legal subsistence uses of Dall sheep for Kaktovik in the Brooks Range (where it had been openly practiced for decades even though technically illegal), managers were readily able to identify the areas where use had been centered during recorded history. It had been common knowledge for decades that sheep populations on the Hula Hula River supported historic and recent use by Kaktovik residents. These sheep ranges (about 50 miles from Kaktovik) were identified as the impacted populations.

Calculating the harvestable surplus: Biologists disagreed sharply over what constituted the harvestable surplus of Dall sheep. One school of thought argued that Dall sheep are ungulates, and must therefore be subject to general principles of ungulate management. These principles are based on the assumption that ungulate populations grow until limited by their density at carrying capacity. Simply, this assumption predicts populations below carrying capacity will grow (by producing "surplus individuals") until they become so dense that female productivity declines due to lack of food. When this happens, recruitment declines, the population ceases to grow, and appears stable in numbers. In populations at carrying capacity, theory predicts reducing the population will result in increased population growth rate (by again producing "surplus individuals"). According to this construct, any reduction of static populations (which are presumed density-limited) will result in a compensatory increase in productivity (and recruitment) as the population strives to again attain carrying capacity.

This is the dominant theory in wildlife management and it is taught as a principle in wildlife management schools. It has proven generally reliable in temperate ecosystems without predators for members of the deer family, and has predicted well for species introduced into ideal habitats with no predation.

However, Dall sheep in the Brooks Range aren't deer, they don't live in a temperate-zone ecosystem, and they are subject to unchecked predation. These facts led me to question the relevance of "carrying capacity theory" to Dall sheep in the Brooks Range. I, along with other biologists, reasoned that basic adaptational differences to differing habitat types (stable Vs cyclically-changing) and distinctively different animal families (*Bovidae* Vs *Cervidae*) argued against a compensatory sheep population increase simply because harvest of ewes had lowered the population below the observed, apparently stable level.

I reasoned that sheep reproductive biology is different from deer because sheep are adapted to habitats with stable plant communities while deer are adapted to successional habitats. Biologists call these unchanging plant communities "climax ecosystems." Because sheep live in climax ecosystems, they should be adapted to the resulting stable food resource. Sheep adaptations to a stable food source include exclusive single births (never twins or triplets as in deer on super-abundant forage) and apparent universal ovulation at 18 months of age. In deer, ovulation as yearlings is uncommon, usually limited to populations at low density where food is super-abundant. These same density/nutritional conditions result in increased multiple births among deer.

There is no evolutionary (inclusive fitness) advantage for an animal adapted to a climax habitat to have the explosive population growth potential to exploit a transient nutritional bonanza. Hence, Brooks Range sheep should not be expected to respond to population reductions in the same way as deer in temperate ecosystems. In short, reducing sheep populations through ewe hunting shouldn't be expected to result in compensatory population growth (through the unavailable options of even earlier ovulation or multiple births) in an effort to re-attain carrying capacity. Consequently, I argued, the only certain harvestable surplus from sheep populations should be mature rams.

Although carrying capacity advocates argued for the traditional approach to ungulate management, there were no compelling empirical data to support carrying capacity theory for Dall sheep in the Brooks Range. Similarly, because our "climax adaptation argument" is a *post hoc* rationalization for the way things are (which means it's beyond simple experimental verification), there were no specific data supporting it either. Hence the choice was arbitrary.

The "carrying capacity" viewpoint prevailed. It was, after all, familiar (and more acceptable than a modern inclusive fitness argument to ADF&G leaders who still remembered learning it as a wildlife management principle). My suggestion that Dall sheep in pristine ecosystems are exceptions to the accepted principles of ungulate (deer) management (in low predation ecosystems) was new at the time, and is still disregarded as unsupported conjecture by many classically trained wildlife managers.

In accepting the "carrying capacity model," ADF&G leadership assumed the harvestable surplus from a sheep population included significant numbers of ewe sheep, and that such harvests would not notably compromise the long-term use of subsistence users. At that time, I had not yet assembled or articulated the historic, modern, and anecdotal ewe harvest accounts given earlier.

No effort was made to estimate or actually determine the harvestable surplus from the sheep populations on the Hula Hula River when the "Kaktovik program" was established in 1980. Sheep were then quite abundant, and non-subsistence users were limited to harvest of 7/8 curl or greater rams.

Despite anecdotal information that subsistence harvests had "used up" one unusually vulnerable Dall sheep population on the Hula Hula River (S. Pederson, ADF&G Subsistence Div. Fairbanks), no systematic effort was made to assess the impacts of subsistence harvest (other than the voluntary but mandatory reporting) from the exploited sheep populations. The emphasis was to be on defining the subsistence need by allowing "unconstrained" harvest and tallying up the number and sex composition of the sheep taken by Kaktovik residents.

This methodology was in contrast to simply asking local residents how many they had taken in the past or how many sheep they'd like to have in the future. For this reason, (defining subsistence need based on reported actual use) the initial sheep subsistence season was 7 months long, and the bag limit was 3 sheep of any sex or age. Still, feeling a responsibility to provide some protection for the sheep populations of the Northeast Brooks Range, ADF&G established an overall harvest quota of 50 sheep. This figure was considered more than adequate provision for subsistence opportunity based on what was known about past harvest levels by the village of Kaktovik. This was a first, faltering step toward implementing the subsistence preference law. Unfortunately, it was also the final step.

Cloning the "Kaktovik Program"

The original rationale for the "Kaktovik program" was to offer a liberal season, and see how many Kaktovik residents took from the sheep-rich Northeast Brooks Range. However, once the Kaktovik subsistence harvest had been legally recognized, other Brooks Range villages demanded similar preference. To meet these demands, *the experimental "Kaktovik program" was implemented as though it were a functional management scheme* throughout the Brooks Range (Arctic Village/Wiseman, the South Central Brooks Range, Anaktuvuk Pass, and ultimately the Western Brooks Range) without regard to whether it made biological sense or was sustainable. Hence, none of these seasons were ever rationally based on what is actually biologically sustainable. All these hunts involve extensive (typically seven-month) seasons for ewe sheep, voluntary reporting, and from Anaktuvuk Pass eastward, the most liberal bag limits in the history of regulated sheep management.

When this social experiment reached the Western Brooks Range, managers realized sheep populations there couldn't support the potential harvest provided by the original "Kaktovik program." Consequently, the bag limit was reduced from three to one sheep, but ewes remained available for harvest because subsistence hunters had "always" taken ewe sheep. This was a social, not biological, decision.

Except where subsistence is involved, the only justification for harvesting Dall sheep ewes is to lower population sizes where local managers don't think predators (and other components of environmental resistance) are keeping population densities low enough to protect their ranges. *In these places, ADF&G area management biologists assume (based on carrying capacity theory) there are too many sheep for the range, and justify ewe hunts to lower population densities.* Carefully controlled ewe harvests are allowed on Round Mountain on the Kenai Peninsula and in the Chugach Mountains behind Anchorage as expressions of this rationale. ***Only where subsistence sheep hunting dominates is biological relevance superseded by social and political agendas.*** *In these subsistence areas, there is no intent to suppress resident Dall sheep populations. Paradoxically, sustained subsistence opportunity demands the populations be maintained or enhanced.*

MANAGEMENT CONSIDERATIONS

Biological Reality:

Unfortunately, biological relevance asserted itself in the Western Brooks Range. Bad weather in the late 1980s and early 1990s resulted in sheep population declines across Alaska, including the Brooks Range. In sheep-rich areas, subsistence sheep harvest managers made no management responses to these population declines. In the Wrangell Mountains and Northeast Brooks Range, many sheep remained despite populations being lowered by about 30 percent. In these units, ADF&G managers don't consider the reported level of ewe sheep harvests biologically significant to the overall, area-wide populations. Hence, these ewe seasons persist to serve the same social and political justifications originally given for their establishment.

When its low-density sheep populations declined, ADF&G's Nome Region no longer enjoyed this luxury; the Western Brooks Range was, by comparison, "sheep-poor" from the beginning. Hence, sheep managers in the Western Brooks Range had to deal with the *biological complications* of socially-generated ewe harvests. In its official account of the sheep decline in the Western Brooks Range, ADF&G blamed weather events but failed to mention liberal seasons and ewe harvests, probably for the same reasons other subsistence sheep managers haven't responded to population declines. The reported ewe harvest was viewed as biologically insignificant.

Failure to include harvest of ewes as a possible contributing factor may represent an interestingly selective perspective. In explaining the decline, ADF&G apparently decided to be inclusive enough to speculate that disease might (with predation) have compounded negative weather effects, but not inclusive enough to suggest ewe hunting might also have been a contributing factor. It is, of course, technically fair to speculate about disease (because anything *could* happen), but there are no pathological data suggesting disease was a factor.

> *[Author's note: During sheep surveys documenting the decline, ADF&G biologists found several intact dead sheep. Rather than using ADF&G specialists in wildlife disease to see if there were a disease problem, local managers opted to use local veterinarians trusted by local residents. Whether wildlife disease specialists networking with other world-class experts would have found something the local vets missed is unknown. The sheep carcasses were sufficiently decomposed that no conclusive results could be obtained. At least no results have ever been published, and ADF&G disease specialists have no knowledge of unpublished positive findings. Neither do I. Hence, it appears that no disease agents were ever identified, and the cause of these isolated deaths remains unexplained and open to speculation. Even though ewe hunting (typically practiced specifically to lower mountain sheep populations) was obviously occurring, the ADF&G summary of the decline failed to include this traditional subsistence harvest practice as a possible contributor to lower population numbers. Instead, it invoked the theoretical possibility disease may have contributed to the decline. I consider this further evidence that social management considerations in Western Alaska pre-empted biological ones. WH]*

Management Reality:

Even the most socially or politically correct subsistence harvest management plans and regulations require eliminating human use when its continuance threatens population welfare. Hence, the unsustainable subsistence harvest of ewes in the Western Brooks Range had to be curtailed after the population declined. This did not require a complete closure of sheep harvests as first begun by ADF&G in 1991. Here's why:

Dall sheep responses to bad weather in the Alaska Range have been well documented (Watson and Heimer 1984). These data showed bad winter weather affected sheep population dynamics primarily through lamb production failure. Additionally, most adults of advanced age (nine years and up) died; but survival of sheep in their prime years (two through eight) was not greatly affected. Sheep survey data from the Western Brooks Range during the decline suggested a similar pattern. Because sheep in their prime maintain high survival, there should still have been a biological surplus of full curl rams when ADF&G began to close ram seasons in 1991 (lamb production and ram recruitment had apparently been good prior to the bad winters, and it takes nine to ten years for a ram to reach full curl in this area).

Managers in the Nome region realized this biological fact, but decided on a total closure because they anticipated explaining (to their local constituents) that ewe hunting couldn't be allowed, but that hunting for mature rams (disdained as "trophy hunting" by the locals) could still take place, would be socially unacceptable. In spite of this sensitivity to local feeling, there was still a surplus of adult rams in the early 1990s.

ADF&G's print media account (Fairbanks Daily News-Miner Aug. 4, 1988) pointed out that ewes, not mature rams, are the preferred subsistence food. Ewes are usually easier to harvest, and are better eating (they are fatter than rams because they are pregnant (and near term) in April when most subsistence harvest takes place). That is, ADF&G managers chose not to allocate the known harvestable surplus. Local users didn't normally prefer eating mature rams, and managers were certain local residents would not approve of allocating these mature rams (even though they were not preferred subsistence food) to "trophy hunters," (who preferred to harvest (and eat) mature rams). Here it is noteworthy that much of the mature ram harvest was taken by local non-subsistence hunters participating in the normal fall harvest period (which is now understood as non-subsistence).

The cumulative effect of all these management-relevant factors was that the first closure was *not* the biologically risky ewe harvest, but harvest of mature rams in the Baird Mountains. The subsequent management choice was complete closure of Dall sheep hunting in the Western Brooks Range. Local residents were told that when the sheep populations recovered, they could resume traditional harvest practices. Until then, there would be no sheep hunting.

Legal Considerations:

Despite the social awareness of regional ADF&G managers, both state and federal subsistence laws said (and still say) that as long as there is a biologically sustainable harvest, it is to be allocated to humans. Hence, it seems likely the Department and the Alaska Board of Game may have been violation of both state and federal subsistence laws. Even the US Department of the Interior, which frequently, and righteously, asserts its "rural preference mandate" failed to challenge ADF&G's social conscience. The uncontested total closure stood.

Further Developments:

Weather eventually normalized somewhat, ewes were seen with lambs, and some were recruited to the populations. Still, the populations did not show notable growth. Environmental resistance to population growth, (including predation--and perhaps the hypothetical disease which still *could* be there) was apparently limiting population growth. Slow growth should be expected for sheep populations because they don't have the ability to grow explosively in the face of normal environmental resistance just because food is abundant.

Where there is "normal" environmental resistance in the form of predators and weather, sheep populations grow slowly. Nevertheless, with improved weather, the sheep populations began to look better. As a result, local users began to press for resumption of sheep hunting as had been promised when the harvest season was closed.

Political Reality:

Given the local demand for resuming sheep hunting, ADF&G managers decided to appropriate the harvestable surplus of mature rams they had previously with-held. Perhaps maintaining a closed sheep season until the public was ready for restriction of harvest to mature rams was a master-stroke of social management, but it may also be interpreted as paternal manipulation of the local residents. In either case, the good news was, the local public was apparently ready to learn that harvest of mature rams is biologically safe even when ewe harvest can't be allowed.

The bad news, was that by the time managers got around to allocating the sustainable harvest of full-curl rams, the federal government had pre-empted state management on federal lands. Additionally, up to seven years of normal age-associated mortality had claimed most of the harvestable surplus available when the weather turned bad. This meant the currently available surplus of rams was considerably less than it had been in 1991 because there had been several years of failed recruitment and continued predation in the meantime. It also meant that total harvest of these full-curl rams carried a higher biological risk than it would have if phased in during 1991. Nevertheless, ADF&G managers began to work through the allocation process, which requires a great deal of public involvement.

Part of this public involvement required ADF&G to identify the number of Dall sheep required by subsistence users and recognition of this "need number" in codified regulations by the Alaska Board of Game. Instead of relying on the 12 years of subsistence harvest data it had collected (in which it had sufficient confidence to use it for calculating non-subsistence allocations prior to the decline) to define subsistence need, the Department of Fish and Game, opted for community interviews by subsistence resource specialists. These social scientists conducted interviews to coax the extent of past use from local residents…even though such past use might have been technically illegal. Results of this exercise resulted in the Alaska Board of Game certifying the subsistence needs from the Western Brooks Range at a maximum of 60 sheep per year.

> *[Author's note: I find acceptance of this figure biologically astonishing. Prior to the population decline, the total population of the area was estimated at about*

900 adult sheep. Hence, a 60-sheep annual harvest would have been a rate of almost seven percent per year. Reported subsistence harvest data and Subsistence Division village surveys show ewes typically compose about 40 percent of subsistence-harvested sheep. If applicable here, this would have produced a ewe harvest rate approaching four percent. All population modeling I've ever done suggests there is no harvestable surplus of ewes from a stable Dall sheep population (such as the Western Brooks Rang population appeared to be prior to the decline). ADF&G media releases suggest predation contributed to the decline so I conclude the ecosystem isn't predator-free. Hence, I'd expect even light ewe harvests to lower overall population sizes. A four percent harvest over 12 years of open subsistence seasons should have lead to a notable decline.

Furthermore, the subsistence need defined through community interviews was 6.4 times the mean reported subsistence harvest during the 12 years the subsistence hunt was open; and defined the need at three times the highest subsistence harvest ever reported. Hence, there was a grand disparity between what local residents told interviewers they had taken in the past (which if actually and consistently taken should have caused the population to decline—even without effects of bad weather) and what harvest records indicated as contemporary use. WH]

Once the state had established allocation of the harvestable surplus of mature rams, a few local residents on the Federal Regional Subsistence Advisory Council had their way with the Federal Subsistence Board which ignored the state's work, compliantly "rubber stamped" the Regional Council's recommendation, and nullified the state's regulations on federal land (most of the Western Brooks Range).

[Author's note: "Rubber stamping" of Regional Council proposals has been a Federal Subsistence Board pattern since 1995 when the chief solicitor for Ada Deer's Bureau of Indian Affairs told the Federal Board it had to follow the directions of the Regional Councils unless the Federal Board could give specific reasons why it shouldn't. This solicitor's opinion lifted language from ANILCA Title VIII Sec. 804 ***(which deals with state—not federal—management)*** *and applied it to the Federal Subsistence Board. Since receiving this solicitor's opinion three years ago, the Federal Subsistence Board has established a pattern of passing Regional Council proposals with only cursory consideration of the biology involved or subsequent management impacts. Reference to published proceedings of the Federal Subsistence Board (esp. from Spring 1995) should convince anyone doubting this assertion. WH]*

THE PRESENT CONTROVERSY

The result of Federal Subsistence Board "rubber stamping" the Regional Council's proposal was a difference in allocation. By some cryptic process, the state had established the harvestable surplus this year at 40 mature rams. This figure begs analysis in that it is significantly greater than the maximal full-curl harvest theoretically predicted as sustainable from a stable Dall sheep population of the size remaining in the Western Brooks Range. The latest published data from the Western Brooks Range (through 1995) indicate a mean post-decline population of 570 adult sheep. Five percent of this population (the calculated maximum sustainable harvest of full-curl rams) would be 29 rams. The allocation figure, 40 rams, is 1.4 times this theoretically projected maximum sustainable harvest.

[Author's note: Use of data through 1995 is permissible for these calculations because yearling recruitment, if any, during the last three years would not greatly influence the availability of full-curl rams. It takes three to four years for a ram lamb to be recognized as a ram from aircraft and years for 10 years for a ram lamb to reach full-curl in this area. If the 40-ram harvest limit is attainable, it will apparently require heavy harvest of standing stocks of full-curl rams. WH]

According to the 1995 survey data, the number of 7/8 curl and greater rams totaled 36 for the entire area. Data on full-curl ram numbers are not available. The Nome Region is unique among ADF&G regions in that it has never enumerated full-curl rams (even though the full-curl regulation was implemented there in 1993). Rams between half-curl and 7/8 curl totaled 143 in 1995. If these figures are accurate, and if the harvestable surplus is 40 rams, there must have been little mortality among full-curl rams (whose average age in this area is 10 years) during and following the population decline (further suggestion of an unallocated harvestable surplus in the early 1990s). Alternatively, recruitment above what might normally be expected would also have had to occur to produce a present harvestable surplus of 40 full-curl rams. Neither high survival among rams aged more than 10 years or unusually high recruitment is consistent with a weather mediated population decline. Again, it appears that even if the 40-ram harvest allocation is realizable, attaining it will require virtually complete harvest of all full curl rams in the Western Brooks Range.

[Author's note: I am troubled by the 40-ram harvestable surplus because of its coincidence with the arbitrary 40-sheep quota which existed after downward adjustment from the standard 50-sheep harvest ceiling cloned from the experimental "Kaktovik program" 16 years ago. The "Kaktovik program" carried a protective overall harvest quota of 50 sheep from a population exceeding 2,000 adults. This "standard" quota was eventually extended to Arctic Village, Anaktuvuk Pass, and the Western Brooks Range. After I highlighted the biological risk of this relatively large quota in the sheep-poor Western Brooks Range, Nome Region managers and the Alaska Board of Game reduced the quota to 30 sheep. Local residents protested this reduction, and it was subsequently increased to the 40 sheep now on the books. Because the calculations detailed above suggest the 40-ram quota is too high to be sustainable by a population of 570 adult sheep once possible standing stocks are depleted, I'm concerned that the arbitrary ceiling on overall harvest may have been administratively mistaken for the sustainable harvest. WH]

Prior to the Federal Subsistence Board's actions, local residents appeared satisfied with the state's program. Through the state process, 11 rams from the 40-ram quota had been allocated for non-local, non-rural users. Those local residents involved in the state process did not complain. However, at least some local residents on the Federal Subsistence Regional Council decided they wanted all 40 rams, and told the Federal Subsistence Board so…hence the "rubber stamping" wherein the federal system reallocated all 40 rams to "their recognized hunters."

Because of this federal action, ADF&G leadership felt it had to either cancel its non-subsistence permits or limit their use to state lands. Canceling state hunts (even subsistence hunts) because of federal actions dates from assumption of wildlife management in Alaska by the federal subsistence management system. The state has repeatedly closed its seasons because of federal subsistence allocations.

Because of the narrow focus federal managers place on their perceived mandate to provide subsistence allocations for rural residents, the federal system has a history of "doubling up" the allowable harvest because the federal system refuses to recognize that state hunts actually provide subsistence foods. In cases where "doubling up" the harvest would have been harmful to the affected population, the state has typically canceled its season (realizing that subsistence users will still eat—even if they do it on a federal permit), and that stubbornly sticking to the legal state seasons could result in biological overharvest.

This accountability to conservation carries several consequences for the state:

> First, in protecting the resource in the face of federal intractability, the state abrogates its legal right to manage Alaska's wildlife.
>
> Second, closing state seasons furthers the Alaska Native perception that the state has lesser interest in providing for subsistence users than the federal system. This perception has further implications because of the political influence Alaska Natives have on the direction and level of federal involvement in managing Alaska's wildlife and fish.
>
> Third, the state "shoots itself in the foot" with this policy because it hides the negative impacts and obscures the biological bankruptcy of the federal subsistence management system.

Few Alaskans, legislators, or federal judges realize the significant negative impacts which would have occurred had ADF&G not consistently placed resource health above the state's management prerogative.

Perhaps because the Nome Region has led the way in social biology, or perhaps because of the established "ADF&G tradition" of closing state seasons to protect wildlife populations from overharvest (Kilbuck caribou and Game Management Unit 23 muskoxen are well-documented Nome Region examples), or perhaps because the Nome Region has a complex emerging history of "comanagement" with its constituents which demands harmonious relations with local power brokers, ADF&G mangers moved rapidly to adjust the state's harvest plan for sheep in the Western Brooks Range.

Unfortunately in the case of sheep, adjusting the state harvest plan didn't make biological sense. Mature, full-curl, rams have been conclusively shown to be the consistently available harvestable surplus from Dall sheep populations. The state went to full-curl regulations statewide in 1989 (except for the Brooks Range which followed in 1993) because of this biological fact. Hence, closing the non-subsistence season or restricting use of the 11 non-subsistence permits for full-curl rams to state lands (after it had allocated 29 permits to meet the defined subsistence need) because of presumed biological harvest concerns requires some explaining.

ADF&G biologists asserted a virtual absence younger rams (because of failed recruitment during bad weather years) "in line" behind the full-curl rams allocated for harvest. ADF&G survey data do not support this assertion in a compelling fashion; neither is the 40-ram quota consistent with it. Nevertheless, in the judgment of ADF&G leadership, it would have been biologically irresponsible to allow the potential harvest of eleven "extra" full-curl rams if subsistence users had taken all 40 full-curl rams allocated to federally recognized rural residents. ADF&G leaders reasoned that such an event might leave some populations with no mature rams.

> *[Author's note: Research has established that Dall sheep populations without mature rams suffer low lamb production and subsequent low survival of young rams. Hence, even though the survey data through 1995 did not clearly support the Nome Region's staff assertion that there are no young rams coming into the full curl cohort, there is some conceptual justification for their concern. WH]*

In addition to not being supported by published data, and inconsistent with the apparently high 40-ram quota, this argument appears a selective invocation of sheep biology to justify limitation of non-subsistence users. Remember, ADF&G first failed to acknowledge the effects of ewe harvests in low-density sheep populations, and then withheld allocation of a more abundant full curl ram resource than presently exists (beginning in 1991) because local managers thought it too hard to explain to local residents. Perhaps sheep managers in the Western Brooks Range are now more cognizant of the relevance sheep biology than in the past, but their past emphasis has clearly been on social rather than biological management.

Furthermore, considering that all 11 non-subsistence permits are now "crowded" into a state-owned tract of land in the DeLong Mountains (along with whatever subsistence harvest—both state and federal—might take place there), raises the question of whether a biological justification for restricting harvest to state lands might not place sheep populations on state lands in the DeLong Mountains at greater risk of full-curl ram overharvest than leaving things as the state originally planned.

The ceiling on ram harvest was limited to 40 rams. Now the state has (presumably on the basis of biology) provided that up to a fourth of them will be taken from much less than a fourth of the total Western Brooks Range sheep habitat, the area which already has the greatest ram shortage. ADF&G's 1995 survey data indicated no 7/8 curl or greater rams in the Wulik Peaks area (where state lands are), and only 15 younger rams between 1/2 and 7/8 curl. If these rams were normally distributed among the six sub-7/8 curl age classes, there could now be up to five legal, full-curl, rams available in the Wulik Peaks.

Eleven hunters might be satisfied by five rams (or even one ram) because non-subsistence hunters expect little more than the opportunity to hunt and some reasonable expectation of success. Still, it would be out of character for ADF&G to allocate more permits than have this reasonable probability of success. Perhaps factors other than biological management drove the state's decision.

Subsistence hunters may be expected to expend unusual effort this season to make the political point that they do, indeed, need large numbers of sheep. The new federal regulations will allow use of aircraft for subsistence hunting in the Brooks Range for the first time this winter…for subsistence harvest of full-curl rams. This invites greater expenditure of effort (and money), and should be expected to increase harvest. Expending extra effort to document alleged subsistence needs is not unprecedented. It has been funded as a cultural maintenance program in the Northeast Brooks Range for Arctic Village residents for several years, and Western Brooks Range users appear to have done it in the past. In 1985, when the quota had been reduced from 50 sheep to 30 sheep, the reported harvest jumped from the previous average of three sheep to 21 sheep. Subsequently the quota was raised to 40 sheep, and from 1986 to closure of subsistence hunting, the reported harvest averaged 16 sheep per year.

Even if unusual effort is expended, the additional harvest allocated to non-subsistence users would probably have been biologically insignificant. Three and perhaps four of the non-subsistence permit holders are nonresidents who must hire a guide. Nonresidents typically have an 80 percent success on guided sheep hunts. If all four nonresidents hunted, statistics predict three rams harvested. That leaves seven resident permit holders. I know of one who will not hunt there because of the controversy. That leaves six potential resident hunters. Alaskan resident sheep hunters typically have a 38 percent success (or did before sheep populations declined). If this held for the six remaining permit holders we could anticipate harvest of up to another two rams. This optimistically calculated five-ram harvest would not have been the end of the world. Only if they all came from a single population with only five mature rams, and only if there were no 7/8 curl rams in the population would there have been ***even a transient lowering*** of lamb production in the affected group because of ram harvest by non-subsistence users.

> *[Author's note: We found the presence of 7/8 curl rams assured normal breeding age and frequency among ewes in the Alaska Range. WH]*

A projected five-ram full-curl harvest, three of which must be taken within a restricted guide area on state land, for which no guide had hunters (J. Jacobson Registered Guide pers, commun.) couldn't possibly have compromised subsistence harvest opportunity to an "unreasonable" level. (Subsistence laws prescribe "reasonable opportunity for success" for recognized subsistence hunters.)

Considering these data and projections, a biological justification for closure makes no sense at all, and if restriction of the "unlucky eleven" cannot be justified on the basis of biology, the only other possible justification is prevention of user conflicts.

> *[Author's note: A legal case brought by air boaters excluded from moose hunting in Minto Flats, Alaska, has (pending appeal) established user conflict as an acceptable, but non-biological reason for excluding a class of hunters from participation. Hence, I hypothesize political maneuvering on the rural preference issue as a more robust explanation. WH]*

COMMENTARY

If it is possible for power brokers to orchestrate a high profile, but basically inconsequential action (only 11 non-federally recognized hunters were affected) which demonstrates the horrors of "dual" or federal management, there is reasonable expectation the Western Brooks Range sheep management controversy can be used as political leverage by those advocating amendment of the Alaska Constitution to implement preferential policy. Amendment of the state's constitution to allow rural preference (or non-rural discrimination depending on where you live) has been the proposed "solution" to state/federal conflicts for several years. Alaska's senior Senator is the champion of this movement, and Alaska's Governor his strongest ally. Naturally, because the Commissioner of Fish and Game is appointed by the Governor, the Alaska Department of Fish and Game supports the Governor's position. Amendment advocates have, thus far, been unsuccessful in forcing the Alaska legislature to place an amendment allowing preference/discrimination on the ballot in spite of two special legislative sessions called by the Governor specifically for that purpose. These efforts failed in spite of expenditure of a $400,000 media campaign to force the legislature toward the amendment position. Still, the issue is not settled, and orchestrating a high-profile federal intervention (even one with no biological relevance) would serve the amendment advocates (including the Commissioner of Fish and Game) well politically just before November's general election. This seems a particularly likely possibility given the stridency and power of Alaska Native legislators from the Nome region.

> *[Author's note: I feel slightly sheepish about advancing what may seem like a "conspiracy theory," but because the biology of the situation makes so little sense, I'm driven to consider other explanatory hypotheses for the Department's actions. WH]*

CONCLUSIONS

First, this problem arose because subsistence sheep management was based on social/political comfort/correctness instead established biological facts. Additionally, both state and federal subsistence laws were set aside. Clearly, some managers (particularly at the higher levels in ADF&G) were/are more interested in local and statewide resource politics than in providing for harvest of biologically surplus animals. This shouldn't be a shock. Politics have always been a component of wildlife management, and Alaska's present Governor has used fisheries and wildlife management for political advantage more than any Governor in Alaska's history.

[Author's note: I've worked for all of them. WH]

Second, whatever the details may be, it is clear that the Department (i.e. the Commissioner, i.e. the Governor) did not defend Alaska's sovereign right to allocate wildlife in this instance. Alaska's Governor rolled his Fish and Game Department over for the federal system without an apparent whimper. Altering the state's regulations wouldn't seem so odious if there were some plausible biological protection or realistic allocation issue involved. There isn't.

Third, this lesson showcases not only the heavy-handed arrogance of the federal managers, it also shows the many flaws in both state and federal subsistence allocation systems. Two of these flaws dominated this scenario:

> Under the pretense of increasing local participation in management decisions, the federal system turns management of local resources over to local "lay managers" (Regional Subsistence Council members) who have only one legally defined function…advising the U.S. Secretary of Interior of their needs. These councils have no management mandate, no conservation mandate, and no common use mandate. However they typically display an evident, and sometimes virulent, bias against "outsiders." *Because of the composition and balance of power in these local Subsistence Advisory Councils, a single influential individual can effectively nullify the entire state management effort.* What this means is that a few prominent local citizens appointed by the US Secretary of Interior dictate management decisions. This case may be a striking example.
>
> Typically, local residents, regardless of race prefer excluding outsiders. This is particularly dangerous to conservation because the folks most likely to generate a shortage through overuse (because they live locally and depend on local resources) are empowered to maintain that shortage by dictating local management decisions. If they do not choose to manage for resource abundance, which must be shared under law, but instead opt for local "sufficiency," they will never have to face outsiders using "their" area.
>
> Additionally, the Federal Subsistence Board accepts what it calls "traditional ecological knowledge," as equal to (or in many cases superior to) scientific biological facts. This, of course facilitates "management" by the local residents who resent any use of "their area" by outsiders. In this case, the state's finding that the subsistence need is "up to 60 sheep" seems to have been presented to the Alaska Board of Game without critical, biological scrutiny. Certainly, an empirical measurement of subsistence need holds greater promise of accuracy than asking the beneficiaries of the system to define their need.

Fourth, it demonstrates one hazard of amending the Alaska Constitution. The reason we're told we must amend is so that we can clone the federal system (for implementation as the state system) to provide "federally mandated" rural preference. Were we to do so, there is little reason to anticipate it would lead to better conservation than when the same local folks dominate state management using the mechanics by which they now dominate the federal system.

THE BIGGER MANAGEMENT PICTURE

I suggest ADF&G's loss of "the will to manage biologically" is a major factor in this type of scenario. Persistent federal pressure coupled with political interference at even the most basic management level by the Governor's office (particularly when the Governor is beholden to Alaska Natives who prefer the federal system) has sucked the Department's former commitment to practical biological management right out of the agency. This loss of will to manage biologically provides an adequate explanatory hypothesis for the generally compromised conservation such we see in subsistence management of Dall sheep. The Western Brooks Range sheep management situation has been an ongoing illustration since 1982.

Loss of will to manage was facilitated by regional fragmentation of the Department beginning as far back as 1969. From statehood to 1969 the Department was organized by statewide species project. This didn't make sense then because we didn't know enough species biology to manage at that level. Also, some local management challenges were not amenable to solution by a statewide species project system which was often unresponsive to local concerns. As a result, the Department was reorganized into regions with area offices. Statewide species projects were scrapped.

Over time, the regional (and area) offices became progressively more autonomous. What we now see with respect to the Western Brooks Range sheep situation is the most specific example of this trend. Species biology (perhaps considered as "extra-regional input") was set aside to facilitate getting along with local power brokers (in this case NANA Regional Corporation) which are immensely powerful both politically and economically.

The pitfall of autonomy

While "decentralization" sounds good, it carries inherent risks: Given the autonomy "enjoyed" by the region, the residence of the regional staff within the community, and the absence of "higher authority" (such as a statewide species plan or accepted biological standard) to "blame" for locally unpopular decisions, compromised biological management is inevitable. It is natural for managers assimilated, or sufficiently pressured by their community to accede to local desires…whether biologically sound or not. After all, they have to live there…and they also benefit from excluding outsiders.

> *[Author's note: ADF&G harvest records show the some of the biologists who manage these sheep have taken what might otherwise be considered trophy rams during the winter season. Here, I must emphasize this is entirely legal because biologists cannot be excluded from participation just because they are employed*

as public servants. Because they live in the area like everyone else they are legally entitled to federal subsistence preference and participation in the winter hunt based (which is solely based on residence location). The fact that they may choose to harvest mature rams is perhaps laudable, at least they aren't having a negative impact on population growth. WH]

These pressures inevitably (in an autonomous region) lead to "localized management" to benefit local residents at the expense of other Alaskans.

While public service agencies like ADF&G should be responsive to the publics they serve, the evolution of regionalized management as evidenced in this example, has probably reached the point it is counter-productive to maintaining the proven record of success of constitutionally mandated conservation. I suggest reorganization of the ADF&G regional system would be beneficial. Management based on biology and accountable to law probably wouldn't have kept the weather favorable for sheep, but there is every reason to believe it would have precluded development of the present problem.

COMPENSATORY REPRODUCTION AND DISPERSAL IN AN INTRODUCED MOUNTAIN GOAT POPULATION IN CENTRAL MONTANA

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Abstract: Data on reproduction, population trends, harvest, and dispersal of mountain goats (Oreamnos americanus) on Square Butte, an isolated volcanic formation in the prairies of central Montana, were analyzed for the period from 1971 to 1996. Kid: older goat ratios were correlated with density of older goats ($P<0.01$). Population trend was correlated with harvest rate ($P<0.01$), but was also correlated with goat density ($P<0.01$). This study suggests a compensatory response in reproduction to changes in population size in mountain goats. The results suggest that wildlife managers can expect maximum reproductive response to harvest from introduced mountain goat populations that are still an initial increase phase. Dispersal of mountain goats was documented to two new topographic complexes separated by 4 kilometers of prairie habitat. Mountain goat dispersal was related to density dependent factors in the source population.

Full paper has been submitted for publication to Wildlife Society Bulletin.

WHAT WE LEARNED ABOUT HARVEST MANAGEMENT OF ALASKAN DALL SHEEP: 1971-1997

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Abstract: Prior to the 1960s knowledge of Dall sheep (*Ovis dalli dalli*) was fragmentary and anecdotal. Systematic scientific investigation of Dall sheep ecology for application to Dall sheep management by the Alaska Department of Fish and Game began with Lyman Nichols's Kenai Peninsula work in the late 1960s. This work subsequently expanded to Interior Alaska, and by 1967, a significant Dall sheep research effort which would run continuously for 25 years was underway in the eastern Alaska Range. For 21 of these years, I was principle investigator for this program. During this time, the program established the biological basis upon which Dall sheep are managed throughout most of Alaska. These research efforts defined many characteristics of Alaskan Dall sheep including population identity, population performance, reproductive timing and rates, management-relevant reproductive behaviors, nutritional needs, mineral physiology, habitat constraints, hunter preferences, and societal values. Data from these studies indicated classic density-dependent nutritional constraints are not generally applicable to Dall sheep, and established that, in undisturbed ecosystems, harvest-management-alterable sheep behaviors are of greater importance than density-dependent nutrition. This review article contains a brief history of Dall sheep in Alaska and highlights those aspects relevant to harvest management.

INTRODUCTION

Since the United States purchased Alaska from Russia 130 years ago, Dall sheep have been ignored, exploited, and managed by varying approaches. Present-day management practices range from total protection in state-created viewing areas and Congressionally established national parks, through biologically based harvest management on state and selected federal lands, to highly permissive management for subsistence uses on other federal lands. How this spectrum of management practices evolved is a fascinating, sometimes rough-and-tumble, human adventure in the biology and politics of wildlife conservation in Alaska.

The opportunity to hunt has been the historic linchpin of North American wildlife conservation. Where hunting opportunity has been maintained, wildlife populations thrive through active management programs. World experience shows that where public hunting is not allowed, public interest in wildlife suffers and wildlife conservation becomes an exclusive, expensive "government function" instead of an individual human activity. Broadly stated, preserving hunting opportunity is, at present, the key to maintaining Dall sheep abundance and use through conservation.

Without special effort, funding, and aggressive input from Dall sheep hunters, Dall sheep management would probably be on a less secure course than it is in Alaska today.

EARLY HISTORY

Except for those populations heavily exploited by aboriginal hunters, Dall sheep were basically untouched when Alaska was purchased from Russia in 1867. Early accounts recall that Eskimos harvested significant numbers of sheep from readily accessible populations in the Northern Brooks Range for their own use and for barter to whalers and explorers. During this period, aboriginal use of Dall sheep was part of the nomadic seasonal cycle or as a back-up source of meat when other sources failed (Campbell 1974, S. Pedersen, ADF&G Div. of Subsistence, Fairbanks pers commun.). The harvest activities of these aboriginal hunters may have had significant impacts on locally used Dall sheep populations. At least one modern anthropologist (Campbell 1974), suggested aboriginal overharvest of Dall sheep was responsible for the scarcity of Dall sheep documented in the Brooks Range during the late 19th and early 20th centuries.

As the Territory of Alaska developed, explorers and naturalists became interested in Dall sheep. It was the explorer/naturalists who gave Alaska's wild white sheep their rather intriguing name, Dall's sheep. One of these early explorers, a fellow named Nelson, had an interest in mammals, and named many of them throughout Alaska. Nelson offered the first Latin scientific name for these white sheep in 1884. It was simply "Ovis" (the sheep genus) plus "montana" (for mountain) as the species name. Nelson also proposed the subspecies name, "dalli". Tradition says that Nelson offered the "dalli" subspecies name in honor of another early Alaskan explorer, William H. Dall. W. H. Dall was primarily a mariner and river traveler, and there's no record of him ever having been in Dall sheep country. In 1897, another namer of animals, J. A. Allen, changed the species name from "montana" to "dalli," and the taxonomic designation has remained *Ovis dalli dalli* ever since (Bee and Hall 1956).

Dall's name continues to be associated with Alaska's white sheep because the accepted rules of scientific naming call for it. These rules say the species name (in this case "dalli," the Latinized form of Dall) should be "de-Latinized" and its possessive form (Dall's) used as the scientifically accepted "common name." Under these rules, the scientifically correct common name would be "Dall's sheep."

This technical naming rule causes some confusion where Alaska's wild white sheep are concerned. No wild white sheep were ever possessed by W. H. Dall, and it's unlikely he had anything to do with wild sheep. Eventually common usage by Alaskans who were involved with these sheep changed the "correct" but confusing possessive-form common name to the descriptive form, "Dall" sheep. I prefer "Dall sheep," and will use it rather than the possibly more correct possessive form because I find "Dall's" not only confusing, but hard to pronounce and even harder to type.

Besides being taken by aboriginals and explorer/naturalists, Dall sheep were exploited by the trappers, miners, market hunters, and homesteaders who followed. Some sheep populations were decimated because of harvesting by humans during the early 20th century (Capps 1916).

DALL SHEEP MANAGEMENT DURING TERRITORIAL DAYS

Within a decade after some populations had been decimated, the first closed seasons and restrictive bag limits were established (in 1926) as the emerging science of wildlife management began to influence the Alaska scene. Under this scheme, the open harvest season was scheduled during early fall, primarily because of traditions attending wildlife management in other places. The fall season also made sense to early wildlife managers because Dall sheep were not breeding at that time, and were at their fattest. The bag limit was restricted to two rams. Ram-only hunting appeared to be biologically sustainable because a single mountain sheep ram will breed many ewes. The regulation was also consistent with the "males only" harvest seasons characteristic of early conservation efforts.

During this period, no systematic population monitoring or regulatory program existed, and managers applied their knowledge of local Dall sheep populations over what today would be unthinkably huge areas. For example, the Territory-wide closure of Dall sheep hunting in 1942 was based on the assumption that the harsh weather which decimated Dall sheep populations on the Kenai Peninsula occurred throughout all Alaska. Ram harvest was again allowed in 1943. The one-year closure in 1942 was probably an ineffective management action. Modern studies of population dynamics and weather patterns suggest it was unlikely Dall sheep had suffered throughout the entire Alaska Territory. Additionally, we now know that Dall ewes don't usually reproduce until age three or four years, and twinning has never been seen (Nichols 1978 Heimer and Watson 1986a). Hence the one-year closure was insufficient time for any significant population recovery.

Nevertheless, when the harvest season was re-opened in 1943, the general bag limit was more conservative (one ram) except in the Brooks Range where the limit remained at two rams. Although ewe harvests were prohibited, the more liberal bag limit in the Brooks Range provided greater harvest opportunities for Eskimos and Indians with a history of Dall sheep use there. These bag limits persisted until 1951 when they were revised to an even more conservative harvest regulation.

In 1951, only rams with horns that had grown through 3/4 of a "curl" (the circle described by the outside surface of the horn helix) were legally harvestable. This regulation went a step beyond "males only" hunting, and appears to have been designed either to assure harvest of rams with larger horns or protect young rams from harvest. The 3/4-curl rule was initially a federal regulation which came to the Territory of Alaska from Washington D.C. via Wyoming, where it was first applied to bighorn sheep in 1930 (Dimarchi 1978). Under the 3/4-curl rule, the bag limit remained two legal rams in the Brooks Range until 1970.

By 1970, non-local harvest of rams in the Brooks Range was increasing because of growth in the commercial guiding industry for Dall sheep. At that time, the sheep harvest season opened ten days earlier in the Brooks Range than any big game hunting season in Alaska, and commercial guides were not tightly restricted to specific areas so many guides were offering an early sheep hunt in the Brooks Range. Managers of that day apparently thought it more important to standardize the harvest season at Aug. 10-Sept. 20 (as it remains) and meet a perceived need to limit overall ram harvests for conservation purposes than to provide additional harvest opportunities for resident Indians and Eskimos. Hence the Brooks Range bag limit was reduced from two 3/4 curl rams to one. Besides, it was common knowledge that these Natives had never limited their harvests to rams as specified in regulations 20 years earlier. Managers chose to regulate those who would comply and benignly ignore illegal local uses.

Since 1930, the legal size/age of rams for harvest has been defined by the portion of the "curl" attained by each ram's horns. This still works because horns continue to grow throughout a sheep's life, and unbroken Dall ram horns describe a complete circle (when viewed along their helical axes) at maturity. The horn size/age limit commonly applied throughout North America was arbitrarily set at 3/4-curl in an effort to provide both biological safety and maximum ram harvests among bighorns.

While the 3/4-curl regulation may have been compatible with bighorn sheep biology, it was poorly suited to Dall (or thinhorn) sheep biology. Bighorn (Rocky Mountain, California, and Desert subspecies) and thinhorn (the Dall and Stone subspecies) sheep are behaviorally different. One significant difference is in the frequency and extent of ram horn brooming (the breaking of horn tips during dominance fighting). Virtually all bighorn rams broom both horns back to 3/4-curl by maturity. Brooming in Dall rams is common, but Dall rams seldom break both horns or broom as severely as bighorns. Consequently, many 3/4-curl bighorns are mature, but virtually all 3/4-curl Dall rams are simply young. The 3/4-curl rule, when applied to Dall sheep allowed harvest of juvenile rams. As sheep hunting increased in Alaska, application of the 3/4-curl rule to thinhorned Dall sheep caused subtle, long-term negative effects to the heavily hunted populations where mature rams were completely removed. It took the newly formed State of Alaska decades to discover and rectify this situation.

EVOLUTION OF THE STATE'S BIOLOGICALLY-BASED HARVEST REGULATIONS

The history of Dall ram harvest regulations in Alaska is tied to the re-emergence of Rocky Mountain bighorn sheep in the American West (Heimer and Watson 1986b). Prior to settlement of the western United States by Europeans, bighorn sheep were abundant in suitable habitats. Settlement of the West greatly reduced their numbers, and by 1900 only small relict populations remained in mountainous areas which had limited appeal to stockmen and miners.

The introduction of domestic livestock diseases to bighorn sheep was the primary factor in their demise, but the decline was also aggravated by competition with domestic livestock for grazing lands and overhunting for the frontier meat market (Buechner 1960). When wildlife managers began to practice conservation and restoration of bighorn sheep, the first approach was total protection throughout the western states.

This total protection (along with control of predator populations to benefit the livestock industries) eventually brought many bighorn populations back from the brink of extinction (Trefethen 1975, Hoefs 1985). As sheep populations returned to viable levels, managers sought a balance between protection and use. This meant allowing some harvest but still allowing herds to grow. Wildlife managers understood that herd growth would produce benefits. These benefits included the conservation-funding revenues produced by license and tag sales, the economic benefits from developing and maintaining guiding and outfitting industries, and the high public interest in conservation and management which result from hunting (Heimer and Watson 1986a).

A review of mountain sheep hunting regulations across North America (Dimarchi 1978) shows the most common attempt to balance herd growth and hunter use was the limited harvest of surplus males (rams). Rams, which could be removed by hunters without noticeably compromising lamb production, were defined as surplus. The conclusion reached by most sheep managers was that harvesting rams at the youngest acceptable age (before natural mortality removed any more of them than necessary from the shootable population) would give the greatest sustainable harvest. This data-free assumption, in 1930, came 14 years before the first data on mountain sheep survival were collected (Murie 1944). Although survival of rams in unhunted mountain sheep populations shows a consistently low mortality between one and eight years of age (Deevey 1947, Bradley and Baker 1967) tightly regulated 3/4-curl harvest persisted as the dominant rule governing harvest of bighorn sheep throughout the western United States through the 1980s. In the 1990s a trend toward "any ram" or "any sheep" bag limits gained popularity among bighorn managers. These more permissive regulations don't appear biologically threatening to sheep populations because harvests are specifically held to biologically insignificant levels. Also, harvests under this bighorn management regime are strictly controlled by limited entry permit hunts.

However, when managers formulate broad harvest regulations where general open harvest seasons are provided (such as for 3/4 curl rams in Alaska) the risk is greater. Consequently, the regulations must be more conservative. In these circumstances, it is generally understood that the resource must be conserved even if the allowed harvest takes place at the maximum level. It was in this respect that the 3/4-curl regulation originally developed for bighorn sheep in Wyoming failed when it was applied to thinhorn sheep in Alaska.

When the harvest level of sheep is so low as to be biologically insignificant, it doesn't matter what the regulations are, or even if any regulations exist. Hence, before the human population of Alaska and the interest in Dall sheep hunting increased to the point that harvests could negatively affect local Dall sheep populations, regulations were largely irrelevant. As hunting pressure increased to the point where virtually all legal rams were removed from hunted Dall sheep populations, the 3/4-curl regulation was insufficient to protect the populations from negative impacts. Here's why.

The 3/4-curl regulation provided some conservation benefit in that it protected ewes from harvest; but the overharvest of virtually all mature rams from some populations resulted in social disruption which was harmful to Dall sheep as well as hunter welfare (Heimer and Watson 1986a, 1990). Lamb production declined, and mortality among young rams greatly increased.

Mountain sheep in general, and Dall sheep in particular are intensely social herd animals. In mountain sheep society, each individual has a clearly defined social position keyed to horn size. The behavior, reproductive success, and nutritional condition of each sheep are determined by this social rank (Geist 1968, 1971). This powerful influence on Dall sheep population dynamics was not recognized when the 3/4-curl regulation was implemented.

The two important aspects of Dall sheep ecology which were disrupted by near-total harvest of rams down to the 3/4-curl limit (average ram age of 4.5 years) were lamb production and immature ram survival. When virtually all dominant rams aged seven to eight years and older, were removed, lamb production declined significantly. Some lambs were still produced by adult ewes, but 95 percent of these adult ewes reproduced only in alternate years. This appeared to be linked to a prolonged lactation period associated with low ram abundance and/or the absence of mature rams. Consecutive-year reproductive success among adult ewes was only five percent (Heimer and Watson 1986b). Additionally the frequency of reproductive activity among 18-months old ewes rose from about five percent to 25 percent. These young ewes typically conceived late, and delivered stunted lambs well after the normal peak of lambing by adult ewes.

Survival of young rams was also seriously compromised because immature rams became active breeders and began to pay the energetic and mortality costs associated with dominance before they were behaviorally and physically mature (Heimer et al. 1984, Heimer and Watson 1986b.). This decreased immature ram survival. The cumulative management effect of biological disruption resulting from mature ram overharvesting was lowered sustainable ram harvest (Heimer and Watson 1990).

In 1984, an experimental full-curl regulation was established in a heavily hunted portion of the Alaska Range to see if this single change in ram harvest (which was expected to increase lamb production and immature ram survival) would actually lead to increased harvests of mature rams. Alaska Department of Fish and Game funding for this effort was supplemented by a sheep hunter's organization, the Alaska Chapter of the Foundation for North American Wild Sheep (FNAWS). Additionally, FNAWS members contributed as volunteer field observers during the required field research.

Cumulative results of managing for overall increased ram numbers (and the concomitant increase in mature ram abundance) by implementing a full curl regulation showed highly significant increases in ram harvests through 1989. These increases were results of doubled (annual, not alternate-year) lamb production and an apparent dramatic increase in young ram survival attending the presence of mature rams in the populations (Heimer and Watson 1986b). Eventually harvests of full-curl rams exceeded those sustained by the same populations under the 3/4 curl rule (Heimer and Watson 1990).

Once aware of these results, Dall sheep hunters proposed an end to the 40-year span of 3/4-curl ram harvests in Alaska. This 1989 proposal was the first to factor the subtleties of animal behavior into harvest management of big game in Alaska, and perhaps the entire United States. Consequently, it was highly controversial. Paradoxically, the proposal was opposed by the state's wildlife management agency which had approved the research and analysis upon which it was based. As a result of compelling public testimony, the Alaska Board of Game passed the present regulation limiting ram harvests to full-curl or eight-year-old rams, or rams with horns broomed on both sides.

This regulatory change, assuring the presence of mature rams even in heavily hunted Dall sheep populations, also simplified sheep management (Heimer and Watson 1990). Hunter success was not affected. With few local exceptions, thinhorn sheep throughout North America are now managed for the harvest of full-curl rams. Legal definitions differ between states and provinces (Northern Wild Sheep and Goat Council Workshop 1990).

So, we see it took 39 years (including 29 years of Alaska statehood) to rectify the biologically incorrect 3/4-curl regulation established by a well-meaning, but biologically naive Federal Territorial Government. The State of Alaska now attempts to manage Dall sheep in accordance with a published, biologically based working management hypothesis (Heimer 1988). Unfortunately for sheep hunters, the 3/4-curl regulation was not the end of federal intervention limiting sheep hunting opportunity in Alaska.

FURTHER FEDERAL INTERVENTION

Development of the vast oil reserves in arctic Alaska during the late 1970s caused the most extensive federal intervention in state wildlife management in U. S. history. This story began with Alaska's attempt to settle historic Native land claims.

After the oil discovery at Prudhoe Bay in the 1960s, it became clear that the pipeline required to get the oil to market could not be built until these Native land claims were settled. Not everyone thought building the oil pipeline was a good idea. Alaska Natives joined the environmental preservation community in opposing the pipeline. Compromises between Alaska Native/environmental preservation interests and oil-development interests to allow building the trans-Alaska oil pipeline resulted in a Congressional mandate to place huge tracts of federal public land in federal conservation systems. In these compromises, the Alaska Natives and the environmental community agreed to stop fighting pipeline construction. The final settlement in 1980 resulted in one billion dollars and 44 million acres of land for Alaska Natives and the reclassification of at least 80 million acres of federal land as new wildlife refuges, national forests, wild and scenic rivers, and new national parks for the conservationists.

Initially, lands selected for transfer to the National Park Service contained a large fraction (up to half in some proposals) of the Dall sheep habitat in Alaska. Everyone understood that if these lands were to become National Parks, there would be no opportunity to harvest sheep on them in the future. Consequently, the State of Alaska resisted these land transfers to the National Park Service, at least partly to maintain sheep hunting.

An intense, protracted, and bitter Congressional debate followed. It was during the Congressional debate in the mid to late 1970s that the same organized sheep hunters (who were instrumental in changing to a biologically based harvest system) first became active in Alaska. With contributions of money and grassroots political support from these hunters, Alaska mounted an effort to maintain as much sheep hunting in Alaska as possible. Compromises ending this debate resulted in a 25 percent loss of sheep hunting in Alaska and federal recognition of a subsistence harvest priority for rural residents of Alaska (Heimer 1978, 1980, 1982, 1986).

That is, the state's hunter supported effort was successful in preserving general hunter access to sheep on about 75 percent of the state's sheep habitat. The remaining 25 percent was classified as National Park land where only rural subsistence hunters were allowed to harvest sheep. All others, including non-rural Alaska Natives, permanently lost Dall sheep hunting opportunity on these lands. Subsistence seasons on federal lands are typically lengthy (most last for seven months), and bag limits are liberal (up to three sheep-including ewes and lambs). Subsistence harvest reporting is voluntary. As anecdotal evidence accumulates, it's beginning to look like this liberal approach to management is inconsistent with Dall sheep conservation. Unfortunately, the politicization of harvest allocation for preferential subsistence uses has reduced biological considerations to low, almost incidental, priority (see Heimer's accompanying paper, this symposium).

The most notable state success in maintaining sheep hunting opportunity was in the Northern Wrangell Mountains where a population of 12,000 Dall sheep were kept available for public hunting on federal land. Over the 15 years since ram harvest opportunity was preserved on these sheep habitats, ram harvests from this area have averaged about 250-300 rams per year. This cumulative harvest grossed the state economy approximately $28.9 million dollars and had no negative effect on the overall population of sheep in the Northern Wrangell Mountains. During this same time period, the statewide Dall ram harvest averaged about 1,100 rams per year.

Calculation of the dollar value of Dall ram harvest was made possible by an economic study funded, again, by the hunters interested in Dall sheep conservation. This project (Watson 1990) proved to be a ground breaking effort which foreshadowed other economic assessments of hunting in Alaska. Updated estimates of the dollar value of Dall sheep hunting in Alaska are approximately $12,000,000 per year (McCollum and Miller 1994).

Additionally, fines as high as $5,000 per ram for illegally taken Dall rams have been levied in Alaska. Although this fine is less than half the defined "market value" of a Dall ram, it is ten times higher than the traditional $500 which had been imposed prior to the economic work.

PRESENT CONDITIONS AND FUTURE PROSPECTS

During the late 1980s and early 1990s, Dall sheep populations throughout much of Alaska declined because of difficult weather (Heimer et al. 1994, Heimer 1995). Predator pressure, primarily exerted by wolves on adult sheep, is an additive factor; and may be expected to slow population recovery because it increases what we call "environmental resistance" to population growth. Recent developments have resulted in the addition of major coyote predation on lambs as an additional component of environmental resistance.

Environmental resistance has three components: weather, harvest by humans, and harvest by predators. Wildlife managers can manipulate two of these. The history of changes in hunting management in Alaska shows human harvest is now generally managed so that harvest by humans has a negligible effect on population welfare (except where federal subsistence seasons place populations at risk through long, liberal seasons for ewe sheep with no harvest reporting requirement). The other manageable component of environmental resistance is predation;

managers cannot control weather. At the present time, wildlife managers in Alaska are taking no steps to limit predation to foster Dall sheep population recovery.

The distribution of weather-related population declines and absence of lowering environmental resistance due to predation has significantly decreased mature ram harvests in Alaska. The short term outlook is bleak because these weather-related lamb production failures (Heimer 1995) are just beginning to be reflected in the absence of legal rams. If sheep managers in Alaska are to do more than tally the harvest of mature rams, the time has come to attempt active management. The option available to managers is lowering the non-human component of environmental resistance to facilitate population recovery. This means wolf and coyote control. After all, predation is the only management-alterable factor which has not already been manipulated to favor Dall sheep. It may be difficult, but I remain optimistic for the longer-term future, primarily because of the high public interest in Dall sheep which drives Dall sheep conservation in Alaska.

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POPULATION MONITORING

Average Age of Harvest: What is it Really Telling Us?

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Abstract: The average age of harvested Dall sheep rams (*Ovis dalli dalli*)has been used as a measure of the effectiveness of harvest regimes and as an indirect measure of sheep population status. We examined the relationships between the average age of harvest and the population size in a population in the southwest Yukon. In areas where the harvest is a random selection of full curl rams, such as this, the average age of harvest is a reflection of the existing age distribution of the harvestable rams and gives no indication of harvest intensity or population status. Some cohorts were strongly represented in many years of the harvest and as these cohorts aged, the average age of harvest increased; contrary to our expectation the average age of harvest did not decline as the population declined.

INTRODUCTION

The Ruby Range mountains of the southwest Yukon have been the focus of sheep management efforts for many years. The Government of Yukon has monitored the area since 1974 and it is one of the few areas in the Yukon for which there is long term population information. The area has always been an important hunting area for First Nations people of the region. Non-resident hunters have come to the Ruby Range since the 1920s in search of trophy rams; with the building of the Alaska Highway in 1942 the area became more accessible to all hunters, including Yukon residents. Continued access improvements and local concerns about the sheep population have both served to focus our attention and heighten our concerns about this area.

To address concerns such as these in days of decreasing financial resources, wildlife managers have come to rely more and more on indirect monitoring methods, especially over vast areas such as in the Yukon. Rather than relying on actual aerial counts, managers have sometimes relied on statistics developed from harvested animals. For example, the number and average age of harvested Dall sheep (*Ovis dalli dalli*) have been used in many jurisdictions (Hoefs and Barichello 1985; Poole and Graf 1985; Alaska Department of Fish and Game 1993; R. Marshall, pers. comm. 1997) as a measure of the effectiveness of different management regimes or to set harvest quotas. In the Yukon, the rationale behind aging each harvested ram has been the belief that the average age of harvest in each year provides indications of such potential problems as over-harvest through increased effort or a decline in local sheep populations. It has been expected that either of these situations would be reflected in a trend toward a lower average age of harvest over several years. As well, Yukon outfitters have adopted a high average age of harvest as a marketing tool and hold an annual competition for the highest average age.

In the Yukon, 85% of rams attain full curl status by their eighth year (Barichello et al. 1987). Management goals are to attain an average age of harvest of at least 8 years. If the average age is 8 or less, it is seen as an indicator that rams are being cropped as soon as they become legal i.e. that harvest intensity is too great.

Average age of harvest has come to be seen as a very important piece of information, but does it really tell us what we think it does? In this paper, we examine the relationships between the average age of harvest and the number of sheep in the population.

Methods

The horns of all rams taken by licensed hunters are submitted for inspection by a conservation officer or wildlife technician and are aged using the horn annulus technique (Hemming 1969); various horn growth parameters are measured, a side-view photograph is taken and a uniquely numbered metal plug is inserted.

To obtain population estimates, sheep are counted from a helicopter in June or July when the white sheep are most visible against the green or brown vegetation. A drainage technique is used, whereby each mountain block is contoured at approximately 100 kph at about 150 m above ground level (Hoefs and Barichello 1985). Often, more than one pass is needed to achieve total coverage. It is assumed that close to 90% of the sheep are counted (Hoefs and Cowan 1979) and no allowance is made for missed animals.

All sheep seen are counted and classified as lambs, ewes, yearlings and rams having half, three-quarter or full curl horns. When yearlings cannot be easily distinguished from ewes, the group is termed nursery sheep, which can include ewes, yearlings and some 2-year-old rams. Locations are recorded on a 1:250,000 NTS mapsheet.

Results and Discussion

Population fluctuations observed in the mid-1980s were, in retrospect, a population decline (Figure 1). Numbers went from about 775 in 1974 to almost 1000 in 1985, to less than 500 in 1993 (YTG unpubl. data). Local First Nation residents also noted the decline in the early 1990s, and the overwhelming sentiment was that outfitter and resident overhunting was the cause of the decline.

Faced with the evidence of a population decline, and the contention that overhunting was the cause, we first examined the average annual reported harvest. In years where survey information was available the reported licensed harvest ranged from 1.0 to 4.2 per cent of the non-lamb population (mean=2.5, n=13) (YTG unpubl. data) and was limited to full curl rams. This level of harvest is considered to be within sustainable limits, based on the demographic work done at nearby Sheep Mountain (Hoefs and Cowan 1979, Barichello and Hoefs 1984). However, it was simply not sufficient to tell the local people that hunting was not the cause of the decline. In an attempt to gain a better understanding of the population processes behind this decline, we began to look at the available information in more detail.

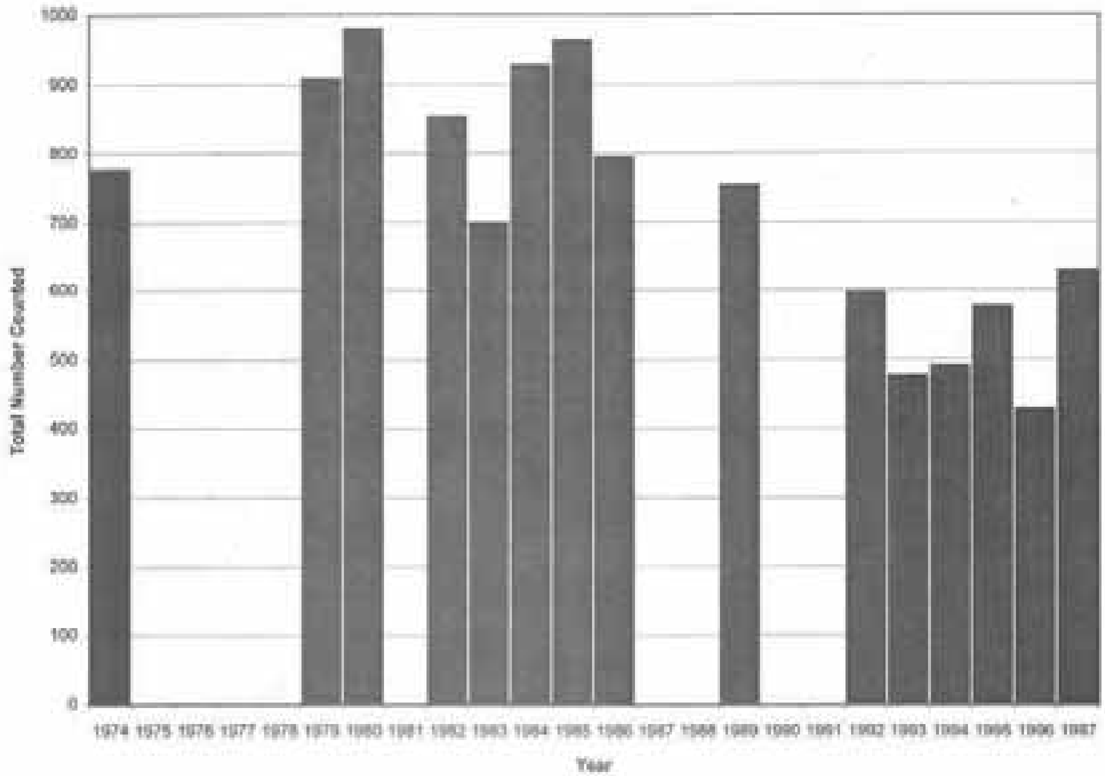


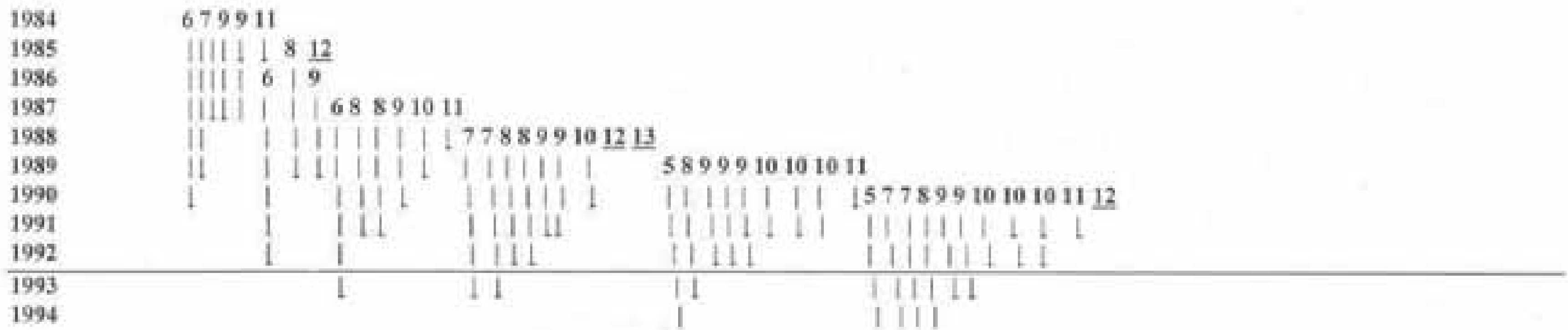
Figure 1. Total number of sheep counted in the Ruby Range mountains, Yukon, 1974 to 1997.

A simple model showed that even if there had been no licensed hunting, a dramatic decline in the huntable population would probably have occurred anyway (Figure 2). At this point, the potential effect of a strong cohort pulse became apparent. Based on the lifetable developed at Sheep Mountain (Hoefs and Cowan 1979) many of the animals in the harvest were "scheduled" to die in the same year.

A frequency distribution chart of the number of rams harvested from each cohort was generated to determine if strong cohorts had a general effect on the harvest as well as the specific effect originally identified. Data from the surrounding region (YTG unpubl. data) was included in this analysis to increase the sample size. Some cohorts were strongly represented in the harvest (e.g. 1979 and 1980, Figure 3) and when we looked at the cohorts represented in each harvest year, it was apparent that a few strong cohorts are heavily represented in many years (Figure 4). Therefore, as these cohorts age, the average age of harvestable rams increases no matter what is happening to the population.

The precise connection between average age of the harvestable population and the average age of harvest depends on how hunters select rams from the pool of full curl rams. We believe the licensed harvest is a random selection of full curl rams for three reasons. First, although some hunters may prefer older, broomed rams as trophies, others are known to select younger ("meat")

Figure 2. Representation of a simple model showing the effect of a cohort pulse in a portion of the Ruby Range mountains, Yukon.



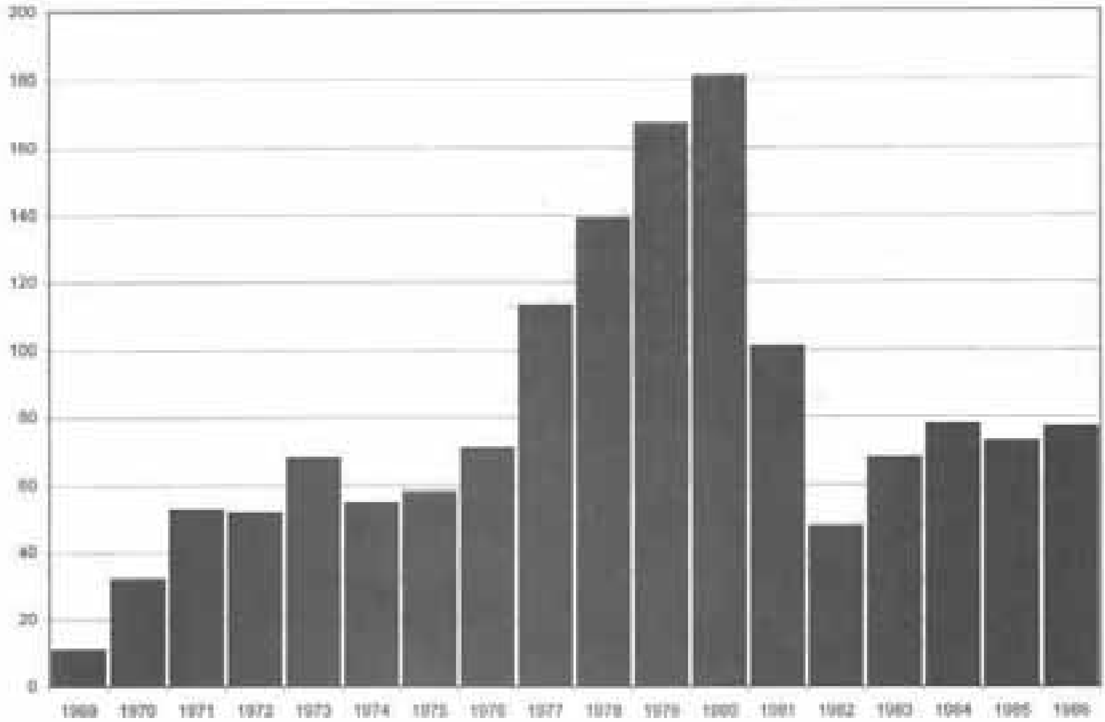


Figure 3. Number of rams harvested 1980 to 1997, from each cohort.

animals. Over large areas, such as this one, preferential selection made at the band level or over a small geographic area must be considered random over the broader area. Second, even for those hunters who do select for large-horned rams, larger horns are not necessarily the oldest animals because all horns do not grow at the same rate, nor are horns broomed at the same rate. Third, the cohort representation in the harvest mirrors the strength of respective lamb crops for all years for which we have data.

Because the average age of harvestable rams increases due to cohort pulses rather than population changes, the average age of harvest will also increase. Because of this the average age of harvested rams provides no indication of the intensity of the harvest. If the harvest were more intense, we would only expect that each of the bars (Figure 4) would be taller but that the proportional representation of each cohort would remain the same. Therefore, the average age would be the same no matter what the harvest intensity. This is an important point because it means that the average age of harvest cannot be used as a reliable indicator of either harvest intensity or population status.

When we looked at the average age of harvest (Figure 5) compared to the population information it was obvious that, contrary to our original expectations and management guidelines, the average age of the rams harvested from this population did not decline as the population declined. In fact, when harvest data from the surrounding area were also included to increase the

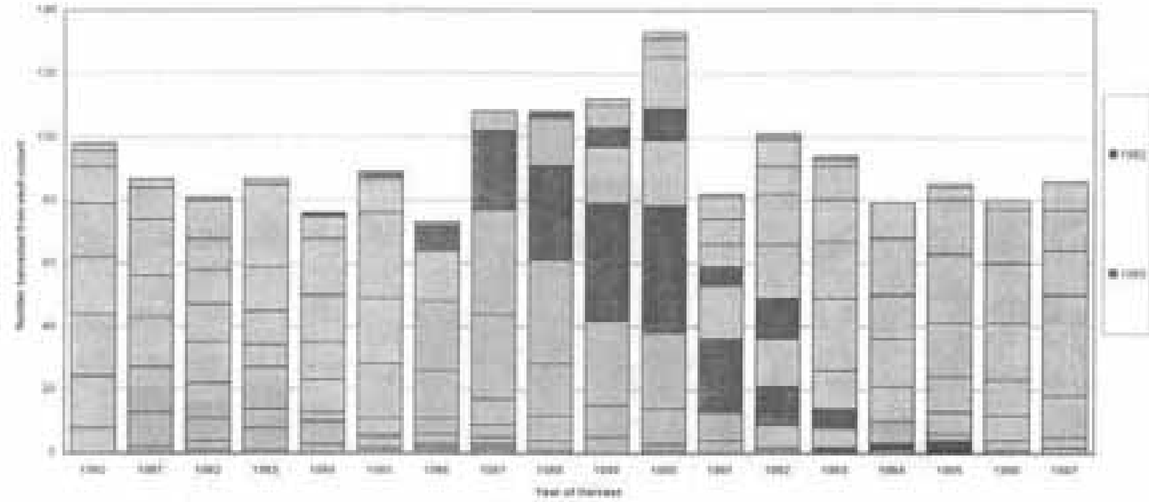


Figure 4. Relative representation of two cohorts of rams in the Ruby Range harvest, 1980 to 1997.

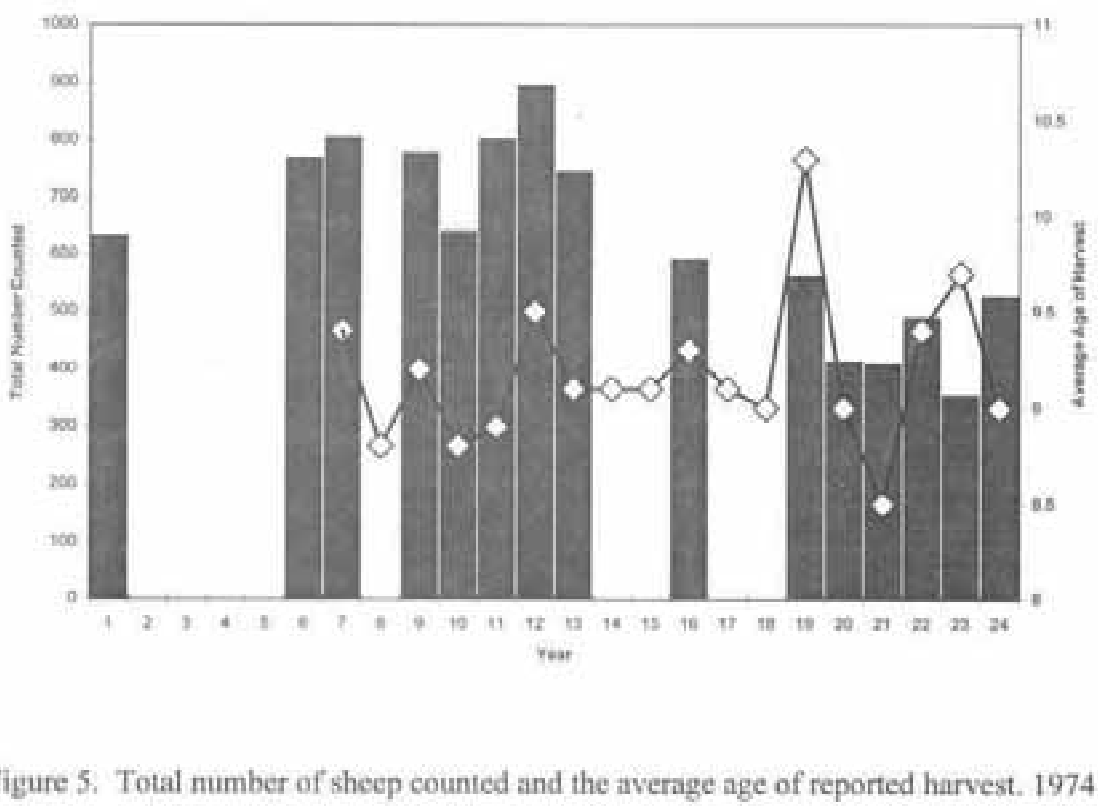


Figure 5. Total number of sheep counted and the average age of reported harvest. 1974 to 1997.

sample size, the average age of harvest clearly increased as the population declined and the strong cohorts of 1979 and 1980 worked their way through the system (Figure 6).

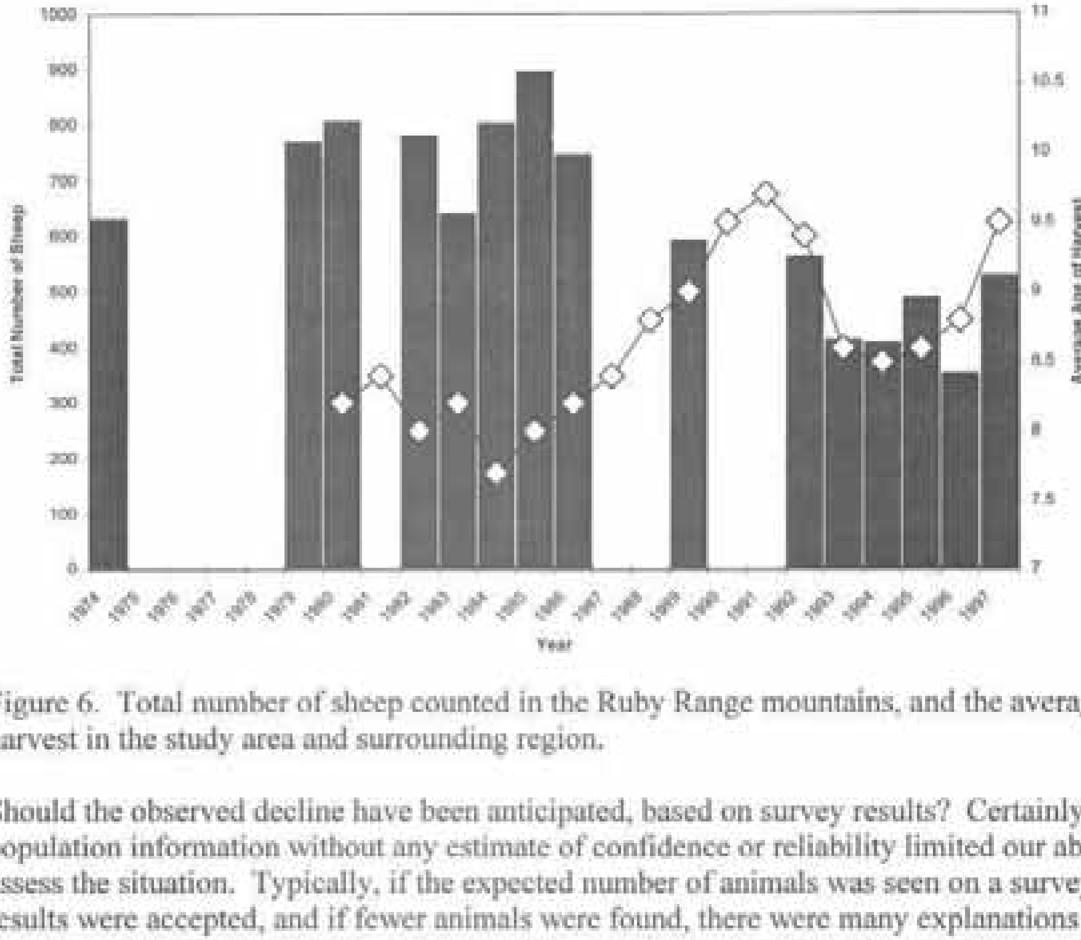


Figure 6. Total number of sheep counted in the Ruby Range mountains, and the average age of harvest in the study area and surrounding region.

Should the observed decline have been anticipated, based on survey results? Certainly having population information without any estimate of confidence or reliability limited our ability to assess the situation. Typically, if the expected number of animals was seen on a survey, the results were accepted, and if fewer animals were found, there were many explanations as to why the survey did not provide a true picture of the population, and we had a tendency to discount those surveys.

We believe that the lamb/nursery sheep ratio may be a good predictor of population levels well ahead of any observable changes in the overall census results. For example, 1982, 1983, 1985 and 1986 had nearly total lamb crop failures which led to a population decline in the early 1990s. But the total number of sheep counted was well within the range of previous results (Figure 7). The importance of these lamb crop failures may seem obvious now, but it was certainly not obvious in the early 1980s when we didn't have the benefit of the subsequent 10 years of data, or of a historical perspective. For example, should the good lamb crop of 1984 have been sufficient to counteract the previous 2 cohort failures? And when we went back in 1989, we found the

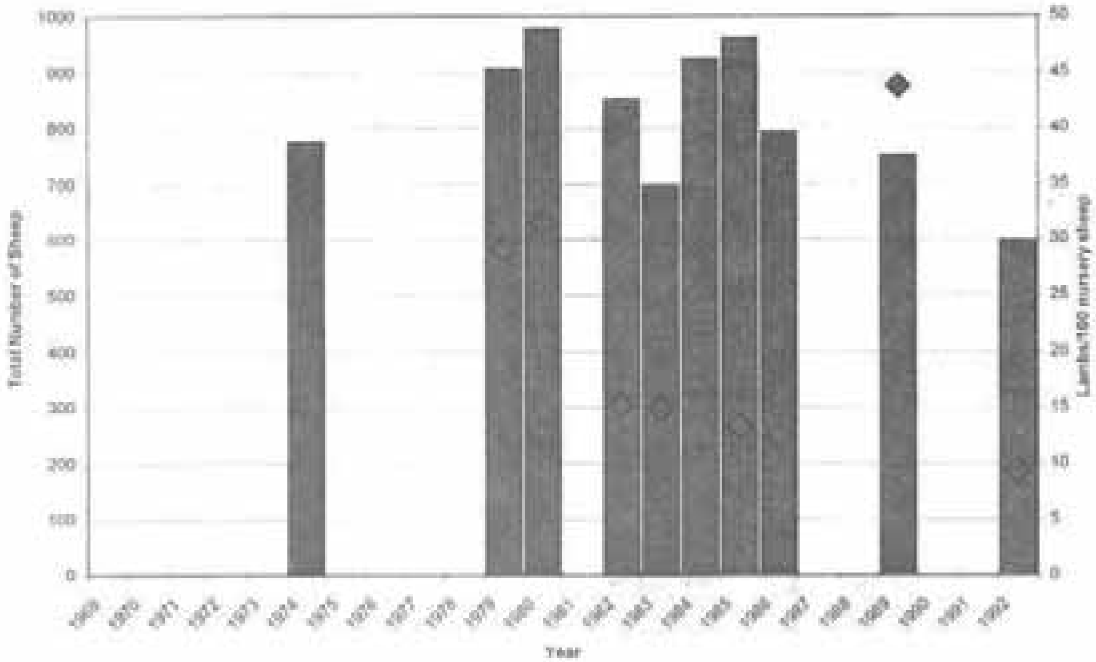


Figure 7. Total number of sheep counted in the Ruby Range mountains, Yukon 1974 to 1997 and the lamb/100 nursery sheep ratio in those years.

highest productivity we'd seen in this population. How should these results have been interpreted? Further modeling has demonstrated that those years of low lamb recruitment clearly led to a population decline, even if it was not the ultimate cause of the decline. We have been surprised at how simple the model can be and still provide accurate results. Clearly, in this population, the number of lambs produced, and not the number of animals harvested, determines the population trends.

Conclusions

In the Yukon, we have found that the average age of harvest is a reflection of the existing age distribution of the harvestable rams, not the status of the population or the harvest rate. In fact, as long as the harvest is a random selection of the available legal rams, harvest monitoring cannot be used as a substitute for population monitoring. The challenge remains to devise a program to monitor large populations spread over half a million square kilometers where both ground access and budgets are extremely limited.

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COMPARISON OF BIGHORN RAM HORN GROWTH BETWEEN ORIGINAL SUN RIVER POPULATION AND THREE TRANSPLANTED POPULATIONS: HEREDITY OR ENVIRONMENT?

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Abstract: A comparison is made of horn growth (average length and base circumference) by age class for 703 bighorn (Ovis canadensis) rams harvested between 1978-1997. Data from the original Sun River herd is compared to three transplant populations in Lost Creek, Upper Rock Creek and the Missouri River Breaks. The transplant herds are well known for producing the "giant" rams of Montana. All three transplant herds showed greater horn growth than the parent population, particularly in younger age classes. Data on frequency composition of the harvested rams are presented, along with life expectancy data.

INTRODUCTION

Montana currently has 42 bighorn sheep populations. Thirty of these populations are transplants. The Sun River population is a native herd and has been used extensively as a source for transplants. Several of the transplanted herds have become nationally know for producing 195-200 Boone and Crockett heads. Three of these transplant populations are Lost Creek (HD 213), Upper Rock Creek (HD 216) and the Missouri Breaks (HD 680). One popular opinion is that "Sun River genetics" are responsible for the horn mass observed in these transplanted populations. Public pressure on management to augment populations with Sun River rams to improve the genetics is frequently encountered. A comparison was made of horn size for harvested rams between the native Sun River population and these 3 transplanted herds.

METHODS

Data were collected from the hunter harvest permits on horn length, base circumference and age. A total of 703 rams were compared with ages from 2.5 to 12.5 years of age. Data was available for 376 rams from the Sun River for 1981-1995. A total of 151 rams were available for the Lost Creek herd for 1978-1997. Rock Creek had 150 rams for 1979-1997. Only 26 rams were harvested in the Missouri Breaks for 1990-1995. Horn size was averaged by 1 year age classes for total length and base circumference for left and right horns for each population.

RESULTS

All 3 transplant populations showed greater average horn length and base circumference by age class than the native population (Table 1). Lost Creek rams were for all age classes an average of 3.1 inches longer and .5 inches greater base circumference than the Sun River rams. Rock creek rams averaged 4 inches longer and 1 inch greater base circumference for all age classes. The Missouri River Breaks population averaged 3.4 inches in greater length than the Sun River and .9 inches greater circumference.

Table 1									
	LENGTH	LENGTH	LENGTH	LENGTH			DIFF	DIFF	DIFF
AGE	SUN R.	213	216	BREAKS		AGE	213/SUN	216/SUN	680/SUN
2.5	21.8	25	25.6			2.5	3.2	3.8	
3.5	21.7	31.3	33.5	30.2		3.5	9.6	11.8	8.5
4.5	31.2	34.5	34.4			4.5	3.3	3.2	
5.5	34.5	34.9	37.4	36.2		5.5	0.4	2.9	1.7
6.5	35.5	37.3	37.7	38.4		6.5	1.9	2.2	2.9
7.5	35.6	37.6	38	36.8		7.5	2	2.2	1.2
8.5	36.2	38.2	40.2	39.1		8.5	2	4	
9.5	36.6	39.1	40	40		9.5	2	3.4	2.9
10.5	36.5	40.4	39.1			10.5	3.9	2.6	3.4
						AVER	**3.1**	**4.0**	**3.4**
	BASE	BASE	BASE	BASE			DIFF	DIFF	
AGE	SUN R.	213	216	BREAKS		AGE	213/SUN	216/SUN	680/SUN
2.5	12.7	13.4	14			2.5	0.7	1.3	
3.5	14.1	14.8	15.7	16		3.5	0.7	1.6	1.9
4.5	14.9	15.3	15.7			4.5	0.4	0.8	
5.5	15.4	15.5	16.1	16.1		5.5	0.1	0.7	0.7
6.5	15.2	15.6	16.1	16.4		6.5	0.4	0.9	1.2
7.5	15.2	15.5	16.1	15.8		7.5	0.3	0.9	0.6
8.5	15.1	15.6	16	15.3		8.5	0.5	0.9	0.2
9.5	15	15.6	16	15.7		9.5	0.6	1	0.7
10.5	15	15.5	16.1			10.5	0.5	1.1	
						AVER	**0.5**	**1.0**	**0.9**

All 3 transplanted populations showed greater horn length and base circumference than the native population for each year class. The 3.5 year old rams demonstrated the most significant difference in horn growth between the Sun River and transplant populations (Figure 1 & 2).

The 3.5 year old rams from the transplant populations average 10 inches in greater length and 1.4 inches in greater base circumference than the 3.5 year old rams from the Sun River.

The frequency distribution of the ram harvest by age class was also reviewed. Table 2 presents the number of rams and frequency distribution by age class and population. The typical bell shaped curve is seen in Figure 3. The 4.5 to 8.5 age classes accounted for 82% of the harvest for all 4 populations. Eleven per cent of the harvested rams were 9.5 years or older and only 3% were 10.5 years or older (Figure 4). The Lost Creek and Rock Creek populations demonstrated a greater survival of 9.5 year old or older rams compared to the Sun River or Missouri Breaks (Figure 5). The Lost Creek herd had 14% of the rams at 9.5 years old or older and Rock Creek was 13%. The Sun River herd had 9% of the rams at 9.5 years old or older and 8% of the Breaks herd was.

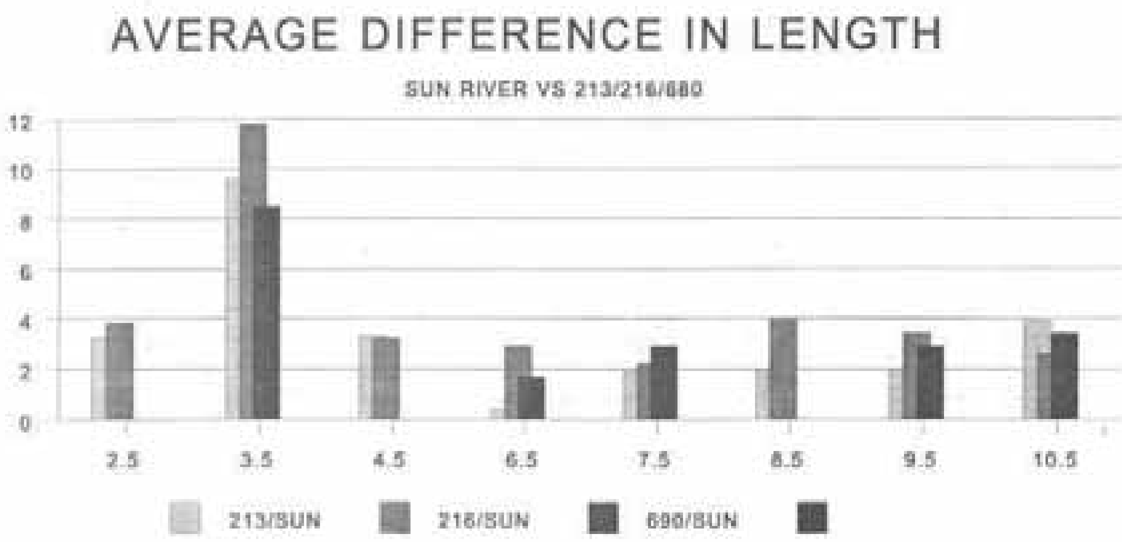

Figure 1.

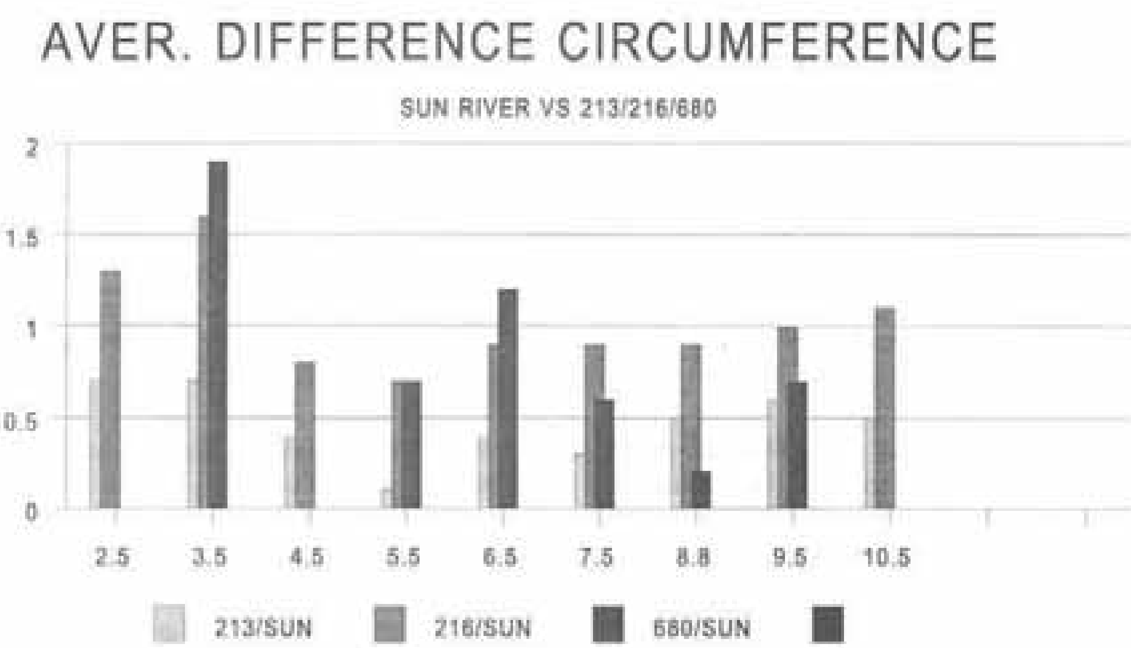

Figure 2.

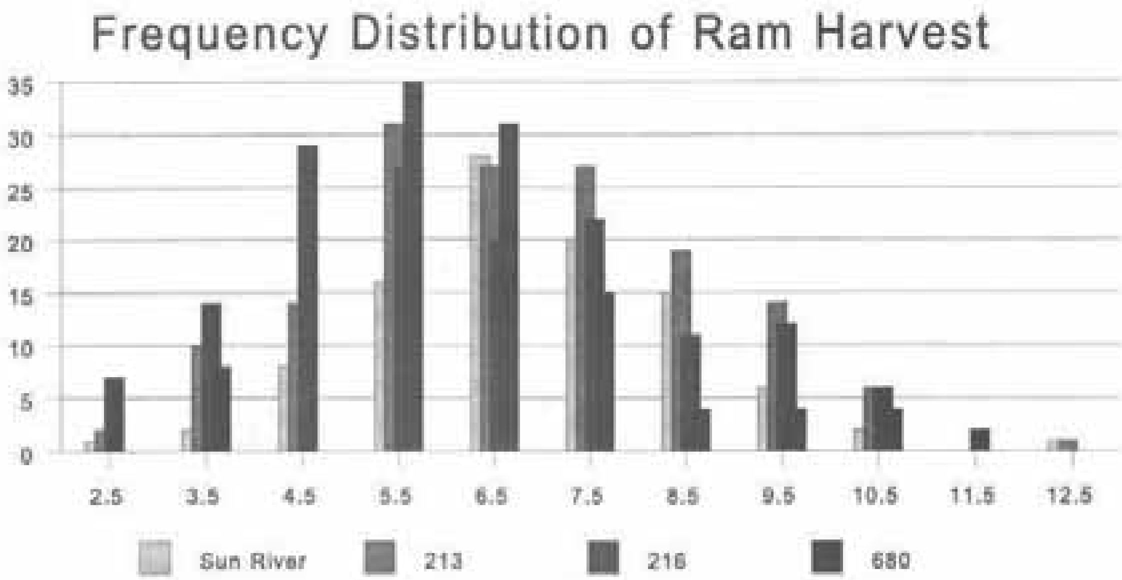

Figure 3.

Table 2 Age and Frequency Distribution of Ram Harvest by Age Class and Population

No. Rams

AGE	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
Sun River	5	7	31	61	106	76	56	24	9		1
213	2	10	14	31	27	27	19	14	6		1
216	7	14	29	27	20	22	11	12	6	2	
680		2		9	8	4	1	1	1		

Frequency

Age	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
Sun River	1	2	8	16	28	20	15	6	2		1
213	2	10	14	31	27	27	19	14	6		1
216	7	14	29	27	20	22	11	12	6	2	
680		8		35	31	15	4	4	4		

DISCUSSION

The significance of "genetics" in bighorn management is a popular concept and undoubtedly has some general relevance. This paper reviewed ram harvest data for 703 bighorns over a 20 year period comparing the native Sun River herd with three transplanted herds (Lost Creek/213, Rock Creek/216, and Missouri River Breaks/680) from Sun River stock. Several basic factors appeared from this review. The transplant herds averaged, for all age classes, 3.5 inches greater horn length and 0.8 inches greater base circumference over the native herd. The 3.5 year old rams from the transplant herds showed the greatest difference in horn growth averaging 10 inches in greater length and 1.4 inches in greater base circumference than the Sun River 3.5 year olds. The Lost Creek (213) and Rock Creek (216) herds demonstrated increased survival in the older age classes (9.5 year old plus). The oldest rams recorded (11.5-12.5 years old) showed smaller than average horn growth.

Based on these findings it appears environment and habitats are playing a greater role in ram horn growth than just genetics. The significant difference in horn growth of the younger age classes (3.5 year olds) between the Sun River and the transplant herds and the increased survivorship of the 9.5+ year old rams in Lost Creek and Rock Creek would indicate better environmental conditions.

EXPERIMENTAL TREATMENT OF LUNGWORM IN WILD BIGHORN SHEEP USING FENBENDAZOLE AVAILABLE AT FREE-CHOICE TREATMENT STATIONS

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We provided fenbendazole treated pelleted feed and salt blocks to lungworm infected bighorn sheep on winter range near Melrose Montana. Between seven and nine treatment stations were maintained and available to approximately 35 bighorn sheep during the winters of 1994-95 and 1995-96. These sheep were the remaining survivors of a recent pneumonia epizootic that removed 87% of a population of approximately 400 sheep. Three of the surviving sheep were radio collared. Treatment stations were visited weekly during two winters to collect fecal samples and evaluate visitation. Sheep found the stations more quickly during the second winter, presumably due to familiarity with sites. Larval output as measured in larvae per gram and prevalence of the parasite declined during the first winter of treatment and remained low through the following winter of treatment. We believe that the free-choice treatment applied in this study reduced the lungworm load and relative infection rate of free ranging bighorn sheep on this winter range. The management implications and potential future of similar treatment protocols are discussed.

Introduction

Bighorn sheep across North America commonly host parasitic lungworm (*Protostrongylus stilesi* and *Protostrongylus rushi*) infections. Many dramatic pneumonia epizootics have implicated lungworms as the predisposing factor contributing to respiratory disease (Marsh 1938, Buechner 1960, Forrester 1971). An additional concern for bighorn sheep is the transplacental migration of Protostrongylus *stilesi* which can produce lambs predisposed to pneumonia and result in what is termed "summer lamb mortality" (Thorne et al. 1982). For sheep populations at very low numbers this lamb mortality may severely hamper recovery and growth of populations to more suitable levels (Jones and Worley 1994).

Most Montana bighorn sheep populations are infected to some degree with *Protostrongylus* spp. (Forrester and Senger 1964, Beckland and Senger 1967, Worley and Seesee 1992). There is considerable variation in the prevalence and parasite load reported depending upon season and geographic location of the herd unit. Lungworm has been implicated in several pneumonia epizootics in Montana (Forrester and Senger 1964, Couey 1950, Rush 1927). Other parasites have been identified and described for various bighorn sheep herds in Montana (Worley and Seesee 1992, Hoar et al.1996)

Lungworm infections have been adequately treated in captive or transplanted bighorn sheep on several occasions with the application of suitable anthelmintics (Layne and McCabe 1986, Miller 1988, Worley and Seesee 1990, Foreyt and Johnson 1980). Several experiments to treat wild bighorns with free-choice treated feeds and/or medicated salt have been successful in reducing larval output (Easterly et al. 1992, Jones and Worley 1997). The most elaborate experiments in treating wild bighorns with free-choice feeds and medicated salt, to date, were conducted in Colorado (Miller et al. 1996). Although successful in treating the parasite the Colorado experiments did not result in improved population performance for the four-year period of the study.

Native populations of bighorn sheep were extirpated from the Highland-Pioneer Mountains in the early 1900's. Sheep were reintroduced to the area in 1967 when 27 sheep were transplanted from the Sun River. The initial transplant population was supplemented with 31 sheep in 1969. The population expanded in size and range up through the mid 1990's so that sheep today extend across the Bighole River and into the foothills of the Pioneer Mountains. The number of males in the population grew and the herd became well known for it large trophy quality rams. The number of sheep was estimated between 350-400 (Wiegand 1994, Semmens 1996). Harvests were increased in 1992 and 1993 to 39 and 40 sheep. In addition, 35 sheep were captured and transplanted from the population in 1992 to reduce sheep numbers. In 1993 the population was at an all time high. Hoar et al. (1996) found that the Highlands-Pioneers bighorn sheep population was infected with lungworms and a wide variety of other gastrointestinal parasites. In addition to mild lungworm loads, gastrointestinal parasite loads were suggestive of clinical parasitism and the combined effects of mixed endoparasites could produce a recognizable stress factor. In late November 1994 sheep hunters reported observing the clinical signs of pneumonia in many sheep. An all age die-off proceeded through the late fall and winter, reducing the population by 87%.

As a result of the severity of this pneumonia epizootic and the known parasite history of this herd unit, a program was initiated to treat the population of bighorns frequenting the critical winter range in the Maiden Rock area. Our objectives were to mitigate the mortality that the herd experienced and to enhance the recovery of the survivors of this pneumonia epizootic. We designed and implemented the treatment to, at the very least, do no harm to the surviving bighorn sheep.

Study Area

The study area included the critical winter habitats along the Bighole River near the Maiden Rock Mine, West of Interstate 15, in southwestern Montana. The elevations range from 1593 m along the Big Hole River to 3108 m on Table Mountain in the Highlands range (Wiegand 1994). Land ownership is a combination of private, Bureau of Land Management, Beaverhead National Forest and Montana Department of Natural Resources and Conservation. Major land use activities are mining, recreation and livestock production. Two domestic sheep producers operate along the lower edges of critical bighorn sheep winter range. Domestic sheep have been husbanded in this area for more than 20 years as the introduced bighorn sheep population flourished. A railroad line follows the river course through the center of the winter range.

Methods

All bighorn sheep mortalities were investigated as opportunity and logistics allowed. Specimens were collected from fresh carcasses during a field necropsy, from hunters and biologists, or by transporting whole carcasses to the laboratory for necropsy. Sheep that could not be transported immediately were occasionally frozen whole in regional freezers for later transport. Individual sheep were necropsied at the MDFWP Wildlife Laboratory or the Department of Livestock State Diagnostic Laboratory to determine cause of mortality. Gross lesions were submitted for histopathologic examination, routine bacteriologic culture and virus isolation. Histopathology was performed by board certified pathologists from the State Diagnostic Laboratory.

Herd health monitoring was performed when animals were captured for translocation or field research in 1992-1994. Blood was drawn from the jugular vein, a pharyngeal swab from the tonsilar crypt was taken and fecal samples collected. Each animal was inspected for external parasites or other indicators of health problems.

Blood samples were transported to the MDFWP laboratory and centrifuged to extract serum. Whole blood samples were submitted to the State Diagnostic Laboratory for hematology. Standard large animal serum chemistries were performed. Standard approved serum tests were performed to determine antibodies for *Brucella abortus*, *Brucella ovina*, Bluetongue, IBR, BVD, PI3, Ovine Progressive Pneumonia, and Leptospirosis (eight serovars). Excess blood serum was archived for future testing.

Following diagnosis of serious lungworm loads in Highland-Pioneers sheep, a strategy was developed to treat surviving animals with fenbendazole treated feed and salt. During the winters of 1994-95 and 1995-96, between 6 and 9 stations were widely distributed across the sheep winter range near Maiden Rock west of I-15. Attempts to treat sheep east of I-15 were unsuccessful due to limited manpower and complex logistics. Each station consisted of a single medicated salt block in a rubber feed tub surrounded with light amounts of weed free alfalfa hay to draw the sheep to treated feed and salt. Small 1 lb. portions of SafeGuard pelleted feed were placed on the hay, salt and inside the tub. Portions were spread for best access by multiple sheep. Sheep use of each station was monitored in weekly field observation sessions and by monitoring tracks in the snow. Cameras triggered by passive infrared sensors were used to monitor some sites until one of the systems was stolen.

Routine fecal collections from sheep bedding areas near treatment stations or from radio monitored study sheep for specific herd units were conducted to monitor trends in parasite loads. Fecal samples were refrigerated and transported to the MDFWP laboratory. A modified Baerman procedure was used to determine the number and relative concentrations of lungworm larvae shed by each animal (Dinaburg 1942, Beane and Hobbs 1983). The modified Lane fecal flotation procedure was used to recover ova and oocysts from feces (Dewhirst and Hansen 1961). Coverslips from each tube were examined with a light microscope to determine the number and type of ova and oocysts present.

Results

Mortality Patterns

Most of the bighorn mortality occurred between January 1 and February 30,1995 (Table 1) during a period of severe cold weather. Sheep continued to die through March and continued to exhibit clinical signs of pneumonia. One hundred and twenty-six carcasses were located in random searches of the critical winter ranges. When discovered, fresh carcasses were collected and decomposed carcasses were flagged or spray painted to avoid duplication in carcass surveys. Most carcasses located were not suitable for tissue sampling. Total mortality exceeded 87% of the populations.

Table 1. The cumulative bighorn sheep carcass count during the Highlands-Pioneers pneumonia epizootic, 1994-95.

	Carcass Counts	Marked Sheep Alive
Dec. 15, 1994	2	29
Jan. 1, 1995	8	
Jan. 15, 1995	27	17
Feb. 1, 1995	49	
Feb. 15, 1995	71	
Mar. 1, 1995	89	
Mar. 15, 1995	94	4
Apr. 1,1995	117	
Apr. 15,1995	120	4
Apr. 30, 1995	126	2

Diagnostic Evaluations

Diagnostic necropsies were performed on 12 sheep. Histopathology indicated numerous nematode cross sections within thick caseated lesions pervasive throughout the lungs.

Bacteriology isolated *Pasteurella haemolytica* from 6 of 12 samples. Bio and serotypes isolated included T-3, T-3,15, T-4, T-4,10, T-4,10,15 and A-2. Other isolates included Streptococcus and *Pasteurella multocida*. Virus isolation attempts were negative for 9 attempts. Although isolation attempts were negative prior serologic evidence indicated antibody prevalence for PI3 and BVD for 90% and 45% of the sheep herd, respectively. Lungworm loads based on larval shedding in 10 fecal samples ranged from 1-164 LPG. Average lungworm larval shedding from 35 bighorn sheep captured for transplant programs two years prior to the pneumonia epizootic was 21.8 ± 74.1 LPG. Average lungworm load just prior to the die-off was 116.6 (Hoar et al, 1996).

Experimental Treatment

In 1994-95 stations became available to bighorn sheep on January 13, 1994 and were first utilized by January 27. In the first winter sheep utilized all 9 stations. In 1995-96 only 6 stations were established due to the limited distribution of sheep on winter ranges. Sheep visited each of the six stations in 1995-96. The proportion of stations visited was higher in the second year of treatment indicating sheep became familiar with the sites and treatment protocol (Table 2).

Table 2. The percent of treatment stations visited by bighorn sheep during time periods of approximately one week for two winter periods, 1994-95 and 1995-96.

Sample Period	1994-95	1995-96
1	25.0	40.0
2	37.5	100.0
3	75.0	100.0
4	77.7	100.0
5	71.4	100.0
6	50.0	100.0
7	62.5	66.6
8	85.7	-----

Field problems encountered included interference with deer, elk and domestic horses at treatment stations. In 1994-95 several sites were rendered inoperable due to visits by free-ranging horses on leased pastures. Human intrusions were also recorded. An initial plan to utilize infrared triggered cameras to monitor stations was discontinued after several stations were sabotoged and one camera was stolen.

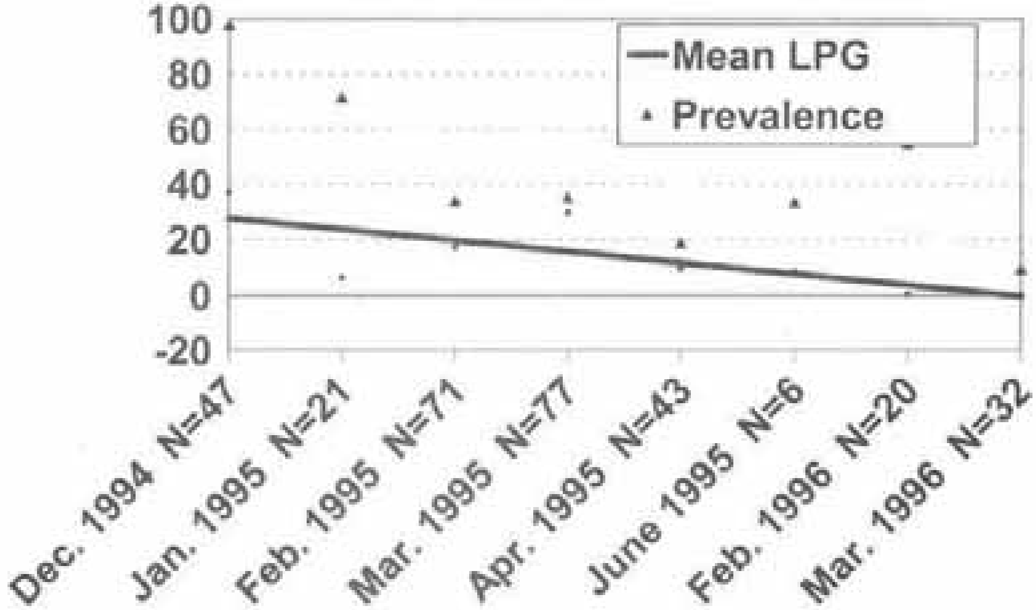
Larval Shedding

Larvae samples collected just prior to the 1994-95 epizootic indicated increasing larval loads and over 30 % of the sheep in the study area were shedding more than 100 larvae per gram (Table 3). During the treatment period the mean LPG and the prevalence of infection dropped substantially (Figure 1).

Table 3. Trend in bighorn sheep larval shedding during experimental treatment with fenbendazole in the Highlands-Pioneers herd unit 1993-1998

	N	Mean LPG	%LPG's > 100	Sheep Population Size
1993-94 (Prior)	78	116.6	31.6	380
1994-95 (During)	212	19.2	4.7	50
1995-96 (After)	68	1.2	0.0	32
1998	17	1.2	0.0	>35

Figure 1. Trend lines for prevalence and mean LPG for Protostrongylus in bighorn sheep from the Highlands-Pioneers herd unit during experimental treatment, 1994-95.



Bighorn sheep in the study area readily found all treatment stations and visited them regularly consuming most of the pelleted feed and hay. Moderate use of the medicated salt block was observed at many stations. Bighorn sheep found the treatment stations more quickly the second year of treatment and visited them regularly indicating the sheep had became familiar with the treatment protocol. We could not determine what proportion of the population received treatment during the experiment. However, there was only a small remnant of about 35 sheep remaining in the population after the pneumonia epizootic subsided. A survey of the remaining sheep population counted 23 sheep within the treatment area.

Two years of treatment with fenbendazol reduced larval shedding in surviving sheep following a significant pneumonia epidemic. The shedding of larvae had not increased substantially for 20 months following the treatment program. Worley and Seesee (1990) demonstrated that fenbendazole successfully reduced larval shedding for 5 months following treatment and they considered the animals cured. Schmidt et al. (1979) reported no recurrence of lungworm larval excretion in bighorn sheep up to 6 months after treatment. The reduced larval output we observed in bighorn sheep for prolonged periods may indicate that adult lungworms were successfully killed in treated animals.

Miller et al. (1996) has shown that several anthelmintic treatment protocols applied in Colorado did not improve population performance or improve lamb survival. Layne and McCabe (1986) found that ivermectin treatment improved lamb survival in Custer State Park. Schmidt et al (1979) observed increased lamb survival in Colorado where several anthelmintics were applied. Foreyt et al (1990) reported increased lamb production when comparing fenbendazole treated and untreated controls. We did not measure lambing success in detail from this population following treatment. However, we have observed lambs in both years following treatment. The long term benefits of treating bighorn sheep populations with fenbendazole remains in question.

The treatment protocol applied to the Highlands-Pioneers demonstrates that intense short-term anthelmintic treatment of wild bighorn sheep is feasible and can reduce parasite loads. The immediate benefits of reducing larval output and perhaps killing adult lungworms are assumed to be beneficial. However, we do not recommend long term application of anthelmintics as a treatment option based on this study. Long term application of anthelmintics may lead to drug resistent parasites and may not be economically or logistically applicable to many situations in Montana.

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Phenotype Evaluation of Free-Ranging European Mouflon (*Ovis orientalis musimon*) on Kahuku Ranch, South Point Hawaii.

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ABSTRACT

Are the free-ranging European Mouflon (*Ovis orientalis musimon*) on the Kahuku Ranch "true" mouflon? Field Surveys conducted during October 1997 examined this question based on phenotype conformation. Five hundred thirty four live mouflon were examined in the field and 17 hunter-harvested rams were measured and photographed. The mouflon on Kahuku Ranch were determined to be phenotypically true, exhibiting typical or classical characteristics attributed to the species *Ovis orientalis musimon*.

INTRODUCTION

The phenotypic status of mouflon sheep (*Ovis orientalis musimon*) on the Kahuku Ranch, near the southern tip of Hawaii's Big Island, is described. South Point Safaris Ltd., the hunting company on Kahuku Ranch, requested assistance in determining the phenotypic status of sheep on their hunting concession. The purpose was to determine the appropriateness of these mouflon for designation as "true" for trophy hunting purposes.

According to Giffen (1979), Hawaii supports both purebred mouflon and feral sheep-mouflon hybrids, a situation similar to many locations on the U.S. mainland and throughout Europe. The situation is common because European mouflon will readily cross with domestic sheep (*Ovis aires)* and will produce fertile offspring (Tomiczek 1985). The question of how "true" various hunted mouflon populations are is one often raised by hunters.

European Mouflon

European mouflon are native to the Mediterranean islands of Corsica and Sardinia. Mouflon are widely distributed due to introductions to the Crimea, Germany, Switzerland, Holland, Luxemburg, Italy, Poland, Czechoslovakia, Hungary, Yugoslavia, Romania, Spain, Finland, Denmark, Bulgaria and the United States (Clark 1964; Uloth 1976; Valdez 1982). Most muflon populations in Europe were established during the past 250 years (Tomiczek 1985, Uloth and Prien 1985). According to Valdez (1982), "The European and Cyprian mouflon probably originated from feral (domestic gone wild) primitive domestic sheep brought to the Mediterranean islands of Corsica, Sardinia, and Cyprus by man." Some reports indicate the mouflon on Corsica have interbred with domestic sheep brought to the island and domestic strains were added to European introductions to provide hunters with larger trophies (Mungall and Sheffield 1994). Mouflon are considered very similar genetically to domestic sheep and may be very similar to those wild sheep originally domesticated by man. Blood analyses reported by Stralit and Bobbak (1988) provide further evidence for close similarity between domestic sheep and mouflon. In a report on a study of hemoglobin phenotypes in wild European mouflon on the island of Sardinia, Naitana, et al (1990) concluded there were structural and physiological homologies between domestic Sardinian sheep and mouflon for specific ß-globin alleles. Hadjisterkotis (1996), in reporting on the taxonomy of mouflon on the Greek island of Cyprus indicates wild sheep on Cyprus stem from a domesticated wild strain of sheep introduced by man around 6000 BC. From analysis for cytochrome b gene in mitochondrial DNA, Arai, et al. (1997) concluded domestic sheep have been established from mouflon. This close association of European mouflon with domestic sheep on both native and introduced ranges has long made their classification problematic.

Because of their origins and close relationship to mainland moufloniforms, Valdez (1982) considered insular Mediterranean mouflon to be conspecific with mainland forms. He recognized mouflon dwelling on Corsica and Sardinia as *Ovis orientalis musimon* and those on Cyprus as *Ovis orientalis ophion*. Cugnasse (1994) classified the mouflon on the Mediterranean islands as three varieties -- *Ovis gmelini musimon,* var. *corsicana; Ovis gmelini musimon,* var. *musimon*; and *Ovis gmelini musimon*, var. *ophion* for the wild sheep on the islands of Corsica, Sardinia, and Cyprus, respectively. Other authors have proposed different classification schemes. *Ovis orientalis musimon* is the classification of choice for this paper. For these reasons visually observable morphological characteristics reported in the literature as typical of "true" mouflon were used to make the phenotypic determination reported here.

Study Area

The South Point mouflon population ranges over several thousand acres of the privately owned Kahuku Ranch and adjacent Kau State Forest. The landform consists of lava flows from Mauna Loa volcano vegetated to shrub steppe plant communities or forest. Some of the more recent flows are not vegetated. Topography created by the lava flow substrate provides the basis for a very diverse landscape. Mouflon are free ranging with only natural topographic features and the Pacific Ocean limiting distribution along a portion of their range. South Point mouflon are separated from other mouflon or feral sheep populations by a distance of about 20 to 30 airline miles (Giffen 1976; Giffen 1975-1979; van Riper and van Riper III 1982).

Mouflon were introduced to the Kahuku Ranch in 1968 and are managed for trophy hunting with periodic culling of females to control the population density. Mouflon are abundant, but population density or trend estimates are not available. O'Gara (1994) studied habitat conditions, food habits, and population dynamics of this mouflon population.

Cattle *(Bos taurus)*, both feral and domestic, are the only other large ungulate occupying the South Point mouflon range. Forage competition may be occurring between mouflon and cattle, but range use for both species only overlaps on a portion of the wild sheep range.

METHODS

Mouflon were observed in the field for European mouflon phenotype characteristics reported by Lydekker (1901), Clark (1964), Uloth (1976), Valdez (1982), Mungall and Sheffield (1994), and others.

For rams, the characteristics include:

Hair that is close, thick, and somewhat stiff. Coarse hair rather than wool forms the outer coat. Distinct neck ruff during the rut.

General color of the coat on mature rams is rufous brown or foxy red shading into chocolate brown on the head and face.

Black on sides of the neck, throat, chest with a band of black on the flanks. Black also as a streak down the withers, on the outer front surfaces of the forelegs above the knees, and on the front and outer sides of the hind limbs above the hocks.

Ears are grayish with the margins and part of their interior white.

Muzzle and chin grayish white shading into grayish rufous in the middle of the black area on the throat.

A broad band grizzled with white defines the rear border of the saddle patch.

The buttocks and all under parts, except for a narrow streak down the forelegs, are white.

Limbs exhibit a streak of white on their back surface above the knees and hocks. Below the knees, legs are white except for a varying amount of black on the front of the anterior pair.

In winter coat the general color of the upper parts deepens and becomes more of a chestnut brown. The saddle patch on each side of body lightens until in many older rams is nearly white.

Horns of mouflon are variable, but most typically are inward at about the 3/4 curl point.

A strong sexual dimorphism exists, especially in older animals. The pelage coloration exhibited by "true" female mouflon varies from light tan to dark brown. The dorsal patch is absent or indistinct. Lambs are similar in appearance to ewes. Adult females may or may not have horns. When horns are present on females they are only a few inches in length.

Binoculars (10X) and spotting scope (15X40) were used to make field observations. Only sheep within a few hundred yards and observed under good lighting conditions were included in the sample. Particular attention was paid to spotting atypical features.

Physical measurements included horn length, horn base circumference, total length, girth, length from top of front shoulder to tip of front hoof, length from crown of rump to tip of hind hoof, ear length, eye to tip of nose length, and live weight. Data were recorded and averages calculated and compared with lengths reported for mouflon in the literature. All measurements were recorded to the nearest 1/8 inch. Each ram was assigned an approximate age. Hawaii's year-round growing season resulted in some growth rings being indistinct.

Visual observations and physical measurements, compared with similar information reported by Clark (1964), Uloth (1976), Valdez (1982), Mungall and Sheffield (1994), and others, formed the basis for an opinion as to the phenotype status of South Point mouflon.

RESULTS AND DISCUSSION

From October 9th to October 13th, 1997, 534 free-ranging wild mouflon were observed. Composition of the sample was 51, 9, and 40 percent ewes, lambs, and rams, respectively. Additionally, horn and body measurements were taken from 17 mouflon harvested by hunters. Horn measurements were taken from two additional mouflon found in the field. Live weights were taken for two harvested rams and one adult ewe.

Population

The proportion of the population sampled is not known, as no estimate of total mouflon numbers is available for this several thousand-acre wild sheep range. Most of the landform exhibits very rugged topography created by recent and historic lava flows. Vegetation consists of forest shrubland and small meadows. The mouflon are free ranging. None of the area is fenced with wildlife-tight fence. A portion of the area bounds the Pacific Ocean. The difficulty of making accurate population estimates in habitats like this is well known. Therefore, since sheep are obviously abundant, sampling effort concentrated on observing the maximum number of sheep possible rather than a predetermined sample size.

Visual Characteristics

All of the 534 mouflon observed exhibited coat coloration patterns and other physical characteristics described for true mouflon by Lydekker (1901), Clark (1964), Uloth (1976), Valdez (1982), and Mungall and Sheffield (1994). All adult rams exhibited pelage typical of the rutting season.

Physical Characteristics

Horn measurements were collected from 19 rams ranging in age from 7 to11 years. Body measurements were taken from 17 hunter-harvested mouflon rams.

Horns

The mean age for rams sampled was 10 years. Mean horn length was 28.49 and 28.48 inches for the right and left sides, respectively. Mean horn basal circumference was 8.98 and 9.23 for the right and left sides, respectively. A tip-to-tip measurement was taken for 15 rams and a mean of 16.28 inches was calculated. The aforementioned measurements are similar to those reported by Clark (1964), Uloth (1976), Valdez (1982) and Mungall and Sheffield (1994). Typically, horns of mature (trophy type) rams were observed to arc in rather than out at the horn tips.

Body Measurements

Mean measurements for total body length, ear length, girth, and tail length were 49.22, 3.47, 32.17, and 3.59 inches, respectively. For five mouflon the, distance from top of the shoulder to the tip of front hoof, and distance from crown of the rump to tip of the hind hoof, was 28.85 and 29.13 inches, respectively. The mean hind foot length for 16 mouflon was 11.80 inches. The mean eye-to-nose distance for 10 mouflon was 5.43 inches. Mungall and Sheffield (1994) reported that purebred mouflon, unlike domestic sheep or many mouflon crosses, have a short tail of 3 to 4 inches. For two adult rams, the mean live weight was 87 pounds. Live weight for one young adult ewe was 51 pounds. Measurements such as these can show considerable variability between different populations and habitats. However, they are within the range of measurements reported by Clark (1964), Valdez (1982), Mungall and Sheffield (1994) and others.

CONCLUSIONS

Wild free-ranging mouflon inhabiting the Kahuku Ranch at South Point Hawaii are true European mouflon, exhibiting all of the typical or classic characteristics attributed to the species *Ovis orientalis musimon.*

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EVALUATION OF A MULTIVALENT *PASTEURELLA HAEMOLYTICA* TOXOID-BACTERIN IN PROTECTING BIGHORN SHEEP FROM PNEUMONIA AFTER EXPOSURE TO DOMESTIC SHEEP

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Abstract: A *Pasteurella haemolytica* toxoid-bacterin which contained serotypes A1, A2, and T10 was evaluated in captive bighorn sheep to determine efficacy in protecting bighorn sheep from pneumonia after exposure to domestic sheep. Six healthy captive bighorn sheep were divided randomly into two equal groups and then balanced for age. Three bighorn sheep were each vaccinated intramuscularly twice with 2 mls of vaccine on day minus 28 and on day minus 14 of the experiment. Three unvaccinated bighorn sheep were each given an intramuscular injection of two mls of sterile water on the same days the other three bighorns were vaccinated. On day 0, three healthy domestic sheep were placed in the pen with the bighorn sheep and maintained with the bighorns for 60 days. All six bighorn sheep died from clinical pneumonia during the experiment, and all three domestic sheep remained healthy. Vaccinated bighorns died on experimental days 30, 30, and 61; unvaccinated bighorn sheep died on experimental days 20, 30, and 32. *Pasteurella* spp isolated from lungs or tissues of dead bighorn sheep included several serotypes of *P. haemolytica* and *P. multocida*. Cytotoxin neutralizing antibodies and agglutinating antibodies against A1, A2, and T10 were present in all bighorn sheep before vaccination. Antibody titers did not differ between vaccinated and unvaccinated bighorn sheep, and were not elevated after vaccination. This experiment indicated that the vaccine did not protect bighorn sheep against pneumonia after exposure to domestic sheep.

Pasteurellosis, caused by *Pasteurella haemolytica* and *Pasteurella multocida*, remains the major mortality factor in free-ranging bighorn sheep (*Ovis canadensis*) populations (Foreyt, 1990; Cassirer et al., 1996). Outbreaks of pasteurellosis in bighorn sheep often results in widespread mortality initially, followed by very low recruitment for several years following the die-off (Foreyt, 1990). Although some strains of *Pasteurella* spp. carried by domestic sheep are directly lethal to bighorn sheep (Foreyt et al., 1994), other factors potentially can predispose to or exacerbate mortality. Such factors include other bacteria, respiratory viruses, other microbial agents, lungworms, gastrointestinal and external parasites, genetics, increased population density, habitat, nutrition, adverse weather, presence of domestic livestock and other wildlife, breeding activity, behavior, capture and restraint techniques, and other stressors. Management methods that have been suggested to prevent pasteurellosis in bighorn sheep include preventing contact with domestic or mouflon sheep (*Ovis musimon*), reducing the factors mentioned previously that can contribute to pneumonia outbreaks, and vaccinating bighorns with a safe and effective vaccine.

Currently, the are no vaccines that have been shown to be effective against the lethal strains of *P. haemolytica*, primarily biotype A, serotype 2, carried by domestic sheep. Previous vaccine studies with captive bighorn sheep exposed to domestic sheep included a commercially available bacterin (Foreyt, 1989), and an autogenous bacterin (Foreyt, 1992). In those experiments, all vaccinated and unvaccinated bighorns died from bronchopneumonia. One additional vaccine study that evaluated a live nonlethal cytotoxic *P. haemolytica* A2 was not successful in preventing pneumonia when vaccinated bighorns were inoculated with cytotoxic *P. haemolytica* A2 from domestic sheep (Foreyt and Silflow, 1996). Recently Miller et al., 1997, and Kraabel et al., 1998, evaluated a multivalent *P. haemolytica* vaccine, containing A1, A2, and T10, in bighorn sheep to determine safety, serologic responses and protection from experimental challenge with a bighorn sheep strain of *P. haemolytica* T10. Results from those experiments indicated the vaccine was safe, increased leukotoxin neutralizing titers and agglutination titers to A1 and A2, and resulted in lower morbidity and mortality in vaccinated bighorn sheep during the 7 days after inoculation.

The purpose of the current experiment was to determine if this multivalent *P. haemolytica* vaccine would protect bighorn sheep against pneumonia after exposure to domestic sheep.

I thank M. Miller for providing the vaccine, H. McNeil for serological analysis, R. Rimler for *P. multocida* analysis, J. Lagerquist for serotyping and parasite analysis, and the personnel in the Washington Animal Disease Diagnostic Laboratory for bacterial and viral evaluations. Partial funding from the Foundation for North American Wild Sheep is appreciated.

MATERIALS AND METHODS

Six captive Rocky Mountain bighorn sheep and three domestic sheep were used in this experiment. The bighorn sheep were divided randomly into two equal groups and then balanced for age and sex. The vaccinated group consisted of two 1-yr-old males and a 5-yr-old male. The unvaccinated control group consisted of a 1 yr-old male, a 1yr-old female, and a 3-yr-old male. The vaccinated sheep were each given an intramuscular injection of 2-mls of an experimental *P. haemolytica* bacterin-toxoid vaccine that contained A1, A2, and T10 on days minus 28 and minus 14 before domestic sheep exposure. Dr. Michael Miller from the Colorado Division of Wildlife kindly supplied the vaccine. Unvaccinated control bighorn sheep were each given an intramuscular injection of 2-mls of sterile water. All injections were in the gluteal muscles of the hind leg.

Four weeks after administration of the first vaccine and two weeks after the second vaccine, three clinically healthy, adult, male domestic sheep were moved into the pen with the six bighorn sheep. The domestic sheep were obtained from the University of Idaho Sheep Center, Moscow Idaho. Pharyngeal swab samples for bacterial analysis were collected from all bighorn sheep on days of vaccination (days –28 and –14), and the day when domestic sheep were introduced (day 0). Pharyngeal swab samples were collected from all domestic sheep on days 0 and 30. Domestic sheep maintained residence in the pen with the bighorn sheep for 60 days, at which time they were removed.

Pharyngeal swab samples from all animals were placed in Amies transport medium (Spectrum Diagnostics, Inc., Houston, Texas, 77032, USA), transported to the Washington Animal Disease Diagnostic Laboratory (WADDL), Pullman, Washington, 99164, USA, and streaked onto 5% sheep blood agar within 2 hr of collection to maximize isolation of *P. haemolytica* (Wild and Miller, 1991). Isolation and identification of *P. haemolytica* and *P. multocida* was accomplished by standard methods (Carter, 1984, Snipes et al., 1992), but hemolysis on 5% sheep blood agar or growth on MacConkey's agar were not requisites for identification of *P. haemolytica* (Onderka et al., 1988). All *P. haemolytica* isolates were identified to biotype and serotype according to established formats (Biberstein, 1978; Frank and Wessman, 1978). When an isolate reacted in antisera to several serotypes, all were listed. Isolates of *P. multocida* were characterized by Dr. Richard Rimler, National Animal Disease Center, Ames, Iowa, according to previously established methods (Rimler and Brodgden, 1986). Capsule group was determined by the mucopolysaccharidase test using chrondroitinase AC, hyaluronidase, and heparinase III. Somatic type was determined by the gel-diffusion precipitin test, and toxin production was determined with monoclonal anti-PMDT in a colony lift assay.

At the beginning of the experiment, nasal swab samples (Marion Scientific Viral Culturette, Marion Scientific, Kansas City, Kansas 69114, USA) also were collected for virus evaluation. Specimens were inoculated onto ovine fetal tracheal cells and bovine turbinate cells for 2 passages at ten-day intervals and were examined daily for cytopathic effect. Additional specimens were tested for respiratory syncytial virus by use of solid phase-enzyme immunoassay (Abbott RSV EIA, Abbott Laboratories, South Pasadena, California 91030, USA). Isolation of *Chlamydia* sp.was not attempted, and fecal samples were evaluated for lungworm larvae by a modified Baermann technique (Foreyt, 1997). A serological screen for antibodies to respiratory viruses, malignant catarrhal fever virus, and *Brucella ovis* was done by WADDL according to established procedures.

Evaluation

For the entire experiment, all sheep were observed at least once daily for signs of respiratory disease. Sheep that died were submitted to WADDL for complete necropsy evaluation. At necropsy, bacterial isolations were attempted from several tissues including tonsil, bronchial lymph nodes, spleen and lungs. Representative tissues also were fixed in 10% buffered formalin, sectioned at 5 μm, and stained with hematoxylin and eosin for microscopic evaluation.

Pasteurella serology

Measurement of leukotoxin neutralizing antibodies and agglutinating antibodies to serotype-specific surface antigens was done by Heather McNeil, Department of Pathology, Ontario Veterinary College, University of Guelph, Guelph, Ontario, Canada, according to the methods published by Miller et al., 1997. Titers were expressed as $\log_2$. For comparative purposes, additional serum samples were collected from 12 adult, healthy, free-ranging bighorn sheep (5 rams and 7 ewes) at Hall Mountain in northeastern Washington (Foreyt et al., 1996).

RESULTS

All six bighorn sheep died from clinical pneumonia between 20 and 61 days after initial exposure to domestic sheep (Table 1). Vaccinated bighorns died on days 30, 30, and 61, respectively, and unvaccinated bighorns died on days 20, 30, and 32, respectively.

Table 1. Identification, age, sex, and day of death of bighorn sheep used on the vaccination experiment.

	Age	Sex	Day of Death[a]
Vaccinated Bighorns			
#1 (Tag 44)	1yr	M	30
#2 (Tag 43)	1 yr	M	30
#3 (Tag 146)	5 yr	M	61
Unvaccinated Bighorns			
#4 (Tag 46)	1 yr	F	20
#5 (Tag 22)	3 yr	M	30
#6 (Tag 47)	1 yr	M	32

[a] Days after exposure to domestic sheep

At necropsy, all bighorn sheep were in good body condition with adequate amounts of body fat. Lesions were similar in all bighorn sheep and characteristic of acute, fibrinohemorrhagic pneumonia and pleuritis. Up to 75% of lung volume was dark red and consolidated with small to moderate amounts of adherent fibrin. On cut surface, lungs were diffusely edematous with prominent interlobular septa. Regional lymph nodes (mandibular, cervical, tracheobronchial, mediastinal) were enlarged. Tapeworms, *Wyominia tetoni* were present in the hepatic bile ducts of two of the sheep.

Histologically, pulmonary architecture was diffusely and severely altered by large areas of necrosis marginated by densely packed or clumped neutrophils and macrophages. The pleura was markedly thickened by fibrin deposits and subpleural spaces plus interlobular septa were widened by collections of fluid and exudate. Densely basophilic bacterial colonies were mixed with the cellular exudates, especially in terminal bronchioles and remaining air spaces. Adjacent alveolar capillary endothelium was disrupted, and fibrin thrombi were common within these blood vessels.

Pasteurella spp. were isolated from pharyngeal swab samples from all six bighorn sheep before exposure to domestic sheep and from two of three of the domestic sheep (Table 2). Most isolates were *P. haemolytica*, biotype T (also called *Pasteurella trehelosi*). *Pasteurella* spp., including *P. multocida* and several serotypes of *P. haemolytica* were isolated from the lungs, lymph nodes or other tissues of all six dead bighorns at necropsy (Table 2). Important *Pasteurella* spp. included *P. haemolytica* A2, which was isolated from two dead bighorn sheep, and P. *multocida* D:3 which was isolated from three dead bighorn sheep.

All domestic sheep remained healthy throughout the experiment. On days 0 and 30, several serotypes of *P. haemolytica* were isolated from two of the domestic sheep, but no *Pasteurella* spp. were isolated from the third sheep. *Pasteurella multocida* was not isolated from any of the domestic sheep (Table 2).

Table 2. Summary of *Pasteurella haemolytica* and *Pasteurella multocida* isolated during the vaccination experiment.

Group	Day B28, -14, or 0[a]	At Necropsy
Vaccinated		
Bighorn 1	*P. haemolytica* $T_{3,4}$; Tunt[b]; $A_{2,5,6}$; A_5	*P. haemolytica* A_2, $A_{2,5}$
Bighorn 2	*P. haemolytica*, $T_{3,4}$; Tunt; $A_{2,5}$	*P. multocida* D:3
Bighorn 3	*P. haemolytica* Tunt, unt	*P. haemolytica* unt, *P. multocida* D:3
Unvaccinated		
Bighorn 4	*P. haemolytica*, $T_{3,4,10,15}$; Tunt; $A_{2,5,6,8,11}$; Aunt	*P. haemolytica* A_2; Aunt
Bighorn 5	*P. haemolytica*, $T_{3,4}$; $T_{3,4,10,15}$	*P. haemolytica* unt
Bighorn 6	*P. haemolytica*, $T_{3,4,15}$; Tunt; $_{2,5,6}$; $A_{1,5,11}$; Aunt	*P. multocida* D:3
Domestic Sheep	Day 0	Day 30
1	*P. haemolytica* T_4	*P. haemolytica*, $T_{3,4,10,15}$
2	*P. haemolytica* $T_{3,4}$ *P. haemolytica* T_4	*P. haemolytica* unt
3	negative	negative

[a] Days B28 and B14 are the days of vaccination; day 0 is the day of domestic sheep introduction
[b] Untypeable

No viruses or lungworm larvae were isolated from any of the bighorn sheep. Antibody titers were not detected against parainfluenza 3 virus, bovine respiratory syncytial virus, infectious bovine rhinotracheitis virus, bovine virus diarrhea virus, ovine progressive pneumonia virus *or Brucella ovis*. Antibodies against malignant catarrhal fever virus were detected in bighorn sheep numbers 3, 4, and 6.

Leukotoxin neutralizing antibodies, and agglutinating antibodies against surface antigens of A1, A2, and T10 were detected in all bighorn sheep on days −28, -14, and 0 (Table 3). Antibody titers were similar between vaccinated and unvaccinated bighorns, and were not elevated after vaccination. Antibody titers from 12 healthy, adult bighorn sheep from the Hall Mountain herd in northeastern Washington are listed in Table 4. Bighorn sheep tested from the Hall Mountain herd had antibody titers that were similar to the titers of the experimental bighorn sheep.

DISCUSSION

The purpose of this experiment was to determine whether vaccination of bighorn sheep with this multivalent vaccine would protect bighorn sheep against fatal pneumonia that predictably occurs after exposure to domestic sheep (Foreyt, 1989; Martin et al., 1996). Because all bighorn sheep died of pneumonia during this experiment, my conclusion is that the vaccine did not protect the bighorn sheep against pneumonia. *Pasteurella haemolytica* A2, which is one bacteria that is carried by a high percentage of healthy domestic sheep and has been shown to be lethal in bighorn sheep (Foreyt, 1989), was isolated at necropsy from one vaccinated and one unvaccinated bighorn sheep. This serotype was not isolated from the three domestic sheep or any bighorn sheep before death; therefore, the source of the bacteria is unknown. However, based on previous experience and data that indicate a major percentage of domestic sheep are carriers of A2, it may be that one or more of these three domestic sheep were sporadic shedders of A2 and it was not detected at the time of sampling, or it was present in very low numbers in the domestic sheep, and was not detected by laboratory personnel.

Pasteurella multocida was not isolated from any live bighorn or domestic sheep from pharyngeal swab samples, but was isolated at necropsy from tissues of three of the dead bighorn sheep. The source of the *P. multocida* could not be determined.

All bighorns had relatively high antibody titers to the components in the vaccine before they were vaccinated, and vaccination did not significantly increase those titers. These data are in contrast to those of Miller et al., 1997, and Kraabel et al., 1998, who evaluated this vaccine for safety, serological responses to the vaccine, and protection from experimental challenge with *P. haemolytica* T10. Miller et al., 1997, reported mean pretreatment titers for *P. haemolytica* leukotoxin neutralizing antibody of less than 1; whereas, in the current experiment, bighorn sheep titers ranged from 2 to 10 (mean of 6.3), and in the healthy free ranging bighorn sheep, titers ranged from 2-7 (mean of 4.8). It may be that many of these titers are cross reactions with nonspecific antigens, and may not accurately reflect exposure to the specific serotypes of *P. haemolytica.* They also reported marked increase in antibody titers to A1 and A2 surface antigens after vaccination. In the current experiment the change from pre to post vaccination titers was negligible.

Although the vaccine did not protect the bighorn sheep from pneumonia after exposure to domestic sheep in this experiment, some of the deaths may have been caused by *P. multocida*, which was not one of the components of the vaccine. It follows that future vaccine research should involve vaccines that contain *P. multocida* as one component. Because *P. haemolytica* A2 is common in domestic sheep and highly pathogenic in bighorn sheep, it is essential that an effective vaccine contain the A2 component to protect bighorn sheep if they are likely to be exposed to domestic sheep. Additional work on *P. multocida* and vaccine evaluation in bighorn sheep is justified because of the severe

Table 3. Antibody titers (log_2) on days B28, -14 and 0 of the vaccine experiment.

	Vaccinated Bighorn Sheep				Unvaccinated Bighorn Sheep			
Pasteurella haemolytica antibody	A_1	A_2	T_{10}	LNA[a]	A_1	A_2	T_{10}	LNA[a]
Bighorn sheep number	1,2,3	1,2,3	1,2,3	1,2,3	4,5,6	4,5,6	4,5,6	4,5,6
Day B 28 (1[st] vaccination)	6,6,6	9,7,14	8,8,8	8,6,10	4,8,5	8,8,9	8,9,8	2,2,10
	(5.7)[b]	(10.0)	(8.0)	(8.0)	(5.7)	(8.3)	(8.3)	(4.7)
Day B14 (2[nd] vaccination)	6,5,11	8,7,15	7,7,9	7,5,11	7,7,5	8,7,9	9,9,8	1,6,10
	(7.3)	(10.0)	(7.7)	(7.7)	(5.7)	(8.0)	(8.7)	(5.7)
Day 0 (Domestic sheep introduced)	5,6,12	7,8,16	8,7,9	3,7,12	5,6,4	7,7,9	8,9,9	0.5,5,11
	(7.7)	(10.3)	(8.0)	(7.3)	(4.7)	(7.7)	(8.7)	(5.5)

[a] LNA = leukotoxin neutralizing antibody titer

[b] Number in parenthesis is the mean titer of the three bighorns

Table 4. *Pasteurella haemolytica* antibody titers (log_2) from adult free-ranging bighorn sheep (n = 12) from a healthy herd in Northeastern Washington.

Antibody	Range of titers	Mean titer	Median titer
A_1[a]	3-6	4.3	4
A_2[a]	5-7	6.3	6
T_{10}[a]	7->12	9.3	9
LNA[b]	2-7	4.8	5

[a] Agglutinating antibody titers (log_2)

[b] Leukotoxin neutralizing antibody titers (log_2)

manifestations of pasteurellosis in bighorn sheep populations and management goals. Use of a safe and effective vaccine against pathogenic strains of *Pasteurella* in bighorn sheep would be a valuable management technique, especially when bighorn sheep are captured or transplanted to new areas.

DISCUSSION

The purpose of this experiment was to determine whether vaccination of bighorn sheep with this multivalent vaccine would protect bighorn sheep against fatal pneumonia that predictably occurs after exposure to domestic sheep (Foreyt, 1989; Martin et al., 1996). Because all bighorn sheep died of pneumonia during this experiment, my conclusion is that the vaccine did not protect the bighorn sheep against pneumonia. *Pasteurella haemolytica* A2, which is one bacteria that is carried by a high percentage of healthy domestic sheep and has been shown to be lethal in bighorn sheep (Foreyt, 1989), was isolated at necropsy from one vaccinated and one unvaccinated bighorn sheep. This serotype was not isolated from the three domestic sheep or any bighorn sheep before death; therefore, the source of the bacteria is unknown. However, based on previous experience and data that indicate a major percentage of domestic sheep are carriers of A2, it may be that one or more of these three domestic sheep were sporadic shedders of A2 and it was not detected at the time of sampling, or it was present in very low numbers in the domestic sheep, and was not detected by laboratory personnel.

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