NUTRITIONAL ECOLOGY AND POPULATION DYNAMICS

OF BIGHORN SHEEP IN CENTRAL IDAHO

by

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Research Proposal

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INTRODUCTION

Prior to the arrival of Europeans, Rocky Mountain bighorn sheep (_Ovis canadensis canadensis_) were widely distributed in western North America, and numbered from 1.5 to 2 million (Buechner 1960). During the late 1800's and early 1900's bighorn sheep suffered severe population reductions across most of their range (Buechner 1960). Overhunting, competition with domestic livestock, and diseases introduced with domestic livestock have been postulated as the causes of bighorn sheep population declines. In modern times bighorn sheep numbers have been estimated at less than 42,000 individuals (Wishart 1978), or less than 10% of their former levels (Buechner 1960).

Many bighorn sheep populations have become small and isolated in remote areas (Trefethen 1975, Wishart 1978, Thorne et al. 1984). Berger (1990) concluded that populations of less than 50 individuals were likely to go extinct in less than 50 years. Reintroductions have been successful in some instances (Goodson 1982), but in other situations populations have continued to decline. Bighorn sheep populations have suffered from a general loss of habitat and more recent disease outbreaks (Risenhoover et al. 1988). In the Northern Rockies, bighorn sheep management has generally offered biologists more challenges than the management of other native ungulates (Cook 1990).

Bighorn sheep have specific habitat requirements and the amount of suitable habitat is limited. Bighorn sheep habitat can be characterized by three major components: high visibility, escape terrain, and abundant continuous forage (Risenhoover et al. 1985, 1988). Suitable habitat areas often exist in discrete patches separated from one another. Habitat patches should be connected by travel corridors where visibility and escape cover are adequate.

Bighorn sheep are characterized as poor disperses (Geist 1971, 1983, Cook 1990) relative to other native ungulates. Juvenile bighorn sheep inherit seasonal home ranges by following adults, and movement patterns are passed on from one generation to the next. An individual may have up to 6 seasonal home ranges, and individuals typically exhibit a strong fidelity to each seasonal home range (Geist 1971). Maintaining mobility is critical to the health of bighorn populations. Man-caused landscape disturbances and disease-related die-offs can sever traditional movement patterns. Consequently, bighorn sheep populations may become sedentary and fail to readily utilize available habitat. Thus, populations may not meet their nutritional needs or other environmental challenges.

Bighorn sheep have appeared to be more susceptible to diseases than other native ruminants, and disease has played a greater role in bighorn sheep population ecology (Stelfox 1976, Geist 1985, Cook 1990). Bighorn sheep evolved in cold climates where the number of pathenogenic organisms was generally low, and where bighorn sheep were segregated from

closely related ruminant species (Geist 1985). Apparently, bighorn sheep populations have recently encountered pathogens to which they have not evolved strong resistance. This line of reasoning has also been used to explain modern differences in disease levels between Dall sheep (Ovis dalli) and bighorn sheep. Hoefs (1984) reasoned northern sheep are exposed to uniformly severe and stable environmental conditions, such as severe winter weather and predation, and sheep in southern areas are exposed to conditions, namely parasites and diseases, that cause drastic fluctuations in sheep numbers.

Risenhoover et al. (1988) state "that unless management priorities are adjusted to focus more closely upon the ecological requirements of bighorn sheep, surviving bighorn populations will remain predisposed to epizootics and land use conflicts, and additional sheep populations will be lost". There is a need to understand the factors that determine bighorn sheep distribution and abundance.

Caughley (1976) presents the classic model of herbivore/forage interaction. When a herbivore enters vacant habitat the population grows rapidly. Eventually, the vegetation's ability to sustain herbivore population growth is exceeded and a decline results. The decline in herbivore population allows vegetation to begin recovering, eventually more forage is available per individual herbivore. This process continues with dampening fluctuations until a dynamic equilibrium is reached between herbivore and vegetation. In the model, density dependent intraspecific competition for

food is the ultimate limiting mechanism of population growth, and nutritional deficiencies cause or trigger population declines. Fluctuations are attributable to changes in forage condition, which alter the carrying capacity of the habitat.

Although most biologists accept food as an ultimate limiting factor of bighorn sheep populations, it is unclear what factors are actually regulating bighorn sheep populations. Limiting factors determine the greatest absolute numbers that a population may obtain in a habitat. However, a population may be regulated by other density dependent factors below the level set by limiting factors. Caughley's classic model offers one possible explanation of bighorn population regulation, where limiting and regulating factors are one and the same. Limited amounts of quality habitat and poor dispersal tendencies may accentuate density-dependent regulation through limited food resources (Cook 1990).

Several alternative hypotheses, that include other factors besides food, have been expressed to explain bighorn sheep population ecology. One hypothesis suggests that declining nutritional status in bighorn sheep predisposes them to disease (Stelfox 1976, Schwantje 1986, Festa-Bianchet 1987, 1988, Cook 1990). In this model, limited food resources are the ultimate factors controlling populations, and diseases are the proximate cause of death.

Another alternative hypothesis is that disease susceptibility is independent of nutrition. Bailey (1986), in the case of an all-age die-off in Colorado, concluded that

dead bighorns were in excellent physical condition; indicating no shortage of forage. Ryder et al. (1992) concluded range conditions were good prior to a die-off of 40% of a bighorn herd in Wyoming. The possibility of virulent density-independent pathogens infusing from outside reservoirs (i. e. domestic livestock) cannot be dismissed (Foreyt and Jessup 1982, Wehausen et al. 1987, Onderka and Wishart 1988, Onderka et al. 1988, Foreyt 1989). Miller et al. (1991) concluded that pneumonia epizootics caused by Pasteurella spp. could be produced through density-independent and/or density-dependent mechanisms.

Population density may increase to a certain threshold level where disease or a combination of factors may begin to regulate bighorn populations. Dunbar (1992) proposed that the additive effects of an array of environmental stressors interact to depress bighorn sheep immunune systems. Population density itself may be an intrinsic stressor that at times may act independently of nutrition (Dunbar 1992). Other stressors may include weather, chronic diseases, parasitism, and harassment. Chronic stress may reduce immunocompetence increasing disease susceptibility (Goodson 1982, Spraker 1979, Harlow et al. 1987).

Bighorn sheep have apparently evolved effective strategies for dealing with predators, and consequently predation has generally not been considered a limiting or regulating factor in bighorn sheep populations (Geist 1971, Cook 1990). Competition with other native ungulates for

forage and space may potentially influence bighorn sheep populations, although competition has been difficult to demonstrate.

THE BIG CREEK HERD

Bighorn sheep have probably occupied the Big Creek and Middle Fork drainages of central Idaho since the late Pleistocene. Bighorn sheep formed an important component of native American culture in the area, and the first Europeans to enter the drainage reported bighorn sheep in the thousands (Smith 1951).

The bighorn sheep herds inhabiting the Big Creek and Middle Fork drainages of central Idaho apparently experienced a severe decline following European settlement of the area (Smith 1951). Overhunting and diseases introduced with domestic livestock were apparently responsible for the decline. Between 1870 and 1880 many sheep died from what appeared to be scabies, caused by Psoroptes spp. mites (Smith 1951, Goodson 1982). Another severe die-off occurred around 1910. Bighorn sheep populations apparently never recovered to pre-European levels. For approximately the last half century bighorn sheep herds in the area have experienced only limited hunting for trophy rams. The female component of the population has not been hunted for generations, and they have basically been left to fluctuate within the carrying capacity of a habitat relatively little affected by modern man. However, limited market hunting may have occurred during the

1910-1920 period (J. Peek pers. commun.). Since the 1930's, numbers of permanent human residents and livestock have steadily declined under wilderness management. Bighorn sheep populations in the Big Creek and Middle Fork drainages have presented the opportunity to study the relationship between a wild ungulate and its environment in a relatively intact ecosystem.

Akenson (1992) studied the interspecific competition of bighorn sheep, mule deer (Odocoileus hemionus), and elk (Cervus elaphus) on the Big Creek winter range. Bighorn sheep and mule deer showed a positive spatial affiliation. Mule deer were not considered important competitors of bighorn sheep for winter forage, because of species specific differences in diet selection. Elk and bighorn sheep associated infrequently. Low use of the study area by elk during the duration of the study made it difficult to assess this relationship. Elk numbers have continued to increase in the Big Creek drainage, and the potential for competition exists between elk and bighorn sheep during severe winters.

Bighorn sheep populations have suffered several declines over the years, but bighorn populations increased to record high numbers in recent times during the late 1980's. However, in 1986, lamb:ewe ratios fell from 35-45 lambs per 100 ewes to <16 lambs per 100 ewes, and ratios remained at this level through 1991. By 1991, the overall population had experienced a sharp decline (Akenson and Akenson 1992).

Akenson and Akenson (1991) studied movement patterns of ewes captured on the Cliff Creek winter range. Previous to this study only the low elevation lambing area on Cliff Creek had been known. Radio-tracking revealed that a number of ewes migrated to lambing areas in other drainages. Some of these areas were at higher elevations in Monumental, Big Cottonwood, and Dynamite Creeks, up to 25 miles from the Cliff Creek winter range. Tissue samples collected from dead ewes ($\underline{n}$ = 3) and lambs ($\underline{n}$ = 7), revealed the presence of several bacterial pathogens including Pasteurella haemolytica and P. multocida (Hunter 1990).

Akenson and Akenson (1991) concluded their study in 1990, and monitoring has consisted of periodic aerial counts conducted by the Idaho Fish and Game Department. Few lambs have been observed in the Big Creek area in recent years, 1992 and 1993 (J. Peek, J. Yeo pers. commun.). Akenson and Akenson (1991) postulated that the bighorn sheep populations were possibly stressed by competition with elk, severe spring weather, or extended drought conditions producing forage of poor nutritional value. Predation was not considered to be an important mortality factor.

JUSTIFICATION

Bighorn populations in Big Creek appear to be fluctuating within the limits imposed by their present environment. However, the factors and the precise relationships between factors that regulate the bighorn sheep herds in Big Creek

remain to be completely understood. The overall objective of this long-term study is to identify the physical and biological factors that regulate bighorn sheep populations in the Big Creek drainage of central Idaho. We hope to improve the general understanding of bighorn sheep ecology, and in particular, how bighorn sheep populations function in wilderness areas.

Bailey and Woolever (1992) recognized the differences between managing bighorn sheep populations outside versus within wilderness boundaries. Due to habitat fragmentation, they concluded most wilderness areas were too small to contain the movements of most bighorn sheep populations, and that wilderness management agencies must begin to actively maintain the natural processes essential for bighorn sheep survival. Bighorn sheep populations of the Big Creek drainage and Middle Fork of the Salmon River are some of the few populations in the lower 48 states who function entirely within wilderness boundaries. The present study should increase our understanding of the natural processes essential for bighorn sheep survival, and provide the information needed to develop management guidelines for bighorn sheep populations within wilderness.

The bighorn sheep herds in central Idaho are a very valuable resource for the people of Idaho and the nation. This study will improve our comprehensive knowledge of these specific herds, and continue long-term monitoring of their ecology. Bighorn sheep populations have experienced modern-

day localized extinctions in other regions of the West (Berger 1990). Learning what natural processes are regulating bighorn sheep in the Big Creek and Middle Fork drainages will help wildlife biologists insure the future for bighorn sheep in central Idaho. We hope to eventually provide wildlife biologists with criteria that predict when bighorn sheep are vulnerable to population declines.

CONSTRAINTS

Wildlife research conducted in legally designated wilderness areas must operate under special constraints. Recent literature (Romesburg 1981, Hurlbert 1984) outline past problems involving pseudo-replication and poor use of the scientific method. A greater use of properly replicated, manipulative experiments is needed in ecological field studies. However, wilderness regulations and logistical difficulties prohibit most physical manipulations of habitat or animal populations within wilderness areas, therefore controlled manipulative experiments are often impossible to conduct. However, wilderness areas provide a place where natural ecological processes can be preserved with minimal interference from modern human activities. Wilderness can provide a means of measuring the divergence of human dominated landscapes from natural processes.

Eberhart and Thomas (1991) recognized that field studies and environmental research often do not meet the criteria for modern experimental design, and that a more flexible approach

may be more realistic in many outdoor situations. Eberhardt
and Thomas (1991) distinguished between conducting a
controlled experiment and observing an uncontrolled process by
sampling. Inferences gained from controlled experiments are
stronger, but in a wilderness context field-study objectives
may be more realistically met by utilizing sampling
procedures. One such procedure is "sampling for modeling"
which provides efficient designs for estimating parameters in
a specified model (Eberhardt 1978, Box and Lucas 1959).
Sampling procedures will be presented to determine empirically
derived estimates of model parameters from the habitat and
from study animals.

Sexual segregation in bighorn sheep habitat use require
considering male and female segments of the population
independently (Jorgenson et al. 1993). Population
characteristics of the female segment most likely influence
long-term trends in the overall population more than the male
segment. Consequently, limited research resources will be
expended upon understanding the dynamics of the female
segment.

STUDY DESIGN

Determining the factors and mechanisms that regulate
bighorn sheep populations in central Idaho is a complex,
challenging goal that will require a collaborative, long-term
effort. The main purpose of the present study is to initiate
research in a direction that will yield reliable knowledge in

the future. The study will be designed to facilitate construction of a multivariate multiple regression model that will eventually be able to predict population fluctuations of bighorn sheep in central Idaho. Construction of a reliable model will likely require many years of data. Therefore, I am faced with the task of defining a study that will accomplish the long-term goal, yet will succeed in producing knowledge within the time allocated to a graduate student. I propose research objectives that will provide a firm foundation for achieving the long-term goal, but will also provide useful results within 3 to 4 years.

Predation, disease, parasitism, poor nutrition, accidents, and extreme weather conditions are mortality agents experienced by bighorn sheep in central Idaho. Although predators and accidents kill bighorn ewes and lambs, based on past studies (Hornocker 1970, Akenson and Akenson 1992, Akenson 1992) we will assume, that these mortality agents are not regulating bighorn sheep populations in the study area. Bighorn sheep are essentially ice-age mammals (Geist 1971), therefore, it is unlikely that extreme weather conditions in the study area directly kill adult individuals. However, newborn lambs may occasionally die from exposure during severe early-spring storms.

Most of the documented die-offs of bighorn sheep in recent times have been disease related. However, the interaction between disease, parasites, and nutrition in bighorn sheep is poorly understood. Strains of Pasteurella

spp. have often been implicated as the acute mortality agent, and strains of _Pasteurella_ spp. have been isolated from bighorn sheep in the Big Creek area (Hunter 1990). Miller et al. (1991) hypothesized that _Pasteurella_-caused epizootics were a function of differential susceptibility among bighorn populations. Novel strains of _Pasteurella_ spp. may be introduced into a bighorn population by immigrating bighorns or by domestic sheep.

In such cases, _Pasteurella_ spp. may act in a random, density-independent manner, because a large portion of individuals of all cohorts are susceptible. In a second scenario, outbreaks of _Pasteurella_ spp. arise from chronic infections carried by resident individuals. Bighorn sheep may carry a unique non-hemolytic strain of _P. haemolytica_, that is opportunistic (Onderka and Wishart 1984, 1988). The proportion of susceptible individuals increases gradually as immunologically naive individuals are recruited into the population, and/or stress reduces the immunity of older individuals. Conditions become suitable for an epizootic to occur at some critical proportion of susceptible individuals. Thus, the pathogen would be operating in a density-dependent manner in this scenario. At higher densities, more individuals may suffer the effects of cumulative environmental and social stress resulting in poor nutrition, and thus increasing disease susceptibility.

Dr. Hunter and the Idaho Dept. of Fish & Game have collected approximately 7 years of disease data on the bighorn

sheep in Big Creek. I propose to concentrate upon the nutrition, behavior, and habitat relations of resident bighorn ewes in conjunction with Dr. Hunter's ongoing disease research. Ultimately, I hope to incorporate disease, nutritional, and environmental aspects into the model.

OBJECTIVES

As much as possible, objectives have been chosen to directly facilitate construction of a multivariate multiple regression model, and address the nutrition and behavior of resident bighorn ewes. However, certain basic objectives (i. e. diet selection, movement patterns) must be pursued to lay the groundwork for other objectives that will directly measure proposed model variables.

Seasonal Diet Selection

Annual and seasonal changes in diet composition must be known with reasonable certainty, before nutritional status of resident bighorn sheep can be determined. Diet composition determines the forage species that should be collected for nutrient analysis. In addition, presence in the diet of species which contain secondary plant compounds, such as tannins, can significantly alter the results of subsequent nutritional indices, such as fecal nitrogen (Robbins 1987).

Bighorn sheep that migrate to high elevation summer range may consume forages that are highly nutritious compared to forages at lower elevations at that time of year (Hebert

1973). However, some bighorn ewes in Big Creek may remain at lower elevations during the summer. I am interested in comparing the species composition and nutrient value of high elevation summer range ewes with low elevation summer range ewes. Hobbs et al. (1983) reported that bighorn lambs selected a diet dominated by forbs, but later determined adult diet conformed to previously held beliefs that bighorn sheep were primarily grazers (Baker and Hobbs 1986). However, in Colorado, adult bighorn sheep diet consisted of 73-94% leaves of woody plants, mainly true mountain mahogany (Cercocarpus montanus) (Rominger et al. 1988). I would like to examine differences in diet selection between lambs and ewes, and determine the amount of browse in the summer diet.

Movement Patterns and Habitat Selection

Within the greater study area boundaries, bighorn ewes are unlikely to use all types of available plant communities and terrain equally. Therefore, to determine the nutritional resources available to bighorn ewes (i. e. where to sample forages) the actual "range" or "ranges" must be delineated.

Northern montane ungulates generally respond to seasonal variations in climate by maintaining different summer and winter ranges. Increasing snow depths typically force animals onto winter range, and late winter conditions generally create the period of greatest stress and subsequent mortality. Consequently, quality and quantity of winter forage has historically been considered the limiting factor for free-

ranging ungulates in the northern Rocky Mountains. However, bighorn sheep may migrate to winter/rutting ranges before being forced to by snow conditions in the Big Creek drainage (J. Peek pers. commun.)

Hebert (1973) demonstrated conclusively that high alpine forages were more nutritious than forages typically consumed on winter ranges. Bighorn sheep that consumed high-elevation forages during the summer entered the winter in better condition, were more efficient at utilizing winter range forages, and responded physiologically faster to spring green-up than sedentary bighorns maintained on winter range forages year-round. Essentially the "alpine" bighorns extended the period of spring green-up and its nutritious forage for months, while "sedentary" bighorns encountered winter forage conditions months earlier.

Winter ranges are critical for the long-term survival of bighorn sheep populations, but the summer nutritional ecology may also determine winter survival. By late winter, available forages usually fail to meet all of the nutritional requirements of bighorn sheep, and bighorns will typically enter a period of negative energy or protein balance resulting in catabolism of body reserves (Hebert 1973). Bighorn sheep entering the winter in better physical condition most likely have a higher probability of survival and greater fitness. However, energy and nutrient requirements for gestation peak during-the-third-trimester.---Bighorn-ewes-generally-reach-this---- stage while encountering late winter forage conditions.--The------

quality of forages at this time of year may profoundly affect female fecundity and vigor of lambs born later in the spring. Annual variations in winter severity and available winter nutrients may produce variations in population parameters while bighorn sheep are on summer range. Thus in reality, summer and winter ranges are not discrete biological entities.

An understanding of the attributes and interactions of all seasonal ranges is needed to fully understand bighorn sheep ecology. Movement patterns, timing of movements, and habitat selection are inextricably linked to the nutrition of bighorn sheep; and hence fitness and disease susceptibility. Therefore, it is essential to verify and refine what is known about the movement patterns and habitat selection of resident bighorn ewes. Bighorn ewes winter near the Taylor ranch, and consequently, much more is known about winter movement patterns and site selection compared to summer. I would like to determine the annual variation in the number of days spent on high elevation summer range, and examine the habitat selection patterns of bighorn ewes on high elevation summer ranges. In addition, I would like to verify and map important migration corridors.

Estimate Nutrient Requirements

Animals require protein for growth and maintenance of body tissues, and consequently, an intake of protein is essential for survival. The protein requirement of bighorn sheep is one of the major determinants of the carrying------------
BIRTH WEIGHT

capacity of their range. Hebert (1973) considered protein the limiting nutrient for bighorn sheep in British Columbia. All protein molecules contain nitrogen (N), therefore, nitrogen levels serve as an index to protein levels. Bighorn ewes must also acquire energy from available forage resources for growth and maintenance of body tissues and processes. I propose to estimate the seasonal energy and nitrogen requirements using models supplied in the literature, and then to contrast estimated requirements to available nutrient resources. I would like to determine the period or periods of greatest nutritional stress in terms of annual nutritional requirements.

Determine Seasonal Activity Budgets and Forage Intake Rates

The calculation of energy requirements requires an estimation of the amount of time bighorn ewes spend engaged in various activities. An estimate of the energy cost and amount of time an animal engages in a particular activity enables calculation of activity requirements in terms of energy (Robbins 1973). Activity budgets and animal behavior in general can also be utilized to examine relationships between animals and their environment. For example, foraging time should increase with decreasing forage quality up to a threshold, then decrease as digestibilities become limiting. I am interested in determining if and when this threshold occurs in Big Creek.

Estimating forage intake rates of bighorn ewes would delineate the nutrient levels that bighorn ewes are actually acquiring, and corroborate diet selection results obtained from microhistological fecal analysis.

Determine the Quality and Quantity of Forage Resources

Species composition, biomass, vegetative structure, and nutrient content of the plant community determine available nutritive resources for bighorn sheep in the Big Creek drainage. Carrying capacity at any point in time will be determined by the quality, quantity, and availability of these resources. Therefore, to understand the ecology of bighorn ewes, a thorough quantification of the attributes of the vegetative community is required. Estimated seasonal nitrogen and energy requirements will be contrasted to seasonal fluctuations of nutritional forage quality and quantity. In addition, forage nutritional characteristics can be used as predictor variables in the model. I am also interested in examining the seasonal, annual, and elevational variation in forage nutrient content and the responses of bighorn ewes to these changes.

Monitor Abiotic Environmental Variables

Forage characteristics, such as biomass and nutrient composition, are influenced by soil moisture levels. Consequently, available resources are determined by precipitation quantities and temporal patterns. In addition,

the energy expended for thermoregulation by bighorn ewes is partially determined by ambient temperature, wind speed, and cloud cover. Winter snow depths and distribution may profoundly affect bighorn sheep foraging ecology. Therefore, variables that depict the abiotic environment will be measured, included as model variables, and correlated with bighorn sheep responses.

Measure Population Responses

The overall question is: What factors regulate bighorn sheep populations in central Idaho? Therefore, measurements of population size, population growth rate, and survival are logical choices for long-term response variables to changes in environmental and habitat variables. Furthermore, Hobbs and Hanley (1990) demonstrated that interpretations of habitat use/availability data were affected by the interaction between resource quantity, habitat quality, and population density. Peek et al. (1982) state that interpretation of habitat preference must include an evaluation of population characteristics. In addition, measurements of animal condition should be obtained when possible. Blood parameters present one possible method of obtaining a physiological measure of animal condition.

Study Genetics and Dispersal

The collection of blood or tissue samples presents the opportunity to estimate the genetic variability of resident bighorn ewes. Collected samples can be analyzed using recently developed molecular techniques. A lack of genetic variability may reduce the vigor and viability of a population. Consequently, population responses may be a function of the interaction between genetic forces and environmental variation. I would like to acquire an understanding of the genetic variability of resident bighorn ewes. Bighorn ewes in Big Creek are most likely connected to other groups of bighorn sheep through dispersal. Therefore, to understand the ecology of the study population, it is essential to gain some understanding of dispersal. Dispersal has both genetic and disease implications. How much dispersal occurs between the different groups of bighorn sheep in the Middle Fork of the Salmon drainage? Could novel disease strains originating from domestic sheep reach the relatively isolated bighorn ewes in Big Creek? Molecular techniques potentially offer a means of studying dispersal.

METHODS

STUDY AREA DESCRIPTION

The study will be conducted within the Big Creek drainage of central Idaho, and the Taylor Ranch Field Station of the University of Idaho Wilderness Research Center will serve as the base of operations. The Big Creek drainage flows from west to east and is a major tributary of the Middle Fork of the Salmon River. Big Creek is located within the 2.3 million acre Frank Church River of No Return Wilderness. Elevations within the drainage range from 3500 feet to 9500 feet, and contain some of the greatest relief in Idaho. Topography at lower elevations is characterized by steep V-shaped canyons. Higher elevations contain alpine basins, forested ridge tops, and meadows. The highly dissected nature of the study area is reflected in the vegetation. Abrupt changes in aspect result in markedly different plant associations.

Southern exposures at lower elevations, where soil development is adequate, are generally dominated by grasslands. The major soil type on southern exposures is brown podzol (Ross and Savage 1967, Tisdale et al. 1969, Claar 1973). Soils are formed from granitic Idaho batholith parent material (Claar 1973), and are generally shallow and rocky. Numerous rock outcrops, cliffs, and talus slopes are present. Bluebunch wheatgrass (Agropyron spicatum), Idaho fescue (Festuca idahoensis), junegrass (Koeleria cristata), needle and thread grass (Stipa comata), Sandberg's bluegrass (Poa

sandbergii), onion grass (Melica bulbosa), and cheat grass (Bromus tectorum) comprise the majority of gramminoid biomass. Big sagebrush (Artemesia tridentata), rabbitbrush (Chrysothamnus nauseosus), and bitterbrush (Purshia tridentata) are important shrub species associated with grasslands. Mountain mahogany (Cercocarpus ledifolius) forms extensive stands on steep rocky outcrops. Wax current (Ribes cereum), Gooding's gooseberry (R. velutinum), Oregon grape (Berberis repens), chokecherry (Prunus virginiana), and serviceberry (Amelanchier alnifolia) are also frequently encountered shrubs. Balsamroot (Balsamorhiza sagittata), Western yarrow (Achillea millefolium), and lupine (Lupinus spp.) are important forbs. Along streams and creek bottoms Douglas fir (Pseudotsuga menzesii), aspen (Populus tremuloides), black cottonwood (Populus trichocarpa), Red-osier dogwood (Cornus stolonifera), hawthorn (Crataegus douglasii), willow (Salix spp.), and thimbleberry (Rhus parviflorus) constitute major species.

Southern exposures comprise the majority of the terrain on the north side of Big Creek. This area serves as important winter range to bighorn sheep, mule deer, and elk. Snow depths are generally low and southern aspects usually remain snow-free for much of the winter. The winter range extends for 30 miles along the lower portion of the drainage.

Douglas fir forests are encountered on north aspects and ridgetops. Small stands and individual Douglas fir are also scattered throughout the grasslands. On north aspects

understory plants include ninebark (<u>Physocarpus</u> <u>malvaceus</u>), shinyleaf spirea (<u>Spiraea</u> <u>betulifolia</u>), snowberry (<u>Symphoricarpus</u> <u>alba</u>), rose (<u>Rosa</u> spp.), mountain maple (<u>Acer</u> <u>glabrum</u>), and serviceberry. Pinegrass (<u>Calamagrostis</u> <u>rubescens</u>) and elk sedge (<u>Carex</u> <u>geyeri</u>) are important gramminoids.

Some bighorn sheep spend the summer at higher elevations. Forests at higher elevations are dominated by lodgepole pine (<u>Pinus</u> <u>contorta</u>), subalpine fir (<u>Abies</u> <u>lasiocarpa</u>), Englemann spruce (<u>Picea</u> <u>englemannii</u>) and white bark pine (<u>Pinus</u> <u>albicaulis</u>). Important shrubs present at higher elevations include Labrador tea (<u>Ledum</u> <u>glandulosum</u>), dwarf huckleberry (<u>Vaccinium</u> <u>caespitosum</u>), blue huckleberry (<u>V.</u> <u>globulare</u>), and grouse whortleberry (<u>V.</u> <u>scoparium</u>). Bighorn sheep frequent the more open alpine basins where important graminoids are bluejoint (<u>Calamagrostis</u> <u>canadensis</u>), and <u>Carex</u> <u>scopulorum</u>. Important high elevation forbs include marsh marigold (<u>Caltha</u> <u>biflora</u>), fernleaf pedicularis (<u>Pedicularis</u> <u>bracteosa</u>), beargrass (<u>Xerophyllum</u> <u>tenax</u>), and shooting star <u>Dodecatheon</u> <u>jeffreyi</u>.

In addition to bighorn sheep, mule deer, and elk, other native ungulates include small populations of Shiras moose (<u>Alces</u> <u>alces</u>), white-tailed deer (<u>Odocoileus</u> <u>virginianus</u>), and mountain goats (<u>Oreamnos</u> <u>americanus</u>). Potential predators of bighorn sheep inhabiting the area include mountain lions (<u>Felis</u> <u>concolor</u>), bobcats (<u>F</u>. <u>rufus</u>), black bears (<u>Ursus</u>

americanus), coyotes (Canis latrans), and golden eagles
(Aquila chrysaetos).

Numbers of bighorn sheep, mule deer, and elk have changed
since the turn of the century. Few elk were living in the
Middle Fork of the Salmon region during the early 1900's
(Smith 1954). Elk numbers have steadily increased since the
1940's (Hornocker 1970). Idaho Dept. of Fish and Game aerial
counts from 1973 to 1989 indicate that elk numbers on Big
Creek have increased dramatically in recent years (Akenson
1992). Mule deer populations have fluctuated markedly over
time, reaching peak numbers during the 1940's and 1950's.
Current mule deer populations appear to be down from 10 years
ago.

SUMMER DIET COMPOSITION

After withdrawal of the Wisconsin ice sheet, bighorn
sheep spread across the dry, cold mountains of western North
America (Geist 1971, Bailey 1980). Bighorns evolved massive
jaws, large molar teeth, and large rumens and omasums when
compared to total body size. Consequently, bighorns have been
regarded as true grazing animals, adapted to a diet of coarse
graminoid vegetation (Geist 1971). However, bighorn sheep at
some locations and life stages have consumed appreciable
amounts of browse and forbs.

Diet composition is commonly determined by four methods:
rumen analysis, fecal analysis, esophageal fistula, and direct
observation. Rumen analysis requires killing the study

animal, or capture and implantation of a rumen fistula. Neither one of these options or the implantation of esophageal fistulas are practical methods for wild bighorn sheep in the study area. Hunting is restricted to only the older male segment of the population, and the use of fistulas would necessitate recapturing bighorns at short time intervals. Direct observation may be possible at times, but this method requires a small observer-animal distance, and vegetative conditions that allow precise identification of plant species consumed. Therefore, fecal analysis represents the best method for obtaining an estimate of diet composition for free-ranging bighorn sheep (McInnis et al. 1983, McInnis and Vavra 1987, Wikeem and Pitt 1992).

In addition to determining the composition of bighorn sheep diet, other hypotheses can be examined. Diet of bighorn lambs can be compared to ewe diets to examine the hypothesis that forbs constitute a higher proportion of lamb diet (Hobbs et al. 1983) than adult diet. Changes in lamb diet compared to adult diets will elucidate age-related differences in diet selection. Annual variation in diet selection will be examined by comparing diet composition during a specified time interval between years.

Mule deer and mountain goat feces can be confused with bighorn sheep feces. Mule deer share winter and summer ranges with bighorns, and mountain goats may share summer range. Therefore, pellets will be collected from directly observed bighorn sheep groups or individuals. A separate composite

sample will be obtained for lambs if possible. Mature rams will not be sampled. Microbial decomposition of collected samples will be prevented by adding an equal volume of table salt and/or air drying (Hansen et al. 1978).

A sample will be composited weekly by collecting 3 pellets from 20 fecal piles. This will yield 48 composite samples per year or > 12 samples per season. This intensity of sampling should yield satisfactory power for statistical purposes (approximately .80). Preliminary sample size and power estimates were developed from tables provided by Cohen (1977) and Bratcher et al. (1970). Variance estimates for graminoids, forbs, and shrubs were obtained from Keating et al. (1985). The largest average standard deviation occurred for graminoids (approximately 13%), and subsequently this value was used in sample size calculations. Ten percent was the difference specified to be detected between means. Composite samples will be shipped to the Composition Analysis Laboratory, Colorado State University for microhistological estimates of diet composition. Five slides per sample will be analyzed by viewing 20 fields per slide.

Results obtained as percentages will be transformed and analyzed by t-test for differences between years for each forage species, and by a completely random design with seasons as treatments. Winter diet composition will be determined by Brian Holbrook as part of his Master's research. Summer diet composition will be determined as part of the present study.

MOVEMENT PATTERNS AND HABITAT SELECTION

Summer Habitat Selection

Several procedures exist for analysis of habitat selection (Friedman 1937, Neu et al. 1974, Quade 1979, Johnson 1980, Marcum and Loftsgaarden 1980, Heisey 1985), and procedures have been clarified and contrasted (Byers et al. 1984, Alldredge and Ratti 1986, Thomas and Taylor 1990, White and Garrot 1990, Alldredge and Ratti 1992). The choice of method depends upon assumptions likely to be satisfied, hypothesis being tested, and how individuals and observations are weighted (Alldredge and Ratti 1992).

All methods assume that observations for a single animal are independent of observations for other animals. Herd-forming species, such as bighorn sheep will tend to violate this assumption. Therefore, when groups of marked animals are encountered the location of only 1 randomly chosen individual will be analyzed.

Neu et al. (1974) proposed a method that employs a straightforward application of the Chi-square goodness-of-fit test. The Neu et al. (1974) method generally performs well when compared to other methods, because it requires the most data (White and Garrott 1990). This method tests the hypotheses that usage occurs in proportion to availability considering all habitats simultaneously, and considering each habitat separately. These hypotheses are appropriate for the present study. The Neu et al. (1974) method also assumes that observations on an animal are independent of previous

observations on that same animal, and that areas of habitats are known. The first assumption can be addressed by separating observations in time. The latter assumption can be addressed by obtaining estimates of habitat areas directly from aerial photographs and/or maps and considering the areas known. The Johnson (1980), Marcum and Loftsgaarden (1980), and non-parametric methods (Friedman 1937, Quade 1979, Alldredge and Ratti 1986) do not require meeting this second assumption, however, a loss in statistical power is associated with using these methods, assuming areas can be accurately determined (White and Garrott 1990). The Johnson, Friedman, and Quade tests assume that all animals within the population prefer the same habitats, an assumption often shown to be incorrect (White and Garrott 1990). The Chi-square approach can be used to test hypotheses for individual animals, and be extended to log-linear models (Heisey 1985) to examine differences between animals using covariates.

Thomas and Taylor (1990) classified resource use and availability studies into 3 design categories. In design 3, the use of each resource is estimated for individuals, and resource availabilities are calculated within each animal's home range. An individual's activities are confined to its home range, not the entire study area, and availability within the home range should be used for habitat selection comparisons (Peek et al. 1982). Comparisons among home ranges with different amounts of the same habitat can be used to determine a potential habitat preference (Peek et al. 1982).

Habitat availabilities will be determined for marked individuals by delineating home ranges into vegetation types on aerial photos and orthophoto maps. Vegetation classifications will be verified in the field. Areas for each vegetation type will be determined by dot grid and/or planimeter.

The power of the Chi-square test to compare habitat selection relative to availability is a function of the accuracy of animal location, the complexity of the habitat, and the number of times an animal is located (White and Garrott 1986). Radio-collared animals can be located by triangulation, direct observation, or with aerial methods. Triangulation provides only an estimate of animal location, and imprecise triangulation bearings can greatly decrease the power of the Chi-square test (White and Garrott 1986, Nams 1988). Mountainous or rugged terrain produce signal bounce that can markedly affect precision of triangulation bearings (Hupp and Ratti 1983). In addition, triangulation is ideally conducted from known points. Due to the nature of the rugged terrain and the uncertain movement patterns of bighorn ewes on summer range, telemetry location points will most likely shift often, making triangulation difficult. Therefore, visual observations will be used to locate animals on aerial photos and orthophoto maps in the field. Radio-telemetry will greatly aid locating bighorn ewes from a distance and binoculars will be used to locate animals more accurately without causing disturbance. The distinct topographical

features and general openness of sheep habitat (Geist 1971)

should make visual locations practical. Aerial methods of

animal location will be employed if and when ewes cannot be

located from the ground. Animal locations will be plotted on

orthophoto maps, and Universal Transverse Mercator coordinates

obtained (Grubb and Eakle 1988). Locations will be determined

to the nearest 20 m. In addition, animal identification

number, age, sex, type of observation, habitat type, time of

location, group size and composition, and aspect will be

recorded at the time of location. Elevation, distance to

nearest escape terrain, distance to nearest water, and

distance to nearest mineral lick will be obtained from maps.

Home Range Estimation

Bighorn ewes generally disperse widely to high-elevation

summer ranges (Shannon et al. 1975). Due to the ruggedness of

the terrain, ewes might be observed only after great

expenditures of time and physical effort. If so, data will be

collected for a relatively extended time period once animals

are located. Although this practice may provide better

behavioral information, it may also produce animal locations

that are too close together in time to be considered

statistically independent. In other words, data will most

likely be collected in bursts, therefore potential

autocorrelations may exist between animal locations.

Swihart and Slade (1985a) concluded that a lack of

independence among observations reduced the effective sample

size, hence the accuracy of the home range estimate. They
(Swihart and Slade 1985b) presented a test of the null model
of independence, and a procedure for determining the time
interval required to yield statistically independent
observations. Reynolds and Laundre (1990) recognized that
studies of daily movements and activity budgets require
relatively short sample periods, and that study designs must
satisfy the conflicting requirements of spatial versus
behavioral studies. Some authors (Gese et al. 1990, Andersen
and Rongstad 1989) reported no statistically significant
difference between home range estimates obtained from
autocorrelated data versus independent data. Reynolds and
Laundre (1990) concluded that autocorrelated data produced a
better estimate of true home range size than independent data.
Nevertheless, lack of independence between animal locations
has been recognized as a potential problem by many authors
(Dunn and Gipson 1977, Samuel and Garton 1985a, White and
Garrott 1990).

Home range can be estimated by a variety of models:
minimum convex polygon (Mohr 1947), bivariate normal (Jennrich
and Turner 1969, Dunn and Gipson 1977, Samuel and Garton
1985), and nonparametric approaches (Siniff and Tester 1965,
Dixon and Chapman 1980, Anderson 1982).

Dunn and Gipson (1977) developed a home range estimate
from a Markovian process that considers the time series nature
of the data. The correlation between successive locations is
recognized, and consequently the Dunn estimator can be used

with autocorrelated data collected in bursts. The one constraint is that the time interval between observations within a burst must be equal, however, the time interval between bursts need not be equal. The Dunn estimator, like the Jennrich-Turner (1969) method assumes an *a priori* bivariate normal distribution of the data. However, actual data may not be distributed as such, and home range analysis is more realistic if based upon the observed data (Samuel and Garton 1985b). Smith (1981) and Samuel and Garton (1985a) provide tests for bivariate normality.

Nonparametric approaches offer an alternative method of home range analysis when the assumption of bivariate normality cannot be met. The Dixon and Chapman (1980) method, based on the harmonic mean of the areal distribution, was modified by Samuel and Garton (1985b) to accommodate discontinuous bursts of animal locations. In a comparison of home range estimators, the harmonic mean method was considered the least biased (Boulanger and White 1990).

In the present study, animal locations will be analyzed using the Dunn estimator and harmonic mean methods. Program HOMER (White and Garrott 1990) will be used to analyze the data with the Dunn estimator and program HOMERANGE (Samuel et al. 1985) will be used to analyze the data using the harmonic mean method (Dixon and Chapman 1980) as modified by Samuel and Garton (1985b). Area-observation curves will be used to assess adequatecy of sample sizes.

NUTRIENT REQUIREMENTS

Estimation of Nitrogen Requirements

Bighorn sheep require nitrogen for maintenance, growth, gestation, and lactation. Determining the nutritional requirements of any animal is a costly labor-intensive process. Consequently, few actual values have been calculated for species of wild ungulates, and many studies have substituted values obtained from domestic livestock research. However, years of artificial selection may have produced animals with markedly different requirements than wild ungulates (Robbins 1993). Because nitrogen has been identified as a potential limiting nutrient for bighorn sheep, we are interested in determining the maintenance N requirement for adult female bighorn sheep.

Maintenance requirements equal the constant N losses in the feces and urine (Robbins 1993). Protein catabolism consists of two distinct forms (Folin 1905). Tissue or endogenous urinary nitrogen (EUN) represents a constant, minimal, one-way loss of creatinine nitrogen, that is independent of N intake. A second form is characterized by urea production, and represents the inefficient utilization of dietary nitrogen. Metabolic fecal nitrogen (MFN) plus EUN losses equals the minimum maintenance requirements for nitrogen.

The simplest method to determine maintenance N requirements would be to feed a nitrogen-free diet with adequate energy to prevent protein catabolism; then all fecal

or urinary nitrogen would be of endogenous origin (Robbins 1993). However, few animals will consume nitrogen-free diets, and ruminants require some dietary nitrogen to maintain the microbial community essential for fermentation. Therefore, an indirect regression approach is required, which involves feeding animals diets composed of different levels of nitrogen. Such feeding trials can also be used to investigate the variability in N metabolism between individual study animals, investigate the degree of curvature in relationships, calculate MFN and EUN, and test the reliability of MFN as a measure of dietary quality.

Due to the importance of obtaining a maintenance N requirement, we hope to have feeding trials conducted as a separate study using the captive bighorn sheep at the Idaho Fish & Game Wildlife Health Laboratory in Nampa, Idaho under the direction of Dr. David Hunter.

Once maintenance N requirements have been determined, methodologies exist to estimate nitrogen requirements for growth, gestation, and lactation. Moen (1973) suggests general formulas for estimating these requirements. The quantity of nitrogen required for daily gain (Q_{ng}) can be estimated from the formula:

$$Q_{ng} = 2.5 \ \Delta W_{kg}$$

where ΔW_{kg} = gain in weight in kg/day, and 2.5 represents the nitrogen retention fraction. Hebert (1973) found that nitrogen retention varied from .42 to -1.00 in bighorn sheep

depending upon the quality of the forage and the nutritional history of the individuals.

Hair growth involves a nitrogen cost, although this cost is a small portion of total nitrogen requirements. Robbins (1973) calculated the nitrogen cost of hair growth for white-tailed deer fawns by shearing the coat and obtaining the protein content. The average nitrogen requirement for hair growth was approximately 0.09 g N/day. Moen (1973) suggests using the formula:

$$Q_{nh} = 0.02 \ W_{kg}^{0.75}$$

where Q_{nh} = quantity of nitrogen required for hair growth. The coefficient 0.02 was derived from cattle (*Bos taurus*) by Blaxter and reported in the ARC (1965). The average nitrogen requirement for bighorn sheep hair growth has not been published. Although hair growth is not a major nitrogen requirement, the quality of the winter coat can have profound influences upon other nutritional requirements, such as winter energy requirements. Bighorn sheep that consume high elevation, more nutritious forages during the summer enter the winter with better quality coats than bighorns that summer on low elevation, poor quality ranges (Hebert 1973).

As gestation progresses, the amount of protein and nitrogen retained per day increases logarithmically (Moen 1973). The total nitrogen content of the uterus and its contents are quite similar among ruminants when corrected for fetal weight at parturition (Robbins 1973). The estimated nitrogen requirements for the productive processes of

gestation can be calculated on a g/day/kilogram fetal weight at parturition basis using the formula for bighorn sheep suggested by Robbins (1973):

$Log_e Y = -5.3896 + 0.367X$

where X = days pregnant.

The average gestation period for bighorn sheep is approximately 150 days (Moen 1973).

The production of milk by lactating female mammals is costly in terms of nitrogen and energy. Nitrogen requirements at peak lactation are greater than for any other process (Moen 1973). The nitrogen requirements for lactation are dependent upon milk composition, amount produced, and the net nitrogen needed for udder development.

The composition of bighorn sheep milk was determined by Chen et al. (1965) for the 1.5 and 3 month stage of lactation. Milk characteristics change overtime and more than a single estimate of milk composition is needed (Robbins 1993). Assuming the nutritional requirements of the nursing young are met by the amount of milk and forage consumed, the nitrogen cost of milk production can be estimated from offspring consumption rates and a knowledge of rumen development in the young (Moen 1973). There is little specific information available on these subjects for bighorn sheep. The milks of wild ungulates generally contain greater concentrations of protein and energy than the milks of domestic livestock (Robbins et al. 1987), and they also differ in quantity produced Cook (1990). Consequently, the best estimates of

milk consumption and rumen development in bighorn lambs come from those compiled for deer fawns or other wild ungulates rather than domestic livestock. Cook (1990) estimated bighorn lamb nutrient requirements, milk yield, crude protein content, digestible energy, and forage required to meet daily lamb nutrient requirements once old enough to begin foraging from data supplied for black-tailed deer by Sadlier (1980) and data supplied for Dall sheep by Chen et al. (1965). Cook's values can be used directly to estimate the nitrogen lactation requirements of lactating bighorn ewes for the months of July through November.

Nitrogen requirements for maintenance, tissue growth, hair growth, gestation, and lactation can be summed to provide an estimate of the overall nitrogen requirements of bighorn sheep. Nitrogen requirements differ among individuals of different body weight and reproductive status.

Estimation of Energy Requirements

The estimation of energy requirements involves the division of body maintenance and productive processes into component parts, and the estimation of the respective energetic cost of each component in terms of energetic cost per unit of time. The energetic cost per unit of time for each component is multiplied times its duration in the animal's daily or seasonal life (Robbins 1993). Summing these products furnishes an estimate of the total energy requirements for a time period.

Maintenance energy requirements include the energy that must be ingested to meet basal metabolism, activity, and thermoregulation costs. Basal metabolic rate is defined as the energy expenditure of an animal in muscular and physic repose, in a thermoneutral environment, and in a postabsorptive state (Brody 1945, Kleiber 1961). McNabb (1988) provides a general formula for calculating the basal metabolic rate of large grazers:

$$Y = 69.1X^{0.808}$$

where X = body weight, and Y = kcal/day.

Northern cervids exhibit a well documented seasonal cycle of energy metabolism where basal metabolic rate is reduced during midwinter (McEwan 1975). Chappel and Hudson (1978) measured the resting or basal metabolic rate in bighorn sheep from October to May, and demonstrated that bighorn sheep also exhibit seasonal changes in metabolic rate. Rates were highest in May and lowest in February. Lowest metabolic rates occurred at -10°C during February (approximately 80 kcal/kg $^{0.75}$ /day). The calculation of basal metabolic rate should consider seasonal differences. Wind had negligible effects on metabolic rate at temperatures above -18°C. However, below this temperature wind speeds as low as 5 meters/second caused substantial increases in metabolic rate. Bighorn may respond behaviorally by seeking sheltered areas under these conditions.

Animals cannot exist indefinitely under basal metabolic conditions, but must engage in additional energy-consuming

activities. These activities include standing, horizontal movements, vertical movements, and feeding. Chappel and Hudson (1979) reported the energy increment of standing as a percentage of expenditure while lying as 18.9% for a 72 kg bighorn ewe measured by open-circuit indirect calorimetry. The lying metabolic rate equaled 69.54 ± 1.25 kcal/kg$^{0.75}$/day, and the standing metabolic rate equaled 82.66 ± 0.96 kcal/kg$^{0.75}$/day. These rates do not include the energetic cost of ruminating, which can be estimated from the equation:

$$Q_{rum} = 0.24 \ W_{kg}$$

where Q_{rum} is expressed as kcal/hr, and W_{kg} is the weight of the animal (Graham 1964, Moen 1973).

The energetic cost of locomotion on level ground can be predicted by the regression formula developed by Taylor et al. (1982):

$$Y = 2.75X^{-0.316}$$

where Y = kcal/kg/km and X is weight in kg. However, bighorn sheep habitat is characterized by precipitous terrain where level ground is scarce, and bighorn sheep evade predators by fleeing to inaccessible steep terrain (Geist 1971). Dailey and Hobbs (1989) used indirect calorimetry to measure energy expenditure of bighorn sheep travel on level surfaces, on slopes, and in deep snow. The cost of travel on level surfaces resembled those reported for domestic sheep, white-tailed deer, and elk calves (Fancy and White 1985), but were approximately 25% higher than the interspecific average predicted by Taylor et al. (1982) for Artiodactyla. Dailey

and Hobbs (1989) reasoned that the relative inefficiency of travel by bighorn sheep represented an evolutionary compromise between predator escape strategies and the need to travel long distances efficiently. Bone structures and musculature adapted for jumping and rapid acceleration are different from structures adapted for efficient travel over long distances. Descending steep slopes can have a greater energetic cost than traveling on level ground, or animals may recover energy during downhill movement. Bighorn sheep recovered approximately 0.07 kcal/kg/km of energy walking downhill (Dailey and Hobbs 1989, Robbins 1993). Energetic cost of travel in snow was a function of snow density and sinking depth relative to brisket height. Travel costs in snow reached an asymptote when sinking depth exceeded roughly 1.2 to 2 times brisket height. Sinking depths twice brisket height can increase travel costs up to 300% with a snow density of 0.07 g/cm^3 (Dailey and Hobbs 1989, Robbins 1993).

Osuji (1974) concluded the large proportion of time ruminants spend feeding makes this activity a considerable contribution to the daily energy budget. The energetic cost of feeding is the cost of manipulating and ingesting food above the general activity state (Robbins 1993). Chappel and Hudson (1978) measured the energetic cost of feeding for captive bighorn sheep using open circuit indirect calorimetry. The average increase in metabolic rate over standing for ewes was 33.4%. This value represents approximately an energy expenditure of 1.27 kcal/kg$^{0.75}$/hr (Robbins 1993). Free-ranging

ungulates would likely expend a greater amount of energy feeding than captive animals, therefore, the value above represents a minimum level that may need to be increased under certain conditions. For example, pawing through snow would increase the energetic cost of feeding, and crusted snow would require greater expenditures of energy than light, uncrusted snow. Caribou expend 0.29 kcal/kg body weight/hr to paw through light, uncrusted snow, and 0.69 kcal/kg body weight/hr to paw through crusted snow (Fancy and White 1985).

A homeothermic animal must maintain a thermal balance with its external environment over the long term. Heat is lost through radiation, convection, conduction, and evaporation (Moen 1973, Robbins 1993). If heat produced from other activities, such as fermentation, locomotion, and metabolism, does not equal the amount of heat lost then an additional energetic cost of thermoregulation must be added to the energy requirements for basal metabolism, activity, and production. Numerous physiological, behavioral, and anatomical mechanisms enable animals to cope with the thermal demands of their external environment. Moen (1973) states, "The complexity of heat transfer is beyond comprehension". Indeed, it would be extremely difficult to measure and understand the interactions of the numerous variables that determine the thermoregulation costs of free-ranging bighorn sheep. As an alternative, Chappel and Hudson (1978) determined that the thermal neutral zone for bighorn sheep ranged from 10 to -20°C for bighorn sheep in winter pelage.

As ambient temperatures declined below this range metabolic rate rose sharply, 109 to 152 kcal · kg $W^{-0.75}$ · day^{-1}. These figures represent a mean increment for bighorn ewes of 39%.

Energetic costs of production in wild ruminants include the costs of tissue growth, gestation, and lactation. The energetic cost of tissue growth has not been determined for bighorn sheep. Energy cost estimations for growth can be calculated from body composition analysis of a range of animal ages and weights (Robbins 1973). Energy is stored as fat and protein, and fat supplies greater energy/kg than does protein. Domestic livestock generally have greater proportions of fat than wild ruminants, therefore it would be inappropriate to use values calculated for domestic sheep. The caloric content of gain (kcal/g) can be estimated from ingesta-free body weight (kg) with the equation:

$$Log_e Y = -0.2720 + 0.3722 Log_e X$$

developed for white-tailed deer (Robbins 1973)

Energy requirements for gestation remain small through the first 2 trimesters. The third trimester is characterized by the rapid growth of the fetus. Consequently, the relationship between time and energy requirements is nonlinear. The energy (kcal/day) required for gestation can be estimated with the equation furnished for bighorn sheep by Robbins (1973):

$$Log_e Y = -1.2205 + 0.0325X$$

where X = days pregnant.

Energy costs of lactating females range from 4 to 7 times the basal metabolic rate, or 65 to 215% higher than the nonlactating female (Robbins et al. 1981; Sadleir 1982, 1984; Nicoll and Thompson 1987; Robbins 1993). As mentioned above values specifically for bighorn sheep have not been determined, and milk of domestic livestock may differ markedly from wild ruminants (Robbins et al. 1987). Energy cost of lactation can be calculated from the milk requirements of lambs. Requirements are dependent upon the rate of rumen development and ability of the lamb to substitute dry feed nutrients for nutrients obtained from milk. White-tailed deer fawns were able to compensate for decreased milk availability by increasing forage intake after 30 days (Robbins 1973). Moen (1973) calculated milk production based on energy requirements for white-tailed deer fawns using the formula:

$$Q_{mp} = [(I_{ma}) (I_{mp}) (70) (W^{0.075}_{kg})] [(RD) (1/E_{net})] /GE_m$$

where

Q_{mp} = milk production based on energy requirements

I_{ma} = energy increment for fawn activity

I_{mp} = energy increment for production

RD = rumen development regression = $(113.6-4.5W_{kg})/100$

E_{net} = net energy coefficient for milk = 0.8

GE_m = energy in milk = 0.7 kcal g^{-1}

Cook (1990) estimated the energy requirements of nursing lambs once old enough to begin foraging using data supplied for black-tailed deer fawns (Sadlier 1980) and Dall sheep (Chen et al. 1965). Cook's (1990) values can be used to estimate the energy requirements of bighorn ewes. Values were obtained at bimonthly intervals starting in July and ending in September, therefore additional estimates for May and June can be calculated from Moen's equation, or by extrapolation from Cook's data.

The energy costs for tissue growth, gestation, lactation can be summed to provide an overall estimate of the energetic cost of production. This sum can be added to the energetic costs of thermoregulation, activity, and basal metabolism to estimate the total energy requirements of female adult bighorn ewes.

Mineral Requirements

Deficiencies and imbalances of minerals can be important determinants of animal condition, fertility, productivity, and mortality (Underwood 1977). Detailed information needed to understand the mineral metabolism of bighorn sheep is lacking. Information on mineral nutrition of domestic livestock may poorly apply to wildlife. Selection for rapid growth and the widespread mineral supplementation of domestic animals may inadvertently select for those animals that utilize minerals poorly (Robbins 1993).

Minerals can be divided into two classifications: macroelements and trace elements. Macroelements include calcium, phosphorus, sodium, potassium, magnesium, chlorine, and sulfur. Calcium is one of the major macroelements required by wild ungulates. Calcium deficiencies can occur as a result of excess P or Mn in the diet of herbivores. The potential for a Na deficient exists especially for herbivores (Robbins 1993). Potassium content of plants is generally high, therefore deficiencies in wildlife are rare. Trace elements include: Fe, I, Cu, Zn, Se, F, and Mn. Trace elements are required in much smaller amounts than marcroelements, yet deficiencies can markedly affect animal health. Iron is an important trace element early in the life of young herbivores during hemoglobin formation. Selenium and copper deficiencies have been observed among ungulates in various locations worldwide.

Bighorn sheep are frequently observed utilizing mineral licks. Apparently, bighorns obtain some portion of their mineral needs from this source. Female bighorns have been documented traveling relatively long, straight line distances to reach mineral licks (Watts and Schemnitz 1985, Festa-Bianchet 1988).

Forage samples will be analyzed for Ca, Na, P, Mg, Cu, Se, and Fe content at Colorado State Univ. concurrently with composition and digestibility analysis.

ESTIMATION OF ACTIVITY BUDGETS

Activity budgets have most frequently been obtained by direct observation of animals (Collins et al. 1978, Belovsky 1981, Bowyer 1981, Seip and Bunnell 1984, Belovsky and Slade 1986, Berger and Cunningham 1988). Generally, observers follow one or a combination of sampling techniques including *Ad libitum*, focal, scan, or behavior sampling (Altmann 1974, Martin and Bateson 1986, Morrison 1992). Data is recorded within time continuously, instantaneously, or by one-zero sampling. Direct observation under proper conditions can yield accurate depictions of activity budgets. However, animals that appear habituated may have simply adopted a modified pattern of foraging that allows them to keep the observer under surveillance (Morrison 1992).

Radio-telemetry employing motion-sensitive collars has been used to obtain activity budgets for non-habituated or cryptic animals. Studied species include elk (*Cervus elaphus*) (Craighead et al. 1973, Green and Bear 1990), white-tailed deer (*Odocoileus virginianus*) (Kammermeyer and Marchinton 1977), and desert bighorn sheep (*Ovis canadensis mexicana*) (Alderman et al. 1989). However, in these studies data needed to be actively recorded by an observer. Radio-telemetry methods that allow automated remote collection of activity data have been developed. These methods offer certain advantages: animals can be observed continuously for a greater length of time, nocturnal behavior can be monitored, and more than one animal can be monitored continuously. The observer

need not be present except to periodically maintain the equipment, therefore, the presence of the observer is less likely to alter animal behavior.

Automated telemetry systems have been used with red deer (*Cervus elaphus L.*) in Germany (Georgii 1981), moose (*Alces alces*) in Alaska (Risenhoover 1986, Miquelle 1990, MacCracken 1992), mule deer (*Odocoileus hemionus*) in California (Kie et al. 1991), black-tailed deer (*O. hemionus columbianus*) in British Columbia (Gillingham and Bunnell 1985) , white-tailed deer in Michigan (Beier and Mccullough 1988), and elk in Yellowstone National Park (Vales in press).

The same telemetry system used by Miquelle (1990), MacCraken (1992), and Vales (in press) will be used to determine the winter activity budget of bighorn sheep in the Big Creek drainage. Winter 1993-1994 activity budgets will be determined on the Big Creek winter range by Brian Holbrook of the University of Idaho as part of his Master's research. Summer activity budgets will be determined as part of the present study, and data will eventually be combined as part of a comprehensive long-term study.

System Description

Signals received from radio-collared animals by a Telonics RA-10 Omni-directional antenna will be received by a Telonics TR-2 receiver, relayed to a Telonics TDP-2 digital processor, and recorded on a Gulton Rustrak (Manchester, New Hampshire) dual-channel strip-chart recorder. Three such

systems will be used, enabling data to be collected on three animals simultaneously. Each system will be placed in 30 gallon plastic coolers for protection. Chart speed will initially be set at 5 inches/hour. The faster the speed the more easily changes in behavior are detected. Batteries and chart paper will be changed every 6 days. Batteries will be recharged by portable generator at Taylor Ranch.

Chart Interpretation

The speed of each Rustrak recorder varies from exactly 10 inches/hour, and the exact speed must be calculated. Both beginning and ending times are marked on the chart paper, and a ruler is used to measure the distance. The chart paper is divided into quarter inch increments to aid measurement.

During operation, two lines are recorded on the chart paper; one for signal strength and one for motion/behavior changes. Motion/behavior changes are actually changes in pulse rate determined by the animal's head position. A slow pulse rate is emitted when the head is in a raised position, and a fast pulse rate is emitted when the head is in a lowered position. Variations in signal strength aid interpretation of the pulse rate line. Weak signals can create ambiguous pulse rate recordings. An interpreter places tick marks at abrupt changes in pulse rate, and then measures the distance between changes. The length of time an animal engages in an identified behavior can be calculated by multiplying the distance times the time/distance conversion factor. The

pattern of recorded pulse rates indicates the type of activity. Therefore, activity categories must be subjectively determined from the recordings by an experienced interpreter. Focal animals will be monitored continuously for approximately 6 days, the length of time between battery and chart paper changes. The duration of time spent bedded-ruminating, sleeping, feeding, moving-not foraging, and standing alert will be calculated from the Rustrak recordings.

The validity of activity data collected by remote means was questioned by Gillingham and Bunnell (1985). However, other authors have rated system accuracies > 90% (Vallenberghe and Miquelle 1990, Vales pers. commun.). The degree of system accuracy is dependent upon the specific activity categories selected for sampling. The finer the behavioral detail desired the less certain the estimates. For example, the system may be fully capable of distinguishing active from inactive states, but incapable of distinguishing finer degrees of behavior, such as play behavior from rutting behavior.

Vales (pers. commun.) was not certain he could accurately separate feeding from moving-not foraging activity with elk. We will attempt as much as possible to differentiate these behaviors from the Rustrak recordings. Understanding the nutritional ecology of bighorn ewes in the study area requires an accurate estimate of the amount of time spent foraging. Therefore, Rustrak observations will be compared to concurrent direct observations of individual animals. The objective will be to determine which behaviors can be accurately discerned

from the correspondence of telemetric patterns with actual behaviors. The two data sets will consist of minutes of time spent in each activity. Time will be divided into 1 hour increments and the amount of time spent in each activity category calculated for Rustrak data and direct observation data. Time in 1 hour increments will form the basis for conducting a paired t-test. The null hypothesis, no significant difference exists between average time spent engaged in an activity (as calculated by direct observation and automated telemetry methods), will be tested for each activity category. To detect a 10% difference approximately 48 one-hour samples per activity category are needed to produce a power of approximately .80 (Cohen 1977). The animal sampled, and one-hour samples for direct observation will be chosen randomly. Significantly different paired t-tests conducted for each activity category would demonstrate that the two methods are not in agreement, and that direct observation should be used to quantify some activity categories. Direct observation of study animals can generally be conducted without altering animal behavior by using spotting scopes from the opposite (south) side of Big Creek during the winter. Data collected by direct observation should reliably measure activity budgets, and can justifiably serve as a basis for comparison during the winter.

The use of Rustrak recorders during the summer presents logistical challenges. Ewes spend the summer in scattered high elevation ranges, which will make transporting the

recorders and keeping batteries charged difficult. Therefore, data will be collected by direct observation during the summer, when and where Rustrak recorders prove impractical and to compare methods as stated above for winter activity budgets. Focal animals that can be consistently identified by radio collars or other natural markings will be monitored continuously by use of a tape recording device and binoculars. The tape will be replayed and amount of time an animal engaged in each activity category calculated. Focal animals will be monitored continuously for a 1 hr period. Focal animals and the specific hour to monitor will be chosen randomly. At least 48 1-hr samples will be collected to insure adequate statistical power.

ESTIMATION OF FORAGE INTAKE RATES

Ideally, ewes and lambs will become habituated to the close-range presence of an observer. Forage species being consumed, amount, specific plant parts, and bites/minute will be estimated while following a focal animal. Data will be recorded into a portable cassette recorder. Following observation, forage consumed will be duplicated by replaying the tape and clipping forage of similar species and quantity. Forages will be oven-dried at 50 °C for 48 hr and weighed to the nearest 0.01g. Intake rate will be calculated by multiplying bites/min x average g/bite to yield an estimate of g/min forage ingested. This estimate can be multiplied times the average number of minutes spent foraging/time period

obtained from Rustrak recordings and/or direct observation to calculate biomass of forages consumed. Bighorn ewes on the study area have not been consistent in their tolerance of observers (Yeo, pers. commun. 1993). Therefore, portable blinds and binoculars may be utilized if ewes fail to habituate to observation.

Foraging rates of bighorn ewes are likely to change seasonally, therefore separate observations of foraging behavior will be obtained for ewes and lambs on lambing, high elevation summer, fall, and winter ranges. The hypothesis that no seasonal differences exist in intake rates will be tested using a repeated measures ANOVA, considering individual ewes as replicates. Sample sizes required to obtain a power of approximately .80 equal 120 (Kirk 1982).

FORAGE RESOURCES

<u>Winter Range</u>

Three vegetation types important to bighorn sheep have been identified on the winter range: bluebunch wheatgrass-cheatgrass with cheatgrass >50% composition, bluebunch wheatgrass with no cheatgrass, and bluebunch wheatgrass-Idaho fescue. In each vegetation type, two 25 x 25 m permanent plots have been established in areas frequented by wintering bighorn sheep. Within each permanent plot, 30 permanent 20 x 50 cm subplots (Daubenmire 1959) have been established along 5 transects at 3 m intervals from which cover and plant height data has been collected. Biomass estimates have been obtained

by clipping thirty 20 x 50 cm plots alongside permanent plots in conjunction with height measurements. A regression-based model predicting biomass has been developed utilizing cover and height data. Available winter biomass was determined by clipping plots in the spring following departure of bighorns and clipping again in late summer following the growing season, but prior to arrival of bighorns. Clippings were separated by species, oven-dried at 70°C, and weighed to the nearest 0.01 g. Utilization was determined by randomly selecting 50 plants and estimating the grazed portions. Weight distribution of removed portion was determined by dividing 10 plants of each species into 2 cm lengths, oven drying, and measuring the weight to the nearest 0.01 g.

The present sampling scheme is ideal for monitoring long-term trends in vegetative composition. Exotic species of low value, such as cheatgrass, continue to expand their distribution on the Big Creek winter range, and permanent plots will help measure expansion of exotic species. Plots are located in known bighorn sheep feeding areas, therefore, forages sampled are more certain to be synonymous with forage consumed by bighorn sheep. However, as habitat use data becomes available from radio-collared sheep, more plots may need to be established. Establishment of additional plots would increase statistical power.

Summer and Lambing Range

Radio-tracking of bighorn ewes will be utilized to identify and confirm use areas within summer alpine ranges. Within use areas, transects will be determined randomly, and quadrats will be located systematically along transects. An initial sample will be collected to provide variability information needed to calculate sample sizes. The number of plots per transect will be calculated for each forage species using the formula (Bonham 1989, p96):

$$k = \sqrt{\sigma^2_{qd} / \sigma^2_t}$$

where σ^2_{qd} = variance component of plots

σ^2_t = variance component of transects.

The optimum number of transects will be computed using the formula (Bonham 1989, p96):

$$N = \left(\frac{4nV_p}{2\sqrt{pq/k} - 1} \right)^2$$

where n is the number of transects already measured and V_p is the variance of the mean frequency percentage of a given species.

Within each 20 x 50 cm quadrat basal cover measurements will be obtained on important forage species using the same methods established for the winter range plots (Daubenmire 1959). Height measurements will be recorded for each important forage species. Quadrats will be clipped, species separated, and samples air-dried and weighed to the nearest 0.10g. A multiple regression model will be developed to predict available biomass present from height and cover data.

Utilization estimates will be obtained with randomly located line transects. Amount of forage removed will be estimated for each forage species encountered by the transect. Sample sizes will be calculated using the above formulas following an initial estimate of variability. Sampling will be conducted soon after spring green up, at estimated peak growth, and in fall shortly before bighorns depart for winter ranges.

Nutritional Analysis of Forages

Plant species identified as important forage species (>2% of diet, Hobbs et al. 1983) by diet composition study will be analyzed for nutrient quantity and digestibility. While sampling for biomass, samples of important forage species will be collected from the area immediately adjacent to the transect. One composite approximately 100 g oven dry weight sample will be assembeled. The proportions of forage species in composites will reflect the proportions of species occurring in the diet as determined by histological fecal analysis and/or direct observation. Forage samples will be oven dried at 50 °C for 48 hours. Forage samples will be shipped to Colorado State Univ. laboratories for analysis of crude protein, dry matter, ether extract, total ash, gross energy, neutral detergent fiber, acid detergent fiber, lignin, cellulose, hemicellulose, cell solubles and mineral content. Digestiblities of dry matter, combustible energy, cell solubles, crude protein, neutral detergent fiber, acid detergent fiber, lignin, cellulose, and hemicellulose will be

determined from *in vitro* trials (Tilley and Terry 1963,
Goering and Van Soest 1970, Pearson 1970, Krausman et al.
1988). Species important in the diet that possibly contain
digestion inhibiting secondary plant compounds will be
submitted to the Dept. of Chemistry, Miami University of Ohio
for analysis. Adjustments in digestible protein and
digestible dry matter will be made according to Hanley et al.
(1992).

Fecal nitrogen concentrations may be used to monitor
dietary quality if diets do not contain significant amounts of
tannins and other secondary plant compounds (Irwin et al.
1993). Portions of fecal samples collected for diet
composition studies will be used to monitor dietary quality if
and when bighorn sheep diets do not contain secondary plant
compounds.

MEASURES OF THE ABIOTIC ENVIRONMENT

Snow Characteristics

Much of bighorn sheep biology is dominated by the
characteristics, distribution, and quantity of snow. Snow
affects bighorn sheep by limiting forage quantity, and may
force bighorns to exist on a less than optimum nutritional
plane. Geist (1971) observed that bighorn sheep avoid areas
of deep snow. This observation suggests that bighorn sheep
are not adapted physiologically or morphologically to cope
with extreme snow conditions. Telfer and Kelsall (1984)
ranked female bighorn sheep as intermediate in their ability

to cope with snow. Winter ranges are often periodically covered by snow, and bighorn sheep must respond behaviorally to these events (Goodson et al. 1991). Snow is not a uniform substance, and understanding effects of snow on animal populations requires measuring more than a single attribute (Peek 1971, 1986).

Goodson (1991) reported that bite rates, percentage protein intake, and percentage dry matter intake were reduced during periods of snow cover, even with moderate increases in bite size. In addition, bighorns shifted from feeding in open areas to areas of shrub cover with enhanced forage availability. Even small changes in snow cover and characteristics profoundly influenced foraging efficiency and diet quality. Snow depth, hardness, density, spatial distribution, and timing and duration of snow pack may all interact to affect winter foraging efficiency of ewes on the Big Creek winter range. Severe winters may severely restrict available forage, while during mild winters snow may have little effect on bighorn sheep distribution and foraging efficiency. Therefore, snow characteristics should be described each winter for the Big Creek winter range. Snow characteristics may change quickly due to variations in winter weather patterns. Therefore, depth and duration of snowfall events will be recorded. Rapid changes in snowpack distribution and characteristics caused by periodic thaws or "chinooks" will be recorded. Each week an ocular estimate of the percentage of snow-covered winter range will be made from

the south side of Big Creek and photographs taken. Each week an estimate of snow pack hardness will be obtained from 25 m transects located within the nearest snow field to each of the permanent winter range plots. Readings will be obtained approximately every 2 m.

Temperature and Precipitation

Temperatures outside the thermal neutral zone for bighorn sheep increase energy requirements. The number of hours outside the thermal neutral zone each day will be measured by the automatic weather station located at the base of the winter range. Bighorn sheep may respond behaviorally to reduce energetic demands, therefore, the quantity should be regarded as an index and not an absolute value.

During winter, bighorn sheep located at midslopes may experience a substantially different temperature regime than the valley bottom. Therefore, it will be necessary to climb to midslope and manually record temperature. The relationship between manually obtained temperatures and concurrent automatic weather station temperature readings will be examined by regression analysis. Eventually, it may be possible to predict midslope temperatures from weather station data. Windspeed is also an important component of thermoregulation requirements and will be recorded at the automatic weather station and manually at midslope.

Forage nutrient content may reflect changes in soil moisture. Site-specific soil moisture patterns are controlled

by a number of interacting factors, such as slope, aspect, vegetation, soil type, snow melt patterns, and elevation, that vary across the landscape (Ricklefs 1979). Precipitation is recorded at the automatic weather station located at Taylor Ranch. This variable in conjunction with wind speed will be used as an index to marked changes in soil moisture.

MEASUREMENTS OF POPULATION VARIABLES

Population Size

Annual aerial censuses conducted by Idaho Dept. of Fish and Game will be utilized. Mark-resight methods will be used to estimate population abundance. Data collected should include the total number of marked animals at the time of the survey, number of marked animals within the boundaries of the study area, number of marked animals seen during the survey, and total number of animals seen during the survey.

Mark-resight methods are based on the Lincoln-Petersen estimate as presented by Chapman (1951) and Seber (1982), and have been used previously on bighorn sheep (Furlow et al. 1981, Leslie and Douglas 1979, 1986, Neal et al. 1993). Precision of abundance estimations can be improved by increasing the number of surveys (White and Garrott 1990). Several procedures can be used to combine single survey estimates of population abundance into a single estimate. Because unmarked animals counted during a survey are not captured and released, multiple mark-recapture methods are not applicable in this situation (White and Garrott 1990). The

joint hypergeometric maximum likelihood estimator (JHE)
(Bartmann et al. 1987) generally provides shorter confidence
intervals than alternatives due to its minimum variance
property, and it is suggested by White and Garrott (1990).
Assumptions of Lincoln-Petersen based methods of estimating
population abundance include: 1) geographic and demographic
closure, 2) animals must not lose their marks, 3) all marked
animals must be correctly identified and counted, and 4)
animals must have the same independent probability of being
counted (Otis et al. 1978). Neal et al. (1993) examined the
effects of violating these assumptions using bighorn sheep as
study animals, and also recommended the use of mark-resight
methods for bighorn sheep where demographic closure exists
within a well-defined study area. These assumptions can be
reasonably met if aerial surveys are conducted during late
winter or early spring, when bighorn sheep are confined to the
winter range. Neal et al. (1993) suggested a modification of
JHE where the assumption of geographic closure is violated.
Sample sizes can be estimated from Neal (1990).

Estimation of Population Growth

The observed exponential rate of increase, or average r
can be calculated from two or more estimates of population
size (Caughley 1977). Average r is also a logical candidate
for a response variable, that can be obtained from annual
census data. Population estimates should be obtained at
approximately the same time each year. When estimates are

converted to natural logs (N) and regressed on time t, then the average rate of increase over the time period is:

$$r = \frac{\Sigma Nt - (\Sigma N)(\Sigma t)/n}{\Sigma t^2 - (\Sigma t)^2/n}$$

where n is the number of estimates.

Survival Rate Estimation

White and Garrot (1990) present a numerical optimization approach for the calculation of survival rates of radio-collared animals. This method requires the construction of maximum likelihood functions. Program SURVIV was developed to aid the use of this method, and will be used to calculate survival rates of radio-collared bighorn ewes. Information needed include: date of capture, age of animal, and date of death. The age of bighorn ewes will be estimated at time of capture by counting horn annuli and tooth wear.

Natality

Seasonal estimates of lamb:ewe ratios and direct counts of lambs offer the most practical means of indexing annual natality. Some ewes migrate to inaccessible terrain in early May, and lambing areas are widely separated. Therefore, counts could most expeditiously be done from the air.

Pregnancy can potentially be determined from blood samples or by ultrasound. Harper and Cohen (1985) used Doppler ultrasound to diagnose pregnancy in bighorn sheep. Results were very reliable when females were at least 110 days pregnant. Houston et al. (1986) used a serum assay for

pregnancy-specific protein B to detect pregnancy in mountain goats (Oreamnos americanus). In domestic sheep pregnancy is reliably detected by 38 days postbreeding using this method. Brundige et al. (1988) used serum progesterone concentrations to detect early pregnancy in bighorn sheep. Correct detections were made 84% of the time. Incorrect classifications were attributed to sampling too close to estrous. Progesterone levels are elevated by pregnancy and estrous. Accuracy was improved to >90% by sampling >16 days after conclusion of breeding. The first breeding season for bighorn ewes occurs in late November-early December, after which progesterone levels drop to anestrous levels (Whitehead and McEwan 1980). Unbred ewes enter a second estrous period in mid-January, and sampling at this time may produce misclassifications. Progesterone levels greater than 2 and 3 ng/mL indicate pregnancy in bighorn sheep (Ramsay and Sadlier 1979).

Physical and Metabolic Indicators of Animal Condition

Nutritional status of individual bighorn ewes most likely determines fecundity, overall health, and disease susceptibility. Ideally, one would be able to continuously follow nutritional status using an easily monitored characteristic. However, many indices of animal condition require destruction of the study animal or at least its capture. Repeated recaptures over short periods of time is impractical for bighorn ewes in Big Creek.

Blood characteristics offer one method of characterizing the health of bighorn ewes without causing undue injury to the animal. Delgiudice et al. (1990) examined the effects of undernutrition on body composition and blood parameters in white-tailed deer. Biologically significant amounts of protein were catabolized in animals before fat reserves were exhausted. Elevated packed cell volume (PCV), serum creatinine, and Ca concentrations indicated dehydration that accompanied mass losses. Serum urea nitrogen, nitrogen: creatinine ratios, T_4 concentrations, K:creatinine, and Na:creatinine ratios declined as undernourished white-tailed deer decreased food intake when offered poor quality food. Serum cholesterol and triglycerides elevated as fat reserves were depleted and protein catabolized. Seal and Hoskinson (1978) found that serum urea concentrations in pronghorn antelope (Antilocapra americana) were related to the protein concentration of available food plants, and that levels reflected nutritional differences between populations. Levels of nonesterfied fatty acids (NEFA), serum triglycerides, and alkaline phosphate also reflected nutritional differences. Seal (1977) found NEFA to be negatively related to energy intake. Elevated alkaline phosphate levels indicated active bone growth in young animals (Seal and Hoskinson 1978). Franzmann (1971) determined baseline physiologic values for bighorn sheep. Blood urea nitrogen (BUN) values reflected protein intake, glucose and rectal temperature reflected excitability, and PCV reflected

condition.   Ballard (1991) determined levels of BUN, Ca, P,
and Mg in bighorn sheep in the Morgan Creek drainage of
central Idaho.   BUN levels were significantly lower than
levels reported as normal by Franzmann (1971), while mineral
levels were greater.   Since BUN levels are determined from
both protein catabolism and dietary quality, Ballard (1991)
suggested that fecal nitrogen levels be determined at the same
time blood samples are collected.   Hebert (1978) also
concluded that complementary sampling programs were needed to
discern anabolic BUN levels from catabolic levels, and that a
detailed assessment of nutritional condition required a
combination of methods.

Concurrent blood and fecal samples will be collected from
captured bighorns and analyzed by Dr. David Hunter of the
Idaho Fish and Game Department.   Estimates of BUN, PCV, Ca, P,
Mg, Na, serum triglycerides, T_4, and alkaline phosphate
concentrations determined.   In addition, N:creatinine,
K:creatinine, and Na:creatinine ratios will be determined.

The influence of capture stress can affect the levels of
certain blood parameters; potentially overriding the effects
of nutrition (Seal 1972, Wesson et al. 1979).   Blood samples
will be collected expeditiously to minimize the affects of
capture stress.   In addition, certain blood characteristics
need to be measured soon after blood is drawn.

Measurements of overall length, heart girth, femur
length, hind foot length, and weight will be taken on
captured bighorns.   Regression equations will be developed to

estimate weight from heart girth, hind foot, and femur measurements.

CONSERVATION GENETICS AND DISPERSAL

Given their more specialized habitat requirements, bighorn sheep most likely existed in patches of suitable habitat separated by terrain, some of which was suitable for dispersal between habitat patches, but unsuitable for establishment of permanent home ranges. In essence, bighorn sheep populations may have functioned naturally as a metapopulation in certain areas.

Dispersal between habitat patches is obviously a key element of metapopulation dynamics. Yet, bighorn sheep have often been considered poor dispersers in the literature. Due to human settlement patterns, many of the traditional travel routes that existed prior to European settlement have been eliminated in many areas of the West. In addition, many years of fire suppression throughout the western United States may have resulted in plant successional changes that render former travel routes unsuitable (Wakelyn 1987). Bighorn sheep generally avoid areas with dense, tall vegetation (Geist 1971, Risenhoover and Bailey 1985, Arnett 1990). Bighorn populations prevented from migrating to high elevation summer ranges may exist on a much lower nutritional plane.

Bighorn sheep populations existing in small isolated populations could potentially experience a loss of genetic variability. A lack of genetic variability within an animal

population caused by habitat fragmentation and population bottlenecks can result in inbreeding depression (Franklin 1980, Soule' 1980). Inbreeding depression can result in high infant mortality, increased disease susceptibility, decreased vigor, increased morphological asymmetry, and general poor reproductive performance (Soule' 1980, Franklin 1980, O'Brien et al. 1985, Allendorf 1986). A minimum population size of 100 individuals may be needed to prevent short-term inbreeding problems in bighorn sheep (Skiba and Schmidt 1982). Severe disease-related die-offs may have forced many bighorn sheep populations through repeated population bottlenecks even in wilderness areas. In addition, juvenile bighorn sheep obtain knowledge of suitable migration routes by following older individuals (Geist 1971). During severe all-age die-offs, this knowledge may be lost resulting in sedentary populations that fail to take advantage of high elevation summer ranges.

Mitochondrial DNA analysis of bighorn sheep blood samples collected throughout the range of bighorn sheep suggested that gene flow had occurred at a regional scale at some time in the past (Luekart 1992), and that populations had not experienced long-term barriers to gene flow. However, little mitochondrial gene flow existed among current populations. Luekart (1992) concluded that recent habitat fragmentation and population die-offs warranted further genetic assessments of bighorn sheep populations based on nuclear genes rather than mitochondrial DNA.

Bighorn sheep populations inhabiting central Idaho may or may not technically function as a natural metapopulation, given a strict definition of the term. However, they present the opportunity to study gene flow between bighorn sheep subpopulations in an area where highways, cities, and agriculture do not restrict their movements. Within the greater Salmon River area there are several aggregations of bighorn sheep that have acquired the term "herd"; examples are the Big Creek herd, Morgan Creek herd, and Ship Island herd. How much genetic interchange occurs between these populations? Are the herds actually subpopulations or are the bighorn sheep in the main Salmon and Middle Fork of the Salmon drainages really one panmitic population? Have disease related die-offs produced genetic bottlenecks and subsequent inbreeding depression? Are bighorn sheep properly characterized as poor dispersers?

Modern biochemical techniques present methods for examining these questions. The distribution of allele frequencies can be obtained from electrophoretic surveys of tissue and/or blood samples. More recently developed methods, such as DNA sequencing and restriction-fragment length polymorphisms, provide additional genetic information.

Slatkin (1985) and Slatkin and Barton (1989) presented methods using rare alleles, Wright's F_{ST} statistic, and maximum likelihood to estimate Nm, the number of individuals on an island replaced by immigrants from a source population with fixed gene frequencies. The F_{ST} and rare alleles methods

provided comparable results under a wide variety of conditions, however, the F_{ST} method presented fewer practical difficulties when interpreting the results of electrophoretic surveys. Slatkin (1987) also presented a method using the average number of sites separating DNA sequences.

Nuclear DNA sequences are more useful with species where dispersal is male-biased. Mitochondrial DNA is sex-linked and inherited from the female parent. A combination of methods should furnish the most accurate portrayal of gene flow. In addition to providing a means of examining dispersal between subpopulations, molecular techniques, at a minimum, will provide an examination of the genetic variability of bighorn sheep in central Idaho compared to bighorn sheep throughout their range. G. Luekart of the Univ. of Montana is currently conducting a study of the genetic variability of bighorn sheep through out their range.

Slatkin (1985) showed that if the sample size per deme and number of demes sampled are fixed, and deme size or number of demes changed, then the average allele frequency found in i of d demes is little affected if Nm is also unchanged. In practical terms this means that the complete structure of the population need not be known to estimate Nm. Average allele frequency is also little affected by changes in the numbers of demes sampled if other parameters are held constant. To produce a better estimate of Nm, greater effort should be put into increasing the number of loci sampled rather than increasing the number of geographic locations sampled.

Therefore good estimates could be obtained by collecting samples from as few as 3 to 5 locations (Slatkin 1985). Very little tissue is needed for analyses. Small, < .25 inch, pieces of skin tissue or < 2cc of blood would be more than sufficient (S. Forbes, pers commun.).

At the time of capture approximately 2 cc of blood will be collected from each ewe captured on Big Creek. Samples will be hepronized, frozen and shipped to G. Luekart and S. Forbes at the Univ. of Montana for nucleic acid sequencing and electrophoresis. Samples of skin could be obtained from rams and ewes killed in other hunting units in the greater Salmon River drainage. Results obtained should give a rough estimate of the genetic variability of bighorn sheep in the central Idaho wilderness compared to bighorn sheep throughout Canada and the western United States, and possibly allow examination of dispersal between subpopulations.

MODEL DESIGN

Two basic approaches exist to modeling (Box and Draper 1987). Mechanistic models attempt to simulate nature by defining the precise relationships between variables with algebraic equations. The second approach is referred to as empirical or response surface modeling. This type of modeling relies upon regression based methods, either linear or nonlinear, univariate or multivariate. Mechanistic modeling requires a greater knowledge of the system being modeled than response surface modeling (Box and Draper 1987). Our

knowledge and understanding of some important variables influencing bighorn sheep biology is limited (i. e. minimum mineral and vitamin requirements). Therefore, the objective will be to construct a response surface model that predicts the population fluctuations of bighorn sheep in central Idaho using Big Creek as the study area. Where possible, the Big Creek habitat and study animals will be sampled to construct the model, thus conforming to Eberhardt and Thomas's (1991) "sampling for modeling" design.

In general, response surface modeling involves measuring a number of independent variables that are used to predict one or several dependent variables. Naturally, choice of independent variables to measure is crucial to the success of the modeling effort. Choice of independent variables is largely determined by the response variable or variables that we are wishing to predict. Conceptually, environmental variables that determine carrying capacity or regulate the population would be good choices for predictor variables, and population parameters would be good choices for response variables.

Multivariate multiple regression will be used to model the relationship between a series of independent variables and response surface variables. Independent variables will include digestible protein, digestible dry matter, forage mineral content, fecal nitrogen, elk numbers, percent time spent feeding-moving, number of days spent on high elevation summer range, percent of winter range covered by snow, snow

hardness, number of hours spent outside the thermoneutral zone, precipitation, and wind speed. Response variables include population size, lamb:ewe ratios, survival, and average r. Canonical correlation analysis will also be used to examine relationships between environmental variables and aniamal behavior.

Johnson (1981) outlined general guidelines for determining sample sizes in multivariate statistical analyses. Johnson (1981) reported 20 observations per variable as a general guideline, with more required if the number of independent variables is large. Block et al. (1987) reported that larger numbers of observations were needed for habitat analysis, up to 75. Morrison et al. (1992) suggest that between 35 and 75 observations are needed per dependent group in order to apply multivariate analyses.

Therefore, if a response or dependent variable is measured on an annual basis (i. e. population size), then at least 35 years of data would be required to appropriately model bighorn sheep population levels as predicted by the proposed independent variables. Obviously, this time period is beyond the scope of the present study. However, practically speaking, at least 10 years may reasonably document population changes. In the interim, much can be learned about the nutritional ecology, behavior, and genetics of bighorn ewes in the Big Creek Drainage.

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