Scientific Assessment of the Potential Effects of Mountain Goats on the Ecosystems of Rocky Mountain National Park

John E. Gross
Mary C. Kneeland
David M. Swift
Bruce A. Wunder

Natural Resource Ecology Laboratory
Colorado State University
Ft. Collins, Colorado 80523-1499 (JEG, MCK, DMS)

and

Department of Biology
Colorado State University
Ft. Collins, Colorado 80523 (BAW)

Final Report

National Park Service
Rocky Mountain National Park
Estes Park, Colorado 80517

Contract 1443PX15099062

March 2000
# Table of Contents

**EXECUTIVE SUMMARY** ........................................................................................................ 5

1. **Mountain Goats (Oreamnos americanus) in Colorado: Native or Not?** .................. 11
   - Abstract .......................................................................................................................... 11
   - Introduction .................................................................................................................. 11
   - What is Native? ............................................................................................................ 12
   - Specimens .................................................................................................................... 13
   - Scientific References to Mammals of Colorado ......................................................... 13
   - Early Scientific Reports of Mammals from Colorado ............................................... 14
   - Amateur Collections and Lay Reports ....................................................................... 16
   - Evaluation of Data Provided by Irby and Chappell ................................................... 18
   - Conclusions ................................................................................................................ 23
   - Literature Cited ........................................................................................................... 24

2. **Sightings of Mountain Goats North of I-70 Since 1970** ........................................ 27
   - Abstract ........................................................................................................................ 27
   - Sightings ........................................................................................................................ 27
   - Methods for Tracking Goat Dispersal ......................................................................... 29
   - Literature Cited ............................................................................................................ 30

3. **A GIS-based Habitat Model for Mountain Goats in Colorado** ............................. 35
   - Abstract ........................................................................................................................ 35
   - Introduction .................................................................................................................. 35
   - Methods ......................................................................................................................... 36
   - Results ............................................................................................................................ 39
   - Discussion ...................................................................................................................... 40
   - Literature Cited ............................................................................................................ 42

4. **Population Dynamics and Interactions of Mountain Goats and Bighorn Sheep in**
   **Rocky Mountain National Park: A Simulation Model** ............................................ 55
   - Abstract ........................................................................................................................ 55
   - Introduction .................................................................................................................. 55
   - Model Description ....................................................................................................... 56
   - Results ............................................................................................................................ 63
   - Discussion ...................................................................................................................... 66
   - Appendix 1. Sensitivity to Mountain Goat Patch Definition ..................................... 69
   - Literature Cited ............................................................................................................ 69

5. **Potential Impacts of Rocky Mountain Goats on the Alpine and Subalpine**
   **Ecosystems in Rocky Mountain National Park** ......................................................... 87
   - Abstract ........................................................................................................................ 87
   - Introduction .................................................................................................................. 88
   - Methods ......................................................................................................................... 89
   - Results and Discussion .............................................................................................. 90
Impacts on Native Vegetation ................................................................. 94
Foraging Habits of Mountain Goats and Bighorn Sheep ....................... 96
Threatened and Endangered Plant Taxa, and Species of Concern occurring in RMNP ...... 98
Potential Effects on Spread of Exotic Plant Species .................................. 100
Use of Natural Mineral Licks .................................................................. 100
Effects on Other Native Animals ............................................................. 101
Effects on Other Park Resources and Visitors .......................................... 102
Impact of Fire Management on Mountain Goats and Bighorn Sheep .......... 103
Literature Cited .......................................................................................... 104
APPENDIX 1. Community Types in RMNP which might be Utilized by Mountain Goats . 119
APPENDIX 2. Detailed Information on Forage Preferences of Mountain Goats ........... 127
APPENDIX 3. Detailed Information on Threatened and Endangered Plant Taxa, and Species of Concern in RMNP ................................................................. 133
EXECUTIVE SUMMARY

INTRODUCTION

Mountain goats (*Oreamnos americanus*) were translocated into Colorado in 1948 by the (then) Colorado Department of Game, Fish and Parks. Their populations have expanded in size and distribution since then to the extent that they now sustain an annual harvest of more than 100 animals from 12 management units. This species is considered non-native by the National Park Service (NPS) but was recently designated as native to Colorado by the Colorado Wildlife Commission. Thus, there is a clear need to clarify the status of mountain goats.

The recent appearance of several mountain goats in Rocky Mountain National Park (RMNP) has been a cause for concern. These animals presumably came into RMNP from the south, having dispersed from the thriving population around Mount Evans. Such dispersals are likely to happen again. If the animals are not native to Colorado, their presence in RMNP would be counter to Park Service policies concerning native and introduced species. The Park Service believes there is considerable suitable habitat for goats in RMNP and that a newly established population could easily grow in size to the point of having impacts on native animal and plant species and perhaps on alpine and subalpine ecosystems within RMNP, contrary to the Park’s congressional mandate to protect park resources.

The authors of this report were asked by the Park Service to consider this issue; specifically to assess the evidence concerning the native/non-native status of mountain goats and to predict the impact that a newly established population of the animals would have in RMNP. In this report, we:

1. Review the question of the native/non-native status of goats in Colorado (Chapter 1);
2. Assemble and map verified, recent sightings of mountain goats in and around RMNP (Chapter 2);
3. Present a habitat model for mountain goats which is applied to RMNP to estimate the extent of potential goat habitat in the Park (Chapter 3);
4. Present a model of goat and bighorn sheep population dynamics which estimates the equilibrium size of a newly established goat population in RMNP, and assesses the effect of goats on bighorn sheep populations within the Park (Chapter 4);
5. Assess the potential effects of such a population of goats on other Park resources, including the alpine and subalpine ecosystems, rare and endangered plant taxa, other native animal species, archeological resources, visual integrity of wilderness, and visitor safety and enjoyment of wilderness (Chapter 5);
6. Assess potential conflicts between the fire management program at RMNP and
the establishment of a mountain goat population, with particular reference to the possibility that current fire management practices may facilitate the invasion of the Park by goats (Chapter 5).

STATUS OF GOATS IN COLORADO AND RECENT SIGHTINGS

Most scientific literature reporting on the mammals of Colorado does not consider the mountain goat to be native to the state. Recently Irby and Chappell (1993, 1994) evaluated historical literature and concluded that there is strong evidence that goats were native to the state but had been extirpated by market hunting. Recent literature cites their report as evidence that goats are, in fact, native.

There are no fossils or archeological remains known for goats in Colorado, nor are there any specimens from periods prior to 1948, when they were introduced. Our evaluation of the records of many early survey expeditions within the state reveal no firm reports of goat sightings, but they do report other species known to use the same or similar habitats, suggesting that goats were not seen. The reports and records of amateur collectors, and lay records of natural history observations for the state during the 1800s provide no verifiable observations of goats in Colorado.

Irby and Chappell reviewed and cited several intriguing reports supporting their conclusion that goats were native to the state. We were unable to verify these reports. In some instances, records were clearly references to pronghorn antelope (referred to as “white goats” in many reports from the 1800s). Their single new report of a mountain goat specimen in a lay collection was determined, by us, to have been collected in Idaho.

We conclude that there is no evidence that mountain goats inhabited Colorado during historical times, and that they should be considered non-native to the state.

There have been some verified sightings of mountain goats north of Interstate 70 during recent times. Although there has been no systematic attempt to monitor goat presence in this area, there were 17 sightings in the 1980s and 1990s which we consider to be genuine sightings of goats. There were verified observations of mountain goats in RMNP during 1987, 1995, 1996, and 1997. The pattern of sightings suggests that most of the goats seen are dispersing males, although groups of animals, sometimes including kids, have been seen near Berthoud Pass.

EXTENT OF SUITABLE HABITAT WITHIN RMNP

We developed models to account for patterns of habitat use by mountain goats in Colorado. The models used topographical information derived from digital elevation maps and manipulations that are easily accomplished using standard GIS software. We developed the models from observations of 815 groups of mountain goats (5343 individuals) near Mount Evans, Colorado, collected over a 6-year period from a fixed survey route. Logistic regression models for seasonal (all year, summer, and winter) habitat use correctly classified 81-83% of all observations while classifying 20-23% of the study area at Mount Evans as suitable habitat, representing improvements of 59-62% over random
classification. A second, highly parsimonious model, based solely on distance to escape terrain, correctly classified 87% of observations while considering 38% of the study area as suitable habitat.

When we applied this habitat model to RMNP, it identified 277 km² as suitable habitat for mountain goats, which we divided into 5 distinct habitat patches. Each of these approximated the area that an identifiable sub-population of goats would be likely to use. These areas included an almost continuous zone along the continental divide, and large areas in the Never Summer and Mummy Ranges that are suitable for habitation by both mountain goats and bighorn sheep. There is extensive overlap between areas suitable for mountain goats and the area currently occupied by bighorn sheep populations within RMNP.

GOAT POPULATION MODELING AND POTENTIAL EFFECTS OF GOATS ON BIGHORN SHEEP POPULATIONS

We developed and used a simulation model to estimate potential mountain goat population levels and to evaluate their effects on bighorn sheep populations. The model was a spatially explicit, individual-based model which simulated populations inhabiting a landscape composed of habitat areas that were suitable for either species alone, or for both species. Populations could expand the area they occupied by “diffusive” movement into nearby patches, and by longer range dispersal to patches of suitable habitat that were farther away.

The extent and nature of competition between the two species in patches inhabited by both species was based on information on diet overlap and behavioral interactions between the two. Diet overlap between bighorn sheep and mountain goats (at the plant genus level) was 0.59 during summer and 0.68 during winter. In aggregate, information on aggressive encounters, habitat overlap and diet overlap supported the hypothesis of asymmetrical competition between the two species and the use of a relatively high competition coefficient for effects of mountain goats on bighorn sheep but a relatively low coefficient for the reverse.

Mountain goat population dynamics were simulated in the five habitat patches identified from the application of the habitat model discussed above. We simulated growth of a population arising from a few individuals colonizing the southern end of RMNP.

We simulated population dynamics of bighorn sheep inhabiting four patches of suitable habitat in RMNP, consistent with historical observations of bighorn use within the Park. Dynamics of these populations were simulated in patches derived from GIS coverages obtained from RMNP, but restricted to areas that were not heavily forested. This resulted in bighorn sheep habitat patches that varied in size from 28 to 108 km². Vital rates of bighorn sheep inhabiting each patch were matched to observations, and the populations varied widely in potential growth rates. Sheep populations were subjected to disease within the model, either once or recurrently as a function of population density.

Simulations were performed to evaluate growth of each species independently and together, both in the presence and absence of disease that caused precipitous declines in bighorn sheep.
populations. When both species occurred together, competition was either symmetrical or mountain goats reduced growth of bighorn sheep populations to a greater extent than bighorn sheep reduced growth of mountain goat populations.

Simulated populations of both mountain goats and bighorn sheep attained a size of about 950 in the absence of competition or recurrent disease. Disease had a profound effect on bighorn sheep population dynamics, and competition with mountain goats exacerbated these effects. Bighorn sheep populations subjected to moderate competition and disease were on average 30% lower than those without these effects. Mean size of bighorn sheep populations with strong competition and disease was 47% lower than populations without these effects, while competition reduced mountain goat populations by only about 9%.

Parameters used for these simulations were based on observations of bighorn sheep populations in RMNP, but because of the limited number of years from which data were available, they probably incorporated less annual variation than the populations actually experience. While projections revealed potentially large effects of mountain goats on population size of bighorn sheep, these results are probably conservative in their estimate of stochastic effects that may be particularly important to the smallest herd (North Saint Vrain), which is potentially at risk of extirpation.

We estimate that a herd of mountain goats, once established, would reduce bighorn populations within RMNP by 10 to 50%.

**EFFECTS ON OTHER PARK RESOURCES**

Mountain goats are well suited to the alpine and sub-alpine zones of the Park. They prefer to use very steep and rocky terrain for foraging, or areas in close proximity to such escape terrain. During summer the animals would be found above tree line almost exclusively, while in winter they might retreat as far as the sub-alpine zone, but would probably still be found above timberline on wind swept areas which are snow-free.

The animals readily accept a wide variety of plants including graminoids, forbs and shrubs. In summer they consume almost exclusively grasses and forbs, while during the winter, browse may form an important additional component of their diet, particularly for those animals which winter below treeline. They appear to be quite selective but adaptable foragers within a very broad food niche.

We anticipate that an established population of mountain goats would compete successfully with bighorn sheep. Their habitats and diets overlap to a large extent. In addition, behavioral observations suggest that goats are normally dominant over bighorns and might displace them from areas suitable for both species. There is the potential for competition with elk, mule deer, and moose; but we would not expect important negative impacts of mountain goats on these species.

Mountain goats would probably not have major impacts on the general native vegetation of the Park beyond the impacts already attributable to other grazing animals, except in the very steep and clifffy areas which they often use for foraging in the summer. These areas are presumably being grazed
only by small herbivorous mammals at present. We find no evidence that goats would have any
significant effect upon stands of aspen within the Park. Mountain goats might impact stands of willow
in the alpine and subalpine zones. It appears, however, that while goats might have a greater impact in
these communities during winter than would a similar population of bighorn sheep, sheep would have
a greater impact during the summer. Thus, the precise effect of a population of goats on willows is
difficult to assess; but a combined population of sheep and goats would presumably have a greater
impact than the current population of sheep alone. Where goats develop dust bathing areas, there
would be severe local effects on vegetation.

We documented 27 rare or other plant taxa of concern as being present in RMNP. Of these, 22
would likely be found at elevations which could bring them into contact with mountain goats. We
rated 11 of the 22 taxa as being most likely to be negatively impacted.

We do not expect that goats would have a major impact on the spread of exotic plants within
the Park. It appears that there are very few exotic plants with an effective seed source in the area which
are capable of surviving in the severe environments chosen by goats.

We can find no unequivocal evidence that mountain goats would develop and utilize mineral
licks in the Park to an extent greater than the existing large ungulates, even though anecdotal evidence
from other parts of the Colorado mountains, and from Glacier National Park, suggests that goats avidly
seek sources of mineral nutrition.

The other native animal that seems likely to be impacted by a newly established population of
mountain goats appears to be the pika. Several other species of small mammals might also be affected
along with 8 species of native birds.

Archeological sites are likely to be impacted only if they coincided with a wallowing area.
Visual integrity of the alpine wilderness would suffer from the presence of mountain goats, but visitor
satisfaction is likely be enhanced by them. Goats do present a potential source of injury to visitors, but
it is not deemed to be severe.

RELATION TO FIRE MANAGEMENT

Current fire management procedures within the Park probably favor the spread of goats, but we
believe that goats will re-enter the Park and (if not prevented) establish themselves regardless of the
nature of fire management in RMNP.

CONCLUSIONS

We conclude that mountain goats are not native to the state of Colorado and should not,
therefore, be part of the fauna of RMNP. If a population of these animals was to become established in
the Park, their habitats would overlap broadly with those of bighorn sheep, and they would compete
successfully with that species. Bighorn sheep populations would undoubtedly be reduced (by up to
50%) by the presence of mountain goats.
Mountain goats are very obvious animals in the alpine zones that they utilize and because they are exotic to the Park, their presence would be a pervasive reminder of a non-natural situation within the Park.

Mountain goats have the potential to have a negative effect on several species of alpine birds and small mammals that use the steep and rocky areas favored by goats. While it is difficult to assess with precision the effects that goats might have on other Park resources such as rare and endangered plant taxa, willows, elk, deer, and archeological sites. It is certain that a combined population of mountain goats and bighorn sheep would be a greater risk to these resources than is currently presented by the bighorn population alone.
1. Mountain Goats (*Oreamnos americanus*) in Colorado: Native or Not?

B. A. Wunder¹

Abstract

The status of mountain goats in Colorado is contentious. Most scientific literature reporting on the mammals of Colorado does not consider the mountain goat, *Oreamnos americanus*, to be native to the state, the species being introduced by state wildlife personnel in 1948. However, recently Irby and Chappell (1993, 1994) evaluated historical literature and concluded that there is strong evidence showing goats were native to Colorado, and that they may have been extirpated by market hunting. Recent literature cites their report as evidence that goats were native to Colorado. Further, their report was used in 1993 to support a resolution adopted by the Colorado Wildlife Commission declaring mountain goats a native species in Colorado. This designation has considerable significance for how the species is managed in the state.

Populations of goats are now expanding in Colorado and individuals have been found in Rocky Mountain National Park (RMNP). Given National Park Service policies regarding "alien or exotic species" the status of goats becomes important in how they should be managed in RMNP. For that reason we thoroughly investigated all available information to evaluate the status of goats.

There are no fossils or archeological remains known for goats in Colorado. Nor are there any specimens known prior to their introduction in 1948. Evaluation of the records for many early government survey expeditions across the state reveal that although they do provide records for species known to occur in similar habitats, there are no records for sightings of goats. The reports and records from amateur collectors, and lay records of natural history observations for the state during the 1800s provide no verifiable observations of goats in Colorado.

Irby and Chappell referred to several intriguing reports to support their contention that goats were native to Colorado. Upon evaluating each of these we found they did not support Irby and Chappell’s assertion. In some instances records were clearly reference to pronghorn antelope which were known as 'white goats' in many reports during the 1800s. The one new report of a specimen in a lay collection was determined to have been collected in Idaho, well within the known range for the species.

We conclude that there is no evidence that mountain goats inhabited Colorado during historical times (last 200 years).

Introduction

Mountain goats, *Oreamnos americanus*, herein referred to as goats (domestic or other goats will be referred to with an appropriate adjective), were introduced into various mountainous regions of

---

¹ Department of Biology, Colorado State University, Fort Collins, CO 80523
Colorado over the years 1948-1971 and animals from various herds have been transplanted around the state since then (Denny 1977). Most of these herds have done well, sustaining harvests and expanding their ranges. Although no goats were introduced into very northern Colorado, goats have been noted north of highway Interstate 70, and in 1997, two goats were found in Rocky Mountain National Park (RMNP). Because of the U.S. National Park Service (USNPS) policy and mandates related to "alien species", there is considerable concern about the possible movement of goats into the Park, and therefore, much interest in the question of whether goats were ever native to the Park, or even to the state of Colorado. If goats are not native to the region of RMNP, USNPS policy suggests that they should be kept from the Park as an "alien or exotic species". If there is reason to believe they once existed there, then their movement into the Park could be considered re-establishment of an extirpated species with associated protection of goat populations.

Most scientific literature does not consider goats to be native to Colorado but lists them as an introduced species (Lechleitner 1969, Armstrong 1972, Barrows and Holmes 1990, Fitzgerald et al. 1994). The accepted southern limits to their distribution are Montana, Idaho and Washington (Rideout and Hoffmann 1975). However, in a recent paper and an unpublished report, Irby and Chappell (1993, 1994) provide an extensive review of historical literature and conclude that there is reasonably strong evidence showing that goats are native to Colorado, and that they may have been extirpated by market hunting during the time of gold and silver mining in the state (1859 to the late 1870s depending upon location). The published paper is now being cited as evidence that goats are, indeed, native to Colorado, and that they historically maintained a much more southern distribution than previously accepted (Lyman 1998). The 1993 paper by Irby and Chappell was also used as the basis for a resolution adopted by the Colorado Wildlife Commission declaring that goats are native to Colorado (Colorado Division of Wildlife 1993). That declaration is significant in that it affects the management of goats with the state including RMNP.

Because of this controversy we re-evaluated the evidence used to determine if goats are native to Colorado. We rank the data according to their strength in providing documentary evidence of residency: 1) actual specimens, 2) dated fossil or archeological evidence, 3) scientific reports, and 4) amateur collections and reports. Because Irby and Chappell (1993, 1994) provide new information supporting their claim that goats are native, we evaluate in particular detail the accounts they provide. To place evidence (or lack thereof) in perspective, we compare evidence for goats to evidence for other species that would be expected to occur in similar habitats, and species which might be considered difficult to see or hunt.

What is Native?

We chose to evaluate the evidence for goat occupation of Colorado over the past two hundred years. Although this may seem somewhat arbitrary, there is some precedence for using this time period (Laundre 1990, Schullery and Whittlesey 1999), and it spans the time during which Europeans started to explore and inhabit the area of present day Colorado.
It is certainly possible that goats existed in Colorado during the last glacial period with their distribution contracting to the north following the receding ice shields (see below).

**Specimens**

To our knowledge there are no known fossils of goats from Colorado. A listing of all known fossils and archeological evidence for various species in North America shows no records in Colorado (Graham and Lundelius 1994a, 1994b). The fossil record for goats is not extensive (Rideout and Hoffman 1975; Graham and Lundelius 1994a, 1994b), so lack of fossils may simply mean they have not been found as the environments which are inhabited by goats do not lead to good fossilization. Nonetheless, there are paleontological records of other alpine dwellers such as bighorn sheep and pika (Graham and Lundelius 1994a, 1994b), demonstrating that some inhabitants of such environments have left a fossil record. Fossils of goats have been found in caves just north of Colorado in Wyoming suggesting goats could have lived in Colorado during the last glacial periods 30,000 years or so ago. There are fossils of *Oreamnos harringtoni*, a smaller form of *Oreamnos*, known from Colorado. Recently, Meade and Taylor (1998) report fossils from Porcupine Cave in Colorado. The estimated date for presence of these smaller goats is ca. 350,000 years ago. *O. harringtoni* records have been found in seemingly dryer, lower, more southern locations than those of *O. americanus* (Harrington 1971, Meade and Taylor 1998). Thus, it is possible that *O. americanus* inhabited regions of Colorado several thousand years ago. However, goats no longer show range distributions into southern Wyoming and it is suggested that their range moved further north during the hypsithermal warming trends following the last glaciation.

To our knowledge there are no museum specimens, nor any archeological evidence of goats in Colorado prior to their introduction in 1948. Again, this simply means there is no evidence. However, there are records of goats at more northern locations during times within the past 200 years. According to Burroughs (1961), Lewis and Clark reported seeing a goat near Lemhi Pass, along the present-day border between Idaho and Montana, and they obtained robes made of goat hides from local natives while in their winter quarters along the Columbia River. Further, Baird (1858) reports a specimen of a goat taken by War Department Survey parties from Montana in the mid-1800s.

The lack of specimens or scientific reports of goats from Colorado while specimens were taken and sightings made at more northern locations does not prove goats did not exist in Colorado. However, unless we accept that goats were much harder to see in Colorado or observers were not as thorough as in other surveys, the absence suggests that goats did not occur here. Further, as we will discuss below, some of the Colorado surveys did report sightings or specimens of bighorn sheep or pika, other forms which inhabit alpine areas, suggesting that those surveyors were in appropriate habitat for goats.

**Scientific References to Mammals of Colorado**

The first book specifically listing all the mammals of Colorado is E. R. Warren's *Mammals of Colorado* published in 1910. In this publication Warren makes no mention of goats, implying that, in
his estimation, they did not occur in the state. Prior to this book, Warren had published a short note on new records of mammals for Colorado (Warren 1908) and does not mention goats. Any concerns about the timing of his publication (1910), information base, or experience can easily be dispelled. He arrived in Colorado in 1882, and with training as a mining engineer from Massachusetts Institute of Technology in 1881, he started working in Gothic, near Crested Butte in 1882 (Armstrong 1986). With his interest in natural history, one can presume that he noted the fauna of the area during the 28 years before he published his book. Thus, if goats were present in the area and were extirpated by market hunting, we might presume that Warren would have seen one or talked with miners or hunters who had seen them. Warren's second edition of Mammals of Colorado was published posthumously in 1942, again with no mention of goats. In this second edition there is a section on Accidental, Introduced and Doubtful or Hypothetical Species which lists several species, but goats are not among them.

It was 27 years before R. R. Lechleitner published another book on Colorado mammals, Wild Mammals of Colorado (Lechleitner 1969). In this monograph, goats were not listed as native to the state, and were only mentioned as present after the Colorado Division of Wildlife introduced them in 1948. Shortly thereafter, Armstrong (1972) details the distribution and systematics of mammals of Colorado. Armstrong says goats are not native to Colorado. He notes the reference by Coues and Yarrow (1875) that Lt. Martin's party reported seeing a goat in Colorado, and the inclusion of a goat in the list of mammals reported by Trippe (1874), but suggests they are errors. Warren (1911) also noted these reports in the history of Colorado mammalogy and strongly suggested they were errors, a possible confusion with female bighorn sheep. Having read the report by Trippe (1874) we agree with Warren that this is an error as Trippe does not list bighorn sheep which should have been more common.

The most recent book on Colorado mammals, Mammals of Colorado, by Fitzgerald et al. (1994) discusses goats only as an introduced species to the state.

**Early Scientific Reports of Mammals from Colorado**

Warren (1911) gives a very detailed account of the history of Colorado mammalogy pointing out that most of the early specimens and reports of mammals came from U.S. government surveys. Such information came not only from the reports, journals, and specimens collected during these expeditions, but also from syntheses of these provided by zoologists, usually with the Smithsonian Institution in Washington, D.C. We will not reiterate a discussion of the various papers here as Warren is quite detailed in pointing out specimens or sightings recorded specifically for Colorado from these reports (most of the expeditions covered other areas of the West besides Colorado). Moore (1986) also lists and discusses the importance of these surveys. Warren (1911) discusses collections from the expeditions of Pike (during 1807), Long (during 1819-20), Fremont (several expeditions, but especially during 1844-5), Gunnison (during 1853), and several expeditions which only crossed corners of the state. In addition, Hayden's U.S. topographic survey parties crossed the mountainous regions of the state from 1873 to 1877 starting in the southern part of the state prior to extensive mining in those areas. They spent much time in alpine areas using mountain peaks as reference points from which to
survey drainages. In fact, A. D. Wilson and Franklin Rhoda, two of Hayden’s chief topographers, are credited with several of the first climbs of high peaks in the southern part of the state, including the San Juan Mountains. They mention grizzly bears and bighorn sheep in their reports but there is no mention of goats (Bueker 1986). In fact, none of the reports from the expeditions through Colorado list specimens or sightings of goats yet they do report bison in montane regions, and bighorn sheep and pika from alpine areas. In Baird’s (1858) synthesis of mammals from many of the early U.S. War Department Surveys he only lists goats from the northern expeditions in the areas of Montana and Idaho (and only one actual specimen is listed). Warren (1911) does note the report by Trippe (1874) which we discussed above. He also notes the reference by Coues and Yarrow (1875) to the report by Marshall’s party and states that this is ”A record never verified and no doubt erroneous*” with the asterisk relating to a footnote in which he states, ”*Possibly Marshall’s party may have seen a domestic goat which had run wild, as it occasionally does.” In these reports Warren notes various records of lynx (now *Lynx lynx*) and wolverine (now *Gulo gulo*), suggesting that collectors were able to acquire reasonably rare and timid species. So if goats were present, we would expect them to have been sampled.

Warren (1911) also notes that J. A. Allen from the Museum of Comparative Zoology, Cambridge, brought a survey party to Colorado in the summer of 1871 and published their results in the Bulletin of Essex Institute in 1874. Not only did Allen’s group do much collecting, they also obtained information about species occurrences through conversations with hunters and others. For example, Warren mentions that Allen lists 25 species of mammals previously unknown from the state (mostly rodents and bats); one of these records is the fisher, *Mustela pennanti*. Warren suggests this is an error as he knew of no records and had found no evidence of fisher himself in spite of having done lots of trapping in the state (thus Allen must have obtained this as a report from a conversation).

Importantly, if Allen talked with hunters and they told him of various mammals such as the fisher, they apparently had no suggestions of goats in the state as Allen does not list goats.

Thus, from none of the scientific reports of early surveys in Colorado do we find reference to the presence of goats in Colorado with the exceptions of the reports by Trippe and Marshall, both of which are discounted by later authors. In these same early reports, however, there are references to bighorn sheep, mountain bison, pika and other alpine species in Colorado, and to relatively cryptic species, such as lynx and wolverine. Therefore, if goats occurred in these regions, one assumes the collectors in the early surveys would have seen them. Furthermore, goats are documented from the more northern surveys through Montana and Idaho at the same time periods, so we may assume that when goats were around, they were seen and their presence was recorded.

Of all the government surveys that crossed through Colorado, none appears to have surveyed through the area of present-day RMNP as it does not provide obvious railroad routes to the West. However, in Preuss’s (1958) journal from the second Fremont expedition (edited and translated by E. G. and E. K. Budde) the editors report that the expedition crossed Fall River Pass from North Park into
the area of present day Estes Park. This appears to be the editors' interpretation of the route of the expedition. Buchholz (1983) discounts any reports of surveys, especially Fremont's, passing through the Estes region. In evaluating the latitude given by Fremont's journal, we agree with Buchholz that the error appears to be in interpreting where Old Park and New Park were in this area and what they meant in the 1850s. Fremont appears to have been in present-day Wyoming. However, his group did move through present-day North Park, and probably crossed Muddy Pass into Middle Park. They report shooting buffalo, bighorn sheep, deer and antelope in abundance, but do not report goats. They may, however, not have gone high onto the surrounding peaks and the bighorn sheep may have been at lower elevations than those typically occupied by goats.

**Amateur Collections and Lay Reports**

*Collections*

Martha Maxwell was an educated woman and self-trained naturalist and taxidermist, best known for her collection of Colorado mammals. She was especially well known for her dioramas, a new form of museum display at that time (Dart 1879, Schantz 1943, Benson 1986). She first visited Colorado in 1860 when she and her husband came to the Central City area in search of gold. In 1862 she returned to the family home in Baraboo, Wisconsin, but was back in Colorado in 1868 when she began her collection of Colorado mammals. In 1870 she sold her first collection to the Shaw Gardens in St. Louis and began collecting for a second. Her collection was so good and so well known that the Colorado Legislature, through its Centennial Commission, asked her to take the collection to the U.S. Centennial exhibit in Philadelphia (Benson 1986). Prior to this, Spencer Baird, Assistant Secretary of the Smithsonian, had asked her to contribute to a display from the Smithsonian Institution as she had communicated often with him and others at the Smithsonian. Elliott Coues, first mammal curator at the Smithsonian, was so impressed by the exhibit that he provided a write-up on the taxonomy of the grouping which appears as an appendix to Mary Dart's book (1879), *On the Plains and Among the Peaks*, and is reproduced as an appendix to Maxine Benson's (1986) book, *Martha Maxwell, Rocky Mountain Naturalist*. Coues added comments based upon his knowledge gained as a naturalist with the last of the Hayden surveys in the 1879. The collection included lynx, wolverine, bighorn sheep and pika, some of which are rare specimens and some which are found in alpine zones sympatric with goats, but her collection included no goats. Maxwell collected primarily around Boulder, Colorado, but she also made trips to areas around Idaho Springs and Middle Park, often collecting in alpine areas. Both Spencer Baird and Robert Ridgway were so impressed and intrigued by her collection of Rosy finches that they asked her to assist in collecting Rosy finches from several alpine zones in Colorado. Thus, one would assume that, if goats existed in alpine areas, she would have seen them, and tried to add them to her Colorado collection. If goats were extirpated by market hunting following mineral discoveries in Colorado, then their extirpation would have had to occur very quickly for Maxwell to have missed the goats when she began collecting in 1868.
Edwin Carter also originally came to Colorado as a miner, later studying taxidermy and initiating a museum and collection of Rocky Mountain mammals in Breckenridge around 1870. His collection ultimately became the nucleus of the mammal series for what became the Denver Museum of Natural History. He began collecting in the late 1860s (in order to establish his museum in 1870) and continued until his death in February 1900 (Feister 1976). Although he, like Maxwell, had many specimens which one might imagine were difficult to collect, such as wolverine and lynx, and alpine forms such as bighorn sheep (which may also be found at lower elevations), he, too, had no goats from Colorado in his collection (see discussion below of Irby and Chappell 1993 and 1994).

Thus, the two primary amateur collectors of mammals from the late 1800s in Colorado had no goats among their collections.

Estes Park Report

The earliest reported writings about the game mammals in the Estes Park region are provided by Rufus B. Sage (Hafen and Hafen 1956). Sage spent three years traveling in the West and visited what appears to be the Estes Park area in the fall and winter of 1843-44 (Hafen and Hafen 1956, Buchholtz 1983). He reports spending time during fall primarily hunting black-tailed deer (=mule deer) in the area, and shooting many large bighorn sheep during winter. During his stay he mentions a canyon running west, to the north of what is now Estes Park, and from the top of this canyon he says one can see the headwaters of the Grand River (the name then given to the Colorado River). This fits the description of Fall River canyon leading to Fall River Pass. Although he doesn’t specifically say he climbed to the pass, it is unlikely that he could have known what one could see from there without having been there as we know of no other people who would have been there in 1843-4. He mentions shooting bighorn sheep, deer and elk, but does not mention goats. If he had, indeed, climbed Fall River Pass he would certainly have been in habitat suitable for goats. Prior to hunting in this region, he had come through North Park on his return from the West where he mentions seeing deer, bison, bighorn sheep and elk, but not goats.

Probably the naturalist most associated with the Estes Park area is Enos Mills. Not only did he hike and explore extensively in the Estes Park region, writing profusely of his natural history experiences and animals he saw; but he also served as State Snow Surveyor and traveled widely throughout the mountainous regions of the state in the winter to measure snow pack (Hawthorne and Mills 1935). While Mills wrote about his experiences with bighorn sheep in the Flattops area and other alpine parts of the present-day RMNP and of keeping grizzly bear cubs as pets, he never mentions goats. Mills did not arrive in the Estes Park area until 1884, but by 1885 he was intent in his interest of natural history fostered by helping around the Carlyle Lamb ‘guest ranch’. If goats had been extirpated due to market hunting associated with mining (in spite of the relatively low level of mining activity in the RMNP area: Buchholtz 1983), we imagine he would have heard of goats when talking with those who had been in the area earlier, had there been any goats in the area.
Thus the written records left by an early hunter and naturalist provide no record of goats in the area of the present-day RMNP.

**Evaluation of Data Provided by Irby and Chappell**

Since these authors argue that goats were present in Colorado during the past 200 years, we focus here on their data and interpretations. In two papers they present an in-depth review of historical literature containing some interesting observations which support their thesis that goats did, indeed, exist in the area of Colorado during the past 200 years. One paper is a lengthy, detailed review of historical records presented to the Colorado Division of Wildlife as an unpublished manuscript (Irby and Chappell 1993). The published paper is a shorter synopsis of the longer manuscript (Irby and Chappell 1994). Since the published version is the record being cited as support for the contention that goats existed in Colorado with a more southern distribution than previously thought (Lyman 1998), and since it encapsulates the major points from the unpublished paper, we will primarily address arguments in the 1994 paper. However, we add some comments on the 1993 manuscript as it was used by the Colorado Wildlife Commission to declare goats native to Colorado.

In their papers, Irby and Chappell (1993, 1994) admit that the scientific community generally lists the southern limits for the range of goats in the Rocky Mountains to be parts of Montana and Idaho. But they argue that several historical records were not carefully examined and that they uncovered new data. Their data consist of careful examinations of journals and records associated with the early exploration of Colorado, the Pacific Railroad Surveys, evaluation of early sporting and hunting literature, Colorado Legislative session laws relating to game animals, and new evidence suggesting the presence of goat specimens in the Edwin Carter collection (see above).

Their central thesis is that goats existed in the state in the early 1800s and were extirpated by market hunting during the times of gold and silver mining (1859-1880s depending upon the mineral discovered and the site). They also note that much of the confusion about records may relate to the fact that this was a new species to science and to the lay public moving west, and that names were confusing. For example, Lewis and Clark called sheep, ‘bighorn’ and they called the goat they saw a ‘sheep’ (Burroughs 1961). Adding to the confusion, pronghorn were often called ‘white goats’ at that time, and in the early records female or yearling bighorn sheep were also confused with goats. Thus, when common names appear in the lay literature of the 1880s, it can be difficult to determine to which species the author refers. Even the scientific names changed as zoologists obtained more information from specimens of bighorn sheep and mountain goats (see Rideout and Hoffman 1975).

Irby and Chappell correctly point out that neither the Pike expedition of 1806-1807 nor the Long expeditions (during 1820) sighted goats. They fail to mention that Edwin James, naturalist for the Long expedition, is usually credited with the first ascent of Pikes Peak. During that ascent James noted that they saw bighorn sheep skulls near the base of the peak and found bighorn sheep tracks and scat on the peak - he does not report seeing goats (Evans 1997, James 1966).
In their longer paper, Irby and Chappell (1993) provide several intriguing reports of goats in Colorado given by early mountain men, although most are secondary accounts and cannot be verified. In the published version they note that most such reports were discredited by the aristocratic sport hunters of the mid-1880s. These sitings were also generally discounted in the scientific literature as confusion with female or young of bighorn sheep. However, Irby and Chappell (1994) do mention a second-hand report that a John Stanton W. Burrington (as discussed in their reference to Messiter, 1878) visited local native Americans (presumably in the Canon City area, although the location is uncertain) between 1838-1842 and noticed that they possessed samples of a shiny, long, black horn. They mention that Burrington negotiated a trip to hunt for the animal possessing such horns, but fail to point out, in the 1994 paper, that the hunt was not successful. Thus, it is not clear whether this artifact was truly the horn of a goat and, if so, whether it was obtained by these natives through trading with other tribes from other locations. It is not entirely clear where Burrington was when he saw this, nor from which species the horns had been collected, therefore this remains a dubious record at best.

One very interesting report by the Irby and Chappell (1994) is that "The first mountain goat specimens given to the Museum of the Royal College of Surgeons of England was [sic.] inventoried as the head and skin of a female and her kid that had been 'shot south of the 40th parallel' in 1849 (Garson 1871)". There is no clarification of whether there is any evidence that this was in Colorado or simply documented an early specimen being taken south of the presently accepted species range. In the longer version of their paper Irby and Chappell (1993) say that the checklist notes that the Museum has 16 specimens of goats (then named Haplocerous montanus), 12 of which were taken by Edmund Loder and a Mr. Smith in British Columbia, 2 from northern Montana, and only the female and kid were apparently taken at lower latitudes, collected by an unnamed hunter. It would be useful to know how this hunter knew his location. The reference to Garson 1871, was given as J. G. Garson 1871, Specimen checklist in the Museum of the Royal College of Surgeons of England. Mammalia. Royal Coll. Surg. London. Checklist Papers, 2. In attempting to verify these specimens and their collector to see whether the Museum may have field notes to document locations more specifically, we contacted Dr. Simon Chaplin, Senior Curator of the Museum of the Royal College of Surgeons in London. He was unable to find this reference by Garson. He was able to document that a John George Garson worked as an Assistant at the Museum from 1878-1888, although he admits that Garson could have worked there earlier or have been an unpaid volunteer of some sort. He notes that they have two published Osteological catalogues in which these goat specimens are likely to have been listed. The first was published in 1853 under the direction of Richard Owen. The second was published in 1884 and was compiled by William Flower and John George Garson. Dr. Chaplin checked catalogue and acquisition records for the period from 1853 to ca. 1879 and found no obvious records of goats, so he also checked annual reports for those periods and still found no obvious collection of goats. Further, the only specimen of goat (and there is some question about whether these were goats or sheep) donated by Sir Edmund Loder were taken in British Columbia in 1889. Chaplin does note that there
was apparently some exchange of specimens between the College Museum and the Smithsonian Institution, in particular, a large collection North American mammals was received in 1871. There is no checklist for this, but it could be the list of Garson. Thus, we could not verify this record.

Another intriguing reference is to a record associated with the Gunnison expedition. The authors (Irby and Chappell 1994) state that "A party scouting the region around the Gunnison River in 1853 killed several mountain goats..." and reference records in the U.S. Archives. Fortunately, in their longer paper they detail these records. One is a hunting record kept in a journal. In this record there are various columns headed by names of specific game animals collected for food, and there are marks in a column headed by the term 'white goats'. The authors suggest the hunters were collecting goats. Since that term was also used for pronghorn antelope, it would have been valuable to know whether pronghorn were also listed. Unfortunately the records were not dated, nor were locations given, so the information is of limited value. Irby and Chappell (1993) point out that in this journal there are frequent references to Lt E. B. Beckwith. Beckwith was second in command of the Gunnison expedition and assumed command when Gunnison was killed. Thus, if something as unique as a goat were taken, it should have been reported in the collections from the expedition - there are no records of goats. The second interesting reference from the Gunnison expedition is to a letter dated 20 July 1853 from a Sgt. Brye to a Dr. Morgan indicating that he was sending over to the doctor's camp the horns and wool of the goats which he shot "on top of the mountain." He notes that the troops only ate the kid as the adults were "poor meat." Indeed, shooting goats on top of a mountain and having them be of poor meat sounds like mountain goats. Unfortunately, at the time of this letter the Gunnison expedition was still on the Santa Fe Trail in Kansas or eastern Colorado, and they did not reach Bent's Fort, in present-day eastern Colorado, until 29 July, nor did they cross La Veta Pass into the San Luis Valley until later in August. There they stopped at Fort Massachusetts while they got scouts from New Mexico. They camped near what is now Saguache on 29 August and report seeing bighorn sheep near camp on 1 September. They did not cross Cochetopa Pass into the Gunnison Basin until 2 September and by 9-10 September report difficulty crossing the Lake Fork. At this point Gunnison writes that this would be a difficult, and certainly costly, railroad route so they moved on quickly reaching the Uncompahgre River by 15 September (U.S. War Dept. 1855, Vandenbusche 1980). From there they moved on quickly to the site of present-day Grand Junction. It is also unlikely that troops straggled or spread out much (as suggested by Irby and Chappell 1993) as the Gunnison party consisted of 16 wagons drawn by 6 horses each and an instrument wagon and ambulance; and there was the constant concern for attack by natives. Indeed, Gunnison and his chief naturalist, Kreutzfelt, were among those killed by Paiutes in Central Utah on 25 October. Troops were also needed to help with clearing a path and fording rivers with these wagons, especially at the Lake Fork. Thus, the Gunnison expedition actually spent little time in the mountainous regions of Colorado. It is unfortunate that the reference to 'goats' in the longer paper was changed to 'mountain goats' in the shorter version as the reference by Sgt. Brye to 'goats' being shot in July clearly refers to pronghorn. The broken hills of western Kansas
and eastern Colorado could certainly have seemed to be mountains to troopers from the East.

The suggestion that market hunting during the gold and silver mining days in Colorado could be responsible for extirpation of goats is speculation. The authors themselves make reference to reports that goat meat does not taste good. Indeed, Hornaday (1914), Director of the New York Zoological Park, points out that "This animal is not likely to be extirpated very soon...." noting that they live in inaccessible areas and the flesh is so musky and dry that it is not palatable. Roosevelt (1907), who hunted in the West, also says that they would not go after goats for meat as ".....the flesh usually affords poor eating, being musky..." While there is support for the idea that mountain bison may have been hunted to extinction, we doubt such is the case for goats. Indeed, as late as 1879 Kokomo's newspaper reports that hunters brought in three wagon loads of elk from the Green Mountain area north of Breckenridge and hunters were busy hunting elk, deer, bear, mountain sheep and antelope - goats are not mentioned in the paper. We would certainly expect bighorn sheep, elk and deer to have been driven to extinction first and they were not. Numbers were definitely depleted but not to extinction.

Irby and Chappell (1993, 1994) provide a thorough review of the early sport literature describing game animals available for hunting and where they could be found in the West. Unfortunately, most of these reports are secondary sources which, at best, give very general range descriptions. For example, the authors note that Theodore Roosevelt (1888, 1893) suggests that goats can be found down to Arizona or New Mexico. However, ten years later (Roosevelt 1907) he describes their range as only down into "...Montana, Idaho and Washington." Seemingly the most authoritative reference of these sorts presented by Irby and Chappell (1994) is a publication on which game to hunt and where to hunt them published in 1898 by the U.S. Cartridge Company. The authors report that the company said that they sent questionnaires to all state governors asking for information, and based their report on those responses. Irby and Chappell note that the response sent from Colorado was prepared by "....Gordon Land, the Colorado State Fish Commissioner...." indicating that "....there are some Rocky Mountain goats in the state, but they are not abundant." Indeed, Land served as State Fish Commissioner from 1889-93 and again from 1895-97 (presumably this would have been when he sent information for the U.S. Cartridge publication). However, he was first and foremost a fisheries biologist with primary interest in developing hatcheries. In 1891 he became State Game and Fish Warden but he did not want warden duties and spent most of his time with the hatcheries. Although he was given 4 district wardens with two deputies each, he still complained to the Legislature that he should not be involved with warden activities and needed more funding for hatcheries, and that is why he quit in 1893. He accepted the position again in 1895 because he was concerned about the fishery programs (Barrow and Holmes, 1990). With only 4 wardens and 8 deputies to cover all fish and game activities throughout the state, and no interest in game, it is doubtful that Land would have had direct evidence for the presence of goats in the state. This is also about the same time that the Legislature was modifying game laws (see below) and it does not list goats in those laws. Since the information
sent to the U.S. Cartridge Co. was to influence hunters about where to hunt, it is not surprising that the availability of species listed may have been unrealistically optimistic. Thus, this record must remain a secondary report and cannot be verified (also see below; a letter Edwin Carter sent to John Campion about this same time, 1898, indicating he knew of no records for goats in Colorado).

Irby and Chappell (1994) also note that certain laws passed by the Colorado Legislature suggest goats were present in the state in the late 1800s. In 1887 the legislature passed a set of laws that established hunting seasons for the first time and banned the killing of bison for 10 years, bighorn sheep for 8 years and Rocky Mountain goats for 10 years. The 1889 laws made it easier to prosecute poachers. These same laws are mentioned by Barrow and Holmes (1990), but they add the comment that goats were included "...although it was not believed there were goats until 1947." (This should read 1948, not 1947). It is not clear whether this statement is the authors' own conclusion or their understanding of the law at the time. However, in the 1897 legislative session there were several changes to the game laws. Elk were protected and a bounty was placed on eagles as it was argued that they kill bighorn lambs. There is no mention of continuing protection of goats, nor is killing goats or kids listed as a rationale for the bounty on eagles. Further changes arising from the 1903 Legislative session list new fines for poaching various species, but again, goats are not listed (Barrow and Holmes 1990).

Thus, the session laws relating to game mention goats at only one point and fail to mention them again. This suggests that as more complete data were available, there was no reason to list a species that was not present. Whether this was thought to have been due to an initial error in listing, or to belief, at the time of the later sessions, that goats had been extirpated, is unknown.

The most interesting new evidence introduced by Irby and Chappell (1994) was a report of goat specimens from Colorado in Edwin Carter's collection (see description above). The authors point out that they found new photos in the records of the Summit County Historical Society, one of which shows Carter displaying a wolf mount with a mounted goat in the background. They then note that in the probate of Carter's will he lists goat specimens, although they are not listed as mountain goats. Given the appraised value of these specimens, the authors suggest that the specimens are truly (rocky mountain) goats. In the will, the goat specimens were left to Ben S. Revett, and thus removed from the Carter collection (the remainder of which was housed in what became the Denver Museum of Natural History). Irby and Chappell assert that Ben S. Revett was a mining engineer rather than a hunter, and probably had nothing to do with the original collection of these specimens. In fact, Revett is well known in Colorado, especially in Breckenridge, as the "Father of gold dredging" and was manager of many different mining operations throughout his life, including some in Salmon, Idaho during 1897 (Ellis 1967). A letter from Edwin Carter (see below) confirms that Revett had, indeed, obtained mountain goat specimens while in Idaho.

Irby and Chappell contend that when Carter's goat specimens left the Denver Museum collection, Victor and Rudolf Borchert mounted an expedition to Idaho to collect animals for a
Colorado exhibit, and that the later removal of those specimens from the Colorado exhibit was part of the reason the Borcherts left the museum. If they really believed that goats were part of the native fauna of Colorado, they apparently never shared this idea with E. R. Warren, or he chose to ignore them, for in his *Mammals of Colorado*, (which does not include goats), Warren (1910) mentions that he reviewed the Carter collection at the Denver Museum of Natural History and thanks Victor Borchert for useful discussion.

The source of those goats in the Carter Collection is clearly addressed in two letters in the Archives of the Denver Museum of Natural History (Denver Museum of Natural History Archives 1898). Indeed, Carter had several specimens of goats and they came from Ben S. Revett who obtained them near Salmon, Idaho. On 21 January 1898 a Mr. W. S. Patterson of Dillon, Colorado wrote to John Campion, President of the group which became the Board of what is today the Denver Museum of Natural History, asking if he wanted to buy a goat specimen. Campion was not interested and passed the letter to Edwin Carter asking if he had such specimens in his collection. Carter wrote back on 31 January 1898:

My Dear Sir

Mr. Pattersons [sic] specimen is the "Mountain Goat"--Aplocerus Montanus [sic]--one of the two species of the Antelope Family belonging to North America. The Mountain Goat is a sub Arctic animal and is abundant throughout its habitat which embraces the whole of the great North West from the Mackenzie River through to the British Columbia and Alaskan Pacific Coast range. It skin is much used by the Natives for clothing, bedding [sic] and rugs. Its southern limit is or was Wyoming and is yet found in Idaho, Montana and westward through Northern Washington. Their [sic] is no authentic record of its having inhabited Colorado.

Mr. Revett secured several that were taken last winter in mountains adjacent to Salmon City, Idaho. One of these a "kid" five months old I mounted of which the enclosed photo was taken. One each male and female I shall mount during the next three or four weeks.

I have not seen Mr. Pattersons [sic] specimen but it is reported to me as a badly handled subject I presume that in size it is an average adult male.

Very Truly Yours
(signed) Edwin Carter

Conclusions

After thoroughly examining all available information, we conclude that mountain goats did not occur in Colorado in historic times. Our examination of specimens, dated fossils and other archaeological information, scientific reports, and amateur collections and reports failed to reveal the
presence of definitive evidence of mountain goats. The lack of evidence is compelling, especially because these records documented the presence of rare and cryptic species, and the presence of species that occupied the same habitats as mountain goats. If goats had been in Colorado before 1948, we contend that unequivocal records of this would exist.

Acknowledgements

This study was supported by funding from the U.S. National Park Service. B.A.W. also thanks the U.S. Air Force Academy for providing time for analysis and writing. We thank the Tutt Library at Colorado College for access to records and early reports by E. R. Warren and early U.S. government survey documents. Thanks to Cherie Jones and Russell Graham of the Denver Museum of Natural History for discussions about the records of goats in Colorado and special thanks to Kris Haglund of the Museum Archives for her time, knowledge of records in her care and allowing access to those records.

Literature Cited


2. Sightings of Mountain Goats North of I-70 Since 1970

B. A. Wunder

Abstract

There is no single source of information for sightings of mountain goats (*Oreamnos americanus*) north of I-70. However, two game management units do extend into this area, G7 (near the Eisenhower tunnel) and G9 (the Gore Range). We focused our efforts on collecting and evaluating reports of animals along the Front Range, extending from I-70 toward Rocky Mountain National Park. In the field, mountain goats can be confused with bighorn sheep, if one is not trained to distinguish between them. Thus, we did not consider reports as verified unless they were made or evaluated by trained observers (e.g. personnel from the Colorado Division of Wildlife, U.S. Forest Service or National Park Service). We collected records from employees of these agencies who work in the Park or in areas surrounding it. Most reports of animals north of I-70 (except immediately north of I-70 near Game Units, G4 and G7) and in the Park are of single individuals, and there are few records indicating animals stay in one place for any period. The only reports of groups of goats (i.e. 6-8) or those with kids north of Berthoud Pass are in the Byers Peak/Gordon Creek area (near the Fraser Experimental Forest). These observations suggest that, with the exception of the area around Byers Peak, most animals moving any distance north of I-70 are individual dispersing males. There were verified observations of mountain goats in RMNP from 1987, 1995, 1996, and 1997. There has been no apparent increase in the frequency of observations in recent times, but this may reflect a lack of consistency in observation efforts more than anything else.

Sightings

To our knowledge there has been no concerted effort by any agency to census mountain goats outside prescribed mountain goat hunting units. There are now two goat herds in game management units (G7 and G9) which include land north of I-70, and a herd in unit G4 immediately to the south of I-70. The G9 unit covers much of the Gore Range extending east to Colorado highway 9 in Summit County, and is thus quite a distance southeast of Rocky Mountain National Park (RMNP). Although activities of this herd have recently been reported by Hopkins (1992), we have not included sightings from Game unit G9 because of the relative remoteness of this area to RMNP. The boundaries of the G7 Game unit have recently been extended in the area north of I-70. The northern boundary now extends to the Ute Pass road (USFS road 132), USFS roads 138 and 139 and Grand County road 50 (near Fraser), and the east boundary is defined by US 40 (the Berthoud Pass road). We were primarily interested in sightings of mountain goats along the Front Range which might be dispersing from populations on Mt. Evans (Game unit G4) and the Grays-Torreys area (Game unit G7) northward.

---

1 Department of Biology, Colorado State University, Ft. Collins, Colorado 80523
toward RMNP.

In the field, mountain goats can be difficult to distinguish from bighorn sheep (*Ovis canadensis*), especially ewes or young with bleached coats. We therefore did not consider reports as verified unless they were made by trained naturalists, such as Colorado Division of Wildlife (CDOW) or U.S. Forest Service (USFS) personnel, or trained volunteers working with them, who were likely to know the difference. For reports from visitors, hunters or others, we note them only if verified by trained personnel (i.e., either observing the animal or interviewing the reporter to determine his/her ability to distinguish animals) or if they may be of particular significance (and then we note that they were not verified). Many of the early reports from RMNP do not indicate whether or not they were verified. Thus, we tried to determine the reliability of the observations of goats from comments in the reports or characters used to describe the animal combined with locations and dates. For completeness, we list all reports we could find for RMNP and mark those which seem to truly be goats (Table 1 and Figure 1). To obtain records of sightings, we contacted agency employees working in relevant areas: Jeff Connor at RMNP, Janet George, Chuck Wagner and Jerry Claassen of the CDOW, Becky Parmeter of the USFS (Boulder District), and we tried contacting Doreen Sumerlin of the USFS, but were referred back to CDOW personnel by that ranger district.

Denny (1977) summarized introductions and most of the sightings in the state prior to 1977. In that report he notes that goats "...have been reported for a number of years north of Rocky Mountain National Park but have never been observed in the Park itself." However, he also noted that "...Early reports of goat sightings on the Poudre River are now considered to have been female bighorn sheep in molt." He reported one sighting in 1976 that was confirmed by CDOW personnel. This was a young nanny that escaped as a kid from holding facilities at Colorado State University. Denny mentions several sightings reported by hunters during the 1970s in the areas immediately northwest of RMNP in areas around Long Draw and on Mt. Cindy (two miles west of Mt. Cumbulus) in the Never Summer Range. However, Denny notes that "...Division personnel have not been able to observe or confirm any of these ..." reports. To our knowledge there have been no recent reports in those areas.

In our discussions with the personnel listed above, who are not associated with RMNP, we find few verified sightings outside the Park during the 1980s (one listed in Table 2 and noted on Figure 1, and reports from Claassen below). Whether this was because there were no animals there, or a consequence of less-vigilant survey work, is unknown. There are several reports of goats north of I-70 in the 1990s (Table 2 and Figure 1), mostly from the areas just north of I-70. The only reported observations of goats north of Berthoud Pass are from Byers Peak and the Gordon Creek area, near Fraser Experimental Forest for 1997 and 1999, and of a single billy reported in 1996 by the USFS near Arapahoe Pass (actually along Caribou Pass above Lake Dorothy). Jerry Claassen has worked in the areas just south of the Park since the late 1970s, and although he did not have specific written records, we note some of his reports here. He recalled seeing a billy on Berthoud Pass and noting occasional reports of goats from the areas around Rollins Pass and Byers Peak in the 1980s, but did not know the
date or year. He could not recall any reports (verified or not) of goats from the areas of Willow Creek or the Never Summer Range over the past 10-15 years.

In all of the reports we examined, including written reports, card records, and information in a computer database provided by Jeff Connor at RMNP, all observations of goats in RMNP are of one or two individuals. None of the reports indicates an animal stayed in the Park, or at a particular location, for any extended period of time. It seems most likely that these sightings were either dispersing mountain goats rather than permanent occupants of newly extended home ranges, or bighorn sheep mistakenly identified as mountain goats. There is a report of a goat near Chasm Lake on 4 April 1954, but notes suggest that it was a female sheep. The report in early July 1979 near the continental divide sign along Trail Ridge road seems valid. Although RMNP personnel did not see this animal, they did verify that the visitor could differentiate between sheep and goats. Two reports from the 1980s were verified by photographs of mountain goats (RMNP, unpublished data). One report verified by a photograph was of a mountain goat in the parking lot at the Alpine Visitor Center, unafraid of visitors. The 15 June 1994 report, which described the animals as being "tawny mammals" with "light rumps", was almost certainly sheep; goats are uniformly white. The report of 17 June 1994 near Chasm Lake could be a goat, but there is no information describing it. There were a series of reports from the summer of 1996, with three verified sightings of mountain goats within RMNP.

In June 1997 two male goats were removed by helicopter from the area of Chasm Lake and taken to Mt. Evans. Chuck Wagner reported that one of those goats (identified by a neckband) was seen near Rollins Pass in Clear Creek County in 1998 or 1999. Steve King of RMNP was unable to verify either of the two sightings of goats near Milner Pass in June 1999. He interviewed both observers and determined they were unable to differentiate between goats and female sheep, and at this time of the year, sheep move through this area on their way to Specimen Mountain.

Most reports of goats north of I-70 and outside the Park are for males or single individuals (most likely to be males). Thus, these may be primarily dispersing individuals. However, there are several reports of mixed bands with kids just north of I-70 near the Eisenhower tunnel. There are also two reports of groups of 6-8 individuals (sex unknown) along Gordon Creek and on Byers Peak in Grand County, near the Fraser Experimental Forest. These were the only mixed bands reported north of Berthoud Pass.

During August 1999, Janet George, Tom Kroening and Russ Mason flew over the area of Game unit G7 (Grays Peak) in a helicopter in order to count goats in that area (as they have since 1993). During the flight, they counted at least 390 goats, which is the highest number recorded to date in that area. This suggests that dispersal pressure may be high at this time, encouraging the movement of individuals.

Methods for Tracking Goat Dispersal

An almost continuous corridor of terrain suitable for mountain goats extends from vigorous populations of mountain goats in the Mt. Evans/Grays-Torreys area to RMNP (Figure 2). Mountain
goats are likely to continue to disperse along this corridor. Perhaps the simplest method for tracking
goat movements in the areas surrounding RMNP would be to fly over the alpine areas during the snow
free periods. Goats in Colorado tend to use high-elevation habitats and do not often move into the
trees, thus observers should have good opportunity to see animals present in those areas. Surveys
should be conducted by either CDOW or NPS personnel, and observation records should include
locations, dates, sizes of groups and sex determination, if possible. Special effort should be made to
note whether kids are present as they would indicate movement of herds rather than simply dispersing
males.

If it seems valuable to understand the source of dispersing individuals, then collecting tissue
samples from the potential source herds (animals in G4 and G7) could be useful. With these samples,
DNA profiles for the source herds might be developed. Then as animals disperse north into the Park,
tissue could be collected to determine the 'relatedness' of these animals to possible source populations.
It is possible that as goats shed their winter coats, hair samples could be collected in G4 and G7 to
allow development of genetic profiles without disturbing animals. This may necessitate being able to
find hair follicles with some of those hairs so that sufficient DNA could be collected. Before mounting
a large effort using this approach, however, some pilot studies should be done. Because the goat herds
in Colorado come from a small number of individuals, goats have been moved around the state, and the
goats in G7 are thought to have colonized from the G4 herd, there may not be enough genetic variation
to allow good genetic differentiation between herds.

Literature Cited
of the First International Mountain Goat Symposium (W. Samuel and W. G. MacGregor, editors.).
Hopkins, A. L. 1992. Behavior and population dynamics of mountain goats in the Gore Range of
Table 1. Records of possible mountain goat sightings in Rocky Mountain National Park.

<table>
<thead>
<tr>
<th>Record</th>
<th>Date</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>4/24/54</td>
<td>Chasm Lake near Longs Peak</td>
</tr>
<tr>
<td>2.*</td>
<td>7/79</td>
<td>Continental Divide sign, Trail Ridge Road</td>
</tr>
<tr>
<td>3.*</td>
<td>7/5/87</td>
<td>North inlet, Lake Powell</td>
</tr>
<tr>
<td>4.</td>
<td>7/7/87</td>
<td>Tundra, north of Toll Memorial</td>
</tr>
<tr>
<td>5.</td>
<td>7/21/87</td>
<td>Ute trail, 1.5 miles from road</td>
</tr>
<tr>
<td>6.*</td>
<td>8/31/87</td>
<td>Alpine Visitor Center, parking lot</td>
</tr>
<tr>
<td>7.</td>
<td>6/15/94</td>
<td>Near Mills Lake</td>
</tr>
<tr>
<td>8.</td>
<td>6/17/94</td>
<td>Chasm Lake near Longs Peak</td>
</tr>
<tr>
<td>9.</td>
<td>7/17/95</td>
<td>North side Mt. Fairchild (distance w/binoculars)</td>
</tr>
<tr>
<td>10.*</td>
<td>7/9/95</td>
<td>below Chasm Lake, in meadow</td>
</tr>
<tr>
<td>11.</td>
<td>6/25/96</td>
<td>Junction of Loch and Mills Lake trails</td>
</tr>
<tr>
<td>12.*</td>
<td>7/20/96</td>
<td>St. Vrain Mountain</td>
</tr>
<tr>
<td>13.</td>
<td>8/2/96</td>
<td>Forest Canyon Overlook</td>
</tr>
<tr>
<td>14.*</td>
<td>8/8/96</td>
<td>near Toll Memorial</td>
</tr>
<tr>
<td>15.</td>
<td>8/13/96</td>
<td>Near hitchrack on Flattop Mtn. Trail, 3 reports</td>
</tr>
<tr>
<td>16.</td>
<td>8/14/96</td>
<td>Flattop Mountain</td>
</tr>
<tr>
<td>17.*</td>
<td>8/15/96</td>
<td>Trough on Longs Peak</td>
</tr>
<tr>
<td>18.</td>
<td>8/16/96</td>
<td>Chasm Lake Junction</td>
</tr>
<tr>
<td>19.</td>
<td>6/16/97</td>
<td>Colorado River Trail, 2 miles from trail head</td>
</tr>
<tr>
<td>20.*</td>
<td>6/28/97</td>
<td>Chasm Lake near Longs Peak--2 males removed</td>
</tr>
<tr>
<td>21.</td>
<td>7/3/97</td>
<td>Along Trail Ridge road between Lake Irene and Fairview [sic] Curve</td>
</tr>
<tr>
<td>22.</td>
<td>6/30/99</td>
<td>Milner Pass</td>
</tr>
</tbody>
</table>

* Verified or seemingly correct goat report. Others were unverified and may be reports of female bighorn sheep.
Table 2. Records of mountain goat sightings north of highway I-70 outside of Rocky Mountain National Park

<table>
<thead>
<tr>
<th>Record</th>
<th>Date</th>
<th>Location</th>
<th>Number/Sex</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1987</td>
<td>Pettingill Peak</td>
<td>2 unk</td>
<td>Wagner</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(see # 7 below)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>9/97</td>
<td>near Byers Peak, Grand Co.</td>
<td>6-8 unk.</td>
<td>Wagner</td>
</tr>
<tr>
<td>3.</td>
<td>8/99</td>
<td>Gordon Creek, Grand Co.</td>
<td>8 unk.</td>
<td>Wagner</td>
</tr>
<tr>
<td>4.</td>
<td>&gt;97</td>
<td>Rollins Pass (one of the goats removed from RMNP in '97)</td>
<td>1 male</td>
<td>Wagner</td>
</tr>
<tr>
<td>5.</td>
<td>7/96</td>
<td>Caribou Pass</td>
<td>1 male</td>
<td>Ken Watson via B. Parmenter</td>
</tr>
<tr>
<td>6.</td>
<td>7/93</td>
<td>Mt. Trelease, 1 mile N Eisenhower tunnel</td>
<td>2 unk adult</td>
<td>George</td>
</tr>
<tr>
<td>7.</td>
<td>8/94</td>
<td>Pettingill Peak, 3 miles N Eisenhower tunnel</td>
<td>1 male</td>
<td>George</td>
</tr>
<tr>
<td>8.</td>
<td>8/94</td>
<td>Mt. Parnassus, 3 miles N, 4 mile E Eisenhower tunnel</td>
<td>1 unk.</td>
<td>George</td>
</tr>
<tr>
<td>9.</td>
<td>7/97</td>
<td>Dry Gulch, 1.5 miles N, 1 mile W Eisenhower tunnel</td>
<td>4 unk adult</td>
<td>George</td>
</tr>
</tbody>
</table>

\(^1\)See text for sighting sources.
Figure 1. Locations of mountain goat sightings north of I-70. Counties are outlined, RMNP is shaded.
Figure 2. Area from Mt. Evans to north of RMNP showing escape terrain (slopes at least 33 degrees), buffered by 258 m. These are geographical areas readily used by mountain goats. RMNP is shaded; counties are outlined.
3. A GIS-based Habitat Model for Mountain Goats in Colorado

J. E. Gross\textsuperscript{1,2}, M. C. Kneeland\textsuperscript{1}, D. F. Reed\textsuperscript{3} and R. M. Reich\textsuperscript{4}

Abstract

We used multiple logistic regression to develop habitat models that accounted for presence or absence of mountain goats (\textit{Oreamnos americanus}) in alpine habitats near Mt. Evans, Colorado. Habitat models were based on observations of mountain goats, digital elevation maps, and data manipulations that were easily accomplished using a geographical information system (GIS). We developed models from observations of 815 groups of mountain goats (5,343 individuals) collected over a 6-year period from a fixed survey route. Compared to random locations, mountain goats were near escape terrain, on steep slopes, at mid-elevations, and on southern exposures. Logistic regression models for summer, winter, or all-seasons correctly classified 81-83\% of observations while classifying only 20-23\% of the study area as suitable habitat, nearly a 3-fold improvement over a random model. A model based simply on distance to escape terrain correctly classified 87\% of observations, including 38\% of the study area as suitable habitat. These models offer simple and inexpensive methods to rapidly identify habitat suitable for mountain goats in the Southern Rocky Mountains.

Introduction

Mountain goats (\textit{Oreamnos americanus}) and bighorn sheep (\textit{Ovis canadensis}) are known to occur in broadly similar habitats and elevations, thus there is strong potential for competition and transmission of disease between these species (Williams et al. 1979; Hobbs et al. 1990; Fitzgerald et al. 1994; Laundre 1994; chapter 5). Mountain goats from the Mt. Evans area have tested positive for paratuberculosis, a disease that can be transmitted to bighorn sheep (Williams et al. 1979), and disease associated with \textit{Pasteurella} that can cause high rates of mortality in both species (Sohn 1997). To evaluate long-term effects of mountain goats on habitats or other species, we need a method for identifying areas most likely to be inhabited and impacted by mountain goats. Efforts to evaluate impacts of mountain goats or to identify areas suitable for goat colonization have been hampered by the absence of a GIS-based model for identifying suitable habitat from remotely-sensed data. To meet this need, we analyzed observations of mountain goat habitat use from the area northeast of Mt. Evans, Colorado. We used these observations to construct a GIS-based model for identifying areas suitable for occupation by mountain goats.

Our goals were to determine whether habitat use by mountain goats could be predicted from widely available GIS-based data, and to evaluate seasonal differences in intensity and spatial patterns

\textsuperscript{1} Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, Colorado 80523
\textsuperscript{2} current address: CSIRO Davies Laboratory, PMB Aitkenvale, Queensland, Australia 4814
\textsuperscript{3} Colorado Division of Wildlife, Mammals Research Section, 317 West Prospect, Ft. Collins, Colorado 80526
\textsuperscript{4} Department of Forest Sciences, Colorado State University, Ft. Collins, Colorado 80523
of habitat use.

Methods

We evaluated habitat use by mountain goats from observations collected from a fixed survey route over a 6-year period. Weekly surveys were conducted near Mt. Evans, Colorado and these observations were used to develop habitat models based on topographic features.

Study Site and Population

Our habitat models were based on observations of mountain goats in alpine and subalpine habitats at elevations from ~3500 to 4300 m, including several sub-summits of approximately 4000 m. The summit of Mt. Evans (4340 m) was on the southwestern boundary of the study area. The primary habitats consisted of alpine meadows, krummholz, wind-blowen fellfields, scree slopes, subalpine forest, and cliffs. Dominant species in meadows included willows (Salix), sedges (Carex spp.), grasses (Poa spp., Koleria, etc.), and forbs (Trifolium, Geum sp.) (Braun 1969). Krummholz was composed of subalpine fir (Abies lasiocarpa), Engelmann spruce (Picea engelmannii), and juniper (Juniperus communis) (Marr 1967; Braun 1969). Habitat models were developed from observations of mountain goats in the area readily visible from the survey route.

Mountain goats were translocated to the Mt. Evans area in 1961, when 15 mountain goats were released. They subsequently exhibited a period of sustained growth and expanded to a population of at least 168 animals by 1983 (Reed and Green 1994). During the study period of 1981-1986, population counts conducted by the Colorado Division of Wildlife yielded an estimate of average minimum-number-alive of approximate 130 goats inhabiting an area of about 100 km² (Reed and Green 1994). About 15 goats were harvested from the population each year during the period of the study and the population was thought to be relatively stable.

Observations were collected from sightings along a 16.9 km survey route that crossed terrain at elevations from 3460 to 4040 m and permitted views of all slopes and aspects and of terrain that ranged from flat to vertical. The observer recorded (when possible) the sex, age, location, time, identifying marks, and activity of all mountain goats and bighorn sheep seen from the route. Animals were categorized into classes of kids, yearlings, adults, or unclassified (when age and/or sex of an animal could not be determined). Surveys were conducted by a single observer who walked the route during daylight hours. The survey route permitted clear views of hillsides, cliffs, and valleys and each survey entailed approximately 6-8 hours of observations. Surveys were attempted at weekly intervals from June 1981 through June 1986, but some surveys were not completed during winter because bad weather conditions limited visibility. During the study period, 69 mountain goats were marked with collars that allowed recognition of individual animals.

Data Analysis and Model Development

We divided observations into biologically-defined seasons of winter (Nov. – Apr.) and summer (Jun. - Sep.). Because mountain goats rarely occur singly, and the individuals in a group do not represent independent samples, most analyses were conducted on the locations of groups, rather than
individuals. Observations of groups were assigned to social classes: males, females/kids, mixed, or unclassified.

We modeled mountain goat habitat selection by first testing the null hypothesis that observations of mountain goats were distributed in a spatially random pattern. To do so, the spatial pattern of observations was compared to random spatial distributions from a Poisson process. Differences in spatial pattern were evaluated by a Cramer-von Mises test statistic (Cressie 1993). The probability of the test statistic was evaluated by ranking the k-value for each simulation and placing the observed k-value in the ranking. The value of the test statistic was \( (R + 1 - r)/R \) where \( R \) is that total number of simulations and \( r \) is the ranking of the observed pattern. A value of \( k < 0.05 \) resulted in rejection of the null hypothesis.

We then fitted multiple logistic regression models to topographic features of active (used) and inactive (unused) sites (Hosmer and Lemeshow 1989; Manly et al. 1993). Because mountain goats are strongly associated with topographic features (Saunders 1955; Varley 1994), we developed the model using elevation (m), slope (degree), aspect (N-S and E-W) and distance to escape terrain as predictive variables. Topographic information was derived from a USGS digital elevation map at 30 m resolution. Aspect and slope were calculated using SLOPE and ASPECT functions in ArcInfo GRID (ESRI 1999). Aspect was transformed into two continuous variables that described E-W and N-S exposures, with values from 0-180 where 0 = due E or N and 180 = due W or S.

Mountain goats are associated with steep terrain, which they use to escape from predators. Escape terrain has been described as steep slopes of broken, rocky terrain (Adams et al. 1982; Smith et al. 1991; Varley 1994), but no consistent criteria exist for identifying escape terrain. Varley (1994) defined escape terrain for mountain goats as slopes > 25°, while Smith et al. (1991) and Johnson and Swift (1995) defined escape terrain for bighorn sheep as slopes > 27°. To define escape terrain, we used field observations to locate areas that goats appeared to use as escape terrain, and we then used the GIS to determine the slope of these areas. Based on our somewhat subjective evaluation, we defined escape terrain for Colorado mountain goats as slopes ≥ 33°.

Model development required that we compare attributes of active sites to those of randomly selected inactive sites. Active sites consisted of points where mountain goats were observed. To create a set of inactive points for comparison, we first calculated the density of mountain goats in each 30 m pixel of the study area using a kernel density estimator (bandwidth = 100 m; Silverman 1986; Reich and Davis 1998). Mountain goat densities were estimated from observations of individual goats. Areas with an estimated density > 0 defined the spatial extent of areas used by mountain goats. Inactive sites were chosen from randomly selected coordinates in areas where the estimated density was 0.

Other habitat models have been developed and evaluated from data sets that contained a highly variable ratio of active to inactive sites. In general, model precision is thought to be greater when models are developed from data that include a greater number of inactive sites than active sites,
perhaps because most study sites contain more unsuitable than suitable habitat (Capen et al. 1981; Kvamme 1985; Pereira and Itami 1991; Fielding and Hayworth 1995). The larger unsuitable area presumably includes more variation than the suitable area, therefore more points are needed to characterize the unused area with the same degree of precision as the used area. To determine the appropriate ratio of active to inactive sites to be used in the models, we developed several trial models using ratios of active to inactive sites of 1:1, 1:2, and 1:10. The best fit trial model, signifying the most appropriate ratio of active to inactive sites was selected by minimizing the Akaike Information Criteria (AIC: Akaite 1973; Burnham and Anderson 1998) and maximizing the coefficient of determination.

The predictive model for mountain goat habitat selection was created using the logistic regression equation where the probability of use of an active site \( pr(x) \) is

\[
pr(x) = \frac{e^{\beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n}}{1 + e^{\beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n}}
\]

where \( x_1, \ldots, x_n \) are independent predictor variables and \( \beta_0, \ldots, \beta_n \) are logistic coefficients.

The strong association of mountain goats with precipitous mountain terrain suggested that escape terrain could be the most important factor influencing mountain goat habitat selection, and that a model based on this feature alone might offer some predictive value (Fox 1983; von Elsner-Shack 1986). We developed a simple ‘distance’ model using distance to escape terrain as the sole predictor of suitable habitat. We estimated the single model parameter by comparing the proportion of mountain goat observations at all distances to escape terrain to the proportion of the entire study area at the same distances. We defined suitable habitat as the area within \( x \) m of escape terrain where \( x \) was the distance at which the difference between the proportion of mountain goat observations and available habitat was greatest.

We tested the predictive ability of the models using two techniques. First, we employed a standard procedure used in classification analysis for separating observations into groups used for model development and model testing (Periera et al. 1991; Devroye et al. 1996; Beard et al. 1999). For each season, we created 3 subsets of data for model development by randomly selecting 75% of the observations in the all-season, summer and winter data sets. The remaining 25% of observations were withheld to test model results (Pereira and Itami 1991). We developed models from the three subsets for each data set and selected the best-fit model by comparing the coefficient of determination from each model fit.

As a second test of the predictive ability of the model, we compared model results to independent observations of mountain goats from the study site (but not from the systematic surveys) and from adjacent areas. This data set consisted of 691 opportunistic observations of mountain goat groups that were recorded during the period of the study.
From the survey data, we calculated both average and typical group size (TGS: Jarman 1974) by season. Average group sizes are most commonly reported, while TGS represents the actual group size experienced by the average individual. TGS was estimated as

\[ TGS = \frac{\sum n_i^2}{N} \]

where \( n \) is group size, \( i \) is group stratum (i.e., season and/or sex), and \( N \) is the total number of animals in all groups of that stratum (Jarman 1974).

**Habitat Model Evaluation**

We used classification error rates to evaluate model fit. To calculate classification rates, probability from the logistic regression models, a continuous variable, was compared to a cutoff value and each pixel (30 x 30 m cell) of the study area was categorized into a dichotomous variable with a value of 0 or 1, representing unsuitable and suitable habitat. To determine the optimal cutoff value, we compared model results to those that would be obtained from a random process. The optimal cutoff value was selected by maximizing the improvement of model predictions over a null model of random habitat selection. To do so, the cutoff value was selected to maximize the difference between the proportion of active sites that were correctly classified and the proportion of the study site classified as suitable (Pierera and Itami 1991). In effect, this process was used to determine the trade-off between maximizing correct classification of active sites (by selecting a lower cutoff value) and minimizing the area classified as suitable (by selecting a higher cutoff value).

**Results**

The data set for model development consisted of 815 groups of mountain goats that included 5343 sightings of individuals. When all groups were aggregated, average group size in summer was smaller than winter (5.4 vs. 8.3; \( P < 0.001 \); Table 1). Large differences between TGS and average group size indicated that distributions of sizes were skewed towards large groups. Group sizes were roughly similar for all social groups except mature males (MM), which were typically composed of 1 or 2 males. Because there were few MM groups (<4% of observations during any season), we weighted each group equally in the analyses.

Initial testing of the spatial distribution of mountain goat groups revealed that all three seasonal subsets of goat groups were distributed non-randomly within the study area (\( P < 0.001 \)), and we thus rejected the null hypothesis of a spatially random distribution. We then developed models for observations from all seasons, during summer only, and during winter only using 75% of the data within each season (\( N = 611, 279, 234 \) groups, respectively). The remaining 25% of data within each season was used for model evaluation (\( N = 204, 94, 79 \) respectively).

There was little difference in the estimated regression coefficients between models developed using different ratios of active to inactive sites, but the coefficient of determination (\( r^2 \)) was consistently greatest for models developed from an equal number of active and inactive sites. Models
developed from a data set with the largest number of inactive sites had the lowest coefficient of determination. We therefore used equal numbers of active and inactive sites for model development.

A comparison of active and inactive sites revealed differences in the distribution of predictor variables between areas used and not used by mountain goats (Figure 1), although mean values for predictor variables were similar (Table 2). Mountain goats clearly selected sites that were closer to escape terrain, with an intermediate slope (~20-50 degrees), and at intermediate elevations within the study site (Figure 1).

Independent variables to be included in the logistic models for each season were selected by minimizing the AIC. Model coefficients differed between models, especially between the summer and other models (Table 3), although distance to escape terrain was consistently the strongest predictor of habitat usage. The probability of observing a group of mountain goats was negatively correlated with distance from escape terrain (Table 3; Figure 1). The effects of elevation and slope were represented by positive coefficients while coefficients for elevation$^2$ and slope$^2$ where negative, indicating that goats were most strongly associated with mid-elevations and intermediate slopes. North-south aspect had a relatively small but significant influence on habitat selection and the positive coefficient for NS aspect signified a preference for south-facing slopes.

The optimal cutoff value distinguishing suitable from unsuitable habitat was 64% for the all-season model, 63% for the summer model, and 59% for the winter model (Table 4, Figure 2). Classification of the study area into suitable and unsuitable habitat based on the all-season optimal cutoff value resulted in correct classification of 81% of active sites while including only 22% of the total area as suitable habitat, an improvement of 59% over a random model. Classification rates of other seasonal models were similar (Table 4, Figure 2, Figure 4). There was extensive overlap – 75% or greater – in areas classified as suitable by the three seasonal models (Table 5). Model results were highly insensitive to changes in the cutoff value (Figure 2), suggesting there were sharp distinctions between areas used and not used by mountain goats.

The logistic models were highly successful in classifying ad-hoc observations, and the all-season, summer, and winter models correctly classified 80%, 78%, and 87% of ad-hoc observation ($N = 691, 439, and 141$, respectively).

For the distance model, we determined that habitat ≤ 258 m from escape terrain was suitable for mountain goats (Table 4; Figure 3, Figure 4). The distance model correctly classified 87% of active sites and accounted for 38% of the total study area, a 2-fold, or 49%, improvement over chance.

**Discussion**

The value of an ecological model is ultimately determined by its ability to provide information that improves decisions. Our models provide a simple and readily-available process for identifying suitable habitat for mountain goats in the southern Rocky Mountains. The predictive abilities of the habitat models (>80% correct classification) and improvement over random models compared favorably to models for other species that required information that was far more difficult and
expensive to obtain (Pereira and Itami 1991; Nadeau et al. 1995; Ozesmi and Mitsch 1997). A huge benefit of our models is a reliance on data that, for the United States, can usually be obtained from the Internet without cost. Development of habitat models that rely on simple procedures and inexpensive data are likely to be limited to species that are strongly associated with specific features that are readily captured by remotely-sensed data. The strong affiliation of mountain goats to escape terrain exemplifies this characteristic.

We were surprised at the close correspondence of results from the logistic regression analysis and the distance model. Both types of models exhibited a significant improvement in identifying suitable habitat over random, but the parsimony of the distance model is a strong incentive for its application. Although escape terrain is known to be important in predicting the distribution of mountain goat populations, Adams and Bailey (1982) hypothesized that mountain goats in Colorado may be less restricted to areas near escape terrain than populations in the Northern Rockies or farther west. Colorado supports a lower density of predators than areas in the Northern Rocky Mountains, and the lower risk of predation could result in a reduced association of mountain goats with escape terrain. Where predators are more abundant, most mountain goats observations were reported within close proximity to cliffs (Singer and Doherty 1985; Fox and Streveler 1986; Varley 1996). When in large groups, mountain goats in Colorado have been observed more than a kilometer from escape terrain (Adams et al. 1982; Hopkins 1992). The large buffer around escape terrain that we identified is consistent with these observations; mountain goats were far more common near cliffs, but some observations were up to nearly 1 km from areas that we identified as escape terrain.

Observations used to build the habitat models were from high-elevation areas, but mountain goats may use lower elevation sites that offer good visibility and are close to escape terrain (Brandborg 1955; Rideout 1974; Smith 1976; Fox and Streveler 1986). Mountain goats have occasionally been observed below treeline in Colorado (Hopkins 1992), and it seems likely that they would colonize habitats at lower elevations if populations continue to increase. Our observations were limited to alpine and subalpine habitats, thus we were unable to evaluate the extent of use of lower elevation areas, although we suspect that goats rarely occur in forested habitats in Colorado. Hibbs and Glover (1965) reported mountain goat locations from Mt. Shavano, Colorado, at elevations from 2,900-4,250 m (9,500-14,000 ft). They noted that 81% of mountain goats observed from ground surveys were between 3,950-4,250 m (13,000 -14,000 ft). During aerial surveys, most mountain goats (61%) were observed between 3,650 and 3,950 m (12,000-13,000 ft). There were no apparent differences in the elevation of habitat used during winter or summer, but in all seasons mountain goats were predominantly seen on south-facing slopes (86% of 5,039 observations). While we did not address use of subalpine areas, observations from Colorado are consistent in their suggestion that mountain goats in the Southern Rocky Mountains are less likely to use forested areas than mountain goats in other parts of North America.

Our results showed little difference between summer and winter habitat use by mountain goats.
Most previous studies concluded that winter ranges of mountain goats were frequently at lower elevations (Brandborg 1955; Smith 1976; Adams and Bailey 1982; Wigal and Coggins 1982), or if at a high elevation, they preferred wind-swept slopes with minimal snow accumulation (Rideout 1974; Rideout and Hoffman 1975; Fox 1983). Summer home ranges of mountain goats are typically much larger than winter home ranges (Hibbs and Glover 1965; Hibbs 1966; Adams et al. 1982), and we thus expected that the areas used in summer and winter would reflect previous observations. However, instead we observed broad overlap in areas used in summer and winter. Model results were consistent with observations that mountain goats use a smaller area during winter. In winter, only 20% of the study area was classified as suitable habitat, compared to 23% in summer, the season in which mountain goats were most dispersed (Table 4). About 70% of the winter range overlapped with summer range, suggesting that during winter mountain goats are occur at higher density and they tend to use areas with slightly different characteristics.

The habitat models for mountain goats described here provide a simple and inexpensive method for quickly locating suitable habitat over large geographical areas. These models appear to have a high predictive value, largely because mountain goats have a strong association with prominent geographic features.

**Literature Cited**


Table 1. Number of groups, typical group size (TGS) (see text) and mean group size of mountain goat groups by season.

<table>
<thead>
<tr>
<th>Season</th>
<th>Type</th>
<th>Groups</th>
<th>Typical</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>FK</td>
<td>191</td>
<td>8.7</td>
<td>5.0 ± 4.2</td>
</tr>
<tr>
<td></td>
<td>MM</td>
<td>14</td>
<td>1.6</td>
<td>1.3 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>MX</td>
<td>54</td>
<td>13.1</td>
<td>8.0 ± 6.5</td>
</tr>
<tr>
<td></td>
<td>UNC</td>
<td>114</td>
<td>12.0</td>
<td>5.2 ± 5.6</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>373</td>
<td>10.5</td>
<td>5.4 ± 5.2</td>
</tr>
<tr>
<td>Winter</td>
<td>FK</td>
<td>95</td>
<td>9.8</td>
<td>5.9 ± 4.9</td>
</tr>
<tr>
<td></td>
<td>MM</td>
<td>5</td>
<td>1.0</td>
<td>1.0 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>MX</td>
<td>70</td>
<td>16.4</td>
<td>11.1 ± 7.9</td>
</tr>
<tr>
<td></td>
<td>UNC</td>
<td>143</td>
<td>15.3</td>
<td>8.8 ± 9.1</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>313</td>
<td>14.4</td>
<td>8.3 ± 8.0</td>
</tr>
<tr>
<td>All Year</td>
<td>FK</td>
<td>347</td>
<td>8.8</td>
<td>5.0 ± 4.3</td>
</tr>
<tr>
<td></td>
<td>MM</td>
<td>28</td>
<td>1.4</td>
<td>1.2 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>MX</td>
<td>138</td>
<td>15.3</td>
<td>9.9 ± 7.4</td>
</tr>
<tr>
<td></td>
<td>UNC</td>
<td>302</td>
<td>14.2</td>
<td>7.3 ± 8.1</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>815</td>
<td>12.6</td>
<td>6.6 ± 6.8</td>
</tr>
</tbody>
</table>

1 FK = female/kid, MM = mature male, MX = mixed, UNC = unclassified.

Table 2. Mean values for independent variables used to develop multiple logistic regression models for mountain goat habitat use, at locations where mountain goats were observed (N = 815 locations).

<table>
<thead>
<tr>
<th>Model</th>
<th>Elevation (m)</th>
<th>Slope (degree)</th>
<th>Aspect (degree)</th>
<th>Distance to escape terrain (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seasons</td>
<td>3775</td>
<td>27</td>
<td>70</td>
<td>123</td>
</tr>
<tr>
<td>Summer</td>
<td>3821</td>
<td>25</td>
<td>59</td>
<td>113</td>
</tr>
<tr>
<td>Winter</td>
<td>3723</td>
<td>29</td>
<td>85</td>
<td>132</td>
</tr>
</tbody>
</table>

1 Aspect was measured from due E or N (degree = 0) to due W or S (degree = 180).
Table 3. Multiple logistic regression coefficients (± SE) for mountain goat habitat suitability models developed from observations of mountain goats near Mt. Evans, Colorado. (x 10^{-5})

<table>
<thead>
<tr>
<th>Model</th>
<th>Constant</th>
<th>Elevation (m)</th>
<th>Elevation^2 (m; x10^{-5})</th>
<th>N-S aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seasons</td>
<td>-236.1 ± 42.8</td>
<td>0.125 ± 0.023</td>
<td>-1.7 ± 0.300</td>
<td>0.0144 ± 0.0016</td>
</tr>
<tr>
<td>Summer</td>
<td>-606.7 ± 107.8</td>
<td>0.315 ± 0.057</td>
<td>-4.1 ± 0.739</td>
<td>0.0107 ± 0.0026</td>
</tr>
<tr>
<td>Winter</td>
<td>-253.8 ± 69.4</td>
<td>0.136 ± 0.037</td>
<td>-1.8 ± 0.495</td>
<td>0.0150 ± 0.0027</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E-W aspect</th>
<th>Slope (degree)</th>
<th>Slope^2 (degree; x10^{-3})</th>
<th>Distance to escape terrain (m; x10^{-3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seasons</td>
<td>0</td>
<td>0.198 ± 0.0327</td>
<td>-3.7 ± 0.0006</td>
</tr>
<tr>
<td>Summer</td>
<td>0</td>
<td>0.292 ± 0.0586</td>
<td>-6.2 ± 0.0012</td>
</tr>
<tr>
<td>Winter</td>
<td>0.0113 ± 0.0031</td>
<td>0.256 ± 0.0592</td>
<td>-4.4 ± 0.0012</td>
</tr>
</tbody>
</table>
Table 4. Optimal cutoff values, classification rates and relative performance of mountain goat habitat models from multiple logistic regression and distance to escape terrain.

<table>
<thead>
<tr>
<th>Model</th>
<th>Cutoff value</th>
<th>Active</th>
<th>Inactive</th>
<th>Total area</th>
<th>Improvement over random (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seasons logistic</td>
<td>0.64</td>
<td>81</td>
<td>13</td>
<td>22</td>
<td>59</td>
</tr>
<tr>
<td>Summer logistic</td>
<td>0.63</td>
<td>83</td>
<td>13</td>
<td>23</td>
<td>60</td>
</tr>
<tr>
<td>Winter logistic</td>
<td>0.59</td>
<td>82</td>
<td>12</td>
<td>20</td>
<td>62</td>
</tr>
<tr>
<td>Distance to escape terrain</td>
<td>258 m</td>
<td>87</td>
<td>--</td>
<td>37</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 5. Overlap of suitable habitat. Values in the table are the proportion of suitable habitat identified by the model corresponding to the column heading that falls within suitable habitat identified by the model corresponding to the row heading. E.g., 83.7% of all-seasons habitat overlapped with summer habitat, but only 74.7% of summer habitat was within all-seasons habitat.

<table>
<thead>
<tr>
<th>Overlapping with:</th>
<th>Proportion of suitable habitat during:</th>
<th>All seasons</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>All seasons</td>
<td></td>
<td>1.000</td>
<td>0.747</td>
<td>0.832</td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td>0.837</td>
<td>1.000</td>
<td>0.707</td>
</tr>
<tr>
<td>Winter</td>
<td></td>
<td>0.834</td>
<td>0.753</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Figure 1. Cumulative frequency distributions of independent variables used for model development. Broken lines represent the entire study area; solid lines represent locations where mountain goats were observed (N = 815 locations).
Figure 2. Classification error rates for sites where mountain goats were observed (active sites; upper solid line), sites where no goats were observed (inactive sites; dashed line), and the improvement over random (lower solid line).
Figure 3. Cumulative distribution of mountain goat observations (mtn. goats), all pixels in the study area (all pixels), and the difference between the proportion of mountain goat observations and all pixels (difference) at distances from 0 m to 600 m to escape terrain (slope ≥ 33°).
Figure 4. Distribution of suitable habitat (colored areas) in the vicinity of Mt. Evans, Colorado as identified by logistic regression models for (A) all seasons, (B) summer, (C) winter, and (D) escape terrain. The study area is outlined; darker shades signify more preferred areas.
4. Population Dynamics and Interactions of Mountain Goats and Bighorn Sheep in Rocky Mountain National Park: A Simulation Model

J. E. Gross

Abstract

We used simulation modeling to evaluate potential interactions between mountain goats (*Oreamnos americanus*) and bighorn sheep (*Ovis canadensis*) in Rocky Mountain National Park (RMNP). Simulations projected population dynamics of bighorn sheep inhabiting 4 patches of suitable habitat in RMNP, consistent with historical observations from the Park. Vital rates of bighorn sheep inhabiting each patch were matched to observations, and the populations in different patches varied widely in potential growth rates.

Mountain goat population dynamics were simulated in 5 patches of suitable habitat that broadly overlapped with habitat suitable for bighorn sheep. Simulations were used to evaluated growth of each species independently or together, and in the presence or absence of disease that caused precipitous declines in bighorn sheep populations. When both species occurred together, competition was either symmetrical or goats reduced growth of bighorn sheep populations to a greater extent than bighorn sheep suppressed growth of mountain goat populations.

After 100 years of simulated population growth, mountain goats and bighorn sheep each attained total population sizes of about 950 in the absence of disease or competition. Disease had a profound effect on dynamics of infected bighorn sheep populations and competition with mountain goats exacerbated these effects. Bighorn sheep populations subjected to moderate competition and disease were, on average, 30% smaller than those without these influences. Mean size of bighorn sheep populations subjected to strong competition and disease was 47% lower than populations without these effects, while competition reduced mountain goat populations by only about 9%.

Parameters used for these simulations were estimated from observations of the populations actually modelled, but they probably incorporated less annual variation than the populations actually experienced because of the limited number of years from which data were available. While projections showed that mountain goats could cause large reductions in the size of bighorn sheep populations, these results are conservative in their estimation of stochastic effects that may be particularly important to the smallest herd (North St. Vrain), which is potentially at risk of extirpation.

Introduction

In 1948, the Colorado Game, Fish and Parks Department successfully translocated 9 mountain goats (*Oreamnos americanus*) into Colorado (Hibbs 1966). Other translocations soon followed and populations of mountain goats grew rapidly, colonizing several mountain ranges in Colorado. Many

---

1 Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, Colorado 80523-1499,
members of the public were happy with growth of mountain goat populations in Colorado, but others were concerned that introduced mountain goats would compete with native bighorn sheep (*Ovis canadensis*), thereby displacing populations or reducing vigor of native sheep populations. The National Park Service (NPS) was particularly concerned with expansion of the Mt. Evans mountain goat population because it is just 80 km south of Rocky Mountain National Park (RMNP) and dispersing mountain goats could become established within Park boundaries. If goats were native to the area, colonization of RMNP by goats would be a natural process and reestablishment of mountain goats should be sanctioned by the NPS, consistent with policy that supports preservation of native species and natural processes (Leopold et al. 1963). On the other hand, if goats were historically absent from RMNP, existing policy provides for actions that would prohibit establishment of mountain goats within Park boundaries.

The historical status of mountain goats in Colorado has been the subject of heated debate. Most authorities consider mountain goats exotic to Colorado (Armstrong 1973, personal communication; Fitzgerald et al. 1994; chapter 1), but the Colorado Wildlife Commission passed a resolution granting native status to the species in Colorado (CDOW 1993). Because mountain goats in other areas have had detrimental impacts on biotic communities (Olmsted 1979), RMNP has clear need to evaluate likely impacts of an established mountain goat population on resources within the Park.

There is particular concern about potential impacts of mountain goats on native sheep in RMNP. Mountain goats and bighorn sheep use similar habitats and exhibit a wide overlap in the forages they consume (Laundre 1994; chapter 5). There is thus a strong potential for competition between mountain goats and bighorn sheep. Competition could lead to direct competitive exclusion of bighorn sheep from native range, but the presence of mountain goats may also impact bighorn sheep through the indirect interactions of competition and disease. Bighorn sheep populations suffer from epidemics that can lead to catastrophic population declines (Festa-Bianchet 1988; Bailey 1990).

Some interactions between mountain goats and bighorn sheep are poorly understood, but simulation models can be particularly helpful in the face of incomplete knowledge by defining the bounds of likely outcomes, thereby facilitating the decision-making process (Starfield 1997). Decisions on management of mountain goats may hinge on the extent to which bighorn sheep populations are affected as measured by depression in population size, likelihood of disease, and susceptibility to extirpation from part or all of their range. To help guide management decisions, a simulation model was therefore developed to forecast population dynamics of mountain goats and bighorn sheep in RMNP, and the potential interactions between these species. The model used information from RMNP to identify suitable habitat, and it explicitly considered interspecific competition, density dependence, disease, and the spatial context of habitat in RMNP.

**Model Description**

We developed a spatially explicit, individual-based model to forecast dynamics of mountain goats and bighorn sheep in RMNP. Simulated populations inhabited a landscape composed of habitat
areas that could be occupied by either species alone, or by both species. Habitat patches could be adjacent or separated by a background matrix through which animals could travel, but which did not support a population. The model simulated growth of mountain goats and bighorn sheep populations and included effects of intra-specific density dependence, competition between the species, and dispersal to unoccupied habitats (Figure 1). The model was spatially explicit to the extent that the population of a species consisted of a set of local populations each inhabiting a specific patch. When the area used by mountain goats and bighorn sheep overlapped, the two species competed for forage and the presence of one species could depress populations of the other. Populations could expand the area they occupied by "diffusive" movement into nearby patches, and by longer-range dispersal to patches of suitable habitat that were further away. Birth, natural mortality not related to disease, and colonization of habitat patches occurred once per year, while population changes due to disease occurred at weekly intervals (Figure 1). Each animal was explicitly represented and its sex, age, location, population membership, and disease status were followed from birth to death.

Rates of population processes were determined by parameters for the probability of events (e.g., birth, death, etc.) for each individual. For each process, the rate parameter was compared to a random deviate from a uniform distribution in the range of 0-1. Comparison of a rate parameter to a random number resulted in a binomial distribution of outcomes that accounted for the stochasticity that is characteristic of small populations.

Habitat Modeling and Landscape Description

The general area used by bighorn sheep in RMNP and adjacent lands was initially identified from a GIS coverage of bighorn sheep distribution provided by RMNP. This coverage provided an outline of areas used by bighorn sheep, but the outlined area included habitat types that were clearly not routinely used by bighorn sheep (e.g., extensive coniferous cover) or that were used primarily for purposes other than sustained habitation. These types included forested habitats that bighorn sheep traversed to reach mineral licks or where bighorn sheep occasionally foraged. The average density of bighorn sheep within these marginal habitats was very low and they do not support persistent populations of bighorn sheep.

To more accurately represent the habitat that contributed substantially to persistence and growth of bighorn sheep populations, areas were excluded if they were > 1 km from escape terrain (slopes > 27°) or if they had a coniferous forest cover type with a canopy coverage > 60% (RMNP 1999). These constraints followed observations that bighorn sheep are very rarely seen farther than 1 km from escape terrain and they avoid areas with poor visibility (Smith et al. 1991; Johnson and Swift, 2000).

Additional bighorn sheep habitat, adjacent to the Continental Divide in the southern half of RMNP, was included in the model because bighorn sheep have been routinely observed in this area (observations by RMNP biological technicians; RMNP, unpublished data).

Habitat suitable for mountain goats was identified by applying a GIS-based habitat model developed from observations of mountain goats from nearby Mt. Evans (Gross et al. 2000; Chapter 3).
with a restriction to areas with an elevation >3200 m (Hobbs et al. 1990). Mountain goat use of alpine and subalpine habitats was most strongly associated with proximity to escape terrain, and this was the primary characteristic used to identify areas of suitable habitat. Although mountain goats may use forested habitats in western North America (Brandborg 1955), concerns in RMNP are focused on high-elevation areas preferred by mountain goats in Colorado (Adams et al. 1982a; Hobbs et al. 1990). Stevens and Goodson (1993) noted that the largest herd of sheep in RMNP (in the NW corner of the Park) was restricted to elevations above 3200 m during throughout the year.

Patches of suitable habitat identified by the GIS models were used to characterize a model landscape consisting of habitat patches suitable for occupation by each species. Each patch consisted of one or more habitat areas that could be used exclusively by one species or shared by mountain goats and bighorn sheep (Figure 1; Table 1). The GIS model for mountain goats identified an area of suitable habitat that was far larger than the area that a single herd of mountain goats could be expected to use. Mountain goat home ranges are typically 5-30 km² in summer and < 1-5 km² in winter (Rideout 1974; Adams et al. 1982a; Hopkins 1992). We used this information and natural topographic features to divide large areas of suitable mountain goat habitat into smaller patches of a size more likely to be used by a group of mountain goats. Population densities were evaluated from the number of animals that used a particular habitat patch, and populations expanded into nearby areas as the density of animals increased beyond a threshold (see below).

Survival, Reproduction, and Density Dependence

Age-specific survival and reproduction rates were described by equations that incorporated terms for juveniles, sub-adults, adults, and senescent individuals (Siler 1979; Eberhardt 1985). The five-parameter equation describing age-specific survival ($l_x$) is:

$$ l_x = \exp\left[-a_1(1 - e^{-b_1 x}) - a_2 x - a_3(e^{b_3 x} - 1)\right] $$

where $a_1$ and $b_1$ are coefficients for early survival. The first coefficient ($a_1$) accounts for the increment of mortality above that of adults, and $b_1$ is typically set large enough that the first term is asymptotic by an early age (say, 3 years). Adult survival is represented by $a_2$, and the final term, involving $a_3$ and $b_3$, accounts for senescence (Figure 2).

Adult survival rates for mountain goats are relatively high and consistent across most habitats and population densities (Hayden 1984; Gaillard et al. 1998). In contrast, recruitment rates of juvenile animals of both species can vary widely with density (Adams and Bailey 1982; Houston and Stevens 1988) and weather (Houston and Stevens 1988; Festa-Bianchet et al. 1998; Smith et al. 1998), a pattern that is consistent with observations of most other ungulates (Fowler 1981, 1987; Sinclair 1989; Coughenour and Singer 1996; Gaillard et al. 1998; Festa-Bianchet et al. 1998). Survival functions were estimated from observations of mountain goats (Adams and Bailey 1982; Hayden 1984; Houston
and Stevens 1988) and bighorn sheep (Festa-Bianchet 1989 and personal communication: McCarty and Miller 1998a; Berube et al. 1999; Loison et al. 1999).

Age-specific birth rates were described by an equation including growth and senescence components (Eberhardt 1985). Age-specific birth rates \( m_i \) were described as

\[
m_i = a_i (1 - e^{-b_i (e^{r_i} - 1)} \right) e^{r_i (1 - e^{b_i})}
\]

where the coefficients of the first term \( (a_i, b_i, x_0) \) describe reproduction by animals prior to senescence, and the second term reduces birth rates of older animals. The second term is the same as that used in equation 1. Age-specific birth rates (Figure 2) are upper estimates from studies of mountain goats (Houston and Stevens 1988; Bailey 1991; Festa-Bianchet et al. 1994) and bighorn sheep (McCarty and Miller 1998, Berube et al. 1999).

We needed to account for the highly variable growth rates of bighorn sheep populations in RMNP. Bighorn sheep in the upper North St. Vrain drainage (SE RMNP) reproduced vigorously and consistently for more than a decade (Goodson 1994). This population uses a high elevation summer range and lower elevation winter range. In contrast, the Never Summer population (NW RMNP) has an unusually low reproductive rate and has increased in size slowly (Stevens and Goodson 1993). Low fecundity and survival of juveniles in the Never Summer population were attributed to loss of high quality winter range (Stevens and Goodson 1993). Because data were used to estimate the upper bounds of vital rates (i.e., fecundity and survival rate that might be expected in good years in good habitat), simulations using these rates resulted in unrealistically high and stable growth rates for both mountain goats and bighorn sheep. An annual environmental quality factor was thus imposed to vary the rate of recruitment (Gross et al., in press). This factor modified recruitment rates and it was calibrated to adjust annual growth rates to match observations. Mountain goat population growth was matched to rates estimated from 8 years of helicopter counts from the Mt. Evans area, where mountain goats exhibited an annual growth rate of about 16% (George 1999). The Never Summer bighorn sheep herd in RMNP has exhibited poor reproduction and low growth (Stevens and Goodson 1993), while the North St. Vrain herd grew vigorously prior to a disease outbreak in the early 1990s (Goodson 1994). The environmental quality multiplier was thus used to calibrate growth rates of each herd.

Mountain goats and bighorn sheep consume a wide variety of plant species, presumably a strategy which provides them with a highly nutritious diet (Dailey et al. 1984; Laundre 1994; Varley 1996). We assumed that high densities of ungulates reduced the availability of highly nutritious forages, and survival of juveniles declined with the nutritional state of the population. Density dependence in mountain goats and bighorn sheep has been reported to reduce rates of recruitment (Woodgerd 1964; Leslie and Douglas 1979; Wehausen et al. 1987; Houston and Stevens 1988; Gaillard
et al. 1998; McCarty and Miller 1998) and increase variance in juvenile survival (Fowler 1981, 1987; Jorgenson and Wishart 1986; Smith 1986; Houston and Stevens 1988; Houston and Stevens 1988; Sinclair 1989; Bailey 1991; Festa-Bianchet et al. 1998). For ungulates with a broad diet, density typically has a nonlinear influence on population growth, and effects of density are manifest only when populations exceed a threshold density (Fowler 1987; Sinclair 1989; McCullough 1990).

Density dependence was simulated by reducing average juvenile survival when populations exceeded a threshold density. Mountain goats have been reported to occur at densities of <1 to >15/km$^2$ (Hebert and Turnbull 1977; Streveler and Smith 1980; Stevens 1983; Singer and Doherty 1985; Hayden 1989; Varley 1996). On nearby Mt. Evans, mountain goats are thought to occur at a density of about 2/km$^2$ with no apparent effect on recruitment. We assumed that density dependence reduced recruitment when density of mountain goats or bighorn sheep exceeded 3/km$^2$, a density somewhat lower than the equilibrium density of 4.5/km$^2$ used by Hobbs et al. (1990). Above this density, birth rates were reduced as linear function of animal density by multiplying the asymptotic birth rate ($a_i$ in Equation 2) by a factor that declined from 1 to 0 as density increased from 3/km$^2$ to 4.5/km$^2$ (Gross et al. 2000).

Interactions between mountain goats and bighorn sheep reduced simulated population growth rates of both species. Analysis of mountain goat and bighorn sheep habitat use on nearby Mount Evans revealed broad overlap in both the actual areas used and in the topographic characteristics of these areas (unpublished data; Reed 1985). In addition, there is large overlap in the diets consumed by mountain goats and bighorn sheep (Dailey et al. 1984; Laundre 1994; chapter 4). These observations support the contention that competition between the species is likely, and they emphasize the need to identify areas where effects of competition may be manifest.

Mountain goats have occasionally been observed displacing bighorn sheep from sites preferred for feeding, resting, or reproduction (Steward 1975; Reed 1985). These observations led to model assumptions on the asymmetry of effects due to competition. As density of both species increased, growth rates of bighorn sheep populations were depressed more than those of mountain goats. Diet overlap between bighorn sheep and mountain goats (at the plant genus level) was 0.59 during the summer and 0.68 during winter (chapter 5). In aggregate, information on aggressive encounters, habitat overlap, and diet overlap supported the use of a relatively high competition coefficient for effects of mountain goats on bighorn sheep, but of a relatively small effect of bighorn sheep on mountain goats.

The effects of competition were explored by varying the strength of competition between the species. Competition was represented in the model by a competition coefficient, $\alpha_{ab}$, that represented the impact of an individual of species $b$ on species $a$, relative to the effect of an individual of species $a$ on species $a$ (Begon et al. 1996). For example, if $\alpha_{ab} = 1$ and the "carrying capacity" of a patch for species $a$ was 100, the patch could support 100 individuals of species $a$, or 50 individuals of species $a$ and 50 individuals of species $b$. If $\alpha_{ab} = .5$ and the patch contained 100 individuals of species $b$, the
patch could support and additional 50 individuals of species \( a \). Because the magnitude of competition between mountain goats and bighorn sheep is unknown, several combinations of parameter values were examined. Competition coefficients used to represent the effects of mountain goats on bighorn sheep \( (\alpha_{gg}, 0.25, 0.50, 0.75) \) were described as weak, moderate, or strong competition. The magnitude of these coefficients was based on observations of behavioral interactions and dietary overlap; competition equivalent to "moderate" or "strong" might be most likely in winter or restricted habitats (e.g., lambing areas) that both species use heavily. In these locations, interactions would probably involve both resource competition and physical displacement. Competition did not influence dynamics of either species until the combined density (sum of both species, adjusted for the degree of competition) exceeded the density threshold.

**Diffusion and Dispersal Movements**

Patches were described by area and distance to other suitable patches. Likelihood of movement between patches was a function of distance between patches and a species-specific dispersal function. The model simulated movements categorized as diffusion or dispersal. Diffusion-type movements were short-distance expansions of the population into adjacent or nearby areas which could result from normal daily or seasonal movement. Dispersal represented longer distance movements from which animals are unlikely to return.

Diffusion occurred when a local population exceeded its density threshold within a patch and there was a nearby patch with few or no animals of the same species. By incorporating diffusion-type movements, the model accommodated observations of short-distance forays that could transmit disease or lead to expansion of the area used by an established population. Wild sheep and goats tend to be highly philopatric, and introduced populations typically achieve a relatively high density before expanding their range (Geist 1971). If patches were close enough to be colonized by diffusion, movements between the patches occurred only as a result of diffusion-type movements.

Dispersal represented movements over distances usually measured in 10s of kilometers and permitted populations to become established at locations distant from the source population. For mountain goats, patches within 3 km were colonized only as a result of the diffusion-type movements, and colonization of patches separated by more than 3 km was a function of distance from the source population and population size and density. Dispersal by mountain goats is much greater in high-density populations (Stevens 1983), and we assumed ecological density was the most important factor driving dispersal by mountain goats. Mountain goats dispersed only from populations that exceeded a threshold density and a minimum size for dispersal.

**Disease**

Bighorn sheep have been highly susceptible to diseases that increase mortality and reduce lamb recruitment (Goodson 1982; Jessup 1985; Bailey 1986; Festa-Bianchet 1988b; Festa-Bianchet 1989; Coggins and Matthews 1992; Bunch et al. 1999). Diseases related to *Pasteurella* spp. (e.g., pneumonia) are most important in Colorado, and they can result in precipitous all-age die-offs of
bighorn sheep, and result in prolonged depression of population size or extinction (Bailey 1986; Festa-Bianchet et al. 1988; Bunch et al. 1999; Gross et al. 2000). The majority of infected sheep die in a severe epidemic, but some bighorn sheep infected with Pasteurella recover and become immune to further effects of the disease. However, these recovered individuals may act as a reservoir for disease, transmitting disease at a much lower rate than actively infected animals.

Parasitic lungworm (Protostrongylus spp.) infections can also lead to increased rates of adult and lamb mortality in bighorn sheep populations (Woodard et al. 1974; Schmidt et al. 1979; Bunch et al. 1999). Lungworm infection also predisposes bighorn sheep to infection by Pasteurella, especially young lambs that are infected in-utero. The likelihood of lungworm infection increases with sheep density because sheep often use habitual sleeping or feeding areas with heavy loads of feces. In these areas, sheep are continually re-infected after lungworm larvae are passed through their intermediate host, either by ingesting infective larvae directly or by ingestion of infected snails (Spraker 1979).

To represent disease dynamics in bighorn sheep, each member of the population was categorized as susceptible (S), infected (I), or recovered (R). Susceptible animals have no immunity and do not transmit disease; infected animals transmit disease to susceptible animals at a high rate, and recovered animals are immune and cannot be reinfected but can transmit the disease to susceptible sheep at a low rate. Dynamics of SIR-type models have most frequently been represented by a series of coupled differential equations (Anderson and May 1991). The use of differential equations was inappropriate for this application because these models can result in misleading conclusions when populations consist of only a few individuals. When pool sizes are small, differential equation models permit pool sizes to be fractions, sometimes with a magnitude of less than one. In these models, disease can therefore be mathematically maintained in a population by less than one individual, and differential equation models may lead to stable-state conditions that are never achieved by models representing each individual (i.e., pool sizes are always integer values). The existence of unrealistic stable-state conditions can easily lead to spurious conclusions.

We chose to use an individual-based model because these models are particularly well suited to evaluating probabilistic outcomes of rare events, model parameters are usually easier to estimate and tend to have a more intuitive interpretation (Huston et al. 1988; deAngelis and Gross 1992). Individual-based models appear to be especially promising for modeling disease dynamics (Barlow 1995). Simulations reported here employed an individual-based disease model developed for bighorn sheep by Hobbs and Miller (1991). The disease submodel was a discrete-time, SIR-type model for bighorn sheep populations infected with disease caused primarily by Pasteurella spp. The model incorporated parameters representing processes influenced by disease and that occur on fundamentally different time scales. Model parameters used in a differential representation were evaluated over discrete time. For example, the probability that an animal remains alive and infected subsequent to infection at $t = 0$ is
\[ P(\text{infected }), = e^{-\alpha t} \]

where \( 1/\alpha \) is the mean life expectancy of an infected animal. Thus over any single time step \( t \), the probability of recovery of an infected animal is

\[ P(\text{infected } \rightarrow \text{ recovered}) = 1 - e^{-\lambda t} \]

where \( 1/\lambda \) is the mean time to recovery for animals that eventually recover. Similarly, the probability that an animal becomes infected is determined by likelihood that it is the recipient of an infectious contact. Each infectious and recovered animal has a fixed number of infectious contacts per time step, thus the transmission process can be represented as

\[ P(\text{susceptible } \rightarrow \text{ infected}) = 1 - (1 - 1/N)^{\beta,1+\beta,S} \]

where \( I \) is the number of infected animals, \( R \) is the number of recovered animals, \( \beta \) is the transmission coefficient (number of infectious contacts per unit time), and \( N \) is total population size (McCarty and Miller 1998). Equation 5 is mathematically equivalent to equation 8 from Hobbs and Miller (1991) where \( \beta \) in Eq. 5 is equal to the product of \( \beta \) and average group size. Disease parameter estimates are listed in Table 2.

**Initial and Reference Conditions**

All simulations began with 100 bighorn sheep in sheep patch 1 (North St. Vrain, NSV, in southeastern RMNP), 300 bighorn sheep in patch 2 (Continental Divide, central RMNP), 200 in patch 3 (Never Summer, NS, in northwestern RMNP), and 250 bighorn sheep in patch 3 (Mummy Range, MR, northeastern RMNP). Population sizes selected for reference conditions approximated the number of bighorn sheep estimated to occur in the area in the absence of an ongoing disease epidemic (Bailey 1990; Stevens and Goodson 1993; Janet George personal communication). All runs for evaluating effects of patch size, structure, or interspecific competition were initialized with 8 mountain goats introduced into mountain goat patch 1, the patch at the southern-most end of RMNP (Figure 3). Runs were initialized with 8 mountain goats because this number minimized the likelihood that goats rapidly disappeared as a result of demographic stochasticity, while it was sufficiently small to permit evaluation of growth from a small colonizing population. Simulations of disease were initialized with 4 infected individuals. Results were evaluated from 100 simulations that were 100 years long.

**Results**

Simulations were conducted in three phases of increasing complexity. First, simulations were used to evaluate single-species dynamics with and without disease. Second, simulations were used to
examine species interactions within a single patch with and without disease. Finally, simulations were conducted with both species in a landscape composed of multiple patches, configured to represent RMNP. Population sizes reported as “averages” or “equilibrrial” are means for years 91-100 of simulations.

*One Species per Patch Without and With Disease*

Mean growth rates were determined by configuring the model to simulate a single species in one patch, without disease, dispersal, diffusion, or density dependence. Initial model calibration resulted in average annual growth rates for bighorn sheep of 4.3%, 12%, and 9% for bighorn sheep patches 1 (NSV), 2 (NS), and 3 (MR), respectively. Growth of mountain goat populations averaged 15%/year.

Bighorn sheep populations regulated by density dependence varied about mean population sizes of 96 ($sd = 5.4$), 343 (11.1), 228 (9.0), and 286 (9.3) for patches 1, 2, 3, and 4, respectively (NSV, CD, NS, MR; Figure 1). These represented densities of 3.41, 3.18, 3.15, and 3.36 bighorn sheep/km$^2$ of suitable habitat. Mountain goat populations stabilized at mean sizes of 149 ($sd = 6.6$), 241 (7.9), 121 (5.8), 140 (6.5), and 312 (9.0) for goat patches 1-5, respectively (Figure 4). Because growth rates of all goat populations were the same, the mean density of goat populations was about 3.5/km$^2$ of suitable habitat. In the absence of disease, simulated populations always increased to a size near an “equilibrium” and then varied about this size. In total, there was an average of 953 ($sd = 19.2$) bighorn sheep and 963 ($sd = 16.0$) mountain goats in populations regulated solely by density dependence.

Effects of disease introduced in the first year on bighorn sheep populations differed with population size and characteristics (Figures 5, 6). Simulated disease typically resulted in an initial decline of the population equivalent to mortality of about 65% of all sheep, although there was a high variation in the effects of disease and over the first year infected bighorn populations declined 0-89% (e.g., Figure 6). Disease generally did not persist in bighorn sheep populations for more than 10-15 years, but overall population size was reduced for a much longer periods – in some cases more for than 50 years (Figures 5, 6). Population recovery time was directly related to growth rate of the population, which varied among herds.

Simulations of recurrent disease in bighorn sheep populations (without competition) resulted in reductions of average total population size during years 91-100 of only 4-15%. However, there were substantial changes in the distribution of population sizes (Figure 7), depending on the likelihood of infections resulting from increasing population density. For the range of infection rates simulated, 21% to 71% of simulations with infection resulted in populations that were smaller than any simulation using baseline parameters.

Population trajectories in figure 8 resulted from the inclusion of a linear increase in the likelihood of infection after populations exceeded the threshold density of 3/km$^2$, without competition. Populations very rarely (<1% of years) exceeded the threshold density by more than 25%, thus the maximum annual rate of infection for any simulation was effectively less 0.1. This low infection rate
resulted in a dramatic increase in disease prevalence. In addition, the most rapidly growing populations were more likely to become infected because they quickly attained a high density that increased the likelihood of infection.

**Interspecific Competition, No Disease**

When effects of competition between mountain goats and bighorn sheep were weak and symmetrical ($\alpha_{sg} = \alpha_{gs} = 0.25; s = \text{bighorn sheep, } g = \text{mountain goat}$), bighorn sheep population sizes were eventually reduced to a total of 820 ($sd = 16$) animals, an average reduction of 14%. The full impact of competition was not expressed until about year 75 of simulations. Overall, the mountain goat population size at year 100 was reduced to 843, a decrease of 12%.

When the effects of competition between mountain goats and bighorn sheep were moderate and asymmetrical ($\alpha_{sg} = 0.50, \alpha_{gs} = 0.25$), the average size of the entire bighorn sheep and mountain goat populations were reduced by 29% and 10%, respectively. Bighorn sheep populations diminished in size only as the mountain goat population grew and expanded its range, hence there was little or no effect until after about year 15, 20, and 40, respectively, for sheep in the North St. Vrain, Continental Divide, and Never Summer/Mummy Range herds. Once the mountain goat population achieved a size sufficient to depress growth of bighorn sheep, the bighorn sheep populations declined for 10-20 years until a lower dynamic equilibrium was reached.

When the effects of competition between mountain goats and bighorn sheep were strong and asymmetrical ($\alpha_{sg} = 0.75, \alpha_{gs} = 0.25$), bighorn sheep populations were reduced by an average of 44%, while the mountain goat population declined by only 8%.

**Interspecific Competition, With Disease**

When bighorn sheep were exposed to a single disease event with infection at the beginning of the run, the outcome of simulations were the same with or without competition between mountain goats and bighorn sheep. This occurred because the population dynamics were most strongly influenced by disease during the period in which mountain goat densities were relatively low. With few mountain goats present, competition had very little effect.

Simulations with competition and recurrent infection crossed degree of competition (weak, moderate, strong) with a relatively low probability of infection (0.10; see above). When both factors were simulated, competition had a far larger effect on average population size than did disease, and the incremental reduction in average population size due to disease was only 5%, 2%, or 3% for weak, moderate, or strong competition, respectively. When subjected to moderate competition and recurrent infection, the total number of bighorn sheep averaged 658 (a 31% reduction from the no-disease, no competition average of 953). Strong competition with recurrent infection reduced mean bighorn sheep population size by 42% (mean = 504 bighorn sheep) over disease alone, or 47% from the no-disease, no competition average (Figure 9). Because disease reduced the density of bighorn sheep, competition had relatively little impact on mountain goats, and the average number of mountain goats across all competition-infection simulations was > 860, or more than 90% of the no-disease, no competition
Discussion

Simulations clearly showed that disease and competition could lead to large reductions in the number of bighorn sheep in RMNP, a conclusion reached by Hobbs et al. (1990) through application of a more general, non-spatial model. Disease has the potential to cause very rapid reductions in bighorn sheep populations and it is clearly the most important factor driving long-term dynamics of bighorn sheep populations in Colorado (Hobbs and Miller 1991; Bunch et al. 1999; Gross et al. 2000).

However, disease and competition interact to keep bighorn populations at a small size for extended periods (Figure 9), during which they are subject to a variety of factors that can dramatically increase risk of extinction or extirpation (Shaffer 1987; Burgman et al. 1993). Small bighorn sheep populations may be at particular risk. Berger (1990) summarized data that revealed a high rate of extinction for bighorn sheep populations that are smaller than about 100 animals (also see Berger 1993; Krausman et al. 1993), a size rarely exceeded under any conditions by the North St. Vrain herd. Disease and other catastrophes are common among large mammal populations (Young 1994; Ebb and Boyce 1999; Young 1999).

These simulations included effects of disease known to influence bighorn sheep population dynamics, but other types of catastrophes were not modeled. High-elevation bighorn sheep herds may be prone to two factors that would be particularly devastating to small populations. High-elevation herds may recruit few or no juveniles when weather is particularly severe (Stevens and Goodson 1993) and bighorn sheep inhabiting the Never Summer and Continental Divide areas may thus need to persist over a series of years with little or no net recruitment. Mountain lions pose a severe risk to small bighorn sheep populations in RMNP. Predation by mountain lions is typically an unimportant factor for bighorn populations, but in several situations mountain lions have had a huge impact on small bighorn sheep populations (Wehausen 1996; Ross 1997). Mountain lions have the capacity to cause rapid extinction of bighorn sheep herds with fewer than 100 or 150 individuals, thus any sub-population of bighorn sheep in RMNP is at risk from the combined effects of disease, competition, and predation. While predation by mountain lions clearly presents a real risk to bighorn sheep in RMNP, particularly the North St. Vrain herd, there are too few observations of predation to realistically estimate the parameters necessary to simulate such a phenomenon.

By not including effects of extreme environmental fluctuations or predation, results from these simulations are likely to present an optimistic appraisal of the potential impacts of mountain goats on bighorn sheep. Bighorn sheep in RMNP were subject to a catastrophic epidemic in the early 1990s (Goodson 1994) and recovery, if any, from this event is still uncertain (Janet George personal communication). Thus the impacts of disease does not appear to be overestimated, while the degree of environmental stochasticity probably introduces less variation than the populations actually experience. Previous simulations of desert bighorn sheep led to estimates of a much greater risk of extirpation for
small populations than did these projections (Gross et al. 2000). Simulations of desert-dwelling bighorn sheep also incorporated more annual variation in reproduction, based on observations of bighorn populations from desert environments (e.g. Leslie and Douglas 1979).

Models can be useful for supporting decisions, but a common criticism of models such as this one is that they incorporate functions that are poorly understood. If the model is sensitive to poorly defined functions, model outputs may not provide the level of resolution necessary for improving decisions. In this model, there was considerable uncertainty in estimating parameters that defined movements of animals, impacts and transmission of disease, and population densities that might be achieved. Model results were almost completely insensitive to animal movements, other than diffusion by mountain goats. Expansion of mountain goats from translocation sites in Colorado has clearly shown that mountain goats readily expand into nearby unoccupied habitat as population density increases (Rutherford 1972; Dale Reed personal communication). In simulations, essentially no long-range dispersal of mountain goats occurred within Park boundaries, thus the poorly defined dispersal function could be left out of the model with very little effect. We are thus confident that dispersal, which is poorly defined for mountain goats or bighorn sheep, does not adversely affect confidence in model results.

Simulations did not include interspecific transmission of disease. Both mountain goats and bighorn sheep in Colorado can be infected with Johne’s disease (Mycobacterium paratuberculosis; Williams et al. 1979). There are, however, no cases where transmission of disease from mountain goats to bighorn sheep has been confirmed or is strongly suspected (M.W. Miller personal communication; E.S. Williams personal communication). In one case bighorn sheep and mountain goat simultaneously suffered very high mortality from an epidemic from which a virulent strain of Pasteurella was isolated, but the source of infection and route of transmission could not be determined (Sohn 1997).

Bighorn sheep can be infected by a large variety of diseases and the effects of disease are highly variable (Jessup 1985; Bunch et al. 1999). The causes of bighorn sheep epidemics are the subject of ongoing debate, but it is well established that stress and malnutrition increase susceptibility to disease. In particular, protein undernutrition leads to suppressed immune function and a profound increase in susceptibility to disease (Scrimshaw et al. 1968). The relationship between nutritional state and disease susceptibility provides a conceptual basis for including density-dependent infection rates, although the relationship does not indicate how much the likelihood of infection increases with density. Sensitivity analysis revealed that a 4-fold change in the rate of infection accounted for changes in average population size of RMNP sheep of approximately 10%, and resulted in an undetectable change in size of the mountain goat populations. As measured by population size, the model was relatively insensitive to changes in the likelihood of infection.

Quantitative model results were a direct outcome of terms that defined the magnitude of competition between bighorn sheep and mountain goats, and overlap in the area occupied by the two
species. The ability to predict habitat use by animals frequently limits wildlife management, but both bighorn sheep and mountain goats are tightly linked to topographical features, especially escape terrain. The statistical model used to identify habitat suitable for mountain goats was developed from observations of a population that was regulated by harvest and that was sympatric with bighorn sheep (chapter 3). Both of these factors would tend to lead to a more restricted distribution of mountain goats than would be observed for a population at higher density or without interaction with another species. In addition, more than 15% of mountain goat observations did not occur in areas identified by the model as suitable. Our projection of the area within RMNP that would sustain mountain goats is thus likely an underestimate of the area that a fully established population would occupy. Because total population size was the product of density and habitat area, an underestimate of the area that occupied by mountain goats would lead to over-optimistic forecasts of the impact of mountain goats on bighorn sheep.

Questions remain about the extent to which mountain goats and bighorn sheep are likely to compete. Varley (1994) noted that mountain goats and bighorn sheep in the Absaroka Range, Montana exhibited very little overlap in habitat use or diet. In his study area, mountain goats were restricted to steep and sparsely vegetated sites while bighorn sheep occupied moderately sloping alpine and subalpine meadows. In contrast to the situation in Montana, three lines of evidence support the assertion that substantial competition can occur between bighorn sheep and mountain goats in Colorado. Firstly, habitat segregation by mountain goats and bighorn sheep does not occur on Mt. Evans (Reed unpublished data) or elsewhere in Colorado (Adams et al. 1982b) and there appears to be much greater overlap in habitat use by mountain goats and bighorn sheep in Colorado than elsewhere. Secondly, mountain goats are behaviorally dominant over bighorn sheep and can displace them from preferred sites (chapter 5). Reed (1985) reported that 37% of interactions between mountain goats and bighorn sheep resulted in a negative outcome for sheep (N = 100), while only 8% of observations resulted in a slight to moderate flight reaction by goats. Aggressive interactions are likely to be especially important when lambing areas or escape terrain is limited. Thirdly, diet overlap between the species is extensive (Laundre 1990, 1994; chapter 5). From this evidence, it seems likely that mountain goats will substantially impact bighorn sheep populations when both occur at high density. Most herbivores are thought to be ultimately limited by food (Sinclair 1989), thus observations of substantial overlap in diet and physical displacement support use of a competition coefficients defined above as "moderate" or "strong". However, we can unambiguously quantify the strength of competition coefficients only by experimentally manipulating densities of sympatric populations of mountain goats and bighorn sheep. Uncertainty thus remains on the appropriate magnitude of interaction between these species.

Conclusions

Available evidence supported development of a simulation model that included competition between bighorn sheep and mountain goats. Bighorn sheep populations were invariably reduced when
mountain goats colonized RMNP, but the magnitude of the impact of mountain goats was probably underestimated because of conservative estimates of parameters that account for habitat area, environmental variation, and risks faced by small populations. Observations of dietary overlap and behavioral interactions suggest that competition between these species is probably asymmetrical and the presence of bighorn sheep would probably lead to a slightly lower density of mountain goats, while projected mountain goat populations may depress bighorn sheep densities by 10 to 50%.


The mountain goat habitat model (chapter 3) provided information on the location and extent of habitat areas, but it this particular application it did not identify natural boundaries between habitat patches. If we assumed that mountain goats were uniformly distributed across all habitat patches, there would be no effect of mountain goats on bighorn sheep until the density of mountain goats, averaged over all suitable habitat in RMNP, was great enough to affect the vigor of bighorn sheep populations. Averaging over the entire park would ignore the heterogeneity in animal density that always exists and thus be inappropriate.

To examine the effect of patch definition, different configurations of mountain goat habitat patches were simulated. Simulations varied the number, size, and configuration of mountain goat habitat patches. Over long periods model results were insensitive to the definition of the landscape for mountain goats. In general, the use of smaller patches increased the rate of diffusion into new patches, but reduced rate of spread of mountain goats throughout the entire Park. This occurred because small-scale movements (diffusion) occurred only after the population exceeded a threshold density, thus an overall larger population was achieved before the last patches were colonized. The threshold density for movement was reached more rapidly in smaller patches, because all populations started at a small size and growth occurred almost entirely from reproduction within a patch, rather than migration of animals from other patches. Conversely, a landscape composed of a few large patches resulted in more rapid occupation of the last patch, and thus a shorter time for mountain goats to occupy the entire Park. The effects of landscape configuration were small for all configurations of suitable habitat that were simulated.

Acknowledgements

Special thanks are due to M. Festa-Bianchet for generously sharing unpublished data and insights on bighorn sheep and mountain goat ecology. I thank M. Kneeland for her help with the landscape analysis. Comments from M. Kotzman, D. Swift, C. Axtell, S. King improved the manuscript. This work was supported by the National Park Service, Rocky Mountain National Park, Colorado.

Literature Cited


Naturalist 54:114-121.


Biology 8:410-418.
Figure 2. Age-specific rates of (A) fecundity and (B) survival for bighorn sheep and (C) mountain goats. In B and C, open circles are males and closed circles are females.
Figure 3. Map of Rocky Mountain National Park showing patches of suitable habitat for mountain goats and bighorn sheep. See table 1 for area of each patch and area of overlap between species.
Figure 4. Population dynamics of simulated mountain goat populations in 5 patches of suitable habitat in RMNP. Runs were initialized with 8 mountain goats in patch 1 (mean ± 1 sd).
Figure 7. Distribution of population sizes at year 100 for simulations using different rates for the probability of infection. Probability of infection is relative, since it varies with population size.
Figure 8. Population dynamics of 20 simulated bighorn sheep populations subject to density-dependent, recurrent infection, without interspecific competition. All runs were initialized with 4 infected sheep, and the probability of infection was a linear function of animal density. Herd units: NSV = North St. Vrain, CD = Continental Divide, NS = Never Summer, MR = Mummy Range. Note different scales of vertical axes.
Figure 9. Population dynamics of 20 simulated bighorn sheep populations inhabiting RMNP, with interspecific competition and density-dependent probability of infection. All runs were initialized with 4 infected sheep in each sheep population and 8 mountain goats. The probability of infection was a linear function of animal density. Plots A-D are simulations with $\alpha_{sg} = 0.50, \alpha_{gs} = 0.25$; plots E-H with $\alpha_{sg} = 0.75, \alpha_{gs} = 0.25$. NSV = North St. Vrain, CD = Continental Divide, NS = Never Summer, MR = Mummy Range. Note different scales of vertical axes.
5. Potential Impacts of Rocky Mountain Goats on the Alpine and Subalpine Ecosystems in Rocky Mountain National Park

D. M. Swift\textsuperscript{1} and C. A. Popolizio\textsuperscript{1}

Abstract

In this paper we review the literature concerning mountain goats (\textit{Oreamnos americanus}), in terms of habitat use and distribution, food preference, and foraging relations with bighorn sheep (\textit{Ovis canadensis}). We then evaluate the probable effects that an established population of these animals would have on the native vegetation of the Park, rare and endangered plant species, exotic plants, other native animals in the Park, and other Park resources. We also consider the probable use of mineral licks by goats and the implications of the current Rocky Mountain National Park (RMNP) fire management policy for establishment and spread of a population of goats.

Mountain goats are well suited to the alpine and sub-alpine zones of the Park. They prefer to use very steep and rocky terrain for foraging, or areas in close proximity to such escape terrain. Summers would find the animals above treeline almost exclusively, while in winter they might retreat as far as the sub-alpine zone, but would probably still be found above timberline on wind swept areas that were relatively snow-free.

The animals readily accept a wide variety of plants including graminoids, forbs and shrubs. In summer they consume almost exclusively grasses and forbs, while during the winter, browse may form an important additional component of their diet, particularly for those animals which winter below treeline. They appear to be quite selective but adaptable foragers within a very broad food niche.

We anticipate that an established population of mountain goats would compete fairly severely with bighorn sheep. Their habitats and diets overlap to a large extent. On average, the diets of the two species, assessed at the plant genus level, appear to overlap about 59\% in summer and 68\% in winter. In addition behavioral observations suggest that goats are normally dominant over bighorns and might displace them from areas suitable for both species. There is also the potential for competition with elk, mule deer, and moose, but we would not expect important negative impacts of mountain goats on these species.

Mountain goats would probably not have major impacts on the general native vegetation of the Park beyond the impacts already attributable to other grazing animals, except in the very steep and clifffy areas which they often use for foraging in the summer. At the present time, these areas are probably only grazed by small herbivorous mammals. We find no evidence that goats would have any significant effect upon stands of aspen within the Park. Mountain goats might impact stands of willow in the alpine and subalpine zones. It appears, however, that while goats might have a greater impact in

\textsuperscript{1} Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, Colorado 80523-1499
these communities during winter than would a similar population of bighorn sheep: sheep would have a greater impact during the summer. Thus, the precise effect of a population of goats on willows is difficult to assess, but a combined population of sheep and goats would presumably have a greater impact than the current population of sheep alone. Where goats develop dust-bathing wallows, there would be severe local effects on vegetation.

We documented 27 rare or other plant taxa of concern as being present in RMNP. Of these, 22 would probably be found at elevations that could bring them into contact with mountain goats. We rated 11 of the 22 taxa as being most likely to be negatively impacted.

We do not expect that goats would have a major impact on the spread of exotic plants within the Park. It appears that there are very few exotic plants capable of surviving in the severe environments chosen by goats that have an effective seed source in the area.

We can find no unequivocal evidence that mountain goats would develop and utilize mineral licks in the Park to an extent greater than the existing large ungulates. Anecdotal evidence from Glacier National Park and from other parts of the Colorado mountains suggests however, that goats avidly seek sources of mineral nutrition.

The other native animal most likely to be impacted by mountain goats appears to be the pika. Several other species of small mammals might also be affected along with 8 species of native birds.

Archeological sites would probably be impacted only if they coincided with a wallowing area. Visual integrity of the alpine wilderness would suffer from the presence of mountain goats, but their presence would probably enhance visitor satisfaction. Goats do present a potential source of injury to visitors, but it is not deemed to be severe.

Current fire management procedures in RMNP probably favor the spread of goats in the Park, but we believe that goats will enter the Park and (if not prevented) establish themselves regardless of the nature of fire management in RMNP.

**Introduction**

Mountain goats (*Oreamnos americanus*) were transplanted to Colorado by the Colorado Department of Game, Fish and Parks (now the Colorado Division of Wildlife (CDOW)) in 1948 (Denney 1977). Recently, two mountain goats were located within the boundaries of Rocky Mountain National Park (RMNP). Resource managers from the National Park Service (NPS) are confronted with the issue of removing the individuals as alien to the RMNP or allowing a free-roaming population to become established. The controversy concerning the status of mountain goats as native or alien to Colorado had not been fully resolved previously, and this determination (chapter 1) will affect the way that the NPS will manage these animals. In addition, the NPS is interested in having a better understanding of the effects that a population of goats would have on RMNP resources and visitors.

A thorough review of pertinent literature and information from professional experts were used to document potential impacts of mountain goats on: (1) alpine and subalpine plant community types in RMNP, (2) rare plant taxa documented as present, or potentially present, within these communities,
(3) establishment and spread of exotic plant species, (4) populations of native animal species currently in the Park, with emphasis on inhabitants of the alpine tundra, and (5) other resource preservation and protection objectives in RMNP, including archeological sites, visual integrity of wilderness and issues of visitor safety and enjoyment of wilderness resources. The effects of an established goat population on bighorn sheep within the Park are evaluated in chapter 4 of this report.

Mountain goats are known to occupy alpine and subalpine community types during summer months and alpine to upper montane zones in the winter. These communities are well represented in RMNP. The communities which are most likely to be impacted by mountain goats include tundra, limber pine, Engelmann/subalpine fir, lodgepole pine, blue spruce and alder, aspen, Douglas fir, willow, grasses-wet, and grass. Descriptions of these community types, taken from Marr (1967), Mutel and Emerick (1992) and the Colorado National Heritage Progam (1999) are presented in Appendix 1.

Methods

Information on the distribution of mountain goats and the habitats they use was derived from studies conducted by researchers in Colorado, Wyoming, Montana, Idaho, Washington, Alberta, and Alaska (Saunders 1955, Hjeljord 1973, Olmsted 1979, Reed 1982, Pfitsch and Bliss 1985, Von Elsner-Schack 1986, Haynes 1988, Hayden 1989, Varley 1994 and 1996). These studies describe the general plant community types and the habitats preferred by goats, with emphases on seasonal movements and adaptive uses of plants and plant communities. Methods of data collection vary widely among these studies, particularly in relation to classification of plant community types which tend to be very generalized, particularly in older studies. An effort was made to group them according to similarities of types and correlate them to the classification scheme adopted in this paper.

Food preferences of mountain goats were assessed in relation to major plant life forms (graminoids, forbs, browse, ferns, mosses, and lichens) according to seasonality of use (summer, fall, winter, and spring). In Table 1, we present the results from all of the studies we could find on mountain goat diet selection.

An extensive literature review was conducted to assess the palatability of individual plant species to mountain goats (Anderson 1940, Cowan 1944, Casebeer 1948, Hanson 1950, Saunders 1955, Hibbs 1967, Herbert and McTaggard Cowan 1971, Richardson 1971, Peck 1972, Hjeljord 1973, Pallister 1974, Stewart 1975, Johnson et al. 1978, Olmsted 1979, Pike 1981, Thompson 1981, Adams and Bailey 1983, Campbell 1983, Johnson 1983, Dailey et al. 1984, Pfitsch and Bliss 1985, Hayden 1989, Varley 1994). A list of plant species growing in Colorado which have been reported to be preferred foods of mountain goats is presented in Table 2 along with a grazing preference rating (high, moderate, low) and a reported seasonality of use (summer, fall, winter, and spring). Harrington (1964) was consulted to determine if the plant species reported as utilized outside Colorado are also found in Colorado. When only generic names were presented in these studies, these were listed in Table 2, if the genera occur in Colorado. The latter findings should be interpreted as the general palatability of
particular genera to goats. An attempt was made to combine information on individual plant species of known palatability to goats with known occurrences of these taxa within plant communities at RMNP.

Impacts on native vegetation were derived from studies by Saunders (1955), Olmsted (1979), Pike (1981), Pfitsch and Bliss (1985), and Varley (1996). These authors describe the grazing habits of mountain goats in relation to available forage and browse, as well as the intensity of use of palatable plant species, and potential changes in plant composition within community types. Disturbances caused by trampling and wallowing were also considered. Information was provided on grazing and browsing selectivity that goats may have for specific plant parts, such as flower, fruits, leaves, stems, roots, or twigs. In general terms, the impacts of goats on preferred common plant genera and on sensitive plant species were assessed.

Information on threatened, endangered, and/or rare, plants occurring in RMNP was obtained from the Colorado Natural Heritage Program, Colorado State University (Spackman et al. 1997, Colorado Natural Heritage Program draft information 1999). Information on exotic plant species and the role that mountain goats might play in their establishment on goat ranges came primarily from the ongoing work of Tom Stohlgren and others, who are investigating plant diversity and the factors affecting the prevalence of exotic plants in RMNP (see, for example, Stohlgren et al, in press).

Foraging relationships of mountain goats with bighorn sheep (Ovis canadensis) were assessed by interpreting information provided by Adams et al. (1982), Dailey et al. (1984), Goodson and Stevens (1988), Hayden (1989), Laundre’ (1990, 1994), and Varley (1996). In particular, attempts were made to describe overlaps in communities, habitats, terrain, and escape routes used by both species. Forage overlap was assessed in terms of seasonal selection of plant species, as well as by plant parts (flower, fruits, leaves, stems, etc.) preferred by goats and sheep. Information on the interactions of goat and sheep, where they live in close proximity, was also extracted from the literature.

Herbert and McTaggard Cowan (1971), Hayden (1989), and Varley (1994, 1996) provided information on the use of natural mineral licks to supplement salts potentially lacking in forage and browse. Emphases were placed on seasonality of use and mineral content in forages.

Information on visitor response to goats in National Parks, goat/human interactions, and goat behavior in protected areas came from discussions with personnel at Glacier National Park, and from reports they provided. Additionally, we searched the “chat room” on the Glacier National Park web site (www.glacier.national-park.com) for comments about mountain goats, and we posted there a query for other web site visitors to describe interactions they had had with goats in the Park, or elsewhere. The respondents to this query and the people who had previously posted comments on goats are referred to as our “informants”.

Results and Discussion

Habitat Use and Distribution

Mountain goats are well-suited to alpine and subalpine zones of the Alaskan range, the northern and central Rocky Mountains of Canada and the United States, and the Cascades of the Pacific
Northwest. The broad distribution of mountain goats in North America indicates that they are capable of adapting to a variety of alpine and subalpine plant community types.

Overall, rocky slopes, ridge tops, open meadows, talus slopes, riparian zones, and shaded areas are preferred by goats as summer foraging, safety, rest, and travel sites. These are found within tundra, limber pine, Engelmann spruce, Douglas fir, and/or wet grass communities. Winter foraging sites extend from the tundra to grass communities of the montane zone. Throughout the year, subalpine and upper montane forested areas are usually selected as travel corridors, shaded areas, and nocturnal bedding sites. According to Hayden (1989), Douglas fir and limber pine trees at the edge of steep slopes were preferred locations for seeking shade throughout summer. Von Elsner-Schack (1986) reported that large, active herds spent most of their time in grassy areas, choosing rocky habitat when inactive. Safety appeared to influence habitat selection, as large herds selected open areas with abundant forage when active, while conversely, small herds spent most of their active time in gravel sites nestled between escape routes to rocks and forage-rich grassy areas.

In the Snake River Range of Idaho, Hayden (1989) reported that mountain goats, with the exception of mature females, appeared to leave their winter range in late March, well ahead of snow melt and green-up in the alpine zone. Remnants of snowdrifts were used heavily whenever present. Varley (1994), over an entire growing season in Montana, observed mountain goats feeding in the following habitats (quantified as percentages of total selections): ledge (31%), rocky scree (24%), sandy scree (11%), turf (11%), turf scree (10%), subalpine (10%), and talus (3%). Forty-six percent of all observations of feeding occurred within escape terrain. Mountain goats selected wet areas with young vegetation during the summer. Haynes (1988) presented results for the use and availability of three generalized cover types in Wyoming (cliff-rock, grass-forb-shrub, and forest-krummholz), determining that cliff-rock habitat within tundra and timberline communities was the only one used more than its availability (i.e. was preferred). The other two components, grass-forb-shrub (probably alpine meadows and willow habitats) and subalpine forest-krummholz, though not preferred, were used for foraging and travel, respectively. According to Saunders (1955), the most important community types were those of tundra and subalpine zones that encompass grassy slide-rock slopes. These sites were occupied by goats during spring, summer, and fall, and were visited in the winter as well, particularly those blown free of snow. Ridge tops were of secondary importance. These areas were visited by goats in summer and winter. Alpine meadows that were deeply covered with snow during the winter months and well into July were occupied by goats in August and September. Hjeljord (1973), in a study of habitat preference on Kodiak Island and the Kenai Mountains, Alaska, reported that mountain goats congregated in the higher elevations during the summer months, feeding on gentle slopes rather than steep and broken terrain. On Kodiak Island, Carex meadows and Erigeron slopes were most heavily utilized, followed by Lupinus ridge, Carex ridge, and snow bed. In the Kenai Mountains, mountain goats utilized the following vegetation types: Artemisia slope, Carex slope, Sedum ridge, and Stellaria ridge.
Olmsted (1979), in documenting the impacts of mountain goats on alpine and subalpine vegetation in Olympic National Park, reported that all of the following habitat types and communities were used by goats: south-facing slopes with meadow types; crevices and ledges with alpine cushion plants; slide rock; ridge tops with dwarf sedges, dwarf forbs, and alpine cushion plants; and north-facing slopes with scree plants, .upines, heath shrubs, and dwarf sedges/forbs. Conversely, Pfitsch and Bliss (1985) reported that goat populations in Olympic National Park were highly selective of areas with rocky outcrops. However, many highly productive meadows were located proximal to rocky outcrops, probably influencing the summer distribution of these goats.

Typically, upper montane and subalpine community types such as limber pine, Engelmann spruce, lodgepole pine, blue spruce/alder, aspen, and Douglas fir are not intensively grazed/browsed by goats during the summer and early fall (Saunders 1955). However, coniferous forest types may be of importance during winter months, as 30% of goats' diets was derived from coniferous trees, particularly Douglas, and/or subalpine fir in Saundier's study. According to Varley (1996), goats demonstrated strong affinity for localized areas throughout the winter, particularly windblown ridge lines and isolated rocky outcrops. Dense stands of trees provided thermal cover during periods of extreme cold or deep snow. During the winter, Hjeljord (1973) found that, in the snowy winter of 1969, mountain goats avoided areas of deep, crusted snow of lower elevations, congregating on south-facing rocky outcrops, and wind-blown slopes and ridges. However, during the winter of 1970, mountain goats preferred a relatively snow-free subalpine habitat, particularly alder-covered slopes.

In Montana, nannies utilized Douglas fir for food and cover during the parturition period in the spring (Saunders 1955). However, von Elsner-Schack (1986) stated that, in Alberta, rocky habitats, which provide relative safety, had their highest use during parturition.

Based on published reports of the habitat preferences of mountain goats elsewhere in the United States and Canada, it appears that a substantial amount of suitable habitat for the species exists within RMNP (chapter 4). It seems likely that animals would use areas close to escape terrain in the alpine zone most heavily, with particular preferences varying considerably from year to year, and that such suitable areas are widely spread throughout the back country of the Park. We would expect, therefore, that any established population would eventually become widespread in the Park, and would be highly visible to back country visitors and other users of the alpine zone. There appears to be the potential for substantial overlap in habitat selection or use between mountain goats and bighorn sheep (chapters 3 and 4).

Food Preference

We made a thorough review of the literature relating to food preferences and foraging by mountain goats. A detailed summary of these studies (at the level of plant genus or species) can be found in Appendix 2. Table 1 includes the results from all the studies we could find on diet selection by these animals summarized at the plant functional group level (graminoids, forbs, trees and shrubs, ferns, lichens and mosses). Table 2 lists plant species found in Colorado which are preferred foods of
mountain goats. Here, we summarize the studies we found which focussed on plant functional groups.

A. Summer

Hibbs (1967) reported that, in summer, 83% of the stomach contents of four mountain goats from Mt. Shavano, Colorado, was comprised of graminoids. Further studies in the same general area revealed that graminoids and forbs comprised 83 and 14% of summer diets, respectively (Johnson et al. 1978). Dailey et al. (1984) conducted a study at the University of Colorado Mountain Research Station at Niwot Ridge in 1979-80 on summer diet selection by mountain goats. Observing immature, tame mountain goats, they recorded a foraging preference for forbs. It is possible that these younger, smaller animals had higher nutritional requirements than adults, and hence selected forbs which are frequently higher in cell solubles and lower in fiber than graminoids.

In Montana, Saunders (1955) studied food habits of mountain goats in the Crazy Mountains and observed that 56% of the diet was composed of graminoids. Forbs made up 26% of their diet, shrubs comprised 16% of the diets, while browsing on trees was minimal. Varley (1994) reported that mountain goats in the Absaroka Mountains selected graminoids (75.6%) as their preferred summer and early fall forage. Forbs comprised 19.6% of the total diet.

Laundre’ (1994) summarized various studies of alpine and subalpine habitats in the western United States occupied by mountain goats in the summer. On the average, goats incorporated in their diets 52% graminoids, 30% forbs, and 16% browse.

B. Winter

Mountain goats preferred graminoids to any other food group during winter in Colorado (Hibbs 1967). Adams and Bailey (1983) report results of a study of food preference by mountain goats on alpine and subalpine winter ranges in central Colorado. They reported that grasses and sedges were the preferred food of individuals wintering above timberline (38 and 53% in 1978 and 1979, respectively). Woody plants were consumed more heavily in 1978 than in 1979 (35 and 26%, respectively), even though the snow was 15% above normal during the winter of 1979. The authors indicated that the heavier accumulation of snow forced the goats to forage on wind-swept, snow-free ridges where woody species are absent. Selection of graminoids increased by 15% in 1979. Forbs were heavily utilized in 1978 (28%), but consumption declined in 1979 (19%). Woody plants were much more important forages in the subalpine area. On these ranges, goat diets were composed of 23 and 42% graminoids, 44 and 51% browse (mostly coniferous species) and 34 and 5% forbs in 1978 and 1979, respectively.

Fox and Smith (1988) conducted a study of mountain goat winter diets in southeastern Alaska and reported that conifers, mosses, and lichens were most commonly represented in the fecal material of these animals. Browse on shrubs and foraging on ferns was of secondary importance. Goat wintering sites were densely forested, with tree bark covered with lichens and mosses; this may explain the presence of these particular species in goat winter diets at all snow depths.

Laundre’ (1994), in his summary of various studies of alpine and subalpine habitats in the
western United States occupied by mountain goats reported that, on the average, goat winter diets were composed of 60% graminoids, 8% forbs, and 32% browse.

C. Spring and Fall

In Montana, graminoids were the major food source of mountain goats in the fall (75% of rumen content by dry weight) followed by forbs (21.5%), while shrubs decreased (1.2%) and trees remained unimportant until winter, when utilization of conifers increased to 30.4% Saunders (1955). In the spring, graminoid selection and use was at comparable levels to those documented in summer and fall, but fewer species of forbs were used. Browsing of trees remained high (18% of rumen contents by dry weight) in spring and fall.

D. Synthesis

Mountain goats would be classified as intermediate feeders using the scheme of Hofmann (1973). They consume grasses, forbs and browse of a wide variety of species, with the mixture of the major forage classes varying seasonally and with the foraging habitat selected. Grasses dominate adult goat diets in the summer with a significant forb component as well. Browse is of limited importance at that time. Limited evidence suggests that young goats consume more forbs and less grass than adults. Spring and fall diets are similar to summer diets.

The composition of winter diets depends to a large extent on where the animals are wintering. When in alpine areas, grasses and sedges continue to dominate the diet, but browse may contribute up to 25% to the mix. When wintering in subalpine areas, browse becomes much more important, frequently comprising over 50% of the diet.

Mountain goats are very adaptable foragers, and the types of forage available to them is less likely to control their distribution than is the presence of suitable steep and rocky terrain.

Impacts on Native Vegetation

In Montana, mountain goats rarely graze intensively in any particular spot (Saunders 1955). Varley (1996) was not able to document changes in plant communities in Montana resulting from mountain goat impacts. Trails, day-beds, and weed invasions were present in certain well-traveled areas, but were not widespread. Extensive disturbances such as wallows and trampling were not observed. Varley (1996) concluded that mountain goats in the Absaroka mountains goats did not seem to have reached ecological carrying capacity ~40 years following introduction, although it should be noted that the growth of this population was controlled by hunting. He did predict that certain alpine habitats might show signs of overuse within 15 years because of their isolation from larger, suitable habitats. In Washington, Pfirsch and Bliss (1985) reported that goats are selective foragers. Plant species highly preferred by goats are heavily grazed, while plant species with a low preference are grazed lightly.

In Montana, Saunders (1955) observed goats grazing/browsing on flower stalks, stems and foliage of forbs, foliage and seed heads of graminoids, leaves and twigs of shrubs and trees, foliage of ferns, and the entire aerial portion of lichens. In Washington, Olmsted (1979) observed mountain goats
feeding on different species, and at different stages of their growth, although they appeared to select young shoots and small leaves. Only a portion of a given bite was consumed, the remainder falling on the ground. Following close observation, it was concluded that a fair portion of this material contained roots and stolons.

Willows are palatable to wildlife such as mountain goats (Saunders 1955, Hibbs 1967, Johnson et al. 1978, Thompson 1981, Campbell and Johnson 1983, Dailey et al. 1984, Varley 1994). Continued heavy browsing may weaken the root systems of willows (Padgett et al. 1989). Late summer and fall browsing result in pruning damage due to limited regrowth at the end of the growing season (Hansen et al. 1995). Given that goats tend to feed on very steep, rocky areas during the summer, and include less browse in their diets, they are unlikely to have as great an impact on willows during the growing season as would a similar number of bighorn sheep.

During winter, we would expect heavy use of Salix nivalis where it occurs in alpine areas, and moderate use of other willow species in the willow communities. Dailey et al. (1984) reported that goats browsing on willows ate more leaf and catkin tissue and less stem tissue than did bighorn sheep. However, the goats studied were young, and this pattern of browsing might not be true for mature goats. It is probable that, during winter, goats would have a greater impact upon willows than would a similar number of bighorn sheep.

Palatable sedge species provide a valuable source of forage and can be heavily utilized in riparian areas in mid- to high-elevation zones. Overutilization can increase non-native grass cover, and result in decreased vigor of native species root structure (Hansen et al. 1995). Sedges occur on soils that are typically wet throughout the growing season, and grazing can often cause compaction, pitting and hummocking of the soil (Padgett et al. 1989). In alpine wetland areas, it is therefore undesirable for grazers to remain in any area for very long.

Trampling and dust-bathing were listed as damaging behaviors in Olympic National Park, Washington (Olmsted 1979). Trampling occurred during feeding, between feeding areas, and to and from bedding places. Trampling effects were compounded by steep slopes and goats congregating in groups of up to 20 individuals. Dust-bathing or wallowing is a common activity aimed at removing biting insects. Wallow areas became totally denuded and were used repeatedly, although new ones were created every year. One wallow was measured to be three feet deep; the wind constantly undercutting the margins and removing more soil. There is the potential for goats to contribute to soil loss and the establishment of exotic plants through this behavior.

Pike (1981), in a thesis on the impact of mountain goats on endemic and rare plant species in the Olympic Mountains, Washington, documented that saxifrages (in particular the rare Saxifraga debilis, Saxifragaceae) were detrimentally affected by scrambling of goats over moist, shady rocky outcrops. The disappearance of the Mt. Angeles population of S. debilis was attributed to mountain goat impacts. Snow willow was listed as moderately susceptible to trampling. Polygonum viviparum and P. bistortoides were heavily affected by grazing. The former was drastically reduced in some
areas, while the latter was prevented from flowering under intense use. Delayed flowering resulting from grazing and trampling was also documented in the following genera: *Aster, Astragalus, Campanula, Carex, Castilleja, Collomia, Draba, Erigeron, Lewisia, Oxytropis, Phlox, Poa, Sedum, Senecio*, and *Viola*. *Aster* spp. responded to grazing pressure by producing >100 additional branches per ramet, but their overall cover was less than that of ungrazed individuals. Overall, goats were found to have detrimental effects on rare and/or endemic species, even at low levels of grazing pressure.

Aspen is an important species in RMNP from a management perspective. We find no evidence in the literature to suggest that aspen stands at any elevation in the Park would be significantly impacted by a population of mountain goats.

**Foraging Habits of Mountain Goats and Bighorn Sheep**

Adams *et al.* (1982) reported that mountain goats and bighorn sheep in Colorado occupy different environmental gradients with partial overlap. He concluded mountain goats are capable of exploiting smaller areas of rugged and steep terrain by accepting a wider range of forages than bighorn sheep. Bighorn sheep are more adapted to flat and rolling terrain near escape routes, including riparian meadows, shrub community types, lodgepole pine and aspen associations, as well as spruce-fir forests and alpine tundra, with associated rock slides, boulder fields, and cliffs. During late spring and early summer, mountain goats and bighorn sheep leave the subalpine zone and move to south-facing slopes of the alpine zone, slowly moving to north-facing slopes as summer progresses (Adams *et al.* 1982, Goodson and Stevens 1988). During winter, mountain goats are more capable of foraging in deep snow, when it is not heavily crusted, than are bighorn sheep (Adams *et al.* 1982).

In a comparative study of winter diet selection by mountain goats and bighorn sheep on Niwot Ridge, Colorado, Dailey *et al.* (1984) reported that mountain goats ate a significantly higher proportion of forbs than did bighorn sheep. This study, however, reported more forbs in goat diets than do most other studies. For a short period during winter, goats ate more browse than sheep. Foraging overlap of the two species based on commonly utilized plant taxa was estimated at 59% during the summer and 41% during the winter. Goats ate more leaves and flowers than did bighorns, the parts of plants which are more nutritious than stems. Leaves and catkins comprised 90% of all *Salix* parts consumed by goats, compared to only 57% by sheep.

For summer range, Varley (1996) found that *Carex, Juncus*, and *Poa* spp. were consumed by both sheep and goats. Five forage species with the highest mean canopy cover on summer range formed > 50% of both species' diet. Utilization of rare and uncommon taxa was not documented for either species. With few exceptions, sheep and goats utilized different forbs. Sheep were more prone to browsing and less inclined to ingest lichens. Selection of summer feeding areas was dissimilar, with goats foraging on steep, rocky, and sparsely vegetated sites and often sites associated with melting snow. Conversely, sheep were attracted to drier, turf sites with high vegetation biomass. As reported in relation to feeding site selection, sheep are capable of relying on group size to fend off predators, while goats tend to respond to threats by individually seeking steep escape terrain. Nonetheless, as
goat populations increase, they tend to form bigger groups foraging further from escape terrain, so habitat overlap and conflicts with bighorn sheep herds are likely to increase. During winter months, habitat overlap is likely to increase in some places, such as in the Beartooth Mountains of Montana, but not in others, such as in Yellowstone National Park.

Laundre’ (1994) summarized various studies in alpine and subalpine habitats occupied by mountain goats and bighorn sheep. On the average, goats and sheep incorporated in their summer diets 52% and 56% graminoids, 30% and 23% forbs, and 16% and 21% browse, respectively. During winter months, goat and sheep diets were composed of 60% and 64% graminoids, 8% and 15% forbs, and 32% and 21% browse, respectively.

Although overlap appeared to be pronounced, it was reduced when the individual plant genera selected were identified. Dietary overlap as calculated by Laundre’ (1994) averaged 0.95 in summer and 0.82 in winter (complete overlap = 1.0) when analysed by forage class (grasses, forbs, shrubs). When overlap was calculated at the level of plant genera, the averages were 0.59 for summer and 0.68 for winter. Overlap estimates were not available at the species level. These estimates of diet overlap are, by themselves, not good estimates of competition between the two species, as competition depends on not only the overlap of diet, but also on specific overlap in habitat use.

In summer, goats consumed greater amounts of the graminoids *Agropyron* spp. and *Koeleria macrantha*, while sheep preferred *Carex* spp., *Festuca* spp., and *Deschampsia caespitosa.* Among forbs, goats utilized greater quantities of *Mertensia* spp., while sheep more often chose species such as *Potentilla* and *Trifolium* spp. In the winter, goats chose *Festuca* and *Poa* spp., while sheep selected *Agropyron* spp., *Carex* spp., *Koeleria macrantha*, and *Artemisia* spp. As a result, forage utilization overlap and competition for preferred plant species may be more pronounced when considered over a yearly cycle than on seasonal bases.

Varley (1996) reported only six interactions between mountain goats and bighorn sheep over an entire growing season. In one interaction, eleven bighorn sheep were grazing within 20 m of seven bedded goats. The sheep departed as the observer approached, carefully avoiding the place where the goats were bedded, preferring closer proximity to the observer to find an escape route; the goats appeared unperturbed by the event. This may indicate that goats are dominant over sheep in regard to habitat occupation. Laundre’ (1990) witnessed groups of mountain goats and bighorn sheep feeding within 100-200 m of each other without any apparent concern. Fifty-four percent of 69 interactions were neutral. Forty-one percent of the time, goats prevented sheep from foraging in an area, while sheep caused goats to leave an area in only 5% of the instances. The fewest interactions occurred over the winter months, and all were neutral.

Laundre’ (1994) provided a summary of studies comparing distance from escape terrain, degree of slope, and preferred elevation for mountain goats and bighorn sheep. In the summer, goats moved farther from escape terrain than sheep (goats: 305 ± 25.6 m; sheep: 120 ± 11.6 m; P < 0.01). In both summer and winter, goats and sheep utilized areas with different slopes [goats - summer: 41 ± 5.2°;
sheep - summer: 22 ± 11.6° (P = < 0.01); goats - winter: 47 ± 8.4°; sheep - winter: 24 ± 6.5° (P = < 0.01). Preference for elevation was similar in all ways for the two species.

In many ways, mountain goats would appear to have a competitive advantage over bighorn sheep. They can utilize slopes which are too steep to be used by bighorns, and because they can forage farther from escape terrain, are not excluded from the milder slopes used by the sheep. In addition, observations suggest that goats are dominant over sheep in most instances. Thus, we would predict that competition between the two species would be asymmetrical, with goats having a greater negative impact upon bighorns than the bighorns would have upon the goats.

**Threatened and Endangered Plant Taxa, and Species of Concern occurring in RMNP**

A total of 27 threatened and endangered plant taxa and plant species of concern were documented to occur within the boundaries of RMNP (Spackman *et al*. 1997, Colorado Natural Heritage Program 1999). All of these taxa are listed at the State of Colorado level; *Cypripedium fasciculatum* and *Potentilla rupincola* are also listed as species of concern at the Federal level. Most of these taxa enjoy greater abundance outside Colorado as a result of extensive distributions in North America, but are rare in our State as a result of being disjunct from their primary ranges, or at the periphery of their distributions. Detailed information on the status of these species, their distribution and ecology are provided in Appendix 3.

The potential impacts of mountain goats on these rare plant taxa varies according to the elevation at which they grow, the habitats favorable to the persistence of these plant species, and their relative palatability to goats. Impacts may result from direct utilization by grazing or browsing, or indirect damage from occasional trampling, wallowing, bedding, and root-digging. The palatability of these rare species to goats has been documented in a few instances, while it remains unknown for others.

Five of the 27 species, *Carex limosa, Lilium philadelphicum, Penstemon cyathophorus, Unamia alba,* and *Viola serkirkii* occur, for the most part, in low elevation habitats within RMNP and are therefore unlikely to be endangered by goats. Other species, such as *Listera borealis,* and *Listera convallarioides* have a distribution that reaches intermediate elevations within RMNP which might be subjected to trampling by goats in the spring. Other species, such as *Aquilegia saximontana,* and *Cypripedium fasciculatum,* are probably unpalatable to goats, but occur throughout elevation gradients that goats would occupy portions of the growing season.

Rare plant taxa which occur in habitats that would be utilized by goats are *Carex leptalea* (in rich fens of the subalpine zone), *Draba fladnizensis* and *Draba grayana* (in wet meadows, dry tundra, rocky alpine areas, gravelly alpine slopes and fell fields), *Eriophorum gracile* (in fens in alpine and subalpine zones), *Parnassia kotzebuei* (on high elevation rocky ledges, streamlets, and moss mats), *Sisyrinchium pallidum* (growing next to water), and the extremely rare *Mimulus gemmiparous* (on granitic seeps and alluvium in open areas within spruce-fir and aspen forests), and *Isoetes setacea* subsp. *muricata* (very few populations occurring in the alpine zone).
Draba spp. have been recorded as palatable to goats, although consumption appeared to be low (Saunders 1955). Therefore, the rare Draba fladnizensis and Draba grayana may be subject to occasional grazing and trampling, thus resulting in potential loss of reproductive capabilities over its very short growing season (which is characteristic of alpine/tundra plants). The same conclusions are valid for the federally listed Potentilla rupeicola, a taxon that grows on granitic outcrops and gravelly soils in the subalpine zone. The genus Potentilla is moderately palatable to goats (Hibbs 1967, Peck 1972, Pallister 1974, Johnson et al. 1978, Thompson 1981, Adams and Bailey 1983, Varley 1994), although no mention of goats utilizing this specific taxon was encountered in the literature. Finally, Salix serissima, a willow species critically imperiled in Colorado, which has been recorded in the upper montane zone of RMNP, may be damaged by goat browsing, particularly during the cold season. Salix species are good goat browse food throughout the year (Saunders 1955, Hibbs 1967, Johnson et al. 1978, Thompson 1981, Dailey et al. 1984, Varley 1994).

Saunders (1955) and Hjeljord (1973) documented utilization by goats of fern fronds and root systems, although on different species of ferns than those listed as rare in Colorado and occurring in RMNP. Therefore, Botrichyum echo, B. hesperium, B. lanceolatum, B. lunaria, the extremely rare B. minganense, Cystopteris montana, and Dryopteris expansa may be sensitive to grazing, trampling, and root digging by goats.

Clearly, it is not easy to predict with any accuracy the effects that a population of goats would have on the 22 plant species with which they would probably have contact. By virtue of their rareness, little is known about these plants in most cases, and this is particularly true of their palatability to mountain goats. Additionally, since their populations are small, random events may determine whether or not they survive in RMNP. For example, one or two trampling or grazing events on individual plants might extirpate an entire species from RMNP, when it otherwise might have survived there. Obviously, it is impossible to predict whether or not those events will occur. The best we can do is to attempt to assess the general level of risk presented to each plant species by goats, based on the likelihood that they might be grazed, or physically damaged by trampling or wallowing. This assessment is based on the environment inhabited by the plants and its overlap with the areas used by goats, what is known of the palatability of the plants, and the presumed susceptibility of the plants to physical damage based on their growth form and the nature of the substrate in which they grow.

Of the 22 threatened and endanger plant species occurring at relevant elevations in RMNP, we rate the following 11 as being most likely to be negatively impacted by mountain goats:

- Aquilegia saximontana - grows mainly on rocky slopes
- Carex leptalea - probably palatable and associates with other palatable species
- Draba fladnizensis - probably palatable
- Draba grayana - probably palatable
- Eriophorum gracile - associates with other palatable species
- Mimulus gemmiparus - delicate growth form
Papaver kluanensis - overlaps extensively with habitats used by goats

Parnassia kotzebuei - prefers wet, fragile habitats

Potentilla rupincola - probably palatable

Salix serissima - probably palatable

Sisyrinchium pallidum - associates with other palatable species.

The following 11 species would be likely to come into contact with a population of mountain goats, but we rate them as being less vulnerable to damage:

Botrychium echo

Botrychium hesperium

Botrychium lanceolatum

Botrychium lunaria

Botrychium minganense

Cypripedium fasciculatum

Cystopteris montana

Dryopteris expansa

Isoetes setacea

Listera borealis

Listera convallarioides.

Potential Effects on Spread of Exotic Plant Species

Based on ongoing work in RMNP, it seems unlikely that mountain goats would have a major impact on the presence or spread of exotic plant species there. At present, exotic species are limited to the low elevation parts of the Park, and it is suggested that this is because exotic species are unable to deal with the low temperatures and short growing season of the alpine and subalpine zones (Stohlgren et al, in press). Most exotic plants threatening the Park are annuals, which are probably at a disadvantage in the severely unpredictable environments of the higher elevation zones. Additionally, there may be no effective seed source for exotic annuals that could thrive at high elevations because there has never been any particular impetus to bring such plants to this country from abroad.

The tendency of mountain goats to develop wallowing areas that are devoid of vegetation is a cause for concern in relation to exotic plants. Such disturbed areas, at lower elevations, are often the first site of infection by non-native plants. If suitable seed sources were to become available, this behavior on the part of goats might provide a foothold for exotic plant species in the higher elevation zones.

Use of Natural Mineral Licks

Herbert and McTaggart Cowan (1971) studied the use of natural salt licks by mountain goats, and the mineral content of forage plants from the Rocky Mountain Trench in British Columbia. They reported that male goats sought natural licks as early as April, when their diet changed from winter browse to new, herbaceous growth. As a result of the new seasonal diet, a change in fecal texture from
pellets to diarrhea occurred with consequent loss of sodium in fecal material. Females sought natural salt licks as well, but only after giving birth in June. The delay in females was explained as a behavioral pattern which keeps females on higher, more remote ranges until the young are born. Preferred forage and browse species were found to be deficient in minerals; no differences were found in plant species from high and low elevations. Nonetheless, analysis of blood serum throughout the growing season indicated that mountain goats were not mineral deficient. Goats appeared to prefer dry earth licks, occasionally visiting mineral springs. The use of natural licks was confined to spring and summer months.

The use of natural mineral lick areas was not observed by Varley (1994, 1996) in Montana, probably because mineral concentrations were abundantly present throughout the Absaroka range. Hayden (1989) reported that the Snake River Range of Idaho had an abundance of natural salts as well, therefore, there was apparently no need for long-distance travel to lick areas.

It is not known whether goats would need to rely heavily upon licks as a source of mineral nutrition if they were to become established in RMNP. Anecdotal evidence that goats express a keen gustatory interest in human urine and perspiration in Glacier National Park, and in other parts of the Colorado mountains where they are present, suggests that minerals are likely to be limiting to them. If this is the case there is the potential for the development of denuded areas associated with localized mineral rich areas.

In Glacier National Park, it is reported that mountain goats regularly visit parking lots where they are attracted to, and consume, the coolant fluids which leak from the parked cars (Rick Yates, Glacier National Park, pers. comm.).

Effects on Other Native Animals

Hayden (1989) reported that in addition to overlapping with bighorn sheep, mountain goat habitat overlapped with that of mule deer, elk, and moose in the Snake River Range of Idaho. Most overlap was documented during late winter and early spring. Competition among these species was not deemed severe, although it was not quantified. Houston et al. (1994) believed that, in Olympic National Park, goat competition with large ungulates other than bighorn sheep was minimal. We would expect some overlap between goats and mule deer, elk and moose in RMNP, but we would not anticipate that competition would be severe among these species.

Many elk summer in the alpine zone of RMNP and some winter there as well. Thus, there is the potential for greater competition between goats and elk in RMNP than has been reported elsewhere. In most cases, however goats would probably be selecting feeding sites that would not normally be used by elk. Given the apparent health of the elk population in RMNP, we would not predict that mountain goats would have significant negative impacts on this species. However, given the current situation of apparently declining mule deer populations in Colorado, there may be some cause for concern with this species.

Houston et al. (1994), suspected that Rocky Mountain goats in Olympic National Park might be
in competition with the Olympic marmot (*Marmota olympus*) there, but were unable to demonstrate that this was true.

Certainly there is the potential for competition between goats and herbivorous small mammals which occupy the alpine and subalpine zones of RMNP. The small mammal with the greatest overlap with goats in terms of habitat use is probably the pika (*Ochotona princeps*). Their predilection for rock slides and talus slopes as living and foraging areas would probably put them in more or less continuous contact with goats. If pikas are food limited, a goat population in the Park could have a negative effect upon them. Overlap between goats and yellow-bellied marmots (*Marmota flaviventris*) would also be expected, but at lower intensity than the overlap between goats and pikas. Other small mammals which would overlap with mountain goats in RMNP in habitat and foraging include the northern pocket gopher (*Thomomys talpoides*), the bushy-tailed wood rat (*Neotoma cinerea*), and the montane vole (*Microtus montanus*) (Lechleitner, 1969).

A few species of native birds could also be affected by a population of mountain goats. Wilson's Warbler (*Wilsonia pusilla*) and white-crowned sparrows (*Zontrichia leucophrys*), both nest in willows above and below timberline (Andrews and Righter 1992), and, as such, might be affected by over-browsing of this shrub. We suspect that an expansion of the moose population would be a greater cause for concern for these bird species.

Three species of birds nest in the alpine tundra (Andrews and Righter 1992) and so might be affected by goats, particularly through wallowing or trampling. These are the American pipit (*Anthus rubescens*), the white-tailed ptarmigan (*Lagopus leucurus*) and the horned lark (*Eremophila alpestris*). In addition, the most important food of the ptarmigan in all seasons, except summer, is buds and leaves of various willow species, including *S. nivalis* (May and Braun 1972). These authors did not consider the birds to be food limited however, so competition for this food may not be important. Ptarmigan depend upon willows for winter cover and a reduction in willow could impact them.

Three additional bird species nest on cliffs in the alpine area and might be affected by goats. These are the prairie falcon (*Falco mexicanus*), the common raven (*Corvus corax*) and the brown-capped rosy finch (*Leucosticte australis*).

**Effects on Other Park Resources and Visitors**

**Archeological Resources**

The major threat to archeological resources within the Park would appear to be associated with the development of wallowing areas by goats during the summer. These would be expected to be developed in relatively flat areas within the alpine zone. If a wallow was developed in an archeological site, that site could be very severely disturbed. Otherwise, we would not anticipate that goats would have a significant impact upon archeological resources in excess of what other ungulates are currently having. The only areas that would be exploited by goats that are not currently being used by other large ungulates would be very steep slopes in the alpine zone, and we assume that these areas are unimportant in terms of archeological resources.
Visua lntegrity of Wilderness Resources

Since it is our belief that mountain goats are not native to Colorado, we believe that their presence in RMNP would very significantly reduce the visual integrity of the alpine wilderness. Because they are not native to these systems in the Park, every observation of them would be a reminder of the non-pristine conditions of the alpine zone. While this is factually true, it would probably not be apparent to the vast majority of naïve visitors who observed the animals.

Beyond this, the wallows created by the goats, being the impact of an introduced species, would also reduce the visual integrity of the alpine zone. Given the very open nature of alpine areas, it is assumed that goats and their workings would be very easily observed by visitors to this zone of the Park.

Visitor Safety and Enjoyment

Rocky Mountain goats do present a potential threat to the safety of users of the alpine zone - both in back-country areas and (presumably) along roads, such as Trail Ridge, which run through alpine areas. Ancedotal information suggests that mountain goats habituate very quickly to the presence of humans and are unconcerned about approaching them. They are reported to avidly seek out urine patches left by humans (sometimes before the urinating individual has finished), and to approach camp sites looking for salty items such as back packs. Given that goats are large and powerful animals, the potential for injury to users is substantial, although most of our informants believed that reasonable caution would minimize this threat.

Greater danger probably exists in parking areas along the alpine roads. If goats were to congregate in these areas, as they do in Glacier National Park, looking for food or sources of minerals, there would be the potential for more goat/human interactions than in the back-country. The combination of less naïve, more habituated goats with more naïve visitors, unaware of the potential dangers of the animals, would mean that sooner or later, someone would get hurt. It would presumably provide a significant management problem for Park personnel.

Visitor enjoyment would most likely be enhanced by the presence of a population of goats. The vast majority of our informants report great satisfaction in having seen or interacted with mountain goats. Many of them clearly feel that observing the animals was the high point of their outdoor experience, and many are in the field primarily, if not solely, to observe them. Many of our informants gave the impression of being habitual and reasonably informed back-country users. Nevertheless, only one of them raised the issue of the nonsuitability of non-native species in the National Parks, saying that if they were not native, they shouldn't be there, and that he would be willing to go elsewhere to observe them. The others are either unaware of this issue or not concerned about it. While observing goats in parking lots may not be an aesthetic experience for the ecologically sophisticated, it would be at least an interesting one for more naïve visitors.

Impact of Fire Management on Mountain Goats and Bighorn Sheep

Fire management within RMNP has the potential to influence the distribution of mountain
goats and their interactions with bighorn sheep. Mountain goats in the northwestern United States and western Canada apparently make much more extensive use of timbered habitats than do mountain goats in the southern Rocky Mountains. If mountain goats were to colonize RMNP, we may thus expect that they would be largely restricted to open habitats. If fire management included burning subalpine forests or other areas that provided suitable escape terrain, mountain goats would almost certainly colonize these areas, and they may use them in preference to higher elevation alpine habitats. When mountain goats were first introduced to the Mt. Evans area in 1961, they were reported to prefer subalpine habitats, where several forest fires had occurred in the previous 20 years, to higher elevation alpine areas (Rutherford 1972). Rutherford (1972) noted that the population had rapidly increased to about 100 animals by 1972, yet most observations were from the burned areas, with few sightings of mountain goats in alpine habitats. He also noted that the burned area contained rugged granitic outcroppings that provided good escape terrain.

Any activities that encouraged or facilitated mountain goat use of subalpine habitats may be highly detrimental to bighorn sheep. In Colorado, bighorn sheep populations that have exhibited robust growth rates have typically inhabited areas that included high-quality, lower elevation habitat, and the loss of low elevation winter range has been posed as a cause for poor performance of bighorn sheep in the Never Summer Range, RMNP (Goodson 1978, 1980, 1982). Existing populations of bighorn sheep in RMNP are thought to have relatively poor reproduction rates compared to other populations in Colorado (Stevens and Goodson 1993; McCarty and Miller 1998). Fecundity is usually considered to be a sensitive indicator of the health status of a population (Gaillard et al. 1998), thus we can reasonably infer that these populations are currently limited by an environmental factors rather than genetic potential. Any additional stressor, such as competition with mountain goats, may have an immediate and detrimental effect on such marginal bighorn sheep populations.

It seems unlikely to us that either continuation or modification of the current fire management program will have a major effect on whether or not goats voluntarily return to the Park, however. Given that goats have recently entered the Park, and that goat populations continue to exist in close proximity to it, it seems almost certain that goats will appear there again regardless of how fire is managed in the Park.

Literature Cited
Campbell, E.G. and R.L. Johnson. 1983. Food habits of mountain goats, mule deer, and cattle on

Colorado Natural Heritage Program. Report Generated on May 27, 1999. Global and State Rarity Ranks, Agency Sensitive Status, Federal and State Legal Status and State Habitat Description for Species Known from the Rocky Mountain National Park Project Area. Note: State habitat descriptions for individual sensitive plant species are provided in draft form.


Johnson, B.K., R.D. Schultz, and J.A. Bailey. 1978. Summer forages of mountain goats in the
Biological Bull. # 18. 196 pp.
Jones, G.W. and C.E. White, Jr. 1950. Colorado Game and Fish Federal Aid Quarterly Report,
Denver, 1:51-53.
Laundre*, J.W. 1990. The Status, Distribution, and Management of Mountain Goats in the Greater
Yellowstone Ecosystem. Final Report. NPS Order # PX 1200-8-0828. Idaho State University,
Pocatello. 58 pp.
Naturalist 54:114-121.
Lechleitner, R.R. 1969. Wild Mammals of Colorado: Their Appearance, Habits, Distribution and
36: 1180-1186.
McCarty, C.W. and M.W. Miller. 1998. Modeling the population dynamics of bighorn sheep: a
Olmsted, I.C. 1979. Alpine and subalpine vegetation under the influence of non-native mountain
goats, Olympic National Park. Proceedings of the Conference on Scientific Research in the
National Parks 5:1143-1148.
Mountains, with Special Reference to the West Rosebud and Stillwater Herds. Master Thesis.
Montana State University, Bozeman. 65 pp.
Peck, S.V. 1972. The Ecology of the Rocky Mountain Goat in the Spanish Peaks Area of
Pfistch, W.A. and L.C. Bliss. 1985. Seasonal forage availability and potential vegetation limitations to
a mountain goat population, Olympic National Park. The American Midland Naturalist
113(1):109-121.
Pike, D.K. 1981. Effects of Mountain Goats on Three Plant Species Unique to the Olympic
Reed, D.F. 1982. Rocky mountain goat-bighorn sheep competition study. W-144-R-1; Final Report
4; Big Game Investigations - Noncervids; Rocky Mountain Goat Investigations, Colorado
Division of Wildlife, Colorado.
Information Leaflet 90. 4pp.
Saunders, J.K., Jr. 1955. Food habits and range use of the Rocky Mountain goat in the Crazy
Mountains, Montana. J. Wildl. Manage. 19:129-137.
Singer, F.J. and J.L. Doherty. 1985. Movements and habitat use in an unhunted population of
Colorado Rare Plant Field Guide. Prepared for the Bureau of Land Management, the U.S.
Forest Service and the U.S. Fish and Wildlife Service by the Colorado Natural Heritage


Table 1. Percent composition of diets of mountain goats from studies reported by other authors (± 2 SE in parentheses where available).

<table>
<thead>
<tr>
<th>Sampling Period</th>
<th>Trees &amp; Shrubs</th>
<th>Grasses</th>
<th>Forbs</th>
<th>Ferns</th>
<th>Lichen</th>
<th>Moss</th>
<th>Method</th>
<th>Location</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 1952 &amp; 53</td>
<td>19.1</td>
<td>75.8</td>
<td>4.8</td>
<td>trace</td>
<td>Trace</td>
<td>-</td>
<td>1</td>
<td>Crazy Mtns, MT</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Summer 1952 &amp; 53</td>
<td>3.1</td>
<td>75.5</td>
<td>13.9</td>
<td>4.5</td>
<td>Trace</td>
<td>-</td>
<td>1</td>
<td>Crazy Mtns, MT</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Summer 1964</td>
<td>-</td>
<td>96.6</td>
<td>3.4</td>
<td></td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>Collegiate Range, CO</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Summer 1964</td>
<td>0.5</td>
<td>96.8</td>
<td>2.8</td>
<td></td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>Collegiate Range, CO</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Summer 1971</td>
<td>0</td>
<td>22.0</td>
<td>78.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Spanish Peaks, MT</td>
<td>Peck (1972)</td>
</tr>
<tr>
<td>Summer 1973</td>
<td>0</td>
<td>40.0</td>
<td>60.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Beartooth Mtns, MT</td>
<td>Pallister (1974)</td>
</tr>
<tr>
<td>Summer 1974</td>
<td>0</td>
<td>47.0</td>
<td>53.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Beartooth Mtns, MT</td>
<td>Stewart (1975)</td>
</tr>
<tr>
<td>Summer 1973 &amp; 75</td>
<td>7 (+6)</td>
<td>60 (+14)</td>
<td>29 (+14)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Collegiate Range, CO</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Summer 1980</td>
<td>79.0</td>
<td>11.0</td>
<td>9.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Sawtooth Range, MT</td>
<td>Thompson (1981)</td>
</tr>
<tr>
<td>Summer 1980</td>
<td>1.0</td>
<td>84.0</td>
<td>15.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Eagles Nest, CO</td>
<td>Thompson (1981)</td>
</tr>
<tr>
<td>Summer 1982</td>
<td>36.0</td>
<td>43.0</td>
<td>20.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>WA</td>
<td>Campbell &amp; Johnson (1983)</td>
</tr>
<tr>
<td>Summer 1977 &amp; 80</td>
<td>35.0</td>
<td>44.0</td>
<td>20.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>WA</td>
<td>Johnson (1983)</td>
</tr>
<tr>
<td>Summer 1979</td>
<td>0.7</td>
<td>11.0</td>
<td>88.3</td>
<td></td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>Niwot Ridge, CO</td>
<td>Dailey et al. (1984)</td>
</tr>
<tr>
<td>Fall 1952 &amp; 53</td>
<td>trace</td>
<td>74.7</td>
<td>21.5</td>
<td>trace</td>
<td>trace</td>
<td>-</td>
<td>1</td>
<td>Crazy Mtns, MT</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Fall 1964 &amp; 65</td>
<td>3.2</td>
<td>82.5</td>
<td>14.2</td>
<td></td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Collegiate Range, CO</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Fall 1991 - 93</td>
<td>0.4</td>
<td>75.6</td>
<td>19.6</td>
<td>2.3</td>
<td>trace</td>
<td>-</td>
<td>1</td>
<td>Absaroka Mtns, MT</td>
<td>Varley (1994)</td>
</tr>
<tr>
<td>Winter 1952-53</td>
<td>30.4</td>
<td>58.8</td>
<td>10.4</td>
<td>trace</td>
<td>trace</td>
<td>-</td>
<td>1</td>
<td>Crazy Mtns, MT</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Winter 1964-65</td>
<td>12.1</td>
<td>87.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>Collegiate Range, CO</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Winter</td>
<td>1.0</td>
<td>90.0</td>
<td>6.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Spanish Peaks, MT</td>
<td>Peck (1972)</td>
</tr>
<tr>
<td>----------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>-------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Winter 1970</td>
<td>13.4</td>
<td>0.9</td>
<td>2.8</td>
<td>81.7</td>
<td>trace</td>
<td>trace</td>
<td>1</td>
<td>Kenai Mtns, AK</td>
<td>Hjeljord (1973)</td>
</tr>
<tr>
<td>Winter 1979</td>
<td>51.0</td>
<td>47.0</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Sawtooth Range, MT</td>
<td>Thompson (1981)</td>
</tr>
<tr>
<td>Alpine ranges, winter 1978</td>
<td>35 (+13)</td>
<td>38 (+13)</td>
<td>28 (+11)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Sheep Mtn, CO</td>
<td>Adams &amp; Bailey (1983)</td>
</tr>
<tr>
<td>Subalpine ranges, winter 1978</td>
<td>44 (+8)</td>
<td>23 (+8)</td>
<td>34 (+11)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Sheep Mtn, CO</td>
<td>Adams &amp; Bailey (1983)</td>
</tr>
<tr>
<td>Subalpine ranges, winter 1979</td>
<td>51 (+6)</td>
<td>42 (+5)</td>
<td>5 (+3)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>Sheep Mtn, CO</td>
<td>Adams &amp; Bailey (1983)</td>
</tr>
<tr>
<td>Winter 1977-80</td>
<td>30.0</td>
<td>45.0</td>
<td>24.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>WA</td>
<td>Campbell &amp; Johnson (1983)</td>
</tr>
<tr>
<td>Winter 1982</td>
<td>65.0</td>
<td>31.0</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>WA</td>
<td>Johnson (1983)</td>
</tr>
<tr>
<td>Winter 1978-79</td>
<td>5.5</td>
<td>34.5</td>
<td>60.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>Niwot Ridge, CO</td>
<td>Dailey et al. (1984)</td>
</tr>
<tr>
<td>Winter 1979-80</td>
<td>20.3</td>
<td>21.3</td>
<td>58.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>Niwot Ridge, CO</td>
<td>Dailey et al. (1984)</td>
</tr>
<tr>
<td>Winter 1980-82**</td>
<td>44</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>18</td>
<td>31</td>
<td>1</td>
<td>SE Alaska</td>
<td>Fox &amp; Smith (1988)</td>
</tr>
<tr>
<td>Winter 1980-82***</td>
<td>40</td>
<td>trace</td>
<td>1</td>
<td>1</td>
<td>30</td>
<td>27</td>
<td>1</td>
<td>SE Alaska</td>
<td>Fox &amp; Smith (1988)</td>
</tr>
</tbody>
</table>

Methods:
1=relative density or abundance in fecal or rumen samples
2=percent of diet by forage removal
3=by direct observation of animals
* Snow depths 0-50 cm
** Snow depths 50-150 cm
*** Snow depths > 150 cm
Table 2. Plant species occurring in Colorado that are preferred food by mountain goats, by season of use.

<table>
<thead>
<tr>
<th>Genus and Species</th>
<th>Family</th>
<th>Life Form</th>
<th>Preference (Season)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adiantum sp.</td>
<td>Adiantaceae</td>
<td>Fern</td>
<td>High (W)</td>
<td>Hjelland (1983)</td>
</tr>
<tr>
<td>Polystichum lonchitis</td>
<td>Polypodiaceae</td>
<td>Fern</td>
<td>Low (S, F, W, S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Woodia scouliana</td>
<td>Polypodiaceae</td>
<td>Fern</td>
<td>High (S), Low (W)</td>
<td>Saunders (1955)  Saunders (1955)</td>
</tr>
<tr>
<td>Unidentified ferns</td>
<td>Polypodiaceae</td>
<td>Ferns</td>
<td>Low (S, F, W, S)</td>
<td>Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Carex albonigra</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Moderate (S)</td>
<td>Pallister (1974)</td>
</tr>
<tr>
<td>Carex engelmanii</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Carex festivilla</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Moderate (F, S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Carex geyeri</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Low (S), Moderate (Sp)</td>
<td>Casebeer (1948)  Saunders (1955)</td>
</tr>
<tr>
<td>Carex nigricans</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Moderate to low (S)</td>
<td>Pfitsch and Bliss (1985)</td>
</tr>
<tr>
<td>Carex phaeocephala</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Moderate (F, S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Carex rossii</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Pfitsch and Bliss (1985)</td>
</tr>
<tr>
<td>Kobresia myosuroides</td>
<td>Cyperaceae</td>
<td>Graminoid</td>
<td>High (S/W), Low (S)</td>
<td>Hibbs (1967)  Johnson et al. (1978)</td>
</tr>
<tr>
<td>Synonym: K. bellardi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juncus parryi</td>
<td>Juncaceae</td>
<td>Graminoid</td>
<td>Very low (S), High (S), NA (F)</td>
<td>Casebeer (1948)  Saunders (1955)  Saunders (1955)</td>
</tr>
<tr>
<td>Juncus spp.</td>
<td>Juncaceae</td>
<td>Graminoid</td>
<td>High (S), High (F), Low (S)</td>
<td>Saunders (1955)  Varley (1994)  Johnson et al. (1978)</td>
</tr>
<tr>
<td>Luzula parviflora</td>
<td>Juncaceae</td>
<td>Graminoid</td>
<td>Moderate (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Luzula spicata</td>
<td>Juncaceae</td>
<td>Graminoid</td>
<td>High (S), NA (F), Low (W)</td>
<td>Saunders (1955)  Saunders (1955)  Peck (1972)</td>
</tr>
<tr>
<td>Luzula spp.</td>
<td>Juncaceae</td>
<td>Graminoids</td>
<td>Low (S), Moderate (F), Low (S)</td>
<td>Hibbs (1967)  Varley (1994)  Johnson et al. (1978)</td>
</tr>
<tr>
<td>Allium cernuum</td>
<td>Liliaceae</td>
<td>Monocot</td>
<td>Low (S, Sp)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Smilacinia racemosa</td>
<td>Liliaceae</td>
<td>Monocot</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Smilacinia spp.</td>
<td>Liliaceae</td>
<td>Monocot</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Zygadenus elegans</td>
<td>Liliaceae</td>
<td>Monocot</td>
<td>High (S)</td>
<td>Cowan (1944)</td>
</tr>
<tr>
<td>Agropyron dasystachyum</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (S), NA (S)</td>
<td>Cowan (1944)  Herbert and McTaggard Cowan (1971)</td>
</tr>
<tr>
<td>Agropyron latiglume</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Moderate (S), NA (F)</td>
<td>Saunders (1955)  Saunders (1955)</td>
</tr>
<tr>
<td>Agropyron scribnieri</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (S), W, High (S), Moderate (S), NA (F)</td>
<td>Hibbs (1967)  Johnson et al. (1978)  Saunders (1955)  Saunders (1955)</td>
</tr>
<tr>
<td>Agropyron subsecundum</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S), NA (F)</td>
<td>Saunders (1955)  Saunders (1955)</td>
</tr>
<tr>
<td>Agropyron spp.</td>
<td>Poaceae</td>
<td>Graminoids</td>
<td>High (F), Low (W), Moderate to high (S), High (S)</td>
<td>Varley (1994)  Peck (1972)  Stewart (1975)  Johnson (1983)</td>
</tr>
<tr>
<td>Species</td>
<td>Family</td>
<td>Class</td>
<td>Water Quality</td>
<td>Reference</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------</td>
<td>-----------</td>
<td>---------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>Agrostis humilis</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Agrostis scabra</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (F), Low (S), NA (F), Low (S)</td>
<td>Varley (1994); Saunders (1955); Saunders (1955); Thompson (1981)</td>
</tr>
<tr>
<td>Avena spp.</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Bouteloua gracilis</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Bromus anomalus</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Moderate (S)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Bromus spp.</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W), Low (S), Low (S, F, W, Sp)</td>
<td>Adams and Bailey (1983); Dailey et al. (1984); Johnson (1983)</td>
</tr>
<tr>
<td>Calamagrostis canadensis</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Calamagrostis rubescens</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (S), Moderate (S, F, W, Sp)</td>
<td>Herbert and McTaggart Cowan (1971); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Calamagrostis spp.</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W), High (S), Moderate (S), Moderate to low (W)</td>
<td>Adams and Bailey (1983); Dailey et al. (1984); Johnson (1983)</td>
</tr>
<tr>
<td>Danthonia intermedia</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (F), Moderate (S)</td>
<td>Saunders (1955); Pfitsch and Bliss (1985)</td>
</tr>
<tr>
<td>Deschampsia atropurpurea</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S), NA (F)</td>
<td>Saunders (1955); Hibbs (1967); Varley (1994); Johnson et al. (1978); Saunders (1955)</td>
</tr>
<tr>
<td>Deschampsia caespitiosa</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S), Moderate (F), Moderate (S), Moderate (S), NA (F)</td>
<td>Hibbs (1967); Varley (1994); Johnson et al. (1978); Saunders (1955)</td>
</tr>
<tr>
<td>Elymus elymoides Syn.: Sitanion hystrix</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W), Low (S, F, W, Sp)</td>
<td>Adams and Bailey (1983); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Elymus spp.</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (F)</td>
<td>Varley (1994)</td>
</tr>
<tr>
<td>Festuca arizonica</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (W), High (W)</td>
<td>Hibbs (1967); Adams and Bailey (1983)</td>
</tr>
<tr>
<td>Festuca idahoensis</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (F), High (S), Na (S), High (S, F, W, Sp)</td>
<td>Saunders (1955); Pfitsch and Bliss (1985); Herbert and McTaggart Cowan (1971); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Festuca ovina var. brachyphylla</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W), Moderate (F), High (W), Moderate (S), NA (F)</td>
<td>Hibbs (1967); Varley (1994); Adams and Bailey (1983); Saunders (1955); Saunders (1955)</td>
</tr>
<tr>
<td>Festuca Thurberi</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Festuca spp.</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Moderate (S), High (W), Moderate (S), Moderate to high (W)</td>
<td>Thompson (1981); Thompson (1981); Johnson (1983); Johnson (1983)</td>
</tr>
<tr>
<td>Helictotrichon mortoni ana</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Koeleria macrantha Syn.: K. cristata</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (W), Low (S), Low (F), Moderate (S), Low (S, F, W, Sp)</td>
<td>Casebeer (1948); Hibbs (1967); Varley (1994); Johnson et al. (1978); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Muhlenbergia montana</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (S), High (W), Moderate (S)</td>
<td>Hibbs (1967); Adams and Bailey (1983); Johnson et al. (1978)</td>
</tr>
<tr>
<td>Phleum alpinum</td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S), NA (F), Moderate (S), Moderate (S, F, W, Sp)</td>
<td>Saunders (1955); Hibbs (1967); Varley (1994); Johnson et al. (1978); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Species</td>
<td>Family</td>
<td>Lifeform</td>
<td>Description</td>
<td>References</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------</td>
<td>----------------</td>
<td>------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td><em>Phleum s pp.</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W)</td>
<td>Adams and Bailey (1983)</td>
</tr>
<tr>
<td><em>Poa alpina</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S); High (S)NA (F, Sp)</td>
<td>Casebeer (1948); Saunders (1955); Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa arctica</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa cusickii</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa epilis</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Moderate (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa fendleriana</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa pattersonii</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa rupicola</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (S)NA (F)</td>
<td>Saunders (1955); Saunders (1955)</td>
</tr>
<tr>
<td><em>Poa spp.</em></td>
<td>Poaceae</td>
<td>Graminoids</td>
<td>High (S, W); High (F); High (S)NA (F); High (S)Moderate to low (S); High (S)Moderate to high (S, W); Moderate (S, F, W, Sp)</td>
<td>Hibbs (1967); Varley (1994); Johnson et al. (1978); Pallister (1974); Thompson (1981); Stewart (1975); Johnson (1983)</td>
</tr>
<tr>
<td><em>Stipa comata</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (S)</td>
<td>Herbert and McTaggart Cowan (1971)</td>
</tr>
<tr>
<td><em>Stipa robusta</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W); Low (S)</td>
<td>Hibbs (1967); Johnson et al. (1978)</td>
</tr>
<tr>
<td><em>Stipa spp.</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>Low (W)Na (S); Low (S, F, W, Sp)</td>
<td>Adams and Bailey (1983); Herbert and McTaggart Cowan (1971); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td><em>Trisetum spicatum</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>High (S)Moderate (S)Moderate (F); Low (S)Moderate (S)NA (F); Low (S)NA (S)</td>
<td>Cowan (1944); Hibbs (1967); Varley (1994); Johnson et al. (1978); Saunders (1955); Saunders (1955); Pfisth and Bliss (1985); Herbert and McTaggart Cowan (1971)</td>
</tr>
<tr>
<td><em>Trisetum wolffii</em></td>
<td>Poaceae</td>
<td>Graminoid</td>
<td>NA (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Heracleum lanatum</em></td>
<td>Apiaceae</td>
<td>Forb</td>
<td>Moderate (S)Moderate (F)Low (W)</td>
<td>Hibbs (1967); Saunders (1955); Peck (1972)</td>
</tr>
<tr>
<td><em>Lomatium foeniculaceum</em></td>
<td>Apiaceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Oreoxis spp.</em></td>
<td>Apiaceae</td>
<td>Forbs</td>
<td>Low (W)</td>
<td>Adams and Bailey (1983)</td>
</tr>
<tr>
<td><em>Achillea millefolium</em> (var. occidentalis) Syn. = A. lanulosa*</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Very low (S); Low (F); Low (F, W, Sp); Low (S); Low (W); Moderate to low (S); Moderate (S, F); Low (W, Sp)</td>
<td>Casebeer (1948); Varley (1994); Johnson et al. (1978); Saunders (1955); Pfisth and Bliss (1985); Peck (1972); Johnson (1983); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td><em>Agoseris glauca</em></td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Agoseris spp.</em></td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>High (S); Low (S)</td>
<td>Pfisth and Bliss (1985); Peck (1972)</td>
</tr>
<tr>
<td><em>Antennaria alpina</em></td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (W)</td>
<td>Peck (1972)</td>
</tr>
<tr>
<td><em>Antennaria media</em></td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Antennaria rosea</em></td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td>Casebeer (1948)</td>
</tr>
<tr>
<td><em>Antennaria spp.</em></td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Low (F); Low (S)</td>
<td>Varley (1994); Johnson et al. (1978)</td>
</tr>
<tr>
<td><em>Arnica cordifolia</em></td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Arnica latifolia</em></td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Very low (S); High (S)</td>
<td>Casebeer (1948); Stewart (1975)</td>
</tr>
<tr>
<td><em>Arnica spp.</em></td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Low (F); Low (S)</td>
<td>Varley (1994); Pfisth and</td>
</tr>
<tr>
<td>Species</td>
<td>Family</td>
<td>Life Form</td>
<td>Phenology</td>
<td>Notes</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Artemisia franseroides</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>High (W)</td>
<td>Adams and Bailey (1983)</td>
</tr>
<tr>
<td>Artemisia ludoviciana</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>High (W)/Moderate (S)</td>
<td>Adams and Bailey (1983); Pfiffisch and Bliss (1985)</td>
</tr>
<tr>
<td>Artemisia norvegica</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>High (W)</td>
<td>Adams and Bailey (1983)</td>
</tr>
<tr>
<td>Artemisia scopulorum</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>High (W)/Low (S)</td>
<td>Adams and Bailey (1983); Johnson et al. (1978)</td>
</tr>
<tr>
<td>Aster spp.</td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Low (F)/Low (S)</td>
<td>Varley (1994); Pallister (1974)</td>
</tr>
<tr>
<td>Aster foliaceous</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Moderate (S)</td>
<td>Olmstead (1979)</td>
</tr>
<tr>
<td>Cirsium spp.</td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Low (S)/Low (F)</td>
<td>Johnson et al. (1978); Saunders (1955)</td>
</tr>
<tr>
<td>Erigeron compositus</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Erigeron formosissimus</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Erigeron peregrinus</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>High (S)</td>
<td>Pfiffisch and Bliss (1985)</td>
</tr>
<tr>
<td>Erigeron simplex</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Erigeron subirinervis</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Moderate to low (S)</td>
<td>Pfiffisch and Bliss (1985)</td>
</tr>
<tr>
<td>Erigeron spp.</td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Low (F)/Low (S)/Low (S)/High (S)/Low (S, F, W, Sp)</td>
<td>Varley (1994); Johnson et al. (1978); Peck (1972); Stewart (1975); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Hieracium spp</td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Moderate (S, F, Sp)/Low (W)</td>
<td>Campbell and Johnson (1983); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Senecio crassulus</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>High (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Senecio saxosus</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Senecio triangularis</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Very low (S)/High (F)</td>
<td>Casebeer (1948); Saunders (1955)</td>
</tr>
<tr>
<td>Senecio spp.</td>
<td>Asteraceae</td>
<td>Forbs</td>
<td>Low (S)/Low (F)/Low (S)/High (S)/Moderate to low (W)/Low (S)/Moderate (S, F, Sp)/Low (W)</td>
<td>Hibbs (1967); Varley (1994); Johnson et al. (1978); Peck (1972); Peck (1972); Pallister (1974); Campbell and Johnson (1983); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Solidago multiradiata</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Solidago sp.</td>
<td>Asteraceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Eritrichium elongatum</td>
<td>Boraginaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Lithospermum spp.</td>
<td>Boraginaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Mertensia alpina</td>
<td>Boraginaceae</td>
<td>Forb</td>
<td>High (S)/Low (F)/High (S)</td>
<td>Jones and White (1950); Varley (1994); Pallister (1974)</td>
</tr>
<tr>
<td>Mertensia ciliata</td>
<td>Boraginaceae</td>
<td>Forb</td>
<td>High (S, F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Mertensia spp.</td>
<td>Boraginaceae</td>
<td>Forbs</td>
<td>High (S)/High (S)/Moderate to low (S)/High (S)/Low (W)</td>
<td>Johnson et al. (1978); Pallister (1974); Johnson (1983); Peck (1972); Peck (1972)</td>
</tr>
<tr>
<td>Descurainia sp.</td>
<td>Brassicaceae</td>
<td>Forb</td>
<td>Low (W)/Low (S)/Moderate to low (S)</td>
<td>Adams and Bailey (1983); Johnson et al. (1978); Thompson (1981)</td>
</tr>
<tr>
<td>Draba spp.</td>
<td>Brassicaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Ervysium spp.</td>
<td>Brassicaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Lesquerella spp.</td>
<td>Brassicaceae</td>
<td>Forb</td>
<td>Low (W)/Moderate to low (S)</td>
<td>Adams and Bailey (1983); Thompson (1981)</td>
</tr>
<tr>
<td>Campanula rotundifolia</td>
<td>Campanulaceae</td>
<td>Forb</td>
<td>Low (F)/High (S)</td>
<td>Saunders (1955); Pfiffisch and</td>
</tr>
<tr>
<td>Common Name</td>
<td>Family</td>
<td>Type</td>
<td>Seasonality</td>
<td>Acknowledgments</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------</td>
<td>-------</td>
<td>-------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><em>Campanula spp.</em></td>
<td>Campanulaceae</td>
<td>Forbs</td>
<td>High (S)Low (S)</td>
<td>Bliss (1985)</td>
</tr>
<tr>
<td><em>Arenaria congesta</em></td>
<td>Caryophyllaceae</td>
<td>Forbs</td>
<td>Low (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Arenaria fendleri</em></td>
<td>Caryophyllaceae</td>
<td>Forbs</td>
<td>Moderate (S)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td><em>Arenaria obtusiloba</em></td>
<td>Caryophyllaceae</td>
<td>Forbs</td>
<td>Low (F)</td>
<td>Varley (1994)</td>
</tr>
<tr>
<td><em>Cerastium arvense</em></td>
<td>Caryophyllaceae</td>
<td>Forbs</td>
<td>Low (F)Moderate (S)Low (S, F, W, Sp)</td>
<td>Varley (1994)Johnson et al. (1978)Saunders (1955)</td>
</tr>
<tr>
<td><em>Silene acaulis</em></td>
<td>Caryophyllaceae</td>
<td>Forbs</td>
<td>Low (F)Low (F)</td>
<td>Varley (1994)Saunders (1955)</td>
</tr>
<tr>
<td><em>Silene spp.</em></td>
<td>Caryophyllaceae</td>
<td>Forbs</td>
<td>High (S)Low (W)</td>
<td>Pfistch and Bliss (1985)Johnson (1983)</td>
</tr>
<tr>
<td><em>Sedum lanceolatum</em></td>
<td>Crassulaceae</td>
<td>Forbs</td>
<td>Moderate (F)</td>
<td>Varley (1994)</td>
</tr>
<tr>
<td><em>Sedum stenopetalum</em></td>
<td>Crassulaceae</td>
<td>Forbs</td>
<td>Low (S)Low (S, W)Low (W)</td>
<td>Casebeer (1948)Saunders (1955)Peck (1972)</td>
</tr>
<tr>
<td><em>Asiagalis alpinus</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>High (S)Low (F)</td>
<td>Cowan (1944)Saunders (1955)</td>
</tr>
<tr>
<td><em>Hedysarum occidentale</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>High (S)</td>
<td>Pfistch and Bliss (1985)</td>
</tr>
<tr>
<td><em>Lupinus argenteus</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>Moderate (F)</td>
<td>Varley (1994)</td>
</tr>
<tr>
<td><em>Oxycopit sericea</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>Moderate (W)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Trifolium dasyphyllum</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>High (S)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td><em>Trifolium nanum</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>High (S)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td><em>Trifolium parvifolium</em></td>
<td>Fabaceae</td>
<td>Forbs</td>
<td>High (S)</td>
<td>Pallister (1974)</td>
</tr>
<tr>
<td><em>Gentiana spp.</em></td>
<td>Gentianaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td><em>Sveria radiata</em> (Syn. = Frasca speciosa)</td>
<td>Gentianaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Phacelia sericea</em></td>
<td>Hydrophyllaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Hypericum formosum Syn.: H. scouleri</em></td>
<td>Hypericaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Casebeer (1948)</td>
</tr>
<tr>
<td><em>Phlox diffusa</em></td>
<td>Polemoniaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Pfistch and Bliss (1985)</td>
</tr>
<tr>
<td><em>Phlox multiflora</em></td>
<td>Polemoniaceae</td>
<td>Forbs</td>
<td>Low (F)</td>
<td>Varley (1994)</td>
</tr>
<tr>
<td><em>Polemonium viscosum</em></td>
<td>Polemoniaceae</td>
<td>Forbs</td>
<td>Low (W)High (S)</td>
<td>Peck (1972)Pallister (1974)</td>
</tr>
<tr>
<td><em>Polemonium spp.</em></td>
<td>Polemoniaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td><em>Eriogonum flavum</em></td>
<td>Polygonaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td><em>Eriogonum ovatifolium</em></td>
<td>Polygonaceae</td>
<td>Forbs</td>
<td>Low (F)High (W)</td>
<td>Saunders (1955)Saunders (1955)</td>
</tr>
<tr>
<td><em>Eriogonum umbellatum</em></td>
<td>Polygonaceae</td>
<td>Forbs</td>
<td>Very low</td>
<td>Casebeer (1948)Johnson et al. (1978)</td>
</tr>
<tr>
<td>Plant Name</td>
<td>Family</td>
<td>Type</td>
<td>(S)</td>
<td>(F)</td>
</tr>
<tr>
<td>----------------------------</td>
<td>--------------</td>
<td>---------</td>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Oxyria digyna</td>
<td>Polygonaceae</td>
<td>Forb</td>
<td>High (S)Low (F)</td>
<td></td>
</tr>
<tr>
<td>Polygonum viviparum</td>
<td>Polygonaceae</td>
<td>Forb</td>
<td>Low (S)Low (S,F)High (S)</td>
<td></td>
</tr>
<tr>
<td>Rumex spp.</td>
<td>Polygonaceae</td>
<td>Forbs</td>
<td>Low (F)</td>
<td></td>
</tr>
<tr>
<td>Actaea arctica</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Anemone spp.</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Aquilegia flabescens</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (W)</td>
<td></td>
</tr>
<tr>
<td>Aquilegia spp.</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Callichia lepissopala</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Moderate to low (S)</td>
<td></td>
</tr>
<tr>
<td>Clematis pseudocultiva (C.</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Delphinium hicolor</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Ranunculaceae</td>
<td>Ranunculaceae</td>
<td>Forbs</td>
<td>Low (S)Low (S)</td>
<td></td>
</tr>
<tr>
<td>Thalictrum dasycarpum</td>
<td>Ranunculaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Fragaria ovalis Syn.:F. glauca</td>
<td>Rosaceae</td>
<td>Forb</td>
<td>High (S)</td>
<td></td>
</tr>
<tr>
<td>Geum rossii</td>
<td>Rosaceae</td>
<td>Forb</td>
<td>High (W)High (S)</td>
<td></td>
</tr>
<tr>
<td>Potentilla diversifolia</td>
<td>Rosaceae</td>
<td>Forb</td>
<td>High (S)Low (F)</td>
<td></td>
</tr>
<tr>
<td>Potentilla glandulosa</td>
<td>Rosaceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td></td>
</tr>
<tr>
<td>Potentilla nivea</td>
<td>Rosaceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td></td>
</tr>
<tr>
<td>Sibbaldia procumbens</td>
<td>Rosaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Galium boreale</td>
<td>Rubiaceae</td>
<td>Forb</td>
<td>Low (S,F)</td>
<td></td>
</tr>
<tr>
<td>Heuchera bracteata</td>
<td>Saxifragaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Heuchera spp.</td>
<td>Saxifragaceae</td>
<td>Forb</td>
<td>Low (W)Moderate to low (S)Low (S)Moderate to low (S)Low (S)Low (S,F,Sp)Low (W)</td>
<td>Peck (1972)Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Saxifraga bronchialis</td>
<td>Saxifragaceae</td>
<td>Frob</td>
<td>Low (S,F,W)Low (W)</td>
<td></td>
</tr>
<tr>
<td>Saxifraga montanensis</td>
<td>Saxifragaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td></td>
</tr>
<tr>
<td>Saxifraga spp.</td>
<td>Saxifragaceae</td>
<td>Forbs</td>
<td>Low (F)Low (S)</td>
<td></td>
</tr>
<tr>
<td>Besseva cinerea</td>
<td>Scrophulariaceae</td>
<td>Forb</td>
<td>Low (S,F)</td>
<td></td>
</tr>
<tr>
<td>Pedicularis groenlandica</td>
<td>Scrophulariaceae</td>
<td>Forb</td>
<td>Moderate (S)Low (S)</td>
<td></td>
</tr>
<tr>
<td>Penstemon attenuatus</td>
<td>Scrophulariaceae</td>
<td>Forb</td>
<td>Low (F)</td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
<td>------------------</td>
<td>-------</td>
<td>---------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Veronica wormskjoldii</td>
<td>Scrophulariaceae</td>
<td>Forb</td>
<td>Very low (S)Low (S, F)</td>
<td>Casebeer (1948)Saunders (1955)</td>
</tr>
<tr>
<td>Verbascum sp.</td>
<td>Scrophulariaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td>Johnson (1983)</td>
</tr>
<tr>
<td>Solanum spp.</td>
<td>Solanaceae</td>
<td>Forbs</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Viola adunca</td>
<td>Violaceae</td>
<td>Forb</td>
<td>Low (S)</td>
<td>Pfitsch and Bliss (1985)</td>
</tr>
<tr>
<td>Artemisia frigida</td>
<td>Asteraceae</td>
<td>Subshrub</td>
<td>High (W)</td>
<td>Adams and Bailey (1983)</td>
</tr>
<tr>
<td>Gutierrezia sarothrae</td>
<td>Asteraceae</td>
<td>Subshrub</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Apocynum androsaemifolium</td>
<td>Apocynaceae</td>
<td>Shrub</td>
<td>Low (F)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Artemisia michauxiana</td>
<td>Asteraceae</td>
<td>Shrub</td>
<td>Low (S, F, W)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Berberis repens</td>
<td>Berberidaceae</td>
<td>Shrub</td>
<td>High (W)Moderate (Sp)Low (S, F)</td>
<td>Campbell and Johnson (1983)Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Alnus spp.</td>
<td>Betulaceae</td>
<td>Shrub</td>
<td>Low (W)</td>
<td>Peck (1972)</td>
</tr>
<tr>
<td>Betula glandulosa</td>
<td>Betulaceae</td>
<td>Shrub</td>
<td>High (W)Low (S)</td>
<td>Cowan (1944)Hibbs (1967)</td>
</tr>
<tr>
<td>Sambucus pubens</td>
<td>Caprifoliaceae</td>
<td>Shrub</td>
<td>Moderate (W)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Symphoricarpos albus</td>
<td>Caprifoliaceae</td>
<td>Shrub</td>
<td>Moderate (S, F, W, Sp)</td>
<td>Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Cornus sericea Syn.: C. stolonifera</td>
<td>Cornaceae</td>
<td>Shrub</td>
<td>High (W)</td>
<td>Cowan (1944)</td>
</tr>
<tr>
<td>Juniperus communis</td>
<td>Cupressaceae</td>
<td>Shrub</td>
<td>Low (S, W, Sp)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Kalmia polifolia</td>
<td>Ericaceae</td>
<td>Shrub</td>
<td>Low (Sp)</td>
<td>Saunders (1955)</td>
</tr>
<tr>
<td>Vaccinium scoparium</td>
<td>Ericaceae</td>
<td>Shrub</td>
<td>Moderate (S)Moderate</td>
<td>Casebeer (1948)Saunders (1955)</td>
</tr>
<tr>
<td>Specie</td>
<td>Family</td>
<td>Type</td>
<td>Activity Levels</td>
<td>References</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------</td>
<td>----------</td>
<td>-----------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Vaccinium spp.</td>
<td>Ericaceae</td>
<td>Shrubs</td>
<td>Low (S)Low (F)</td>
<td>Hibbs (1967); Johnson et al. (1978); Peck (1972)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(W)</td>
<td></td>
</tr>
<tr>
<td>Ribes cereum</td>
<td>Grossulariaceae</td>
<td>Shrubs</td>
<td>Low (W)</td>
<td>Hibbs (1967)</td>
</tr>
<tr>
<td>Ribes lacustre</td>
<td>Grossulariaceae</td>
<td>Shrubs</td>
<td>Low to moderate (F, Sp)</td>
<td>Saunders (1955); Saunders (1955)</td>
</tr>
<tr>
<td>Ribes spp.</td>
<td>Grossulariaceae</td>
<td>Shrubs</td>
<td>High (Sp) Low (W)</td>
<td>Anderson (1940); Adams and Bailey (1983) Johnson et al. (1978); Johnson (1983); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate to high (W)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low (W, Sp)</td>
<td></td>
</tr>
<tr>
<td>Ceanothus velutinus</td>
<td>Rhamnaceae</td>
<td>Shrubs</td>
<td>Low (S)High (W)</td>
<td>Saunders (1955); Campbell and Johnson (1983) Johnson et al. (1978)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate (Sp) Low (S, F)</td>
<td></td>
</tr>
<tr>
<td>Ceanothus spp.</td>
<td>Rhamnaceae</td>
<td>Shrubs</td>
<td>Moderate (W)Low (W)</td>
<td>Thompson (1981); Johnson (1983)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate to high (W)</td>
<td></td>
</tr>
<tr>
<td>Amelanchier alnifolia</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>NA (S)High (W, F) Moderate (Sp) Low (S)</td>
<td>Herbert and McTaggard Cowan (1971); Campbell and Johnson (1983); Campbell and Johnson (1983); Richardson (1971)</td>
</tr>
<tr>
<td>Amelanchier spp.</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>High (W)Low (W) Moderate (W)</td>
<td>Anderson (1950); Adams and Bailey (1983); Johnson (1983)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moderate (W)</td>
<td></td>
</tr>
<tr>
<td>Cercocarpus montanus</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Low (W)High (S)</td>
<td>Hibbs (1967); Johnson et al. (1978)</td>
</tr>
<tr>
<td>Drusas octopetala</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Moderate (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Holodiscus spp.</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Low (W)</td>
<td>Adams and Bailey (1983)</td>
</tr>
<tr>
<td>Physocarpus malvaceus</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Moderate (S, F, W, Sp)</td>
<td>Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Physocarpus spp.</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Low (W)Low (S)</td>
<td>Adams and Bailey (1983); Johnson et al. (1978)</td>
</tr>
<tr>
<td>Potentilla fruticosa Syn.: Pentaphylloides floribunda</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Low (S)Moderate (S, Low (Sp)</td>
<td>Hibbs (1967); Saunders (1955)</td>
</tr>
<tr>
<td>Prunus virginiana</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Moderate (S, F, W, Sp)</td>
<td>Richardson (1971) DEALING S</td>
</tr>
<tr>
<td>Prunus spp.</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Moderate (F)Low (S, W, Sp)</td>
<td>Campbell and Johnson (1983); Thompson (1981)</td>
</tr>
<tr>
<td>Rosa nutkana</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Moderate (S, F)Low (W, Sp)</td>
<td>Campbell and Johnson (1983); Thompson (1981)</td>
</tr>
<tr>
<td>Rosa spp.</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Low (W)Moderate (S)</td>
<td>Adams and Bailey (1983); Thompson (1981)</td>
</tr>
<tr>
<td>Rubus spp.</td>
<td>Rosaceae</td>
<td>Shrubs</td>
<td>Low (S, W)Moderate (S, F, W, Sp)</td>
<td>Thompson (1981); Campbell and Johnson (1983)</td>
</tr>
<tr>
<td>Salix nivalis</td>
<td>Salicaceae</td>
<td>Shrubs</td>
<td>High (W)</td>
<td>Pike (1981)</td>
</tr>
<tr>
<td>Salix spp.</td>
<td>Salicaceae</td>
<td>Shrubs</td>
<td>Low (S, W)Low (W)</td>
<td>Hibbs (1967); Varley</td>
</tr>
</tbody>
</table>

- 117 -
<table>
<thead>
<tr>
<th>Species</th>
<th>Family</th>
<th>Life Form</th>
<th>Growth Rate</th>
<th>Other Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juniperus scopulorum</td>
<td>Cupressaceae</td>
<td>Tree</td>
<td>Low (S, W, Sp) NA (S)</td>
<td>Saunders (1955) Herbert and McTaggart Cowan (1971)</td>
</tr>
<tr>
<td>Abies lasiocarpa</td>
<td>Pinaceae</td>
<td>Tree</td>
<td>High (W)High (W, Sp) Low (S, F)</td>
<td>Cowan (1944), Saunders (1955)</td>
</tr>
<tr>
<td>Pinus contorta</td>
<td>Pinaceae</td>
<td>Tree</td>
<td>Low (S)</td>
<td>Johnson et al. (1978)</td>
</tr>
<tr>
<td>Populus tremuloides</td>
<td>Salicaceae</td>
<td>Tree</td>
<td>Moderate (S) Low (S) NA (S)</td>
<td>Anderson (1940), Saunders (1955), Herbert and McTaggart Cowan (1971)</td>
</tr>
</tbody>
</table>

(W) = Winter use  
(Sp) = Spring use  
(S) = Summer use  
(F) = Fall use  
NA = Not available
APPENDIX 1. Community Types in RMNP which might be Utilized by Mountain Goats

Tundra Communities

According to Marr (1967) the alpine tundra is found on all gently rolling meadows, ridges, and peaks rising above timberline at approximately 11,400 feet. Winters are very cold and severe, with strong winds and blizzards. Summer is typically short, cool to cold with frequent thunderstorms. Some areas are snow free for most of the year while others may be covered with snow for 11 months of the year. The alpine environment may contribute up to 20% of all stream flow from the mountains. Overall, soils are very rocky except for those sites where relatively fine grained material has collected over time. Vegetation is influenced by snow fields in terms of how these affect the length of the growing season and other environmental factors. The result is a mosaic of plant associations, some just a few inches in diameter. Marr (1967) described a total of 10 plant associations, which are presented as follows.

(1) The Kobresia meadow occurs in areas relatively snow free for most of the year. The dominant plant species is Kobresia myosuroides [kobresia, Cyperaceae (synonym: K. bellardi)] which grows in tight tufts, often crowding out other species. These meadows occur on level to gently rolling sites where soils are very stable.

Common associates are forb species such as Arenaria obtusiloba (sandwort, Caryophyllaceae), Campanula uniflora (harebell, Campanulaceae), Geum rossii (Ross avens, Rosaceae), Trifolium dasyphyllum and T. nanum (clover, Fabaceae), Phlox pulvinata (phlox, Polemoniaceae), Polygonum bistortoides and P. viviparum (bistort, Polygonaceae), Draba spp. (whitlow-wort, Brassicaceae), and Silene acaulis (moss pink, Caryophyllaceae). Poa arctica (arctic bluegrass, Poaceae) and Carex scopulorum (sedge, Cyperaceae) are two noteworthy graminoids encountered in this association.

(2) The Hairgrass stand represents the best development of a true grass meadow in the alpine tundra. It is dominated by Deschampsia caespitosa (tufted hairgrass, Poaceae) and by sedges. Stands may be small or cover several acres. Basal cover was estimated at 60%, with foliage spreading over the bare ground. This type appears to be more tolerant of snow cover, which may persist until mid summer. Carex spp., Polygonum bistortoides, and Geum rossii are very common within hairgrass stands.

(3) The Parry's Clover meadow occur in shallow depressions which favor snow accumulations in cycles of snow melt and repeated accumulation. The results are concentric zones of this vegetation type which are relatively stable.

Common associates are other graminoids and forbs. Graminoids are composed by Carex scopulorum, C. athrostachya, and C. rupestris, as well as Poa arctica and Kobresia myosuroides. Forbs include Geum rossii, Trifolium parryi and T. dasyphyllum, Polygonum spp., Silene acaulis, Arenaria obtusiloba, Artemisia scopulorum (herbaceous sage, Asteraceae), Sedum lanceolatus (stonecrop, Crassulaceae), and the fern ally Selaginella densa (rock selaginella, Selaginellaceae). Also, Salix nivalis (snow willow, Salicaceae) is a dwarf shrub associate.

(4) The Adoneus Buttercup type occurs on sites with greater topographic relief which hold snow till later in the summer, allowing for a profusion of Ranunculus adoneus (adoneus or snow buttercup, Ranunculaceae). Other species eventually obscure the buttercups, as the season progresses. Stands have irregular shapes, overlapping with stands of Kobresia myosuroides.

Common associates are forbs such as Polygonum spp., Trifolium spp., Arenaria spp., Artemisia
APPENDIX 2. Detailed Information on Forage Preferences of Mountain Goats

A. Summer

1. Graminoids

Hibbs (1967) remarked that the graminoids most utilized by goats in central Colorado were *Kobresia myosuroides* (cited by Hibbs as *K. bellardi*), *Agropyron scirpoides* (Scribner wheatgrass, Poaceae), *Poa* spp., *Carex* spp., and *Luzula* spp. *Agropyron scirpoides* had the highest preference rating of any of the plants utilized (6.7%). *Kobresia myosuroides* had a much lower preference rating, but was the second most abundant species in the study area.

In Montana, Saunders (1955) reported heavy use of *Deschampsia caespitosa*, *Festuca ovina* (sheep fescue, Poaceae), *Poa alpina* and *P. arctica*, high-elevation *Carex* spp., and *Juncus* spp. According to a study by Varley (1994), *Carex* spp., *Juncus* spp., *Poa* spp., *Festuca ovina*, *Luzula* spp., and *Deschampsia caespitosa* were selected by goats in this respective order.

In Washington, *Festuca idahoensis* was a most preferred forage species by goats at Olympic National Park (Pfitsch and Bliss 1985). Olmsted (1979) listed the plant families on which goats forage the most within Olympic National Park. The Poaceae were utilized the most among graminoids. *Festuca idahoensis* was utilized in all habitats where it occurred.

In Alaska, Hjeljord (1973) stated that very few graminoids were selected as forage by goats in the summer, except for *Carex*, *Poa*, and *Festuca* spp. Long-awned sedge and Tolmies sedge (scientific names not provided) were preferred graminoids, as well as *Poa stenantha* (bog bluegrass, Poaceae).

In the Tundra Community of RMNP, high summer utilization by goats may be expected for the following genera: *Carex*, *Kobresia*, *Luzula*, and *Poa* (particularly *P. alpina*). Moderate utilization may occur for *Carex albonigra*, *Deschampsia caespitosa*, and *Trisetum spicatum*. *Juncus* spp. may be grazed heavily or in low quantities. The monocot *Zygodenus elegans* would appear to be highly palatable (Table 2).

In the Limber Pine Community of RMNP, heavy grazing by goats may occur on *Muhlenbergia montana*. In the Engelmann Spruce/Subalpine fir Community, heavy utilization of *Poa* spp. may be expected. *Stipa* spp. may be grazed lightly (Table 2).

In the Aspen Community of RMNP, *Calamagrostis* spp. are highly palatable to goats whenever they occupy this community. *Elymus trachycaulus* may be utilized as well (Table 2).

*Carex*, *Festuca*, *Muhlenbergia*, and *Poa* of Willow and Grass Communities at RMNP would be highly preferred forages by goats, followed by *Deschampsia*, *Agropyron*, *Juncus*, *Koeleria*, *Trisetum*, *Danthonia*, *Phleum*, *Stipa*, and *Agrostis* (Table 2).

2. Forbs

In Colorado, Hibbs (1967) stated that *Heracleum lanatum* was consumed by goats in moderate amounts. Hibbs (1967) also reported a study on the west side of Mt. Antero by Jones and White (1955) in which these researchers remarked about the extensive consumption of *Mertensia alpina*. Johnson *et al.* (1978), in their follow-up study documented a very high preference for *Mertensia* spp. and *Geum rossii*. Dailey *et al.* (1984) reported summer use on forbs such as *Polygonum* spp. and *Campanula* spp.

In Montana, Saunders (1955) reported that *Lupinus* spp., *Mertensia* spp., *Polygonum bistortoides*, and *Potentilla diversifolia* were particularly palatable to goats. According to Varley (1994) preferred forbs were *Sedum lanceolatum*, *Lupinus argenteus*, *Mertensia alpina*, *Antennaria* spp., *Arenaria obtusiloba*, and *Senecio* spp.

In Washington, the Asteraceae, Caryophyllaceae, and Polemoniaceae were utilized the most by goats. *Aster* spp. (*Aster, Asteraceae*) were selected the most among forbs (Olmsted 1979).
In Alaska, Hjeljord (1973) found that mountain goats preferred forbs, particularly Artemisia sp. (arctic wormwood, Asteraceae), Arnica spp., Lupinus spp., Erigeron spp., and Epilobium angustifolium (fireweed, Onagraceae) during the summer. Aconitum columbianum (monk's hood, Ranunculaceae) and Geranium sp. were utilized infrequently.

In the Tundra Community of RMNP, high summer utilization by goats may be expected for the following genera: Mertensia, Campanula, Trifolium, Polygonum, and Geum. Moderate consumption may occur for Arenaria and Caltha. Artemisia, Erigeron, Ranunculus and Pedicularis may be grazed in low quantities (Table 2).

In the Limber Pine Community of RMNP, moderate grazing by goats may occur on Heuchera and Penstemon. Draba may be ingested in low quantities (Table 2).

In the Engelmann Spruce/Subalpine fir Community of RMNP, heavy utilization of Arnica latifolia and Mertensia spp. may be expected. Moderate use of Heracleum lanatum was documented in Colorado. Aquilegia may be grazed lightly (Table 2).

In the Aspen Community of RMNP, Heracleum lanatum and Fragaria may be utilized. In the Douglas Fir Community of RMNP moderate utilization of Achillea may be expected (Table 2).

Mertensia, Heracleum, Arenaria, Epilobium, and Caltha of Willow and Grass Communities at RMNP would be preferred forages by goats, followed by Fragaria, Saxifraga, Pedicularis, Penstemon, and Antennaria (Table 2).

3. Browse

Hibbs (1967) reported that goats selected Sambucus pubens (red-berried elder, Caprifoliaceae) as a favorite summer browse in Colorado. Also, preference for Dryas octopetala was reported by Johnson et al. (1978).

In Montana, Saunders (1955) reported that species such as Vaccinium scoparium, Salix spp., Ribes lacustre (swamp currant, Grossulariaceae), Phyllococe empetriflora (mountain heath, Ericaceae), and Potentilla fruticosa (syn: Pentaphylloides floribunda) (shrubby cinquefoil, Rosaceae) composed the summer browse diet of goats. Varley (1994) suggested that Salix spp. and Vaccinium scoparium were selected, although browsed very sparingly.

In the Tundra Community of RMNP, high summer utilization by goats may be expected for Salix spp. Moderate consumption may occur for Vaccinium scoparium and Dryas octopetala (Table 2).

In the Limber Pine Community of RMNP, heavy browsing by goats may occur on Vaccinium scoparium. Arctostaphylos uva-ursi, Juniperus communis, Ceanothus velutinus, Rubus spp., and Rosa spp. may be browsed moderately to lightly. In the Engelmann Spruce/Subalpine fir and Blue Spruce/Alder Communities, heavy to moderate utilization of Salix, Ribes, Vaccinium, Acer, and Rosa spp. may be expected (Table 2).

In the Aspen Community of RMNP, Ribes spp. are highly palatable to goats whenever they occur in this community. Populus tremuloides, Arctostaphylos uva-ursi, Juniperus communis, Acer glabrum, and Amelanchier alnifolia may be browsed as well (Table 2).

Salix spp. of the Willow Community are highly palatable browse for goats. In the Douglas Fir Community, they may utilize Prunus virginiana followed by Physocarpus, Rubus, and Pseudotsuga in low quantities (Table 2).

4. Ferns, Mosses, and Lichens

Saunders (1955) documented high summer utilization of Woodsia scopulina (wood sia, Polypodiaceae) and low, year-round foraging on Polystichum lonchitis (hollyfern, Polypodiaceae) in Montana by goats. Utilization of ferns, mosses, and lichens at RMNP would probably occur.
B. Winter

1. Graminoids
   For Colorado populations of goats, Hibbs (1967) reported heavy winter use on *Festuca thurberi*, *Poa* and *Carex* spp. Adams and Bailey (1983) found that *Carex* spp. and *Festuca ovina* were most preferred by goats wintering above timberline. *Festuca arizonica* (Arizona fescue, Poaceae), *Muhlenbergia montana*, and *Carex* spp. were preferred graminoids by goats wintering below timberline. Dailey et al. (1984) reported use of *Calamagrostis* spp. in January.
   In the Tundra Community of RMNP, high winter utilization by goats may be expected for *Carex* and *Kobresia*. *Luzula* may be grazed in low quantities (Table 2).
   In the Limber Pine Community of RMNP, heavy grazing by goats may occur on *Muhlenbergia montana*. *Sipa* spp. may be grazed lightly within the Engelmann Spruce/subalpine fir Community (Table 2).
   In the Aspen Community of RMNP, *Calamagrostis* spp. are moderately palatable to goats in the winter. *Carex*, *Festuca*, *Muhlenbergia*, and *Poa* of Willow and Grass Communities would be highly preferred forages by goats, followed by *Agropyron*, *Koeleria*, and *Stipa* (Table 2).

2. Forbs
   *Artemisia norvegica* and *A. scopulorum* were preferred forb species for goats wintering above timberline in Colorado (Adams and Bailey 1983). *Artemisia ludoviciana* and *A. franseroides* (sagewort spp., Asteraceae) were preferred forb species below timberline. *Trifolium* spp., *Oreoxis* spp., and *Potentilla* spp. were not used in proportion to their abundance.
   In Alaska, Hjeljord (1973) reported consumption of *Cornus canadensis* (bunchberry, Cornaceae).
   In the Tundra Community of RMNP, goats might have a high preference for *Artemisia* spp. and *Geum rossii*. *Oreoxis*, *Antennaria*, *Mertensia*, *Arenaria*, *Sedum*, *Polygonum*, and *Potentilla* may be grazed in low quantities (Table 2).
   In the Limber Pine Community of RMNP, low intensity grazing by goats may occur on *Heuchera* and *Sedum*. Low utilization of *Mertensia* spp. may be expected within the Engelmann Spruce/Subalpine fir Community. In the Aspen Community, *Heracleum lanatum* and *Fragaria* may be utilized sparingly. Moderate utilization of *Achillea* may occur within the Douglas Fir Community. *Mertensia*, *Heracleum*, and *Epilobium* of Willow and Grass Communities would be preferred forages by goats in winter (Table 2).

3. Browse
   Moderate browsing of woody species by goats in Colorado was documented by Hibbs (1967), particularly on *Acer glabrum*, *Ribes* sp., *Cercocarpus* spp. (mountain mahogany, Rosaceae), and *Salix* spp. *Pseudotsuga menziesii* was the preferred browse reported by Adams and Bailey (1983), along with *Haplopappus macronema* (goldenweed, Asteraceae) and *Artemisia frigida*, Asteraceae. Dailey et al. (1984) found that winter browse intake was negligible (≤ 1%), whenever wind-compacted snow covered woody plants.
   In Washington, Pike (1981) listed *Salix nivalis*, a species present near Trail Ridge Road in RMNP as well, as a much-preferred mountain goat winter browse.
   In Alaska, Hjeljord (1973) reported summer utilization by goats of *Ribes laxiflorum* (trailing black currant, Grossulariaceae) and *Sambucus pubens*. Fox and Smith (1988) documented mountain goat winter diets in southeastern Alaska and reported that conifers [Alaska yellow cedar and hemlock
spp. (genus *Tsuga*)] were most commonly represented in the fecal material of these animals. Species of secondary importance included *Gaylussacia* sp. (huckleberry, Ericaceae), and *Rubus* spp.

In the Tundra Community of RMNP, high winter utilization by goats may be expected for *Salix nivalis*. Moderate consumption may occur for *Vaccinium scoparium* and other *Salix* spp. (Table 2).

In the Limber Pine Community of RMNP, heavy browsing by goats may occur on *Ceanothus velutinus*, *Juniperus communis*, *Vaccinium scoparium*, *Rubus* spp., and *Rosa* spp. may be browsed moderately to lightly. Moderate utilization of *Salix*, *Ribes*, *Vaccinium*, *Acer*, *Alnus*, *Rubus*, and *Picea* spp. may be expected within the Engelmann Spruce/Subalpine fir and Blue Spruce/Alder Communities (Table 2).

In the Aspen Community of RMNP, *Amelanchier alnifolia* and *Ribes* spp. are highly palatable to goats during winter. *Juniperus communis* and *Acer glabrum* may be browsed as well (Table 2).

*Salix* spp. of the Willow Community at RMNP would be moderately palatable browse for goats in winter. In the Douglas Fir Community, goats might utilize large amounts of *Pseudotsuga menziesii* followed by *Juniperus scopulorum*, *Prunus virginiana*, *Physocarpus*, *Acer*, and *Rubus* in low quantities. *Ceanothus velutinus* would be the preferred browse within the Lodgepole Pine Community. *Rosa*, *Vaccinium*, and *Juniperus* would provide browse of secondary importance (Table 2).

4. Ferns, Mosses, and Lichens

Winter utilization of ferns, lichens, and mosses by goats at RMNP should be expected. Saunders (1955) documented goats’ low winter utilization of *Woodsia scopulina* and *Polystichum lonchitis* in Montana. Hjeljord (1973) reported that goats utilized *Adiantum* sp. (lady fern, Adiantaceae), particularly rhizomes and petioles (an average of 82% of total rumen content) in March 1970 on Kodiak Island and the Kenai Mountains of Alaska. Fox and Smith (1988) reported that *Hylocomium* and *Rhytidiodelphus* spp. (mosses), and *Lobaria* spp. (lichens) were most commonly represented in the fecal material of these animals. Species of secondary importance were *Blechnum spicant* (deer fern, Blechnaceae), and *Alectoria* and *Usnea* spp. (other lichens).

Varley (1996) underlined the importance of lichens in winter diets of mountain goats in Montana. Lichen intake increased in the winter relative to summer and fall, particularly when available on rocks made snow-free by wind or on steep terrain.

C. Spring and Fall

1. Graminoids

Spring and fall selection of grasses by goats in Montana included *Poa* spp., *Agropyron* spp., *Festuca* spp., *Calamagrostis* spp., *Deschampsia caespitosa*, *Phleum alpinum*, *Trisetum spicatum*, and *Danthonia intermedia* (timber oatgrass, Poaceae). *Carex festivella* and *C. phaeocephala* (festive and brown-headed sedges, Cyperaceae) were utilized by goats in moderate quantities during spring and fall, while *Carex geyeri* was selected only in the spring. Conversely, *Luzula parviflora* (small-flowered woodrush, Juncaceae) was utilized moderately in the fall (Saunders 1955).

In the Tundra Community of RMNP, goats might have a high preference for *Carex* spp. in spring and fall. *Deschampsia caespitosa*, *Poa alpina*, *Trisetum*, *Juncus*, and *Luzula* may be grazed in moderate to low quantities (Table 2).

In the Engelmann Spruce/Subalpine fir Community, moderate spring utilization of *Carex geyeri* and *Poa* spp. should be expected. Low grazing on *Stipa* could occur as well. In the Aspen Community, *Calamagrostis*, *Festuca*, and *Elymus* may be utilized sparingly. In the Douglas Fir Community, moderate utilization of *Carex geyeri* may occur. *Carex*, *Agropyron*, *Calamagrostis*, *Danthonia*, *Deschampsia*, *Festuca*, *Koeleria*, *Phleum*, *Poa*, *Trisetum*, and *Agrostis* of Willow and Grass Communities in RMNP would be preferred forages of goats in spring and/or winter (Table 2).
2. Forbs
Saunders (1955) reported that *Heuchera ovalifolia* (alumroot, Saxifragaceae) and *Potentilla multisecta* (cinquefoil, Rosaceae) were very abundant in goat rumen samples in Montana. These two species do not occur in Colorado, according to Harrington (1964).

In the Tundra Community of RMNP, goats may utilize *Erigeron simplex* in the fall, as well as *Arenaria obtusiloba, Silene acaulis, Sedum lanceolatum, and Polygonum* spp. In the Limber Pine Community, moderate grazing by goats may occur on *Penstemon, Heuchera* and *Sedum* in the spring and/or fall. In the Engelmann Spruce/Subalpine fir Community, high utilization of *Senecio triangularis* may be expected in the fall. In the Aspen Community, *Heracleum lanatum, Lupinus argenteus*, and *Fragaria* may be utilized sparingly, the former in the fall, and the latter two in both seasons. In the Douglas Fir Community, moderate utilization of *Achillea* may occur year-round. *Penstemon, Saxifraga, Potentilla, Mertensia, Antennaria, Heracleum, and Epilobium* of Willow and Grass Communities would be preferred forages by goats in spring and/or fall (Table 2).

3. Browse
*Penstemon fruticosum* (desert mountain penstemon, Scrophulariaceae), a species from Montana that is not distributed in Colorado, was the shrub most palatable to goats in spring (Saunders 1955).

In the Tundra Community of RMNP, moderate consumption may occur for *Vaccinium scoparium* and *Salix* spp. (Table 2). In the Limber Pine Community, moderate browsing by goats may occur on *Ceanothus velutinus* and *Vaccinium scoparium*. *Juniperus communis* may be browsed lightly. Moderate to low utilization of *Salix, Ribes, Vaccinium, Acer*, and *Juniperus*, may be expected within the Engelmann Spruce/Subalpine fir and Blue Spruce/Alder Communities (Table 2).

In the Aspen Community of RMNP, *Amelanchier alnifolia, Acer glabrum* and *Ribes* spp. are moderately palatable to goats during winter. *Juniperus communis* may be browsed as well (Table 2). *Salix* spp. of the Willow Community in RMNP would receive low browsing levels by goats in winter. In the Douglas Fir Community, goats might utilize large amounts of *Pseudotsuga menziesii* followed by *Rubus, Juniperus scopulorum, Prunus virginiana, and Acer glabrum* in moderate to low quantities. In the Lodgepole Pine Community, *Ceanothus velutinus* would remain the preferred browse followed by *Vaccinium* spp. and *Juniperus scopulorum* (Table 2).

4. Ferns, Mosses, and Lichens
Saunders (1955) documented low levels of spring and fall foraging on *Polystichum lonchitis* in Montana. Light grazing by goats on these life forms could be expected in RMNP.
APPENDIX 3. Detailed Information on Threatened and Endangered Plant Taxa, and Species of Concern in RMNP

Aquilegia saximontana (Rocky Mountain columbine, Helleboraceae/Ranunculaceae)
This taxon is a densely-tufted perennial forb, usually 8-15 cm tall, rarely extending to 25 cm (Harrington 1964). It occurs in central and north-central Colorado. It occupies cliffs and rocky slopes in the subalpine and alpine zones at elevations between 9,000 and 12,300 feet. Rocky mountain columbine has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G3 (threatened throughout its range) and the State Rank is S3 (between 21 and 100 documented occurrences statewide). The taxon is listed as 3C at the Federal level (e.g., a taxon that has proven to be more abundant or widespread than was previously believed, and/or not subject to any identifiable threat) (Spackman et al. 1997).

Peck (1972) reported a low level of grazing by Rocky Mountain goats on Aquilegia flavescens in southwestern Montana. Johnson et al. (1978) documented similarly low summer use on Aquilegia spp. in the Sawatch Range of Colorado. Overall, columbines are not particularly palatable and this taxon should not be considered a preferred forage species; nonetheless, potential impacts resulting from goat ingestion should not be discounted. Rocky Mountain columbine may be prone to damage caused by trampling throughout its elevation range.

Botrychium echo (reflected moonwort, Ophioglossaceae)
This fern is distributed throughout the Rocky Mountains of Colorado. It occurs in gravelly soils, rocky hillsides, grassy slopes, and meadows in the subalpine zone at elevations between 9,500 and 11,000 feet. Reflected moonwort is a fern that produces spores by July. The taxon has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G2 (endangered throughout its range and imperiled globally because of rarity - only 6 to 20 occurrences have been documented). The State Rank is S2 (between 6 to 20 documented occurrences statewide; imperiled because of rarity). Reflected moonwort has no Federal status, but the U.S. Forest Service lists this species as sensitive (Spackman et al. 1997).

No information is available in the literature on the palatability and utilization by goats of reflected moonwort, but the taxon should be considered vulnerable to winter root-digging, and to incidental grazing, trampling, and wallowing by goats during the early growing season. Saunders (1955) documented goat's high summer utilization of Woodsia scopulina and low, year-round foraging on Polystichum lonchitis, two ferns distantly related to reflected moonwort, in the Crazy Mountains of Montana. Hjeljord (1973) reported high winter utilization of an Adiantum sp., particularly of rhizomatous rootstock, in Alaska.

Botrychium hesperium (western moonwort, Ophioglossaceae)
This fern is not listed by Harrington (1964) and Weber (1976), but it was documented as occurring in RMNP by the Colorado Natural Heritage Program (1999). Western moonwort appears to occupy upper montane and subalpine zones. The Global Rank is G3 (vulnerable throughout its range). The State Rank is S2 (between 6 to 20 documented occurrences statewide; imperiled because of rarity). Western moonwort has no Federal status (Spackman et al. 1997).

No information is available in the literature on the palatability and utilization by goats of western moonwort, but the taxon should be considered vulnerable to winter root-digging, and to incidental grazing, trampling, and wallowing, as discussed previously in regard to reflected moonwort.
No information is available in the literature on the palatability of this taxon and its utilization by goats, but the taxon should be considered vulnerable to winter root-digging, and to incidental grazing and trampling by goats during the early growing season, as reported for reflected moonwort.

*Draba fladnizensis* (Arctic draba, Brassicaceae)

This taxon is a perennial forb with leafless stems (or rarely nearly so) 2-6 cm tall, arising from simple or branched caudices; flowers are white with petals 2-3 mm long and styles lacking or less than 0.2 mm long. Arctic draba is found in Eurasia and from British Columbia south to Colorado and Utah. In Colorado, it occurs in the high subalpine and alpine zones at elevations between 11,000 and 13,000 feet (Harrington 1964). The taxon is known to occur in wet meadows, in dry tundra, and in rocky alpine areas (Colorado Natural Heritage Program draft information 1999). The Global Rank is G4 (apparently secure globally, but likely quite rare in portions of its range, particularly at the periphery) and the State Rank is S2/S3 (between 6-100 documented occurrences statewide; imperiled/vulnerable because of rarity). Arctic draba has no federal status (Spackman *et al.* 1997).

Reportedly, *Draba* spp. are palatable to goats that graze on them lightly during the summer, as reported in Colorado by Johnson *et al.* (1978). This taxon is associated with *Carex*, *Saxifraga*, and other *Draba* spp. which, reportedly, are all palatable to goats (Johnson *et al.* 1978, Varley 1994, Colorado Natural Heritage Program draft information 1999). Arctic draba is, therefore, very susceptible to summer grazing, as well as to trampling and wallowing by goats. The taxon reproduces exclusively by seed. Saunders (1955) reported that goats include an abundance of flowers in their diet; therefore, the taxon may be precluded from reproducing.

*Draba grayana* (Gray's peak whitlow-grass, Brassicaceae)

This taxon is a perennial forb, 2-5 cm tall, from a branched caudex, forming compact tufts (Harrington 1964). It is considered endemic to central and north-central Colorado. Gray's peak whitlow-grass occurs in gravelly alpine slopes and fell fields, at elevations between 11,500 and 14,000 feet. The taxon flowers between July and August and produces seeds between August and September. Gray's peak whitlow-grass has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G2 (endangered throughout its range and imperiled globally because of rarity - only 6 to 20 occurrences have been documented). The State Rank is S2 (between 6 to 20 documented occurrences statewide; imperiled because of rarity). Gray's peak whitlow-grass has no Federal status (Spackman *et al.* 1997).

Similarly to arctic draba, Gray's peak whitlow-grass is susceptible to summer grazing, as well as to trampling and wallowing by goats. The taxon reproduces exclusively by seed as well. According to Saunders (1955), goats include an abundance of flowers in their diet; therefore, the taxon may be precluded from reproducing.

*Dryopteris expansa* (spreading wood fern, Dryopteridaceae)

This fern is not listed by Harrington (1964) and Weber (1976), but it was documented as occurring in RMNP by the Colorado Natural Heritage Program (1999). Spreading wood fern appears to grow in organic matter and moss found in rock crevices. The Global Rank is G5 (demonstrably secure throughout its range, but potentially rare at the periphery of its distribution). The State Rank is S1 (critically endangered in Colorado, where it has been documented in five or fewer occurrences) (Colorado Natural Heritage Program draft information 1999).

No information is available in the literature on the palatability and utilization by goats of spreading wood fern, but the taxon should be considered vulnerable to winter root-digging, as well as
incidental grazing and trampling. Saunders (1955) documented goat's high summer utilization of *Woodsia scopulina* and low, year-round foraging on *Polystichum lonchitis*, two ferns distantly related to spreading wood fern, in the Crazy Mountains of Montana. Hjeljord (1973) reported high winter utilization of an *Adiantum* sp., particularly of rhizomatous rootstock, in Alaska. The critically imperiled status of spreading wood fern in Colorado makes this taxon highly sensitive to potential goat impacts and in danger of extirpation in RMNP.

*Eriophorum gracile* (Slender cottongrass, Cyperaceae)

This taxon is a perennial graminoid with slender, terete or somewhat triangular culms originating from rhizomes, the culms 5-60 cm tall, rather weak and often reclining; heads few to several on distinct peduncles, with white, cotton-like bristles not over 2.5 cm long (Harrington 1964, Spackman *et al.* 1997). Slender cotton grass is distributed from Alaska south to Utah and Colorado. Fens are the unique habitat of this taxon. Slender cotton grass is found in the subalpine and alpine zones, at elevations between 9,500 and 14,000 feet. The taxon produces seeds by late July and August. It is presumed to have occurred in RMNP historically, but its presence has not been documented recently. The Global Rank is G5 (demonstrably secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 20 documented occurrences statewide, or because it is very vulnerable to extirpation) (Spackman *et al.* 1997).

There are no mentions in the scientific literature of goats utilizing slender cotton grass or *Eriophorum* spp. in general. Slender cotton grass should be considered potentially vulnerable to grazing and trampling by goats because of its elevation range and its habitat, which would be occupied by goats during the summer months.

*Isoetes setacea* subsp. *muricata* (spiny-spored quillwort, Isoetaceae)

This fern ally is described as having a two-lobed corm, 10-35 erect to recurved leaves, and spiny megasporas. It is widely distributed throughout North America, especially in the northern portion. In Colorado, it was located at elevations around 11,500 feet by Harrington (1964) and documented in one instance as occurring in the alpine zone by Weber (1976), but details of its habitat are conspicuously lacking. The Colorado Natural Heritage Program (1999) has located spiny-spored quillwort within RMNP. The Global Rank is G5 (demonstrably secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 20 documented occurrences statewide, or because it is very vulnerable to extirpation) (Colorado Natural Heritage Program draft information 1999).

No information is available on the potential utilization of spiny-spored quillwort by Mountain goats. The populations of this taxon at RMNP taxon are very rare and may be detrimentally affected by goats.

*Lilium philadelphicum* (wood lily, Liliaceae)

This taxon is a perennial forb with stems ca. 30-60 cm tall, leafy, from thick-scaled bulbs (Harrington 1964). It is distributed throughout the eastern and central portions of the United States and has its western-most distribution in Colorado and New Mexico. Wood lily inhabits moist woods, thicketts, and wet meadows in the montane and subalpine zones, at elevations between 6,800 and 9,800 feet. The taxon flowers from June to August and produces fruits by August. Wood lily has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G5 (demonstrably secure globally, but possibly quite rare at the periphery of its distribution) and the
State Rank is S3 (between 21 and 100 documented occurrences statewide). The taxon is not listed at the Federal level (Spackman et al. 1997).

No information is available in the literature on the palatability of this taxon and its utilization by goats. Goats may occupy the general habitat where wood lily grows in the spring and late fall.

**Listera borealis** (northern twayblade, Orchidaceae)

This taxon is a perennial forb with rootstocks and fibrous-fleshy roots. Leaves are two, opposite, and narrowly ovate (Harrington 1964, Spackman et al. 1997). It is distributed through the mountainous western region from Alaska to Utah and occurs in south-central to north-central Colorado. Northern twayblade inhabits moist spruce-fir forests in the upper montane and subalpine zones, at elevations between 8,700 and 10,800 feet. The taxon flowers in late June and July, producing seeds by late July. The Global Rank is G4 (apparently secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 20 documented occurrences statewide, or because it is very vulnerable to extirpation). Northern twayblade is listed as a species of concern by the Bureau of Land Management and has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests (Spackman et al. 1997).

No information is available in the literature on the palatability of this taxon and its utilization by goats. Goats may occupy in the spring and late fall the general habitat where northern twayblade grows.

**Listera convallarioides** (broad-leaved twayblade, Orchidaceae)

This taxon is a perennial forb with slender stems 10-25 cm tall, glandular-pubescent above the leaves. Broad-leaved twayblade is distributed from Newfoundland to Alaska, south to Arizona. In Colorado, the taxon inhabits moist areas at elevations between 8,000 and 10,500 feet (Harrington 1964). The Global Rank is G5 (demonstrably secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 100 documented occurrences statewide) (Spackman et al. 1997).

No information is available in the literature on the palatability of this taxon and its utilization by goats. As with northern twayblade, goats may occupy in the spring and late fall the general habitat where broad-leaved twayblade grows.

**Mimulus gemmiparus** (Weber monkey-flower, Scrophulariaceae)

This taxon is an inconspicuous forb, 1-10 cm tall, with modified petioles forming pockets of dormant embryonic shoots. It is considered endemic to central and north-central Colorado. Weber monkey-flower occurs on granitic seeps and alluvium in open sites within spruce-fir and aspen forests, at elevations between 8,500 and 10,500 feet. The taxon flowers in mid July. Weber monkey-flower may be occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G2 (endangered throughout its range and imperiled globally because of rarity - only 6 to 20 occurrences have been documented). The State Rank is S2 (between 6 to 20 documented occurrences statewide; imperiled because of rarity). The taxon is listed as a species of concern (formerly C2) at the Federal level (e.g. a taxon that potentially may be upgraded to threatened or endangered status, but for which substantial biological information is not on file to support an immediate rule-making) (Spackman et al. 1997).

No information is available in the literature on the palatability of this taxon and its utilization by goats. Goats may occupy the general habitat where Weber monkey-flower grows in the spring and late fall. Its extreme rarity and delicate grow form make this taxon very vulnerable to disturbances.
Papaver kluanensis (alpine poppy, Papaveraceae)

This taxon is a forb arising from a slender taproot, with basal leaves and naked, black-hirsute scapes, 5-15 cm tall. It is distributed from Alaska to Greenland, south to New Mexico. Alpine poppy inhabits dry alpine tundra meadows, gravelly slopes, talus, scree, and fell fields of the alpine zone, at elevations between 11,500 and 14,000 feet. The taxon flowers in late June, producing seeds by August. Alpine poppy has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G4 (apparently secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 20 documented occurrences statewide, or because it is very vulnerable to extirpation). The taxon is not listed at the Federal level (Spackman et al. 1997).

No information is available in the scientific literature in regard to the palatability of this taxon and utilization by goats. Its preferred habitats are the same utilized by Mountain goats as summer range, making alpine poppy very susceptible to potential grazing, trampling, and wallowing.

Parnassia kotzebuei (Kotzebue grass-of-Parnassus, Parnassiaceae)

This taxon is a perennial, scapose forb with short rootstocks, basal leaves, and a solitary flower (Harrington 1964, Spackman et al. 1997). It is distributed from northeast Asia to Greenland, south to the mountainous regions of Nevada and Colorado. Kotzebue grass-of-Parnassus inhabits wet, rocky ledges, in streamlets and moss mats of the subalpine and alpine zones, at elevations between 10,000 and 12,000 feet. The taxon flowers in June and July, producing seeds by July and August. Kotzebue grass-of-Parnassus has been documented as occurring on adjacent Roosevelt/Arapahoe National Forests as well. The Global Rank is G4 (apparently secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 20 documented occurrences statewide, or because it is very vulnerable to extirpation). The taxon is not listed at the Federal level (Spackman et al. 1997).

No information is available in the scientific literature in regard to the palatability of this taxon and utilization by goats. Its preferred habitats make Kotzebue grass-of-Parnassus very vulnerable to potential grazing and trampling.

Penstemon cyathophorus (Middle Park penstemon, Scrophulariaceae)

This taxon is a perennial forb with solitary or few, erect, glaucous, glabrous stems, 20-60 cm tall from a basal rosette of leaves; stem leaves are opposite (Harrington 1964, Spackman et al. 1997). It is distributed from southern Wyoming to Colorado. Middle Park penstemon occupies rocky clay loam soils of sagebrush hills and flats of the montane zone, at elevations between 7,000 and 8,500 feet. The taxon flowers in late May and June. It is presumed to have occurred in RMNP historically, but its presence has not been documented recently. The Global Rank is G3/G4 (from threatened in its range to apparently secure globally, but possibly quite rare at the periphery of its distribution) and the State Rank is S2 (imperiled in State because of rarity, with between 6 to 20 documented occurrences statewide, or because it is very vulnerable to extirpation). Middle Park penstemon is considered a species of concern by the Bureau of Land Management (Spackman et al. 1997).

Penstemon spp. receive low summer utilization by Mountain goats in Colorado (Johnson et al. 1978), but this particular species should not be affected as a result of its montane habitat, which is not occupied by goats.

Potentilla rupincola (Rocky Mountain cinquefoil, Rosaceae)

This taxon is a perennial forb from branching caudices; stems are 20-30 cm tall, erect or nearly so; leaves are bright shiny green on both sides (Harrington 1964, Spackman et al. 1997). Rocky