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Inter-Seasonal Range Relationships of Spanish Goats and Mule Deer in a Utah Oakbrush Community

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INTER-SEASONAL RANGE RELATIONSHIPS
OF SPANISH GOATS AND MULE DEER
IN A UTAH OAKBRUSH COMMUNITY

by

Robert Alexander Riggs

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Range Science

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1988
ACKNOWLEDGEMENTS

Rarely does one accomplish anything of significance without help, no matter how hard he or she strives independently. The writing of this dissertation is no exception. Its development spans several years, and many people have contributed to it in their own separate ways. Its value, if any, is a prize to be shared by them all.

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Several people provided technical assistance that was indispensable. Elizabeth Burritt guided my laboratory technique; Chapter III could not have been written without her help. Randy Berger, Terry Hall and Karen Gonzalez each assisted with data collection and processing; without fail, their work was of the highest caliber. Dennis Austin gave graciously of his time, and that
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Robert A. Riggs
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ABSTRACT

Inter-seasonal Range Relationships
of Spanish Goats and Mule Deer
in a Utah Oakbrush Community

by

Robert A. Riggs, Doctor of Philosophy
Utah State University, 1988

Major Professor: Dr. Philip J. Urness
Department: Range Science

Three experiments were conducted to assess the potential for using Spanish goats to manage Gambel oakbrush winter range, dominated by Gambel oak (Quercus gambelii), for mule deer (Odocoileus hemionus). Summer-time food selection of goats, effects on plant community composition, and consequent effects on mule deer nutrition and foraging behavior were examined.

An apparent preference for juvenile oak browse, and low use of oak twigs was observed. Selection for juvenile browse may have been facilitated by the retarded phenology of oak as compared to that of associated flora. This differential was maintained by repeated browsing. Animal performance, reflected in mass-specific gain rates, varied markedly. However, poor performance when observed, was not correlated with high juvenile oak content in diets.

Goat browsing did not affect density of any shrub species. Stem size distributions changed in browsed oak populations only; skewness
of these increased over time because of sprouting. Sprout weights increased in browsed oak populations, but declined in comparably browsed serviceberry (*Amelanchier alnifolia*) populations. The only other significant sprout response was a numerical increase in browsed snowberry (*Symphoricarpos oreophilus*) populations. Relationships between stem size and stem productivity in heavily browsed oak and serviceberry were characterized by lower slopes than those for adjacent control populations. Conversely, relationships in rabbitbrush (*Chrysothamnus viscidiflorus*) populations, which were little used, were characterized by higher slopes than those for adjacent control populations. Sagebrush (*Artemisia tridentata wyomingensis*) production also responded positively, but via increased intercept. Browsing reduced productivity of both serviceberry and oak, but enhanced that of sagebrush. A positive production response was suggested for herbaceous species.

Forage-base changes induced by goats caused wintering deer to increase the proportion of sagebrush in their diets under snow-covered conditions but not under snow-free conditions. Under snow-covered conditions, deer using goat-browsed pastures consumed diets higher in dry matter digestibility, but not protein, than those consumed by deer in control pastures. Dietary quality was unaffected by prior goat browsing under snow-free conditions. Furthermore, quality of diets consumed under snow-free conditions was not better than that consumed under snow-covered conditions.

(92 pages)
INTRODUCTION

The term "Gambel oakbrush", or more simply "oakbrush", refers to various western plant communities in which Gambel oak is potentially dominant. These can be climax in nature (Baker and Korstian 1931, Hayward 1948, McKell 1950, Sweeney 1975) or secondary successional stages leading to coniferous climax (Dixon 1935, Lull and Ellison 1950, Brown 1958, Harrington 1964). Oakbrush is a major component of western rangelands, dominating some 3.6 million hectares in Arizona, Colorado, New Mexico, and Utah (Kunzler 1980); and smaller areas in Wyoming and Nevada (Christensen 1949a), Texas and Mexico (Cottam et al. 1959, Reynolds et al. 1970). It dominates 0.4 million hectares in Utah (Tew 1966) where it is absent from only the western desert areas, Cache Valley, and Uinta Basin. It is distributed from 976 meters to 2744 meters (Dayton 1931; Christensen 1949a, 1949b; Brown 1958; Bradley and Deacon 1965; Barger and Ffolliott 1972).

The broad distribution of oakbrush makes this vegetation an important component of mule deer habitats. Quality of winter range is a greater concern of deer managers than that of other seasonal habitats (Carpenter and Wallmo 1981) although summer range limitations have occasionally been observed (Julander et al. 1961; Russo 1964; Pederson and Harper 1978). The relative importance of oakbrush as winter habitat in Utah was first implied by Smith (1959) in concluding that the importance of Gambel oak ranked behind only that of sagebrush and juniper (Juniperus spp.). Sagebrush-steppe and juniper/piñon communities tend to occupy sites at lower elevations and receive less snow than oakbrush sites. Consequently, sagebrush and juniper/piñon communities are usually viewed as critical winter
range, while oakbrush is often viewed as upper winter range or transitional spring/fall range.

However oakbrush constitutes major portions of certain winter ranges (Smith 1959; Anderson 1969; Boyd 1970; Perry 1980), and its relative importance has increased substantially in some localities as a result of changing land-use patterns. For example, access to low-elevation sagebrush-steppe has been largely precluded along the Wasatch Front by urban development and the character of the remaining portion has been significantly altered by changing grazing practices (Urness 1976, 1979, 1981; Austin et al. 1986). Consequently, the adjacent oakbrush vegetation has become more important as winter habitat, and its management deserves increased scrutiny.

Management of oakbrush for game winter range has historically focused on successionaly advanced stands in which Gambel oak has attained dominance (Engle et al. 1983). Oak typically has grown beyond browsing reach in such stands, and suppressed other species in the process. Thus management has been predicated primarily on a desire to increase forage availability within the reach of wintering ungulates; retention of forage diversity has been a secondary goal. In either case, reduction of oak's dominant status has been considered a prerequisite for long-term success because of Gambel oak's tendency to dominate stands.

In pursuit of these goals, managers of big game range have relied on traditional shrub control techniques, including various mechanical treatments, herbicides and fire. Success has been limited because of the particular ecological characteristics of Gambel oak.
(see Engle et al. 1983 for a review). Single treatments have proven effective over short-term periods for reducing mature stems, but impractical for long-term control because of a need for multiple treatments to control sprouts. The strong sprout response is facilitated by extensive root systems with both shallow and deep-feeding roots (Baker and Korstian 1931, Christensen 1949a, Muller 1951) and high root:shoot ratios, especially in stands that have been top-killed (Engle et al. 1983).

Sprout physiology differs from that of mature stems in several respects. First, sprouts begin to replenish carbohydrate reserves before their leaves are fully developed (Engle and Bonham 1980), whereas mature stems do not begin replenishing reserves until after full leaf size is reached (Marquiss 1969). Initial top-kills, by any means, are most effective when timed to coincide with the lowest point in the carbohydrate storage cycle (Cook 1966, Berg and Plumb 1972, Engle et al. 1983). Thus, sprouts must be treated earlier than mature stems if they are to be controlled, and improper timing may actually stimulate additional sprouting (Engle and Bonham 1980). Furthermore, sprouts are mostly long shoots which tend to have a continuous growth pattern with both an early and a late growth flush. Mature stems, on the other hand, are primarily short shoots, which have only a single flush of growth earlier in the growing season (Engle et al. 1983). Therefore, multiple treatments are required if treatment benefits are to be maintained.

The need for multiple treatments, regardless of the specific technique, has limited oak control efforts on economic grounds alone
(Engle et al. 1983), but economics are not the only limitation. Mechanical methods are not suited to the rugged topography typical of many game ranges. Public acceptance of large-scale herbicide treatments has generally declined. Fire is difficult to manage where adjacent developments are cause for concern; moreover, repeated fire has been discouraged because of attendant lowering of soil-nitrogen availability (Hobbs and Schimel 1984).

Furthermore, repeated treatment by these means may be unwise, regardless of any success in oak control, because of potential shifts in stand composition. The sprouting potential of Gambel oak is enormous, and its sprout physiology gives it a competitive advantage over associated shrubs in disturbed stands. For example, Kufeld (1983:16, fig. 9) reported that following a single treatment, oak's response tended to be stronger than that of any of four associated shrubs (serviceberry; chokecherry, Prunus virginiana; snowberry; and big sagebrush); the contrast was particularly strong in the cases of snowberry and sagebrush. Repeated treatments would only intensify the differences. Thus repeated treatment may facilitate oak control, but associated species are likely to be reduced even more. Stand composition may change, and diversity be reduced, as a result.

This may be cause for concern where oakbrush communities contain sagebrush, a common component of stands abutting sagebrush-steppe communities. In vitro digestibility and crude protein content of sagebrush is significantly higher, and its fiber content lower, than

\[\text{Single applications of three treatments (burning, spraying with 2,4,5-TP, and chaining) were studied.}\]
associated deciduous shrubs during winter (Kufeld et al. 1981, Welch 1983). Therefore, sagebrush reduction may constitute a loss of an important source of digestible nutrients for wintering deer. Yet sagebrush is apt to be reduced more than any other (of those species studied by Kufeld 1983) in the process of achieving long-term oak control.

Ideally, management of oakbrush winter range for deer should be aimed at selective oak reduction that simultaneously enhances more nutritious species. Traditional techniques, as discussed above, are neither apt to accomplish both goals, nor are they liable to be cost efficient if they do so. Alternative management practices should be developed which recognize the ecological characteristics of Gambel oak and the goals of winter-range management as well. This dissertation is a preliminary assessment of one alternative, which attempts to use domestic livestock during early succession to produce the desired effects, thereby circumventing the need for expensive treatment later.

Moderate to heavy grazing by sheep, cattle or horses has been shown to alter the characteristics of game range under certain circumstances (Smith 1949; Smith and Doell 1968; Jensen et al. 1972; Peek et al. 1978; Smith et al. 1979; Willms et al. 1979; Reiner and Urness 1982). A major long-term effect of sustained livestock use is a competitive advantage for shrubs over herbaceous species, which results from disproportionate use of the latter. This is considered beneficial where snow precludes use of the understory for substantial periods in the winter. Increases in the relative availability of
preferred plant parts has also been demonstrated, presumably enhancing dietary quality for deer in the short term. However, none of these livestock classes should be seriously considered for oakbrush management, for two reasons. First, in all the cases noted above, a tendency to selectively graze the understory, while avoiding shrubs, has been recognized as a major factor contributing to success. Yet successful management of oakbrush demands that disproportionate use be made of Gambel oak. Selection of understory plants, in preference to oak, would not produce the desired effect and might even be counterproductive. Second, toxic side-effects have been suggested for livestock that consume large amounts of oak browse (Marsh et al. 1919, Dayton 1931, Stoddart et al. 1949, Muenscher 1957), especially prior to full leaf development (Panciera 1978). Thus, the potential for poisoning is apparently greatest at the time when heavy use of oak is needed. Avoidance of Gambel oak, by cattle at least, may contribute to enhancing its dominance rather than its suppression (see Costello and Turner 1941).

Domestic goats were selected for this work for several reasons. First, goats are generally considered browsers and they have a long history of use in brush control efforts, and interest in their use for this purpose has increased (e.g., Keng 1956; Magee 1957; Huss 1972; Du toit 1973; Green et al. 1978; Spurlock et al. 1980; Sidahmed et al. 1981; Knipe 1983; Provenza et al. 1983; Barstad 1987). Second, they appear to avoid some species that contain high concentrations of monoterpenes such as juniper (Malechek and Leinweber 1972, but see also Knipe 1983) and sagebrush (Narjisse
although they may inflict heavy damage on non-aromatics such as bitterbrush and serviceberry (Urness and Jensen 1982). Third, goats have been used to successfully control Gambel oak sprouts without any apparent toxic side-effects (Davis et al. 1975). Finally, Spanish-type goats were used, rather than Angora or milk goats, because they may consume more shrubs (Warren et al. 1984).

Goats have not been used to manage shrublands specifically for deer winter range values, however, and it is not clear that they can be used successfully for this purpose. Therefore, the work reported here was intended as a preliminary assessment of their potential in this regard. This dissertation is divided into three chapters. Each addresses a separate topic as follows.

The first chapter examines the dietary composition and live-weight changes among Spanish goats stocked at high densities in a typical low-stature oakbrush community. Previous work indicated that: (1) high density stocking, for repeated periods, would be required to significantly reduce dominance of Gambel oak because of its vigorous sprout potential and physiology (see Davis et al. 1975, Engle and Bonham 1980, Engle et al. 1983), and (2) animals would consequently have to consume large quantities of juvenile browse throughout the growing season for the treatment to be successful. As stated above, goats have been used to control oak sprouts successfully (Davis et al. 1975). However, goats were browsing rootplowed pastures in that study, and availability of alternative browse was low. The study did not establish that goats would voluntarily consume large quantities of juvenile Gambel oak where
alternatives existed. Indeed, the literature provides indirect evidence that they would not do so, and that performance might suffer as a result (Nastis and Malechek 1981). This is a crucial concern. There would be no point in pursuing further research or management if goats avoid the species that is the object of management, or if nutritional status is negatively correlated with dietary habits necessary for success. Therefore, this experiment monitored dietary composition and live-weights during repeated browsing trials over a 2-year period (1984-85). Results indicated that goats avidly consumed both juvenile and mature oak browse in large quantities, and that live-weight losses, when observed, were not correlated with juvenile oak content of the diet.

The second chapter describes the effects of the first experiment's grazing trials on community composition and productivity; data was collected over a 3-year period (1984-86). Of primary interest was the extent of oak reduction achieved, and the extent to which other shrub species were either harmed, or enhanced, in the process. Results indicated that productivity of oak and serviceberry populations was likely to be reduced by such treatment, while that of sagebrush was likely to be enhanced.

The third chapter attempts to define the real benefits that might be expected from such management, in terms of winter-time deer nutrition. These were explored using tractable mule deer that were confined to goat-altered and control pastures. Dietary composition, quality, and gross aspects of activity partitioning and foraging behavior are reported. The winter of 1985 was snow-covered; thus the
results for that year estimated the effects goats had on use of the shrub overstory by deer. In contrast, 1986 was snow-free, and the results for that year reflect deer responses when both shrubs and the herbaceous understory were available. Results indicated that goat browsing contributed to improved dry matter digestibility of deer diets under snow-covered conditions, but not under snow-free conditions. Additional grazing management, to alter structure and phenology of herbaceous species, would apparently be required to enhance nutritional plane of deer under snow-free conditions. Energy expenditures, as reflected by activity budgets and foraging behavior, were unaffected by the goat-caused changes in community productivity.
CHAPTER I

DIETS AND WEIGHT RESPONSES OF SPANISH GOATS USED TO CONTROL GAMBEL OAK

Control of Gambel oak is usually the primary goal of range improvement projects on rangelands dominated by this species. Control techniques have traditionally included general shrub removal techniques, including mechanical treatment (e.g. rootplowing, roller chopping, chaining), herbicides and, less frequently, fire. Success of these has been disappointing (Engle et al. 1983). Implementation costs are typically high, and benefits are often short-lived because Gambel oak is usually more robust in its response to treatment than associated flora (Kufeld 1983).

Furthermore, generalized treatments may be inappropriate. A case in point is mule deer winter range supporting big sagebrush as well as oak. Winter-time nutritional quality for deer is apparently higher for sagebrush (Kufeld et al. 1981); therefore short-lived oak reduction coupled with sagebrush removal may simply reduce range quality for wintering deer without significantly enhancing production of livestock forage over the long term. Traditional techniques tend to produce this effect. Development of more selective control techniques is desirable where retention of other shrubs is a management goal.

Davis et al. (1975) reported successful biological control of Gambel oak in mechanically pretreated pastures using Angora and
milk-type goats. Gambel oak was the only significant browse resource available to these animals; their effectiveness in mixed-browse communities was not assessed. Food habits of goats have not been reported under such circumstances and are of interest beyond their descriptive value. Successful biological control of Gambel oak depends on stressing the population via repeated removal of juvenile foliage before nutrients are translocated to the roots (Engle et al. 1983). This means that goats must consume a diet with a high juvenile oak content throughout the growing season where it is the dominant community constituent. Temporary shifts to alternate forages would reduce stress on oak, thus diminishing the degree of control.

Free-ranging animals, however, are not expected to voluntarily consume diets containing very large proportions of juvenile oak browse. Nastis and Malechek (1981) reported that voluntary intake of a pelleted ration composed of 80% juvenile oak and 20% alfalfa was less than that of other rations. On this basis, free-ranging animals might be expected to avoid large concentrations of juvenile oak in their diets, choosing alternate forages instead. Nastis and Malechek (1981) suggested that diets containing more than 80% juvenile material might not exceed maintenance requirements if the balance of the diet was less nutritious than the alfalfa they fed; this might occur because of juvenile oak’s possible depressant effect on voluntary intake. These observations are important to field managers. If they were representative of free-ranging animals, the utility of goats for managing this species in mixed-shrub communities
would be limited.

This study examined the food habits and live-weight changes of Spanish goats in a mixed shrub community under the high stocking densities likely needed for effective control of Gambel oak. The results provided a preliminary field assessment of the potential of goat browsing to control oakbrush, from the standpoint of forage selection and its relationship to animal performance.

**Study Area**

The study site is located near Henefer, Utah (UTM 45800E 4540500N) at the interface between Wasatch chaparral and sagebrush-grass zones (Cronquist et al. 1972). Average annual precipitation and mean temperature for the locale are 350 mm and 7.1°C, respectively (National Oceanographic and Atmospheric Association 1984, 1985). Average summer (June, July, and August) precipitation is 70.6 mm; summer precipitation was 66% above normal in 1984 and 90% of normal in 1985. Summer temperatures were close to the long-term monthly averages for June, July and August (15.7, 20.3, and 19.1°C, respectively).

Experimental pastures were located on two sites. The first was an alluvial fan on a cool aspect (azimuth 295°N). It was gentle (slope 13%), low (1,860 m) and had a deep, well-drained loamy soil. The second was on a ridge that was warmer (azimuth 225°N), steeper (slope 60%), higher (2,012 m), and had a poorly developed but well-drained loamy soil, with abundant cobbles.
Gambel oak was the dominant species in these communities, with lesser amounts of subordinate shrubs, grasses and forbs (Table 1.1). Shrub densities did not differ significantly between sites except that green rabbitbrush was fairly abundant on the alluvial site but absent on the ridge. Oak density was nearly identical on the two sites. Oak was in a shrub stage with rooted stems rarely exceeding 2.2 meters in height. The most important vegetative difference between sites appeared in the understory. Cumulative basal area coverage of understory species was about 15% on the alluvial site, but less than 1% on the ridge; differences in abundance of Kentucky bluegrass (*Poa pratensis* L.) accounted for most of this. Recent grazing prior to this study consisted of occasional light spring use by domestic sheep, and winter use by mule deer (*Odocoileus hemionus* Rafin.), elk (*Cervus elaphus* L.) and moose (*Alces alces* V. Bailey).

**Methods**

On each site, three 0.2 ha pastures were initially stocked with goats in June, 1984; and high stocking densities were employed in order to facilitate oak defoliation. Stocking density was 20 goats per ha (4 per pasture) in 1984 and 40 goats per ha (8 per pasture) in 1985. Both sites were stocked in 1984, but only the alluvial site was stocked in 1985. The ridge pastures were abandoned in 1985 in order to double the stocking density in the alluvial site pastures. Thus, it was possible to collect weight-change data on both sites in 1984, but only for animals on the alluvial site pastures in 1985. Animals were yearling wethers in 1984; the same animals were used...
Table 1.1 Composition summary for the six pastures stocked with goats in this study.

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</tr>
<tr>
<td>Shrubs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amelanchier alnifolia</td>
<td>1.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Artemisia tridentata</td>
<td>5.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Berberis repens</td>
<td>1.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Chrysothamnus viscidiflorus</td>
<td>17.9</td>
<td>13.0</td>
</tr>
<tr>
<td>Purshia tridentata</td>
<td>0.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Quercus gambelii</td>
<td>18.9</td>
<td>28.5</td>
</tr>
<tr>
<td>Rosa spp.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Symphoricarpos oreophilus</td>
<td>25.5</td>
<td>17.7</td>
</tr>
<tr>
<td>Graminoids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poa pratensis</td>
<td>15.9</td>
<td>12.0</td>
</tr>
<tr>
<td>Other graminoids4</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Forbs5</td>
<td>1.0</td>
<td>0.8</td>
</tr>
</tbody>
</table>

1 Shrub data are rooted stem densities (stems/5m²), averaged across 10 1x5-m macroplots in each pasture. Grass and forb data are average basal area coverage (%), ocularly estimated in 2 2x5-dm microplots, nested in each macroplot.

2 Values are mean (x) and standard deviation (se), calculated across pastures.

3 calculated t-values for the difference between site means; asterisks denote significant differences between sites (confidence coefficient = 0.95, 4df).

4 Nine other species were identified; none occurred in more than trace amounts (i.e., >1.00% basal area coverage).

5 Thirty-one species were identified; none occurred in more than trace amounts.
both years.

Pastures were stocked in mid-June shortly after oak leaves had begun to emerge. Animals were confined in the pastures until the oak was completely defoliated in at least one pasture (fig. 1.1). They were then removed to a 0.6 ha holding pasture, of similar vegetative composition, until oak in the experimental pastures resprouted to leader lengths approaching 100 mm. Goats were then returned to their respective pastures for another defoliation. This cycle was repeated as many times as possible during each growing season. The balance between the rate of oak production and the rate of its removal by goats thus limited the number of defoliations per year and the number of days involved in each defoliation. Defoliation periods shortened as the season progressed due to the slowing of the oak growth rate. Ample amounts of other forages remained throughout the grazing periods to meet intake demands; only oak and serviceberry were heavily utilized at the end of any period. Production of new leaders ceased by late August.

Each animal was weighed whenever it entered \((Kg_1)\) and left \((Kg_2)\) an experimental pasture; and a weight change was calculated \((Kg = Kg_2 - Kg_1)\). Changes were expressed as percentages of initial weight at the start of each pasture period \((Kg·100Kg_1^{-1})\) to account for individual differences in size. Confinement periods differed in length; therefore live-weight changes were adjusted again to account for this. The resulting statistic was termed the mass-specific gain rate, or MSGR \((Kg·100Kg_1^{-1}·day^{-1})\); it was the primary parameter by which performance was gauged.
Figure 1.1. Photograph showing the alluvial site pasture complex after defoliation of stocked pastures, 6 July, 1985.
Dietary composition was systematically estimated only in 1985. Composition was estimated via observation of tractable animals; refrigeration facilities were not available, so use of esophageally fistulated animals was precluded. Tractable animals were not available in 1984 and only nonsystematic observations were possible that year. Tractable animals consisted of 3 additional wethers of comparable size and age. They were held without supplementation in the holding pasture except on sampling days which occurred at 1 week intervals during the defoliation periods. On these days, each of the tractable animals was led to one of the three experimental pastures for feeding observations. Observations were made during both morning and evening when the nontractable animals usually fed (see Coates et al. 1987). Observation periods lasted until the animal no longer fed actively. Forage use was recorded by plant species and plant part, and instances of use were summed over the morning and evening observation periods on each day. Dietary composition was estimated from these summations after they were weighted by dry-weight estimates for the items taken.

Dry-weight estimates of food items were arrived at in one of two ways, depending on the type of item taken. Simulated bites were collected, oven-dried, and weighed to estimate weights for grasses, forbs, and individual shrub leaves. On the other hand, twig diameter-weight regressions (e.g., Lyon 1970, Jensen and Urness 1981, Peek et al. 1971, Ruyle et al. 1983, Telfer 1969) were used to estimate dry weight of browse items that included twig and leaf material. Sampling intensity was roughly 10% of recorded bites in
either case. Dietary composition was calculated for each tractable animal on each sample day. Leaf:stem ratios were calculated for oak using diameter-weight regressions; these ratios were compared to those fed in the digestion-balance trials reported by Nastis and Malechek (1981). Means were calculated for each animal during each defoliation period. Parametric statistical techniques were used to estimate live-weight changes and diet parameters (Neter and Wassermann 1974). A simple linear model was used in which site and defoliation period were fixed effects, and animals were random replicates within site or defoliation period. Gain rates were only examined within defoliation periods; these were not compared statistically between defoliation periods because of the serial nature of the observations. Least-squares procedures were employed using RUMMAGE software (Bryce 1980). A confidence coefficient of 0.90 was used to delineate statistical significance unless stated otherwise.

Results and Discussion

Defoliation of oak was slow in 1984 because of the low stocking density. Only 1 defoliation was completed that year over a 67 day period, and use was not uniform across pastures. Abandonment of the ridge pastures in 1985 facilitated more uniform use in the lower pastures; and a total of 3 successive oak defoliations were completed that year. The first of these required 27 days, the second took 11 days, and the third took only 8 days.
Table 1.2 summarizes dates of each defoliation and the live-weight history of the experimental animals. No significant difference in live-weight change was detected between sites in 1984 and, as a result, only the pooled estimate for all 24 animals is reported. Season-long weight change was positive in both 1984 and 1985. Summing the mass-specific gains for the three 1985 periods and adjusting the total by the number of total pasture days yielded a MSGR of 0.122 Kg 100Kg\(^{-1}\)·day\(^{-1}\); this compares favorably with that for 1984. Slower gains were expected in 1985 because the growth rates of 2-year-olds in 1985 would be predictably less than those of the same animals as yearlings in 1984. Performance may also have been negatively affected by the higher stocking density in 1985 as well.

Season-long gain rates did not reflect periodic extremes. In 1985, weight gain was clearly indicated during the June and August periods, while weight loss occurred in July. Gain rates in June and August were apparently twice that for the 1984 season. The estimates for gain rate in July and August should be viewed with caution because of the small number of days involved in each period; changes in gut-fill may be responsible rather than changes in net mass, even though marked changes in diet should have been precluded by the similarity between the holding pasture and experimental pastures. Nature of the weight changes (i.e., positive or negative) during the latter two periods is probably valid but not necessarily the magnitudes. If so, higher periodic performance may be inferred for yearling animals than the 1984 seasonal estimate indicates; assuming
Table 1.2. Summary of stocking dates and live-weight history of the 24 experimental animals.

<table>
<thead>
<tr>
<th>Year</th>
<th>Stocking dates</th>
<th>Live-weight Range(^1) at start/at finish</th>
<th>Weight Change(^2)</th>
<th>Mass-specific Weight Change(^3)</th>
<th>Mass-specific gain rate(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>6/20-8/25</td>
<td>21-34/22-34</td>
<td>2.85±0.35</td>
<td>11.64±1.44</td>
<td>0.17± 0.02</td>
</tr>
<tr>
<td>1985</td>
<td>6/10-7/6</td>
<td>23-39/26-44</td>
<td>2.42±0.12</td>
<td>8.40±0.35</td>
<td>0.31± 0.02</td>
</tr>
<tr>
<td>1985</td>
<td>7/18-7/28</td>
<td>31-45/28-44</td>
<td>-1.85±0.12</td>
<td>-5.30±0.36</td>
<td>-0.48±-0.02</td>
</tr>
<tr>
<td>1985</td>
<td>8/13-8/2</td>
<td>29-44/28-48</td>
<td>0.88±0.18</td>
<td>2.51±0.35</td>
<td>0.31± 0.02</td>
</tr>
</tbody>
</table>

1 Kg.

2 Kg ± standard error.

3 Kg·100Kg\(^{-1}\) ± standard error.

4 Kg·100Kg\(^{-1}\)·day\(^{-1}\) ± standard error.
that a mid-summer loss occurred in 1984 as well. The short length of the July and August periods was unfortunate because consumption of juvenile oak was greatest during these two periods.

Goats apparently selected juvenile oak browse in preference to mature material in 1984. They spent most of their time in corners and along fence lines where they repeatedly defoliated stems of juvenile sprouting material rather than utilize the more mature material to be found toward the center of the pastures. The effect of this browsing pattern was so striking that after 50 pasture days (or approximately 200 goat-days) very little use occurred in the center 1/3 of the pastures. Stems in the peripheral 2/3 were stripped bare at the same time (fig. 1.2). There was, in effect, a horizontal browse line. It is not likely that either forage availability, or distance from water or bed sites was responsible because the pastures were only 0.2 ha in area; the centers of the pastures were only a few meters from any fence line. The pattern may have been initiated due to the tendency for animals to concentrate activity along barriers; and this may have been socially facilitated. However, its maintenance in the confines of such a small area, and for such a long time, seems unlikely if the relative palatability of juvenile oak browse were low. Clearly, some preference for juvenile foliage was suggested.

Observation of tractable animals in 1985 indicated that shrubs dominated the diet during all three pasture periods and the contribution of shrubs increased significantly after the first defoliation (table 1.3). Use of both graminoids and forbs declined
Figure 1.2. A typical browsing pattern in 1984. Date is 14 August, after 54 days of pasture occupancy (1080 goat-days use per ha). A stocked pasture (foreground) and a control pasture (background) are outlined. Oak in the center of the stocked pasture (dashed line) remains unbrowsed.
Table 1.3. Mean contribution (%) of forage classes, and of species within forage class, to the diets of tractable animals, 1985. Letter differences across rows indicate significant differences among periods (confidence coefficient = 0.90).

<table>
<thead>
<tr>
<th>FORAGE CLASS</th>
<th>Mean Dietary Contribution (%)</th>
<th>Species</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SHRUBS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quercus gambelii</td>
<td>94.7 (a)</td>
<td>99.2 (a)</td>
<td>96.8 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other shrubs</td>
<td>5.3 (a)</td>
<td>0.8 (a)</td>
<td>3.2 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GRAMINOIDS</td>
<td>24.3 (a)</td>
<td>12.4 (a)</td>
<td>11.8 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poa pratensis</td>
<td>77.4 (a)</td>
<td>82.6 (a)</td>
<td>98.8 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stipa spp.</td>
<td>22.1 (a)</td>
<td>17.4 (a)</td>
<td>0.0 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other graminoids</td>
<td>0.5 (a)</td>
<td>0.0 (a)</td>
<td>1.2 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FORBS</td>
<td>15.7 (a)</td>
<td>1.1 (b)</td>
<td>0.0 (b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Helianthella uniflora</td>
<td>29.7 (a)</td>
<td>0.0 (a)</td>
<td>0.0 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lathyrus pauciflorus</td>
<td>50.4 (a)</td>
<td>50.0 (a)</td>
<td>0.0 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Verbascum thapsis</td>
<td>10.0 (a)</td>
<td>50.0 (a)</td>
<td>0.0 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other forbs</td>
<td>9.8 (a)</td>
<td>0.0 (a)</td>
<td>0.0 (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sampling Dates</td>
<td>(6/17, 6/23)</td>
<td>(7/20, 7/27)</td>
<td>(8/14, 8/20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(6/30, 7/6)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 All other shrubs present were consumed in small quantities.

2 Two species (S. columbiana, S. comata) had the same utilization pattern and are grouped here.
after the first defoliation; but only the forb decline was statistically significant. Forbs were only a minor component of the diet even at the onset of the experiment and were unavailable during most of the latter two periods.

Dietary quality was not analyzed in the lab, but speculation is possible based on comparative phenology and leaf:stem ratios. Oak browse comprised 95-99% of the browse consumed by the tractable animals. By comparison then, the quality of the other browse species is of little practical importance. The oak fraction was juvenile throughout 1985 because the high stocking density employed did not allow oak phenology to advance (fig. 1.3). This was particularly true during the last two periods when the growth rate of oak declined relative to its removal rate. Oak that was taken also had a relatively constant leaf:stem ratio; twig content of the oak fraction was only 4.4% (SE = 0.76, n = 24 diets), without significant differences between periods (periodic means were 4.4, 5.4, and 3.5 for the three pasture periods, respectively). A twig content of 4.4% translates to a leaf:stem ratio approximating 22:1. The consistently high leaf:stem ratio and young phenology suggests that the ratio of cell-solubles to cell-wall constituents was also consistently high, and that dietary lignin was low. Dry matter digestibility would benefit on this basis (Van Soest 1982).

Graminoids, and bluegrass in particular, made up most of the remainder of the diet during the first period and almost all of the remainder during the subsequent two periods. Therefore, changes in the quality of the grass fraction could indicate the nature of change
Figure 1.3. Comparison of oak phenology at the outset of the second defoliation period in 1985. Light-colored foliage in the stocked pasture is sprouting juvenile material. Dark foliage in the background is typical of mature material in control pastures. Understory phenology is post-fruiting.
in the diet as a whole. Quality of the grass on offer should decline as the season progresses due to the combined effects of selective foraging by goats (for leaf versus stem), and maturation. Leaf:stem ratio of grasses on offer was not systematically monitored but a decline was observationally apparent. The senescent proportion of the dietary grass fraction was monitored by recording whether bites consisted of cured or green material. No difference occurred in the cured grass proportion between the first and second defoliations; but there was a dramatic increase between the second and third periods (fig. 1.4). On this basis, quality of the grass fraction apparently declined between the second and third periods. Thus, free-ranging goats apparently gained weight on a diet composed of approximately 85% juvenile oak browse, and a balance of largely senescent grass.

Juvenile Gambel oak is not currently considered a valuable forage resource because of its potentially adverse affect on intake (Nastis and Malechek 1981). These authors observed reduction in voluntary intake when the juvenile oak content of a pelleted ration was as high as 80%. Therefore, an a priori assumption going into the current study was that free-ranging goats would avoid high concentrations of juvenile oak in their diets since they had opportunities to select alternate forage in the forms of other species or more mature oak foliage. Confirmation of this assumption would have had adverse implications for using goats in oak-control programs because a consistently high intake of juvenile material is apparently requisite for effective control. The high content of juvenile material observed in this study, which exceeded 80% during
Figure 1.4  Percentage of grass in diet that was cured, 1985. Confidence coefficient for intervals is 0.90.
two periods, and the apparent preference for juvenile material was not expected. Goats will indeed voluntarily select very high proportions of juvenile oak browse in their diets; furthermore, it seems highly unlikely that intake is reduced by juvenile oak since this browse is apparently preferred. However the high proportions of juvenile oak consumed in this study may well have been precipitated by the special stocking strategy that was employed; lighter stocking densities that do not maintain the juvenile phenology of oak may fail to produce the same effect.

Likewise, live-weight changes were not expected to be positive. Dietary quality was expected to decline as the summer progressed due to the increase in juvenile oak content, and the apparent consistency in the type of oak browse consumed, coupled with the apparent decline in grass quality. The marked shift from weight gains in the first period to weight losses in the second period of 1985 was anticipated. However, the gains recorded for the third period were not anticipated. Durations of the second and third defoliations were short; perhaps too short to evaluate performance directly from live weights. Short-term differences in live weight may be confounded by gut-fill differences responding to thermal conditions (Curtis 1983) or dietary changes (Van Soest 1982). Yet these pasture periods were of the length typically involved in digestion-balance trials. Performance on high-percentage juvenile-oak diets is an issue remaining to be resolved. However these observations do not suggest that reduced performance, if it occurs, results from low palatability of juvenile oak. Direct assessment may never be possible because
stocking strategies aimed at oak control will always entail short late-season defoliation periods resulting from the decline in shrub growth that occurs as summer progresses. Therefore, further digestion-balance trials are required.

Two possible explanations exist for the apparent difference between this study’s observations of diet composition and those of Nastis and Malechek (1981) regarding intake. First, animals used in this study were pastured and thus able to feed on live foliage whereas in the prior digestion-balance trials experimental animals were confined and fed a ration composed of air-dried, pelleted material. Drying and pelletization may have altered palatability. Second, reduced intake such as they observed might result from aversion to a higher concentration of lignified material in stems and older leaves, irrespective of the effects of drying and pelleting. Oak used to formulate the pelleted rations in their study consisted of twigs up to 150 mm in length with associated leaves and buds, similar to items of shinnery oak (Quercus pungens) selected by goats in a Texas study (Malechek and Leinweber 1972). With this information, the leaf:stem ratio of oak they fed in their trials can be tentatively compared to that of oak ingested by goats in this study using twig length - weight regressions developed here (table 1.4). It seems fair to assume that the average length of their twigs was about 75 mm. A 75 mm twig, if it occurred in this sample, would have consisted of approximately 15% woody material (twig wt. = 0.0001(75)^{1.66}, r^2=0.85, SE=0.56) and 85% leaf (leaf wt. = 0.01(75)^{0.99}, r^2=0.58, SE=0.67). This translates to a leaf:stem
Table 1.4. Twig diameter-weight, and twig length-weight relations used to predict the weights of shrub leaders consumed by goats in this study.

<table>
<thead>
<tr>
<th>Species</th>
<th>Equation</th>
<th>$r^2$</th>
<th>se</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amelanchier alnifolia</td>
<td>(TL) = 0.029(D)².99</td>
<td>0.86</td>
<td>0.37</td>
</tr>
<tr>
<td>Artemisia tridentata</td>
<td>(TL) = 0.101(D)².44</td>
<td>0.86</td>
<td>0.37</td>
</tr>
<tr>
<td>Chrysothamnus viscidiflorus</td>
<td>(TL) = 0.054(D)³.15</td>
<td>0.94</td>
<td>0.28</td>
</tr>
<tr>
<td>Purshia tridentata</td>
<td>(TL) = 0.030(D)³.21</td>
<td>0.82</td>
<td>0.44</td>
</tr>
<tr>
<td>Quercus gambelii</td>
<td>(TL) = 0.045(D)².77</td>
<td>0.82</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>(T) = 0.003(D)³.65</td>
<td>0.91</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>(L) = 0.045(D)².54</td>
<td>0.76</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>(T) = 0.0001(LE)¹.66</td>
<td>0.85</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>(L) = 0.010(LE)⁰.99</td>
<td>0.58</td>
<td>0.67</td>
</tr>
<tr>
<td>Symphoricarpos oreophilus</td>
<td>(TL) = 0.054(D)².79</td>
<td>0.95</td>
<td>0.27</td>
</tr>
</tbody>
</table>

1 Bite weights for species not listed here were estimated by hand-plucking simulated bites.

2 Equations were generated from a random subsample of 50 leaders using a log model (i.e., $\ln[y] = \ln[a] + b[\ln(x)]$); the coefficients of determination ($r^2$), and the standard errors (se) presented above correspond to these. The anti-log form of the equations (i.e., $y=ax^b$) is presented above for brevity. Variable definitions are as follows: TL = dry weight of woody twig and leaves; T = dry weight of woody twig only; L = dry weight of leaves only; D = leader diameter at point of browsing (mm); LE = leader length from tip to browsed point (mm).
ratio of 5.6:1 on average. While the leaf:stem ratio in this study was nearly 22:1. Validity of this comparison depends on two assumptions: (1) the length-weight relationships we observed were representative of the browse fed in Nastis and Malechek's study, and (2) lengths of twigs fed in their study were close to 75 mm on average. Neither assumption can be critically evaluated at this point; none-the-less, the magnitude of the difference in leaf:stem ratios suggests that the twig fraction fed in their experiment was not representative of that which would be selected by free-ranging goats when stocked at the high densities required for efficient oak control.

The season-long selection for oak might be explained on the basis of its phenology relative to other species. Gambel oak is not cold-adapted (Sweeney and Steinhoff 1976, Neilson and Wullstein 1980) and, as a result, its foliage development in spring might be expected to lag behind more cold-hardy species. This is the case in the northern Wasatch area where the species approaches its northern limit. It is consistently the last shrub to initiate spring growth here and many grasses and forbs have begun to flower by the time its first leaves mature. Cell-wall fraction increases and digestibility decreases as plants mature. This is particularly true in shrubs, as the ratio of twig to leaf increases with leader elongation, in addition to the structural changes at the cellular level. Thus, oak's delayed phenology could contribute to high relative palatability compared to other forages. Periodic, selective defoliation of oak, as occurred here, only enhances the phenological
difference between oak and associated forages as summer progresses.

Conclusions

Goats in this study increased their consumption of juvenile oak browse over time, although other forages were available. High intakes of juvenile browse may be facilitated by employing high stocking densities through repeated defoliations, thereby maintaining early phenological status relative to other species. Differential phenology among species at the time of initial stocking probably is also an important factor determining species selection.

Considerable short-term variation in live-weight changes of goats managed in this way may be expected, but low performance in this study was not correlated with juvenile oak content of the diet. Additional digestion-balance trials should be conducted to better ascertain the value of juvenile oak browse. Browse fed in these trials should be fresh in order to avoid bias due to ration processing. It should also have a leaf:stem ratio closely resembling that likely to be selected by free ranging animals; a leaf:stem ratio greater than or equal to 17.2:1 (i.e., not more than 5.4% woody twig) is suggested.
CHAPTER II

EFFECTS OF GOAT BROWSING ON GAMBEL OAK COMMUNITIES IN NORTHERN UTAH

Control of Gambel oak on rangelands is a long-standing interest of range managers in western North America. Improvements in cattle carrying capacity, livestock dispersal and handling, and soil moisture retention have been attributed to oak control (Marquiss 1972, Tew 1969). Not surprisingly, most research on this topic has been motivated by a desire to enhance livestock production. Judicious control of oak may benefit big game in some circumstances as well (Kufeld 1977, 1983). Selective reduction of Gambel oak on winter range might confer a competitive advantage to other species such as big sagebrush, which is apparently more nutritious for wintering ungulates than oak (Kufeld et al. 1981). Selective oak control might also enhance herbaceous species, thereby serving both wildlife and livestock interests.

Unfortunately, selective oak control cannot be efficiently attained using traditional shrub-control techniques such as fire, herbicides or mechanical treatment. Furthermore, rising costs and logistical constraints can preclude their use. Selective browsing by domestic goats may be a viable alternative. Angora and milk-type goats have been used to control resprouting by Gambel oak following mechanical treatment (Davis et al. 1975). More recently, Spanish goats have been shown to have greater potential for shrub control than either sheep or Angora goats (Warren et al. 1984), and to have
dietary habits suited to selective control of Gambel oak under certain management constraints (Riggs et al. 1988).

Data concerning the effects of goat use on undisturbed oakbrush communities is lacking, despite the obvious implications that it might have for management of livestock and big game range alike. This paper reports the effects of intensive goat browsing on composition and productivity of experimental shrub communities located on a big game winter range site in northern Utah.

Methods

Treatment and Response Variables

Responses to goat browsing were investigated in six experimental oakbrush communities that were created by subdividing the naturally occurring parent community into smaller units. The parent community was first divided into three, 0.4-ha blocks, and each block was then subdivided into two, 0.2-ha pastures. One pasture in each block was subsequently stocked during the growing season with Spanish-type goat wethers while the other was maintained as a control pasture.

Stocked pastures each received 1,340 goat-days use per hectare in 1984, and 1,840 goat-days use in 1985; they were rested in 1986. Stocking occurred in a series of repeated, high-intensity, short-duration periods that were designed to maximize defoliation of Gambel oak. Additional information regarding the study site, stocking strategy, and diet selection of goats was published elsewhere (Riggs et al. 1988).

The first response variable was the density of live, rooted
stems. Density was estimated for each experimental shrub population in late June of each year. Stems were counted by species in each of 10 permanent 5-m² macroplots (Oldemeyer and Regelin 1980) in each pasture. Data were compared by analysis of variance (ANOVA).

The standardized skewness coefficient, $g_1$ (Sokal and Rohlf 1981), was used to gauge shifts in stem-size distributions of the experimental shrub populations. Size was calibrated each year, in terms of cross-sectional basal diameter (mm), on 200 randomly selected stems in each experimental population (Cole 1963). A standardized skewness coefficient was calculated for each sample distribution, and the collection of coefficients was compared across treatments and years by ANOVA.

The relationship between stem size and stem production, (i.e., size-specific production) was estimated for non-sprouts in each experimental population using a size-stratified, random sample of 50 rooted stems. Size was calibrated in terms of cross-sectional basal diameter (mm). Productivity (g/stem) was calculated as the product of each stem’s leader count and average leader weight ([stem production] = [mean twig weight] x [twig count]). Twig-diameter - weight regressions were used to estimate twig weights in a systematic subsample of the leaders on each stem. These data were the basis for the relationship between size and productivity of stems in each pasture. The parameters of the relationship (i.e., slope and intercept) were sequentially analyzed for treatment effects using analysis of covariance in which the concomitant variable was basal diameter and the dependent variable was stem production.
Dowdy and Wearden (1983) concisely review the rationale behind covariance analysis. Briefly, the procedure differs from ANOVA of mean stem production in that it incorporates the regression relationship between the response variable and a concomitant variable. In other words, some of the variability that would constitute random error in a simple means analysis (i.e., that correlated with size in this case) is isolated and analyzed separately. Therefore, the analysis makes more efficient use of the data. Assumptions are the same as for the nominal analysis of variance; consequences of their violation have been documented by Cochran (1947) and Glass et al. (1972).

Equations predicting size-specific stem production were generated for experimental populations according to results of the covariate ANOVA. Separate equations were generated according to treatment if the covariance analysis detected differences in either slope or intercept; the pasture samples were pooled to generate a common equation in the absence of such differences. Equations were generated using the simple linear log model: $\ln(P) = \ln(b_0) + b_1[\ln(D)]$; where $P$ was production per stem (g/stem), $D$ was basal stem diameter (mm), $\ln$ was the natural log function, and $b_0$ and $b_1$ were intercept and slope coefficients, respectively. For brevity, the antilog form, $P = b_0(D)^{b_1}$, accompanied by the coefficient of determination ($r^2$) is used in this text. Unplanned comparison procedures for regression coefficients (Sokal and Rohlf 1981) were used to identify specific differences among equations when slope or intercept heterogeneity occurred among more than two populations.
Conditional tests for production homogeneity among populations were conducted for 4 of the 5 species (serviceberry, sagebrush, rabbitbrush, and snowberry) in 1984. Differences were not expected the first year and an abbreviated analysis was considered adequate for detecting any initial differences that may have existed among pastures. Productivity of a predominant size class of stems was sampled in each experimental population and the data were subjected to a blocked ANOVA for treatment effects. None of these tests yielded significant results, and therefore initial homogeneity among pastures was assumed for these species. However, Gambel oak was subjected to covariate analysis in all 3 years because it was the community dominant and the target of the browsing treatment.

Sprouting responses (frequency and weight of sprouts in the production samples) were treated separately. Rooted sprouts were excluded from the covariate production analysis because their size—production relations were expected to differ from those of non-sprouts (Rumble 1987). A rooted sprout is composed entirely of current annual growth, whereas a non-sprout of equal diameter is composed of some current annual growth and some older growth; thus necessitating separate analyses.

Utilization estimates were obtained at the same time as the production estimates. Twig utilization was defined as the percentage of CAG removed or killed by browsing. The weight removed from each twig was predicted using the same twig diameter—weight regressions used to predict twig weights. Browsed diameters were calibrated below the point where twig dessication terminated.
Herbaceous composition was estimated by ocular appraisal of basal area coverage, in 2 permanent 5-dm\(^2\) microplots nested in each 5-m\(^2\) macroplot. Two 1-m\(^2\) circular plots, nested in each macroplot, were clipped for production estimates in August 1986.

The final exercise was to model the cumulative effects of goat browsing, using data for all the various response variables. Model output for species productivity (kg/ha) was generated using the appropriate point estimates for density, size distributions, stem size-production relations, and sprout responses derived in the foregoing statistical analyses. Productivity values were calculated by weighting the density estimates by the proportion of stems in various size classes, and then weighting the resulting histograms by the size-specific stem productivity predicted for the midpoint of each size class, after adjusting for the proportions of sprouts versus non-sprouts.

Experimental Design

All the analyses of variance were computed using least squares procedures (Bryce 1980) and a common experimental design. A 2-factor, complete block design was used. Main effects in the design were blocks, goat use (without respect to density), and years. Blocks were a random effect while both goat use and years were fixed. The year effect was a repeated measure while both goat use and years were fixed. The year effect was a repeated measure while both goat use and years were fixed. The year effect was a repeated measure while both goat use and years were fixed. The year effect was a repeated measure while both goat use and years were fixed.

The year effect was a repeated measure. This basic design was used for ANOVA of stem density, stem-size distributions, and sprout responses. Covariate ANOVA of size-specific stem productivity was facilitated by merely adding stem diameter to the design, as the concomitant. Detection of treatment x year interactions was enhanced
by reducing the model to a completely randomized design if the block term was not significant.

Results

Utilization Levels

Sagebrush, rabbitbrush, and snowberry were consumed little by goats (Riggs et al. 1988). Sagebrush utilization was only 2.4% (SE = 0.8) for both twig and leaf material, with no differences between years. Utilization of rabbitbrush was 2.7% (SE = 0.8) and 3.4% (SE = 0.9) for twigs and leaves, respectively, and no difference occurred between years. Utilization of snowberry twigs and leaves, however, varied between years (p < 0.03). Twig utilization increased from 0.8% (SE = 0.8) in 1984 to 39.8% (SE = 0.1) in 1985; likewise, leaf utilization increased from 1.4% (SE = 1.0) to 52.8% (SE = 0.2). The greater use of snowberry in 1985 resulted from the greater number of animal days applied that year.

Conversely, both serviceberry and Gambel oak were avidly consumed. Serviceberry browse was not abundant in the pastures and its utilization was high, despite its low occurrence in the diet (Riggs et al. 1988); utilization averaged 48.6% (SE = 3.4) and 53.3% (SE = 3.3) of twigs and leaves, respectively, with no significant difference between years (p > 0.10). Utilization of oak fractions was lower (p < 0.05) in 1984 than 1985. Twig utilization was 20.0% (SE = 0.3) in 1984 and 56.2% (SE = 0.3) in 1985; leaf utilization was 43.3% (SE = 8.1) and 64.3% (SE = 3.6) in 1984 and 1985, respectively.
Composition Responses

Botanical composition of the experimental pastures did not differ at the outset of the experiment in 1984 (Table 2.1). No changes (p < 0.10) were detected after 2 years in either density of shrub stems or herbaceous basal area coverage.

Dynamics of Stem-Size Distributions

Minimum and maximum stem diameters were stable in all shrub populations throughout the study, and skewness of the size distributions shifted in only the browsed oak populations (P < 0.08, Fig. 2.1). Size distributions of all oak populations were positively skewed in 1984, indicating an initial abundance of small stems relative to large ones. As the experiment progressed, skewness of browsed populations progressively increased while that of the control populations did not change (Fig. 2.2), and the treatment effect was significant in the third year. This progressive positive skewing, at constant density, indicated an increase in the relative abundance of smaller stems. Oak stem density in 1986 was not different (p > 0.10) from that in 1984; therefore both increased sprouting and mortality of older stems were involved.

Sprout Responses

Browsing did not affect the sprouting rate of serviceberry populations. Sprouts composed 74% (SE = 5.6) of the rooted serviceberry stems less than 4 mm in diameter. This percentage did not differ among populations at any time during the three-year period. However, sprout weights did differ between treatments (p <
Table 2.1. Initial botanical composition of experimental pastures, 1984.

<table>
<thead>
<tr>
<th>PLANT TAXA</th>
<th>Control Pastures</th>
<th>Stocked Pastures</th>
<th>Mean ± S.E. ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Block #1</td>
<td>Block #2</td>
<td>Block #3</td>
</tr>
<tr>
<td><strong>SHRUBS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amelanchier alnifolia</td>
<td>2.70</td>
<td>2.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Artemisia tridentata</td>
<td>3.50</td>
<td>10.60</td>
<td>2.00</td>
</tr>
<tr>
<td>Berberis repens</td>
<td>0.20</td>
<td>3.40</td>
<td>0.00</td>
</tr>
<tr>
<td>Chrysothamnus viscidiflorus</td>
<td>23.30</td>
<td>18.60</td>
<td>32.70</td>
</tr>
<tr>
<td>Purshia tridentata</td>
<td>2.50</td>
<td>1.50</td>
<td>0.80</td>
</tr>
<tr>
<td>Quercus gambelii</td>
<td>36.70</td>
<td>23.30</td>
<td>27.80</td>
</tr>
<tr>
<td>Rosa sp.</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Symphoricarpos oreophilus</td>
<td>4.60</td>
<td>36.50</td>
<td>19.90</td>
</tr>
<tr>
<td><strong>GRAMINOIDS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poa pratensis</td>
<td>8.80</td>
<td>7.70</td>
<td>16.35</td>
</tr>
<tr>
<td>other ²</td>
<td>0.85</td>
<td>2.50</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>FORBS³</strong></td>
<td>0.80</td>
<td>0.05</td>
<td>0.35</td>
</tr>
</tbody>
</table>

¹Differences between controls and stocked pastures were not significant (p < 0.05). Nomenclature follows Cronquist et al. (1972).

²Other graminoids were Agropyron smithii, Agropyron spicatum, Bromus tectorum, Carex geyeri, Stipa columbiana, Stipa comata, and Poa fendleriana. None of these accounted for ≥1% coverage in any pasture.

³Thirty-one forb species were recorded, but none averaged as much as 1% coverage. Species which composed as much as 1% coverage in at least one microplot included Achillea millefolium, Antennaria microphylla, Aster integrifolius, Collinsia parviflora, Comandra umbellata, Erigeron pumilus, Gilia aggregata, Helianthemella uniflora, and Lathyrus pauciflorus.
Figure 2.1. Pooled sample distributions of stem size in 1984 and 1986. Only the size distribution of oak was affected by goats.
Figure 2.2. Changes in the standardized skewness coefficient for sample basal diameter distributions of rooted oak stems, 1984-86. The vertical bar corresponds to the LSD_{10} between controls (solid line) and the stocked pastures (dashed line) observed in 1986.
LSD = 0.8
Sprout dry weights averaged 0.58 g among control populations versus 0.21 g among browsed populations (LSD$_{10}$ = 0.25).

Sprout parameters of green rabbitbrush populations were unaffected. Rabbitbrush sprout diameters did not reach 2 mm and sprouts comprised about 66.7% (SE = 9.6) of all rooted stems less than 2 mm in diameter, regardless of treatment or year. Rabbitbrush sprouts averaged 0.35 g (SE = 0.10).

Increased skewness observed in the browsed oak populations was facilitated by an increase in sprouting. Oak sprouts were less than 10 mm in diameter, and the proportion of sprouts occurring in subsamples of stems under 10 mm diameter varied significantly (p < 0.03) by treatment and year. Sprout numbers increased in the stocked pastures but did not change in the controls (Fig. 2.3). Sprouts comprised 10.7% and 10.0% of all oak stems less than 10 mm diameter in 1984 and 1985, respectively. In 1986, sprouts comprised 90.0% of the browsed-population samples, but only 6.7% of the control samples. Likewise, browsing did not affect sprout weight in either 1984 or 1985 ($X = 1.26$ g, SE = 0.59). However in 1986 sprouts averaged 2.90 g and 1.15 g in browsed and control populations, respectively (LSD$_{10}$ = 0.81).

Snowberry did not exhibit a sprouting response. Basal diameter of snowberry sprouts seldom reached 4 mm (P = 0.03, n = 119), and browsing did not alter the frequency of sprouts under this size. However, the proportion of sprouts in the subsamples varied between years (p < 0.05) regardless of treatment. This proportion increased, in both browsed and control populations, from 31.7% in 1985 to 58.3%
Figure 2.3. Changes in the percentage of live, rooted oak stems under 10 mm basal diameter that were sprouts, 1984-86. The vertical bar corresponds to the LSD.05 between controls (solid line) and the stocked pastures (dashed line) observed in 1986.
SPROUTS IN SAMPLE (%)

YEAR

1984 1985 1986

LSD = 41.3
in 1986 (LSD.05 = 25.9). Dry weight of snowberry sprouts was unaffected by browsing or year; dry weights consistently averaged 0.52 g (SE = 0.06).

Covariate Production Responses of Nonsprouts

A highly significant (p < 0.0001) relationship was observed between basal stem diameter and production for serviceberry. Slope of the relationship differed (p < 0.03) between treatments. Slope in the relation for control populations (P = 0.22(D)1.47, r² = 0.70) was more than twice that of browsed populations (P = 0.28(D)0.63, r² = 0.32) in both 1985 and 1986, indicating that the productivity of nonsprouts was reduced, especially that of larger stems.

Sagebrush also exhibited a highly significant (p < 0.0001) stem diameter - production relationship. Slopes were homogenous but intercepts differed (p < 0.001) between treatments in the case of vegetative leader production. The intercept of the size-production relationship for stems in the control pastures (P = 0.09(D)1.63, r² = 0.87) was lower than that for stems in stocked pastures (P = 0.13(D)1.78, r² = 0.87). Therefore, vegetative production increased in response to the avoidance of this species by goats, but not in a strongly size-dependent manner. Reproductive leader production (RP) was estimated in 1986 only. As with vegetative leaders, there was a highly significant (p < 0.0001) relationship between basal stem diameter and reproductive leader production, but neither slope nor intercept heterogeneity was detected. One regression (RP = 0.33(D)0.99, r² = 0.33) applied to both treatments. Thus reproductive effort was not strongly correlated with stem size and it
did not respond as did vegetative production.

Rabbitbrush populations also had a highly significant ($p < 0.0001$) stem diameter - production relationship and slope heterogeneity was detected for the treatment x year interaction ($p < 0.10$). No treatment effect was apparent in 1985 and one stem diameter - production relationship ($P = 0.62(D)^{1.18}$, $r^2 = 0.61$) applied to both stocked and control pastures. Slope of the relationship declined for both stocked and control pastures in 1986, but less precipitously in the case of stocked pastures; slope for control populations ($P = 1.01(D)^{0.71}$, $r^2 = 0.31$) was lower than that for populations in stocked pastures ($P = 0.88(D)^{0.92}$, $r^2 = 0.42$). Differences were significant between years, but the treatment effect was only significant in 1986 ($MS_{D0.05} = 0.09$). These results imply that the heavy use of other species (particularly oak) in the browsed pastures alleviated the decline somewhat.

Analysis of size-specific oak production was inconclusive using the complete block design. Both the browsing effect ($p < 0.10$) and the year effect ($p < 0.02$) were significant for slope heterogeneity, but the interaction term was not significant ($P > 0.25$). An interaction was expected for oak. Size-specific data were collected from the beginning of the experiment so that any browsing effect would be manifest only as the experiment progressed. Failure to detect the interaction was thought to result from insufficient pasture replication (i.e., blocks), given the response variation. The block effect was tested and found to be insignificant ($p > 0.50$). Therefore the block term was deleted from the statistical model and
the treatment x year interaction was reanalyzed. The interaction was then found to be significant (p < 0.03), as expected. Regressions of control and browsed populations were similar in 1984 and a pooled regression was calculated across treatments \( P = 0.40(D)^{1.41}, r^2 = 0.77 \). Slope coefficients for control populations gradually increased during the course of the experiment. Conversely, slopes declined precipitously in the browsed populations during the second year, and did not recover (table 2.2). Thus the vigor of non-sprout oak stems was severely reduced by goat browsing, especially that of larger stems.

Snowberry, like all other shrubs, exhibited a highly significant relationship between basal stem diameter and stem production (p < 0.0001). However, neither its slope nor intercept was altered by goats (p > 0.10); so only one regression \( P = 0.50(D)^{1.22}, r^2 = 0.54 \) was generated after pooling the data over both treatments and years. Thus this species was not affected by the browsing treatment or by differences in growing conditions associated with year.

**Cumulative Effects on Shrubs**

Reduction in productivity of mature serviceberry stems, coupled with reduction in sprout vigor, lowered productivity of browsed serviceberry populations. Productivity of a model control population was 26 kg/ha versus 4 kg/ha for a browsed population. The difference is depicted under the size-specific production curves (Fig. 2.4).

In the case of Gambel oak, all of the variables responded to the intense browsing and population productivity was severely reduced. Productivity in 1984, when no differences were observed between
Table 2.2. Treatment x year comparisons of rooted-stem diameter - production regressions, \( P = b\phi(D)^{b_l} \) for Gambel oak, 1984-86. Unlike letters indicate significant slope differences among equations (MSD_{0.05} = 0.24).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
<th>( b\phi )</th>
<th>( b_l )</th>
<th>adjusted ( r^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>1984</td>
<td>0.37</td>
<td>1.46 a</td>
<td>0.75</td>
</tr>
<tr>
<td>Stocked</td>
<td>1984</td>
<td>0.43</td>
<td>1.36 a</td>
<td>0.81</td>
</tr>
<tr>
<td>Controls</td>
<td>1985</td>
<td>0.21</td>
<td>1.57 a</td>
<td>0.80</td>
</tr>
<tr>
<td>Stocked</td>
<td>1985</td>
<td>0.92</td>
<td>0.68 b</td>
<td>0.22</td>
</tr>
<tr>
<td>Controls</td>
<td>1986</td>
<td>0.22</td>
<td>1.85 c</td>
<td>0.81</td>
</tr>
<tr>
<td>Stocked</td>
<td>1986</td>
<td>0.69</td>
<td>0.76 b</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Figure 2.4. Comparison of size-specific stem production (kg/ha) as indicated by areas under curves for model shrub populations during 1984 and 1986. Plots for 1985 were intermediate or redundant and are omitted for clarity.
browsed and control populations, was 628 kg/ha. In 1986, calculated productivity for a model control population increased to 1,223 kg/ha, while productivity of a browsed model decreased to 148 kg/ha (Fig. 2.4). The marked increase in productivity of control populations was not expected on the basis of moisture conditions; precipitation was above normal in 1984, below normal in 1985 (Riggs et al. 1988) and declined further in 1986 (N.O.A.A. 1986). Alternatively, the increase may have been an artifact of pasture size. Gambel oak is clonal and the small size of pastures may have simply allowed competitive release of the control populations as vigor of the adjacent browsed populations was reduced. If so, the treatment effect is better reflected by comparing 1984 productivity to that of the browsed populations in 1986. The magnitude of the treatment effect is obviously reduced under this assumption but the conclusion that oak production was reduced is qualitatively unchanged.

Sagebrush was the only species to show a strong positive response to use of communities by goats. Neither density nor size distribution changed in the browsed pastures, but the change in size-specific production relations effected a marked increase in over-all population productivity. Combined production of reproductive and vegetative leaders, was 290 kg/ha in the absence of goat use versus 390 kg/ha in the presence of goat use (Fig. 2.4).

Green rabbitbrush and snowberry were not markedly affected (Fig. 2.4). Rabbitbrush productivity was 132 kg/ha in 1984. Neither the control nor the treatment values differed much in 1986 (106 kg/ha and 128 kg/ha, respectively).
Model snowberry productivity was 130 kg/ha and 134 kg/ha in 1984 and 1986, respectively. The small difference was attributed solely to the increase in sprout rate that occurred in all pastures.

**Herbaceous Production**

Clipping data suggested that understory production increased slightly in the stocked pastures relative to the controls, but statistical evidence was weak. Graminoid production averaged 420 kg/ha (SE = 45) across the control pastures, compared to 660 kg/ha (SE = 43) across stocked pastures; the difference was not significant (p > 0.6). Forb production averaged only 90 kg/ha (SE = 8) across the controls and 110 kg/ha (SE = 8) across the stocked pastures (p > 0.8). Pooling grass and forb data yielded a combined estimate of 510 kg/ha (SE = 49) and 780 kg/ha (SE = 48) for controls and stocked pastures, respectively, (p > 0.6). Herbage density varies spatially in communities such as these because of the clumped distribution of the shrub populations. Lack of statistical significance likely resulted from random plot locations and the small sample size (n = 20 per pasture). Differences were significant when pasture samples were pooled (i.e., n = 60 per treatment without respect to block replication), and the means compared on the basis of the pooled variance (LSD$_{0.05}$ = 0.51). An increase in herbaceous production is expected following uniform shrub control in oakbrush communities (Marquiss 1972, Moinat 1956, Price 1938). Likewise, a positive herbaceous response is expected following partial reduction, but spatial variation should be greater than that following uniform shrub removal. Increased sampling intensity would probably have allowed
detection of a difference in the ANOVA, but the sampling level required may have been prohibitive without prior stratification of plots according to shrub composition.

Discussion

Spanish goats facilitated selective control of Gambel oak. Serviceberry and oak were harmed at the utilization levels imposed by goats in this study; these levels were not as extreme as those required to harm these species in earlier clipping studies (Young and Payne 1948; Shepherd 1971). The apparently lower resilience to goat browsing may be attributed to a timing difference between ungulate browsing and artificial clipping. Clipping is generally imposed between mid-summer and early fall, after plants have been afforded some opportunity to store nutrients. In contrast, goat browsing was initiated early in the growing season, and repeated during the course of this experiment (Riggs et al. 1988); thus the opportunity to store nutrients may have been reduced, and resilience reduced accordingly (Engle et al. 1983). Neutral or positive responses observed for sagebrush, green rabbitbrush, and snowberry contrasted sharply with largely negative responses exhibited by these species following chaining, spraying or burning (Kufeld 1983). However, palatable species that are minor components of the community such as serviceberry may be negatively impacted. Results in any particular situation will be affected by stocking strategy and phenology of community constituents. For example, the selective removal of oak in this study has been tentatively related to the combined effects of
oak's retarded phenology in northern areas and intense browsing; these factors may have acted in combination to enhance and maintain oak's palatability relative to that of species with more advanced phenology (Riggs et al. 1988).

Long-term effects are yet to be assessed. Short-term results presented here do not suggest negative consequences for production of cattle or sheep summer forages. Enhancement of sagebrush may actually improve such ranges for wintering deer by enhancing the quality of forage on offer; sagebrush is likely higher in crude protein and dry matter digestion, and lower in indigestible fiber, than associated deciduous species (Kufeld et al. 1981; Welch 1983; Welch et al. 1983). Thus such treatment may benefit both livestock and deer managers, assuming that ungulates respond positively to such vegetation changes.

The community response was unclear because of the possibility that increased production observed for control populations of oak was clonally facilitated. Importance of the compensatory responses of sagebrush and herbs is diminished considerably if the temporal increase in productivity of the oak controls cannot be discounted as an artifact of the pasture design. This aspect remains unresolved.

Response variables were not equally sensitive. Stem density was insensitive to the effects of ungulate use in this study. Similarly, skewness of stem-size distributions did not respond except in the case of oak, which was severely browsed. Stem diameter - stem production relationships were more sensitive to ungulate use than either density or skewness.
Predictive power of the stem diameter - production relationships, as reflected by $r^2$ values, varied among species; this may be expected to vary with treatment severity as well. The relationship is likely to be strong with wide ranges of basal diameters and weights. This was the case with sagebrush, serviceberry, and oak in this study. In contrast, rabbitbrush and snowberry populations exhibited limited ranges for stem size and production, and weaker regression relationships. Little difference in precision was observed between control populations and those that were only moderately stressed or enhanced. Predictive power declined markedly only if stem damage was severe (e.g., serviceberry and oak), probably because of the heavy damage that some, but not all, stems received. Such high short-term variance is not likely to persist in studies concerned with long-term succession; long-term studies usually involve more moderate treatments and response variation might be less severe.

The skewness coefficient was appropriate for detecting size distribution shifts in this study, but may not be appropriate in other situations. In this study, experimental populations were demarcated via subdivision of a single parent community. Neither minimum nor maximum stem sizes varied among pastures initially, and no changes in these parameters were observed. Therefore, only changes in shape of the distributions were of concern. Skewness is a shape statistic, but it is insensitive to differences in scale or location among distributions. Location differences, in particular, are apt to occur in field experiments that employ block designs based
on site characteristics. For example, shrub populations existing on ridges are likely to have different stem-size distributions than those found in swales. Also, locational shift may be more apt to develop in long-term experiments than in short-term studies like this one. Where locational shift occurs the coefficient of variation or the gini coefficient may be more appropriate than $g_1$ (Bendel et al. 1988).
CHAPTER III

EFFECTS OF GOAT BROWSING ON HABITAT QUALITY FOR WINTERING MULE DEER

Management of oakbrush for big game winter range has historically focused on successationally advanced stands in which Gambel oak has attained dominance. In these stands, oak typically has grown beyond browsing reach and subordinate species have been suppressed, thereby reducing availability of browse for wintering ungulates. Management of such stands for wintering game typically involves some type of mechanical, herbicide or fire treatment (e.g., Plummer et al. 1968, 1970; Marquiss 1971, 1973; Kunzler and Harper 1980; Kufeld 1977, 1983). All shrubs are initially reduced following such treatments, and the post-treatment response of Gambel oak is generally stronger than those of commonly associated species (Kufeld 1983). Thus, while these techniques may increase the availability of oak browse by lowering canopies and increasing sprouting, they may also reduce subordinate browse species, especially if treatment is frequently repeated.

Some of the subordinates may be more nutritious or more palatable than oak. For example, big sagebrush is more digestible, lower in fiber, and contains more crude protein than associated deciduous shrubs in winter (Kufeld et al. 1981; Welch 1983; Welch et al. 1983). Therefore, reduction of sagebrush as an alternative browse could constitute an important loss of digestible nutrients under snowy conditions. Herbaceous species often initiate regrowth
in fall thereby supplying ungulates with a source of highly digestible protein and dry matter, but this nutrient pool is largely lost after snowfall.

Alternative management might involve maintenance or enhancement of sagebrush in low-stature oakbrush stands by selective suppression of Gambel oak. Recent work has demonstrated that this can be accomplished via summer-time browsing with Spanish goats (Riggs et al. 1988; Riggs and Urness 1988). In these experiments goats were managed to select for Gambel oak, thereby reducing its abundance and productivity relative to other species. Sagebrush production was enhanced as the competitive advantage of oak was reduced.

Aside from affecting long-term succession, shifts in forage-base composition may also affect the composition and quality of winter-time diets. This could occur if deer selected greater proportions of sagebrush in their diets in response to lower availability of deciduous browse. The occurrence of such behavior is not currently predictable, and depends on the influences of both relative availability (e.g., Nudds 1980; Shank 1982) and relative palatability as determined by such factors as stand structure, nutrient concentrations, and chemical deterrents (e.g., Belovsky 1981; Kenney and Black 1984a,b; Black and Kenney 1984; Provenza and Malechek 1984; Cooper and Owen-Smith 1985,1986). Sagebrush is not generally palatable (Welch and McArthur 1979, Welch et al. 1982, but see Welch et al. 1981, Welch 1983); therefore any increased use of sagebrush that might result from increased relative availability could be nullified if low palatability motivated selection against it. This
paper examines the winter-time responses of mule deer to prior use of winter range by Spanish goats, which resulted in enhancement of sagebrush relative to Gambel oak.

**Study Site**

The experiment was conducted on an oakbrush winter range community in which Gambel oak was dominant but generally within browsing height. This community was subdivided into six 0.2 ha pastures arranged in three blocks; each block contained one control pasture and one treatment pasture stocked with goats. Goat use was imposed during the summers of 1984 and 1985, and the effects of vegetation change on wintering mule deer were evaluated during the subsequent two winters. Detailed descriptions of the site, vegetation, and the effects of goat browsing on plant composition and production are available elsewhere (Riggs et al. 1988; Riggs and Urness 1988).

Goats had three major effects on the winter forage base (table 3.1). First, they markedly reduced the vigor and availability of the dominant deciduous shrub, Gambel oak. Second, they conferred a competitive advantage to big sagebrush, via avoidance of this species; thus its productivity and availability were increased relative to other browse. Third, the understory, composed primarily of Kentucky bluegrass, was similarly enhanced. Effects on serviceberry, green rabbitbrush, snowberry, and bitterbrush were minor in the context of total community productivity. Snow depth was approximately 23 cm in 1985, and this prevented use of the lowest-
Table 3.1. Forage available (kg/ha) to mule deer in control and treated (i.e., goat-browsed) pastures, 1985 and 1986. Shrub values are model output.

<table>
<thead>
<tr>
<th>Forage</th>
<th>1985 (snow-covered)</th>
<th>1986 (snow-free)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Treated</td>
</tr>
<tr>
<td>Shrubs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amelanchier alnifolia</td>
<td>611</td>
<td>584</td>
</tr>
<tr>
<td>Artemisia tridentata</td>
<td>290</td>
<td>390</td>
</tr>
<tr>
<td>Chrysothamnus viscidiflorus</td>
<td>132</td>
<td>132</td>
</tr>
<tr>
<td>Purshia tridentata</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Quercus gambelii</td>
<td>124</td>
<td>43</td>
</tr>
<tr>
<td>Symphoricarpos oreophilus</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Grasses²</td>
<td>*³</td>
<td>*</td>
</tr>
<tr>
<td>Forbs²</td>
<td>*³</td>
<td>*</td>
</tr>
<tr>
<td>Total Forage Available</td>
<td>611</td>
<td>584</td>
</tr>
</tbody>
</table>

1Stem densities, stem-size distributions, stem-size--production relations, sprout abundance and weight, and utilization were all monitored for each species, in each of the six experimental pastures. Different table values reflect significant effects (p < 0.05) for one or more variables. Values calculated for Artemisia and Chrysothamnus include leaf and woody twig; values calculated for other species include only twig material. See Riggs and Urness (1988) for more detail on the methodology.

2Grass and Forb data were derived by clipping 60 1²m plots (20 per pasture), in each treatment (Riggs and Urness, 1988).

3Snow cover rendered the understory unavailable in 1985.
growing shrubs such as Oregon grape (*Berberis repens*), and herbaceous species. Pastures were snow-free in 1986; therefore treatment effects could be examined under both snow-free and snow-covered conditions.

**Methods**

**Sampling Procedures**

Treatment effects were estimated using tame mule deer that were confined to the six experimental pastures. All of these, with one exception\(^1\), were adults that had been reared at the Utah Division of Wildlife Resources pens in Logan and used in prior experiments (Olson-Rutz and Urness 1987). The animals were acclimated to the pasture forage by ad libitum feeding of cut browse in a nearby holding facility for 10 days prior to confinement; no data were collected for an additional 3 days after confinement. No dietary supplements were offered at any time. Twelve deer were observed in 1985 (2 per pasture) during a two-week period beginning on 29 November; work was terminated on 14 December because of unusually heavy snow that made continuation of the experiment pointless. In 1986, only six deer were observed (1 per pasture) for a seven-week period beginning on 13 November. Use of fewer animals was necessitated because 5 animals died in the intervening summer and could not be replaced.

Diet composition was estimated during feeding bouts that began

---

\(^1\)The exception was a yearling female acquired from a private party prior to the experiment in 1986.
and returned to the bed site or was distracted by external factors. Diet composition was calculated using bite counts and estimated dry weights of individual bites. Weights of bites composed of the current year’s shrub leaders were predicted using twig diameter - weight regressions. All other bite weights were estimated via bite simulation (Neff 1974). Twig calibrations were secured during the course of feeding bouts, and simulated bites were collected immediately thereafter.

Nutritional analyses were performed on feed samples compounded from representative plant parts of the species taken. These were freeze-dried, ground through a 1-mm screen and then mixed according to the dry-weight composition estimated for each sample bout. Neutral detergent solubles (NDS) and neutral detergent fiber (NDF) were determined using microdigestion procedures (Holechek and Vavra 1982). One-gram aliquots were assayed for lignin and cutin (LC) content via sequential treatment with KMnO₄ and H₂SO₄, in that order (Van Soest 1982:84, Goering and Van Soest 1970). Silica (S) content was assayed following Van Soest and Jones (1968). Crude protein (CP = nitrogen x 6.25) was determined colorimetrically (Hach et al. 1985). Protein precipitation capacity (PPC) of tannins was estimated via bovine serum albumen precipitation (BSAP) as described by Martin and Martin (1983). Digestible protein reduction (DPR) was then predicted using the BSAP assay as described by Robbins et al. (1987a). Finally, digestibility coefficients were calculated for cell solubles (CSD), cell walls (CWD), and total dry matter (DMD) using NDS, NDF, LC, S, and DPR as prescribed by Robbins et al.
Activity budgets were estimated in 1985 via 5-minute visual scan samples (Altmann 1974) collected over a 24-hr period beginning at 0700 on 10 December. In 1986, the budgets were estimated using leg-mounted, motion-sensitive radio transmitters. Activity discrimination was limited to inactive (i.e., lying down), moderately active (i.e., standing still, or feeding), or highly active (i.e., walking, pacing or running). Moderate activity was representative of feeding time. Animals were not observed ruminating in the standing position, and the importance of standing rumination as a confounding activity was minimal. Standing idle behavior, which was almost entirely associated with alarm, was the only other activity state that could be confused with feeding; this was rare however, and affected all animals equally; consequently it was assumed to be unimportant as a confounding factor as well.

Foraging behavior was quantified for each sample bout in terms of travel speed (meters · min⁻¹), bite rate (bites · min⁻¹), bite size (gms dry matter · bite⁻¹, averaged over all items taken), and projected intake rate (gms dry matter · min⁻¹).

²Precision of estimates derived using the two methodologies were similar (Riggs et al. in review). Telemetered observations were classified as follows: inactivity included anything done while lying down; moderate activity included any standing activity associated with step rates < 8 steps per minute (e.g., standing idle, standing ruminating, feeding); high-level activity included any activity associated with step rates greater than 8 steps per minute (e.g., walking, pacing, running). Accuracy of telemetered observations (%) for the three activity states were 100% (inactive), 98.5% (moderate), and 66.6% (high).

³Similar observations have been noted previously by Smith et al. (1979).
Experimental Design and Analysis

Data were analyzed in two stages. In the first stage, separate analyses of treatment effects were conducted for each year's data because the nature of samples and subsamples differed between years. The basic experimental design was a randomized complete block in which pasture blocks and treatments were considered random and fixed effects, respectively. The experimental unit was the pasture. In 1985, the deer and bouts were samples and subsamples within the pastures, respectively. However, in 1986 bouts were the samples, rather than subsamples, because there was only 1 deer per pasture.

The second stage involved examining year effects (i.e., snow effects) and any treatment x year interactions (i.e., snow-dependent treatment effects). The basic block design was retained for this analysis, with both treatment and year considered fixed effects. However the data were collapsed to the level of pasture means for this analysis, thereby masking the annual difference in the nature of the samples.

Least-squares procedures (Bryce 1980) were used throughout. The 1985 data set was balanced with 2 bout samples and 1 activity budget per deer. However in 1986 the number of diet samples ranged from 21 to 25 per deer. Similarly, the number of electronically sampled activity budgets was 20 per deer; but not all were successful for various reasons, and the number available for this analysis ranged from 0 to 18 per deer. Differences among pasture means were examined for significance using Fisher's LSD (Dowdy and Wearden 1983). Only significant effects are presented here; unless stated otherwise,
significant effects are presented here; unless stated otherwise, significance was defined at the 5% level for a Type I error (p < 0.05).

Results and Discussion

Diet Composition

Treatment effects observed in 1985 were straightforward in that there was no apparent block effect (table 3.2). Diets of all animals were browse-dominated because snow cover precluded use of the understory. Selection of four shrubs differed because of the changes in availability that resulted from goat use. Goats reduced availability of both bitterbrush and Gambel oak. Consequently, deer confined to the goat-browsed pastures consumed significantly smaller proportions of these species, and significantly greater proportions of sagebrush and rabbitbrush. No significant treatment effects were observed in 1986.

The difference in snow conditions that occurred between years affected use of four taxa. The most obvious effect was the shift away from browse, toward grass, in the absence of snow. Proportional use of both sagebrush and oak declined in the absence of snow, while that of the low-growing shrub, Oregon grape, increased. In addition, there was an interaction effect between snow cover and treatment on the use of sagebrush (figure 3.1). In 1985, when snow reduced forage options, animals in the treated pastures consumed significantly more sagebrush than their control counterparts; in 1986, when snow was not a factor, the treatment effect disappeared. Thus the treatment table
Table 3.2. Effects of pasture treatment (C = control, T = browsed by goats) on botanical composition (%) of winter-time deer diets, 1985-86. Asterisks denote treatment effects within a given year (p ≤ 0.05). Unlike letters denote significant snow effects between years (P ≤ 0.10).

<table>
<thead>
<tr>
<th>FORAGE CLASS</th>
<th>1985 (snow-covered)</th>
<th>1986 (snow-free)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Species</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHRUBS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amelanchier alnifolia</td>
<td>97.4</td>
<td>93.8</td>
</tr>
<tr>
<td>Artemisia tridentata</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Chrysothamnus viscidiflorus</td>
<td>19.7 *</td>
<td>63.4</td>
</tr>
<tr>
<td>Purshia tridentata</td>
<td>15.1 *</td>
<td>0.2</td>
</tr>
<tr>
<td>Quercus gambelii</td>
<td>53.9 *</td>
<td>14.9</td>
</tr>
<tr>
<td>Symphoricarpos oreophilus</td>
<td>6.6</td>
<td>13.0</td>
</tr>
<tr>
<td>Other 3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>GRASSES</td>
<td>2.2</td>
<td>4.6</td>
</tr>
<tr>
<td>FORBS</td>
<td>0.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>

1 Each treatment mean is derived from 3 pasture means.
2 See figure 1 for description of treatment x year interaction.
3 Both horsebrush (Tetrademia canescens) and Oregon grape were taken.
Figure 3.1. Portion of total diet (DM%) consisting of sagebrush. The vertical bar delineates a significant treatment effect under snow-covered conditions (LSD$_{0.05}$).
LSD = 22.0

YEAR

1985

1986

SAGEBRUSH CONSUMPTION (DM%)

70 60 50 40 30 20 10 0

CONTROL -

TREATED -

(\% ~а) NO\!lid~nSN0\!8 HSn\!3~VS
effect for sagebrush use was snow-dependent. Similar observations have been reported by Smith et al. (1979).

Almost all of the shrub material consumed during both years was current season's growth. Averaged across species and pastures, 97% (SE = 2, n = 8) of the deciduous browse consumed in 1985 consisted of current year's growth; all of the rabbitbrush consumed was current year's growth. Only when consuming sagebrush did animals select significant amounts of old woody material. In control pastures, animals selected 13% old material, compared to 6% in treated pastures (LSD$_{0.05} = 16$). All browse consumed in 1986 was current year's growth.

Bites of herbaceous material were classified into three phenological categories: all dead, all green, and mixed. Therefore, it was possible to compare dietary proportions that consisted solely of bites of green material and solely of bites of mature material, but it was not possible to account for green material that was selected in conjunction with dead material. It was assumed that if treatment substantially affected the selection of green material, it would be reflected in the proportion harvested as bites composed solely of green material.

Only dead culms extended above the snow in 1985; fall regrowth was unavailable and deer consumed only mature material. In 1986, when snow was not a factor, substantial herbage was available and consumed. However, there was no evidence for a consistent treatment effect on selection of fall regrowth. Across all pastures, 88% (SE = 2) of the grass dry matter was taken in bites that consisted solely
of dead material, 10% (SE = 2) was taken in bites that consisted of phenologically mixed material, and only 2% (SE = 0.6) was consumed in bites consisting of only regrowth; there was no treatment effect. Similarly, there was no treatment effect on phenology of forbs; approximately 18% of the forb dry matter was fall regrowth and the remainder was dead. A significant effect was observed in only one of the six pastures; in block #2, the deer in the treated pasture consumed a greater proportion of its total dry matter in bites consisting solely of fall regrowth (fig. 2). However the proportion was still small in relation to the total diet.

**Nutritional Fractions**

A significant treatment effect was detected for only one fraction in 1985 (table 3.3). Digestible protein reduction was lower for diets consumed in treated pastures than for those consumed in the controls. Crude protein content was not affected by treatment, therefore the lower DPR for treatment-confined animals meant that their intake of digestible protein (DP, as % of dry matter) was higher. None the less, predictions of digestible protein\(^4\) were very low for diets consumed under both treatment conditions; -0.16% for control diets versus +0.54% for treatment diets (LSD\(_{0.05} = 0.57\)), and neither value was significantly different from zero. Assays were similar for NDS, NDF, LC, and S. Digestion coefficients for cell solubles and cell walls were not significantly different between Fig.

\[\text{Digestible protein (DP) = -3.87 + 0.9283X - 11.82Y; where X is crude protein content as percent of dry matter and Y is bovine serum albumin precipitation (Martin and Martin 1983); from table 3.3, Y = (DPR + 0.01)/11.82. See Robbins et al. (1987a:103) for details.}\]
Figure 3.2. Percentage of dietary dry matter consumed in bites of herbaceous material that consisted solely of fall regrowth, 1986. The vertical bar indicates a significant ($\text{LSD}_{0.05} = 3.0$) treatment effect in the second block only.
Table 3.3. Effects of pasture treatment (C = control, T = browsed by goats) on dietary fiber fractions and digestibility coefficients, 1985-86. Asterisks indicate significant differences within years, and unlike letters denote differences between years (P ≤ 0.05).

<table>
<thead>
<tr>
<th>NUTRITIONAL PARAMETER</th>
<th>1985 (snow-covered)</th>
<th>1986 (snow-free)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>DRY-MATTER FRACTIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDS¹</td>
<td>39.3</td>
<td>47.2</td>
</tr>
<tr>
<td>NDF¹</td>
<td>60.7</td>
<td>52.8</td>
</tr>
<tr>
<td>LC²</td>
<td>26.9</td>
<td>29.8</td>
</tr>
<tr>
<td>S¹</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>CP¹</td>
<td>5.1</td>
<td>5.4</td>
</tr>
<tr>
<td>DPR³</td>
<td>1.2 *</td>
<td>0.5</td>
</tr>
<tr>
<td>DIGESTION (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSD</td>
<td>20.5</td>
<td>30.8</td>
</tr>
<tr>
<td>CWD</td>
<td>16.0</td>
<td>14.6</td>
</tr>
<tr>
<td>DMD</td>
<td>36.6 *</td>
<td>45.4</td>
</tr>
</tbody>
</table>

¹percentage of dry matter
²percentage of NDF
³g/100 g feed
⁴See figure 3.3 for description of treatment x year interaction.
⁵See methods section for definitions.
treatments in 1985. However, a marginally significant ($p = 0.07$) treatment effect was indicated for total dry matter digestibility. This was presumably a cumulative effect of less-marked effects suggested for the individual fiber and protein fractions. This observation should be balanced, however, by the recognition that nutritional plane depends on metabolizable energy and rate of throughput, and these nutritional factors were not assessed.

No significant treatment effect was observed for any nutritional fraction or digestibility coefficient in 1986. Digestible protein averaged $2.2 \text{ g} \cdot 100\text{g}^{-1} \text{ feed}$ across the six animals ($SE = 0.42, n = 6$). The lowest DP value was calculated for the deer confined to the control pasture in block #2 (-1.4); this animal's diet consisted almost solely of deciduous browse. The highest value was calculated for the treatment animal in that same block (+4.0); its diet was mostly grass, and it was the only animal to select for fall regrowth (fig. 3.2). Digestion coefficients were higher for diets of treatment-confined animals, but high variability among animals rendered the differences insignificant ($p \leq 0.10$).

Significant improvement of dietary quality under snow-free conditions depends on understory management. Mature material selected by wintering deer is of generally low quality (Bartmann 1983), and quality of such material declines as winter progresses (Demarchi 1968). Most herbage selected in this study was mature because pastures were rested during the summer of 1986; this allowed the phenology of herbaceous plants to progress. Low-growing fall regrowth was obscured by the taller dead material (Arnold 1964;
Willms et al. 1979; Smith et al. 1979); thus deer were unable to efficiently select for the more nutritious regrowth, and diet quality suffered accordingly. Some sort of annual grazing by cattle or sheep could improve the foraging efficiency of deer in this situation by removing the mature material (e.g., Smith et al. 1979; Willms et al. 1979; but see also Austin et al. 1983). A specific regime is not apparent, however, because relations between sward structure, available biomass, green:dead ratios, and the cumulative effects of these on deer-diet quality remain unquantified.

Lignin and cutin, silica, and crude protein each differed between years without respect to treatment. Lignin and cutin contents were greater in 1985 than in 1986. This was expected on the basis of the shift away from browse that occurred in most pastures in the snow-free year (Robbins 1983:239). Silica was considerably greater in 1986 than in 1985. This could also be expected on the basis of the shift toward grass in 1986, most of which was mature. However, the magnitude of the difference should be viewed with caution because of the possibility of soil contamination; 1986 DMD estimates may be biased as a result, especially where grass and forb consumption was high. Crude protein content of diets also increased in 1986.

Two other nutritional responses were noted between years. First, there was a significant treatment x year interaction for cell wall digestibility (fig. 3.3). This effect, like that on sagebrush consumption, was snow-dependent; CWD increased only under snow-free conditions. Dietary effects that probably played a role in the
Figure 3.3. The effect of treatment on cell wall digestibility, 1985-86; the vertical bar indicates a significant effect under snow-free conditions (LSD.05 = 1.9).
difference were increased consumption of understory plants, some of which were phenologically young, and reduced consumption of previous years' browse material. There was also a significant treatment effect, across years, on DMD. Dry matter digestibility was significantly higher for diets observed in goat-browsed pastures ($\bar{x} = 46.0\%$) than for those observed in control pastures ($\bar{x} = 38.1$, $\text{LSD}_{0.05} = 7.8$); the importance of this difference is questionable, however, in light of the apparent inconsistency of the effect under snow-free conditions.

Activity Budgets and Foraging Behavior

These were monitored in anticipation that energetic expenditures might be affected by changes in the forage base. Differences in the way animals budgeted their time could dampen or intensify nutritional differences. For example, forage quality could affect energy expenditures by regulating feeding time. Rumination time per gram of ingesta increases with cell wall content of feed (Van Soest 1982:224); thus feeding time may be limited by slow passage rates when consuming high-fiber feeds. Foraging time of Alaskan moose is apparently thus limited in winter (Risenhoover 1986). It follows that mule deer ingesting high-fiber feeds, such as deciduous browse, might have their feeding time limited by a need to extend rumination time. Conversely, consumption of lower-fiber diets (e.g., sagebrush or herbaceous regrowth) might reduce rumination time and allow greater feeding time, assuming the later is regulated by gut-fill.

No such treatment effect was observed in either year of this study (table 3.4). Activity budgets were similarly partitioned in
Table 3.4. Comparison of activity budgets (% of time at activity) for animals confined to control pastures (C) and animals confined to treatment pastures (T), 1985-86. Neither treatment nor year effect was significant (p ≤ 0.10).

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>1985 (snow-covered)</th>
<th>1986 (snow-free)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Inactive</td>
<td>70.4</td>
<td>70.0</td>
</tr>
<tr>
<td>Moderately Active</td>
<td>26.6</td>
<td>28.1</td>
</tr>
<tr>
<td>Highly Active</td>
<td>3.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Data were secured via 5-minute visual scan samples in 1985 (Altmann 1974); sample size (n) was 1, 24-hour budget for each of two deer, in each pasture. In 1986, activity was classified on the basis of telemetered step rates. Number of 24-hour telemetry scans varied by animal. Among control-confined animals sample sizes were as follows: Block #1, n = 16; Block #2, n = 0; Block #3, n = 14. Among treatment-confined animals sample sizes were: Block #1, n = 7; Block #2, n = 3; Block #3, n = 18.
all pastures; animals spent most of their time lying down, followed by moderate activity (i.e., feeding), and very little time was spent in highly active states. Data were consistent with observations of other researchers that deer restrict activity in winter as an energy-sparing tactic (e.g., Moen 1976). The lack of a significant treatment effect was not surprising, however, after reviewing the dietary fiber fractions; there were no significant treatment effects for cell wall content as reflected by NDF content (table 3.3). Likewise, there was no significant activity difference between years, and none was expected on the basis of the NDF content. Furthermore, snow depth was not sufficient to restrict movement in 1985 (Parker et al. 1984); and the coldest temperature recorded was -18°C, which was above the lower critical temperature for a standing adult (Parker and Robbins 1985). Thus, in retrospect, activity-budget differences were not anticipated despite forage base and climatological differences, which were within the tolerance range of deer.

Foraging behavior reflects forage-base changes. Search effort, for example, could increase in response to a decline in density of acceptable forage. This, in turn, could be expressed in increased travel rates (Collins et al. 1978; Wickstrom et al. 1984). Bite size and bite rate could also be affected by changes in acceptable forage availability. However, these two variables are related in a strong inverse-curvilinear manner, thereby compensating for one another over a broad range of foraging conditions (Wickstrom et al. 1984). More important is identification of the lowest availability at which the two variables are no longer compensatory; below this point intake
rate, and hence feeding time, could be adversely affected, as well as habitat selection (Collins and Urness 1983). Treatment-related differences in intake rate would be indicative of a biologically significant reduction of acceptable forage. A difference was anticipated in this study, on the basis of the suspected low palatability of sagebrush.

No treatment effect was detected for any foraging variable in either 1985 or 1986 (table 3.5). Therefore, the vegetal changes caused by goats did not substantially impact acceptable-forage density. Of greater interest were significant differences that occurred between years without respect to treatment. Animals moved about much more rapidly, and had much lower bite rates and intake rates in 1985 than in 1986. Bite sizes did not differ between years. Thus snow cover apparently lowered the density of acceptable food items, thereby prompting less efficient foraging. However this observation may not have much practical relevance since the activity budgets did not differ between years; thus the apparent decrease in foraging efficiency which may have been caused by snow did not extend foraging time as reflected by moderate activity.

Lack of any apparent treatment effects on either activity budgets or foraging behavior suggests that the treatment imposed in this experiment can be adequately evaluated on the basis of nutritional variables, without respect to effects on energetic expenditures.
Table 3.5. Summary of treatment (C = control, T = goat-browsed) effects on foraging behavior, 1985-86. No significant treatment effects were observed in either year (p < 0.10); unlike letters denote differences between annual means (p ≤ 0.05).

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>1985 (snow-covered)</th>
<th>1986 (snow-free)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>T</td>
</tr>
<tr>
<td>Travel rate(^1)</td>
<td>5.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Bite Rate(^2)</td>
<td>3.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Bite Size(^3)</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Intake Rate(^4)</td>
<td>0.7</td>
<td>0.5</td>
</tr>
</tbody>
</table>

\(^1\)meters · min\(^{-1}\)
\(^2\)bites · min\(^{-1}\)
\(^3\)gms · bite\(^{-1}\)
\(^4\)gms · min\(^{-1}\)
Conclusions

Previous studies (Riggs et al. 1988; Riggs and Urness 1988) demonstrated that under certain management constraints goats could retard succession in low-stature oakbrush stands, thereby enhancing sagebrush and understory components relative to Gambel oak. This study found that under snow-covered winter conditions deer responded to this management by increasing the proportion of sagebrush in their diets, thereby enhancing dietary digestibility, but not available protein. Beneficial effects were lost under snow-free conditions because animals grazed grasses and forbs, presumably because of the lower palatability of sagebrush. Furthermore, apparent dietary quality was not significantly better under snow-free conditions than when snow-cover precluded understory use; largely because the availability of fall regrowth in understory swards was not substantially affected by the experimental treatment.

Therefore, periodic goat-browsing may provide a practical means of managing the successional trajectory of oakbrush, and deer nutrition under snow-covered conditions. However, more frequent management of the understories, via grazing by sheep or cattle, is probably required to maintain high dietary quality under snow-free conditions; particularly in terms of protein. Many Intermountain oakbrush sites experience intermittent periods of snow coverage in winter. Where this occurs, the nutritional plane of wintering deer may be more responsive to understory management than to shrub management, depending on the frequency and duration of snow cover.
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VITA

Robert Alexander Riggs
Candidate for the Degree of
Doctor of Philosophy

Dissertation: Interseasonal range relations of Spanish goats and mule deer in a Utah oakbrush community.

Major Field: Range Science (Range/Wildlife Relations)

Biographical Information:

Personal Data: Born at Coeur d'Alene, Idaho, January 3, 1952, son of Alex and Rose Riggs.

Education: Graduated from Immaculate Heart of Mary High School in Coeur d'Alene, Idaho, May 1970; received a Bachelor of Science degree in Wildlife Resources from the University of Idaho, December 1974; received a Master of Science degree in Wildlife Resources from the University of Idaho, May 1977; completed requirements for a Doctor of Philosophy in Range Science at Utah State University, October 1988.