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Diet Reconstruction of Bighorn Sheep (Ovis canadensis) Using Stable Isotopes

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ABSTRACT

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We determined the diet contributions of grasses, forbs and shrubs for three herds of bighorn sheep along the Wasatch Front, Utah using stable isotope techniques and determined the electivity values for different forage species for four herds. Forbs were generally the most common forage eaten across all herds while shrubs were the least used forage resource. The Provo Peak and Mount Nebo herds used grasses, forbs and shrubs at proportions similar to other bighorn sheep populations across the west, while the Antelope Island herd used forbs at higher levels than any other local herd. Additionally, the herd on Antelope Island was analyzed to compare differential use by rams and ewes. Our results indicate that there was no significant difference in diet between sexes on Antelope Island. Bluebunch wheatgrass (*Pseudoroegneria spicata*) was a common species across all sites and was an important forage for all populations. Managers may consider these proportions when seeding in bighorn habitat improvement projects.

Key words: bighorn sheep, stable isotopes, habitat improvement

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INTRODUCTION

Mountain sheep occur throughout western North America and are divided into two groups: thinhorn and bighorn (Cowan 1940). Thinhorn sheep include Dall sheep (*Ovis dalli dalli*) and Stone's sheep (*Ovis dalli stonei*). Thinhorn sheep inhabit the northwestern part of North America from near the Arctic Circle extending as far south as northern British Columbia and southern Alaska. Bighorn sheep are separated into desert bighorn (*Ovis canadensis nelsoni*), Rocky Mountain bighorn (*Ovis canadensis canadensis*) and California bighorn (*Ovis canadensis californiana*). Bighorn sheep inhabit the western mountain ranges and deserts. The Rocky Mountain and California bighorn range from North Dakota to California and from British Columbia to Arizona and New Mexico (Krausman and Shackleton 2000).

Male bighorn sheep are known for their massive horns and impressive head butting that occurs during each mating season. Female bighorns also have horns, but they resemble goat horns in size and shape. Mountain sheep exisiting in Utah are of the desert, California and Rocky Mountain subspecies; however, Wehausen and Ramey (2000) have proposed that differences between California and Rocky Mountain bighorn sheep do not warrant their recognition as separate subspecies and this was discussed at the 2008 Northern Wild Sheep and Goat Council biennial symposium. Rocky Mountain bighorn inhabit the northern part of Utah while desert bighorn are found primarily in the southeastern portions of Utah.

Habitat

Bighorn sheep are frequently found in rugged terrain, such as canyons, gulches, talus cliffs, steep slopes, mountain tops, and river benches. Specifically, mountain sheep habitat consists primarily of open areas largely composed of grasses and forbs, with some shrubs (Geist 1971; Utah Management Plan 2008).

Bighorn sheep populations are comprised of gender groups; adult male bachelor herds and female-juvenile herds. Each of these groups occupy somewhat different habitat types until mating season at which time bachelor herds join the ewe-juvenile herd on ewe range for the rut (Geist 1971). For ewes and lambs an important factor determining habitat use is the proximity to escape terrain (Shackleton et al. 1999). Escape terrain consists of rock slides or slopes over 60% that allow bighorn sheep to avoid predators (Sappington et al. 2005). Rocky Mountain ewes remain close to escape terrain during lambing and post-natal periods, generally within 100 m, until late summer when lambs are larger (Pallister 1974, Shackleton et al. 1999). Zeigenfuss et al. (2000) suggests that suitable habitat consists of at least 10% lambing habitat, no contact with domestic sheep (23 km buffer) and habitat patches of at least 200 km^2. Lambing habitat is defined as areas larger than 2 hectares with 27-85 degree slopes within 1,000 meters of water on south, west and east aspects (Geist 1971, Van Dyke et al. 1983).

Another factor that may influence bighorn sheep use is horizontal visibility. Horizontal visibility determines whether or not bighorn sheep will use an area or only pass through and is defined as an area providing 14 meters of unobstructed visage (be it vegetation or boulders) on all sides for a bighorn sheep (Smith 1999, Zeigenfuss et al. 2000). Decreasing horizontal cover is associated with increasing sheep use of an area because predators are unable to approach unnoticed (Smith 1999, Dibb and Quinn 2006). These areas may be created with fire, or mechanical treatments such as chaining, lop and scatter or brush saws.

Dibb and Quinn (2006) found that by mechanically clearing conifer encroachments in bighorn winter habitat greatly increased spring use 0% to 20.4% of time spent foraging. They found that this change in foraging use was due to the removal of Douglas fir (*Pseudotsuga menziesii*) and white spruce (*Picea glauca*) trees followed by an increase in rough fescue (*Festuca campestris*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) growth. By returning an area to an early successional state horizontal cover is reduced and herbaceous vegetation increases. As successional patterns advance to woody vegetation, tree cover and shrub density decrease horizontal visibility and bighorn sheep avoid those areas. They also suggested treatments to improve visibility be performed contiguous with occupied areas to foster use and not create islands of suitable habitat. Smith et al. (1999) supported by Dibb and Quinn (2006), found that bighorn sheep move into treated forested areas after clear cutting or fire, presumably to make use of greater forage availability.

Diets

Bighorn sheep are known as opportunistic, generalist feeders that feed on a wide variety of plant species (Todd 1972, Sudgen 1961). Opportunistic feeders do not select for forage quality (protein and energy content). Work by Wikeem and Pitt (1992), Stewart (1975), Shannon et al. (1975) and Johnson (1975) failed to show a correlation between forage quality and use.

Many different methods have been used to collect information regarding bighorn sheep diets. Methods range from stem counts, snow trailing, feeding site examination, observations from transects, direct observation of foraging sheep, and rumen and fecal sampling (Shackleton et al. 1999). It is important that managers know which species of plants are being utilized so that habitat improvements may be optimal. Krausman and Shackleton (2000), reviewed a number of studies regarding bighorn diets across western North America and found that forbs are the most preferred forage, followed by grasses and then browse. However, because grasses are more common than forbs in many habitats, grasses constitute a greater proportion of bighorn sheep diets than do forbs. Shackleton et al. (1999; see table 1) also reviewed several studies and found that depending on the population, bighorn diets could be dominated (defined as 66% or more of the diet) by grasses, forbs, or shrubs. Mountain sheep diets variesd by age-sex cohort as well. Typically, lamb and ewe diets are more similar to each other than to adult males (Shank 1982). Geographic variation in bighorn diets also occur, as seen in the preference for forbs in California herds while bighorn in Alberta and Colorado consumed more grasses (Shackleton et al. 1999). Table 1 represents the contribution of three forage groups to various bighorn sheep populations' diets as compiled by Shackleton et al. (1999) to give an idea of the variability of diet between populations.

Table 1. Geographic variation in percent composition of three main forage groups in diets of Rocky Mountain and California bighorn sheep

	Forage		
	Grasses	Forbs	Shrubs
Rocky Mountain Bighorn			
Alberta			
Mean (± SEM)	66.2 (14.5)	20.5 (11.6)	12.2 (4.4)
n (range)	6 (0-92)	6 (2-78)	6 (0-28)
Colorado			
Mean (± SEM)	75.7 (15.2)	6.7 (1.9)	17.0 (14.0)
n (range)	3 (46-49)	3 (3-9)	3 (1-45)

Idaho			
Mean (± SEM)	31.4 (9.6)	9.3 (7.0)	59.0 (10.2)
n (range)	4 (12-57)	4 (1-30)	4 (40-86)
Montana			
Mean (± SEM)	41.2 (10.1)	39.4 (11.0)	18.9 (5.6)
n (range)	6 (10-72)	6 (17-78)	6 (6-43)
California Bighorn			
British Columbia			
Mean (± SEM)	49.0 (19.7)	7.7 (5.0)	43.3 (18.8)
n (range)	3 (25-88)	3 (0-17)	3.0 (6-67)
California			
Mean (± SEM)	37.0 (31.0)	67.0 (31.0)	0
n (range)	2.0 (6-68)	2.0 (32-94)	2.0
Idaho			
Mean	50.7	10.5	38.8

From Shackleton 1999, pg. 92

Seasonal variation in bighorn diets has been reported. Forbs play a more important role in spring and summer diets than winter diets, at which time they are less available and have greatly reduced nutrient value. Grass and shrub use varies widely and there was no season of preferred use. In an observational study, Dailey et al. (1984) found that forbs averaged 21.4% of bighorn sheep diets in winter and 70.0% in summer on an alpine site of the Colorado Front Range. Grasses comprised 75.9% in winter and 30.0% in summer. Browse was 2.9% in winter and not utilized in summer. Comparatively, Oldemeyer et al. (1971) reported that grasses, forbs and shrubs comprised 61.4%, 17.2%, and 21.5%, respectively of bighorn winter diets in Yellowstone National Park. Rominger et al. (1988) described bighorn summer diets in central Colorado as averaging 84% shrub browse, 11.5% grasses, and 4.5% forbs. Grasses and forbs were obtained in winter by pawing away snow or under shrub cover. California bighorn have been observed using more than 260 forage species in southern British Columbia; predominantly grasses (66.6% of annual diet) with forbs and shrubs averaging 16% of diet (Wikeem 1984, Wikeem and Pitt 1992). Bluebunch wheatgrass (*Pseudoroegneria* *spicata*) was the most common species at 20.5%, while Prairie junegrass (*Koeleria cristata*) and needle and thread grass (*Heterostipa comata*) combined to provide 24.5% of the diet (Wikeem and Pitt 1992). These studies also determined that most forage species were not selected for, but used opportunistically. As an example, the most common forage, bluebunch wheatgrass, was selected less frequently than it was available. Shackleton et al. (1999) determined that bighorn sheep use of a forage species is seemingly random.

Habitat Use

Lamb growth is most intense from spring to early fall (Festa-Bianchet 1996) so adequate nutrition is highly important at this time; however, lambs are prone to predation and must balance a need for high quality forage with predator avoidance. To avoid predators, ewes and lambs group together on or near escape terrain, generally cliffs or slopes of 40% grade or more. These areas do not always have access to the best or most abundant forage (Festa-Bianchet 1988). The steep slopes and rock slides do not provide areas where herbaceous vegetation can establish and flourish. Risenhoover and Bailey (1985) found that a minimum grouping of five bighorn sheep significantly reduced vigilance and increased feeding rate. Groupings of twenty showed the highest feeding rate and lowest vigilance effort.

Mature males, not encumbered with young, range farter from escape terrain and are able to access greater quantities of forage (Bleich et al. 1997). Males generally band together in bachelor herds while females, and females with young, band together in order to increase ability to forage while decreasing individual vigilance. When in larger groups, individual sheep need not spend as much time looking alert for threats, as the alertness of the group exceeds that of an individual (Pulliam and Caraco 1984). However, even when banded together bighorn sheep avoid areas with poor visibility. Various habitat treatments to improve visibility may be used to improve ranges adjacent to areas of current bighorn use in order to expand ranges and provide more forage.

Population Growth Limitations

Forage availability and favorable habitat are important factors that determine survivability of bighorn sheep, as does disease. Bighorn population die-offs have occurred throughout their ranges due to pathogens from domestic sheep (Foreyt 1998), poor nutrition (Jones and Worley 1994) and low genetic variability (Skiba and Schmidt 1982). High levels of lungworms leave bighorn sheep susceptible to *Pasteurella* bacteria, species which, in turn, predispose sheep to pneumonia (Bunch et al. 1999). The state of Utah has recently initiated a program to purchase grazing allotments in areas such as Desolation Canyon to provide habitat that minimizes contact between domestic sheep and bighorn sheep to a minimum. Bighorn sheep reintroductions tend to be unsuccessful when domestic sheep allotments are within 6 km of reintroduction sites (Singer et al. 2000a). *Pastuerella*-facilitated pneumonia increases when domestic sheep allotments are near bighorn sheep populations (Cassirer and Sinclair 2007, George et al. 2008). Utah Division of Wildlife Resources (UDWR) has worked in conjunction with the Foundation for North American Wild Sheep (FNAWS) to purchase domestic sheep allotments from willing sellers or to switch historical sheep allotments to cattle allotments (Utah Bighorn Plan 2008).

Reintroduction Efforts in Utah

According to the Utah Bighorn Plan (2008), current practices of bighorn sheep management in Utah include the reintroduction of animals to historic ranges and the removal of sheep grazing allotments near bighorn ranges. The primary purposes of bighorn reintroduction is to foster bighorn sheep conservation and provide wildlife viewing and hunting experiences.

Bighorn sheep reintroductions are not uncommon and have been used to augment and re-establish create bighorn populations throughout the western United States (Krausman and Shackleton 2000). Throughout the west there has been approximately 100 sheep reintroductions, 70 of these were either deemed successful or moderately successful (Singer et al. 2000b). A major effort by the UDWR has focused manpower and funding (approximately $2.8 million as of 2008) into reintroducing bothRocky Mountain bighorn (*Ovis canadensis canadensis*) and California bighorn (*O. c. californiana*) sheep to native ranges in Utah including Flaming Gorge and Cache Valley in the north, the Newfoundland Mountains, the Book Cliffs, Antelope Island, the Stansbury Mountains, and the Wasatch Mountains (American Fork Canyon, Rock Canyon, and Mt. Nebo). Seventeen populations of Rocky Mountain and California bighorn exist in Utah, of which four are decreasing in number, including the three populations along the Wasatch Mountains and one near Hoop Lake on the north slope of the Uintah Mountains. Source herds for these reintroductions are located in British Columbia, Manitoba, Alberta, Wyoming, Colorado, Montana, and other Utah populations. The three populations along the Wasatch Mountains have received multiple transplants, yet are still in decline. Although a single or prominent reason for these declines has not been discovered, issues the State of Utah is concerned with include:

disease, namely pneumonia, various parasites that cause respiratory problems, predation by mountain lions, and habitat degradation and loss.

In order to create self sustaining herds in Utah, the Utah Bighorn Plan indicates that research is needed to increase lamb survival and to "initiate vegetative treatment projects to improve bighorn habitat lost to natural succession or human impacts". The three goals and their pertinent objectives of the Utah Bighorn Plan are:

1. Establish optimum populations of bighorn sheep in all suitable habitats within the state.

Objective: By 2013, increase the total number of bighorn sheep by 50% and increase all existing herds to at least the minimum viable level of 125 individuals.

2. Provide good quality habitat for healthy populations of bighorn sheep.

Objective: Maintain or improve sufficient bighorn sheep habitat to allow herds to reach population objectives.

3. Provide high quality opportunities for hunting and viewing of bighorn sheep.

Objectives: By 2013,increase hunting opportunities by at least 50% while maintaining high quality hunting experiences and increase public awareness and expand viewing opportunities of bighorn sheep by 100%.

Each goal has various strategies to reach their objectives but the most pertinent to this study is goal 2: *initiate vegetative treatment projects to improve bighorn habitat lost to natural succession or human impacts*. There are a variety of methods to look at vegetation treatments and habitat loss, but before these treatments can be implemented selectivity of the bighorn throughout the year at the different locations needs to be determined. Electivity indices and the use of isotope techniques are two methods to determine bighorn forage selectivity and use.

Electivity Indices

An electivity index is a method developed by Ivlev (1961) to estimate the preference for different types of available forage. Either biomass or percent of individual plants are used to determine estimated preference. The equation:

$$\mathbf{Ei = ri\text{-}ni/ri\text{+}ni}$$

estimates preference, where Ei is the electivity measure from -1.00 to +1.00, ri is the percentage of species i in the diet and ni is the percentage of species i in the forage base (Ivlev 1961). Value from 0.00 to +1.00 indicate an increasing selection for a plant species or type, while values ranging from -1.00 to 0.00 indicate decreasing selection (Krebs 1989, Beck et al. 1996). Electivity indices can be used to determine plant species that are preferred yet not abundant over the landscape. This information aids in determining when a species is used more than it is available.

Isotope Techniques

Before performing range improvements such as reseeding, it is important to understand the diets of the wildlife species being released. Previously this required many man hours and time consuming practices such as direct observation of bite counts and captive rearing of wild ungulates (Dailey et al. 1984, Goodson et al. 1996). Now, new technology involving mass spectrometry makes it possible to determine the chief components of an animal's diet by analyzing the isotopic composition of various body tissues and products like hair, hooves, muscle and feces (West et al. 2004, Schwertl et al. 2003, Kielland 2001). Kielland (2001) found the seasonal changes in moose diet were apparent in their hooves and that the percent composition of various forage species could be determined using stables isotopes.

The ratio of $\delta^{12}C$ to $\delta^{13}C$ and $\delta^{14}N$ to $\delta^{15}N$ (both of which are expressed in parts per mil, or $^{0}/_{00}$) is very similar within a species/genus at best but is very powerful and useful to determine different forage types and plant families (T. Robinson 2008 personal communication, Kielland 2001). When consumed, these ratios remain constant and are used in the growth of the animal, or in other words there is a set differential offset between diet, feces and/or hair, because this value is set and does not fluctuate, the offset value can be used to indicate the forage signature (Sponheimer et al. 2003d). By determining the presence of these ratios, feces can indicate which plant species or types are consumed over the last 60-200 hours (Sponheimer et al. 2003d) including determining trophic levels in aquatic systems (Vizzini and Mazzola 2008, Yves 2008), analyzing seasonal moose diets (Kielland 2001), the use of different forage types by south African ungulate species (Sponheimer et al. 2003a, 2003b, 2003c), and diet changes in different ungulates fed in laboratory settings (Sponheimer et al. 2003d).

C3 and C4 plants

Temperate and tropical plants tend to differ in their photosynthetic pathways and the way they sequester carbon from carbon dioxide. C_3 plants incorporate ^{12}C predominantly over

^{13}C, while C_4 plants incorporate a higher ratio of ^{13}C. The difference between C_3 and C_4 carbon isotope rations is illustrated in Figure 2. Because photosynthetic pathways differ in the ratio of $^{12}C/^{13}C$ it is possible to differentiate between plants within these groups.

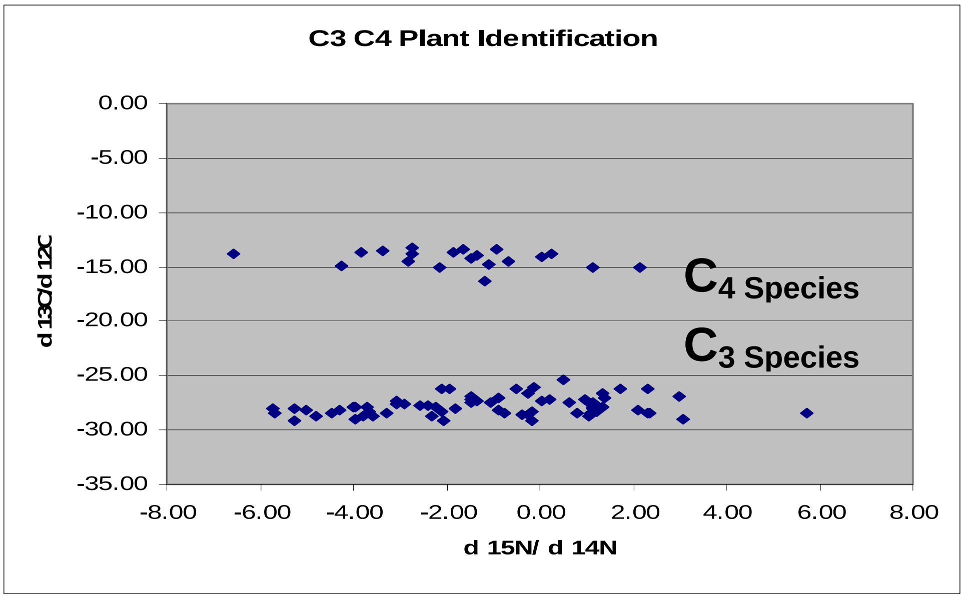

Figure 1. Carbon isotope (^{12}C and ^{13}C) ratio differences between C_3 and C_4 plant species.

C_3 plants (cool season grasses, forbs, and shrubs) have higher ^{12}C ratios than do C_4 species (Kelly 2000, Peterson and Fry 1987). The more negative the value the higher the ratio of ^{13}C to ^{12}C. The ratio of C and N isotope is different for each species and is used as a signature for each plant species of a given area.

Diet reconstruction

Diet reconstruction methods have been used for a variety of species at different trophic levels. Each plant species has a unique carbon (C)/(N) signature, modified slightly by altitude, precipitation and temperature regimes. This unique signature has become a tool researchers are using to reconstruct diets of wild animals. Mizukami et al. (2005) investigated the feeding habits of rural and alpine bears of Japan measuring the C and N stable isotopes of bears from different areas and determined the dependence of problem bears on anthropogenic food sources. The diets of South African ungulates was determined by measuring stable isotope ratios in feces and then compared to the isotope ratios of available forage. These studies were found to agree with diet reconstruction conducted using observational and other diet reconstruction techniques (Codron et al. 2007, Sponheimer et al. 2003, Sponheimer et al. 2003b).

CONCLUSION

The State of Utah has dedicated significant time and money to reintroduce bighorn sheep into suitable habitat throughout northern Utah and along the Wasatch Front. Although many of these populations are stable or increasing, there are a number that are still struggling to persist. The State of Utah has determined that disease, predation, and habitat degradation or losses are the predominant problems responsible for the decline of some bighorn sheep populations. The state yet needs to improve habitat (Dibb and Quinn 2002) in areas currently used by bighorn sheep in order to enhance survival. The diet composition of individual plant families or group can be determined using stable isotopes. With a better understanding of bighorn diets it is possible to improve habitat and available forage.

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DIET RECONSTRUCTION OF BIGHORN SHEEP (*Ovis canadensis*) USING STABLE ISOTOPES

INTRODUCTION

Since the 1980's the Utah Division of Wildlife Resources (UDWR) has been reintroducing Rocky Mountain (*Ovis canadensis canadensis*) and California bighorn sheep (*Ovis c. californiana*) into historic and suitable habitat throughout the state after extirpation in the 1960's (Rawley 1985) due to factors relating to interactions with settlers and their livestock. This includes direct competition for forage resources and diseases, especially lungworm (*Protostrongylous spp.*) and pneumonia (*Pasteurella spp.*) (Shields 1999). Maintaining struggling reintroduced populations needs to include measures to improve the overall habitat of failing herds (Utah Statewide Management Plan for Bighorn Sheep 2008, hereafter the Utah Management Plan).

The primary objectives of this study were to determine the diets of bighorn sheep populations on Antelope Island, Mount Timpanogos, Provo Peak, and Mount Nebo, Utah using stable isotope techniques. Also, we used data collected on Antelope Island to determine if there is a difference in ram and ewe diets. Stable isotopes provide a tool to reconstruct ruminant diets by comparing the ratios of $\delta^{12}C$ to $\delta^{13}C$ and $\delta^{14}N$ to $\delta^{15}N$ in dietary plants species consumed to ratios found in fecal samples. The stable isotope ratios found in consumed plant matter remains constant after consumption, making this comparison possible. (T. Robinson 2008 personal communication, Kielland 2001). Secondly, we determined the selectivity of forage species found in the diets of the various herds as developed by Ivlev (1961).

MATERIALS AND METHODS

Location

We collected data during the summer and fall of 2005 and 2006 in four areas along the Wasatch Front, Utah. These sites include Antelope Island, Mount Timpanogos, Provo Peak, and Mount Nebo (Figure 1). Vegetation types ranged from sage brush steppe to mountain shrub. Antelope Island is situated near the east shore of the Great Salt Lake and is managed entirely as Antelope Island State Park. Study sites on the island ranged from 1411 m to 1669 m above sea level at an average elevation of 1,551 m. Sites on Mount Timpanogos ranged from 1450 m to 2189 m with an average elevation of 1,822 m, Provo Peak sites ranged from 1316 m to 1880 m and averaged 1,740 m, and Mount Nebo sites from 2193 m to 2418 m, averaging 2,342 m in elevation. Exact areas sampled depended on the location of radio collared bighorn sheep.

Climate in these areas was characteristic of the Great Basin; hot dry summers with intense late summer thunderstorms and the majority of precipitation occurring during fall, winter and early spring. Antelope Island average 15.46 inches of precipitation over the course of the study while Mount Timpanogos averaged 42.63 inches, Provo Peak received an average of 21.17 inches, and Mount Nebo averaged 16.08 inches. These data come from the nearest weather stations in the USU Climate Center (2009).

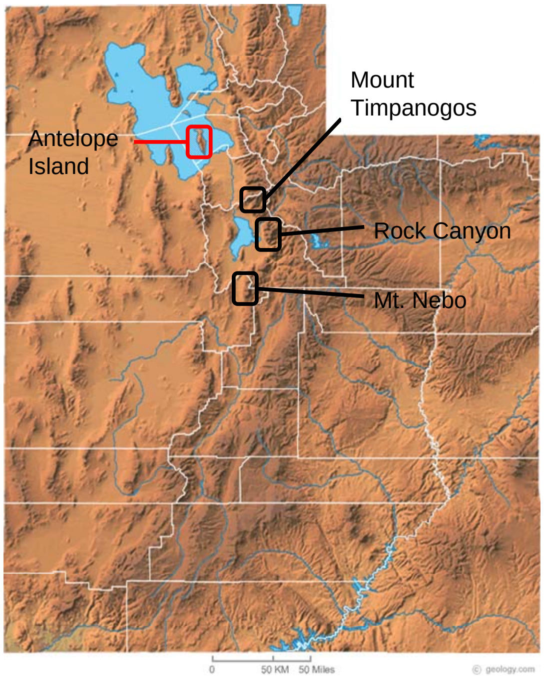

Figure 1. Location of study sites in Utah.

Spring sampling was not conducted to avoid unnecessary disturbance during the lambing season. As a sub-project of a larger bighorn sheep study coordinated by the UDWR and Brigham Young University we located sheep herds by finding individual sheep that had previously been equipped with radio collars using radio telemetry and observed them foraging for 20-30 minutes using spotting scopes and binoculars.

Field Procedures

While watching a group of bighorn foraging, a detailed map of the use area was made by hand showing prominent rocks, trees, or other identifiable landmarks and locations the sheep foraged in reference to those landmarks. After sheep left the site, either later the same day or the next day, researchers returned and using the map located the site where foraging had occurred. Evidence of bites on plants was used to help identify those individual plants that were being eaten (or bitten).

Within 2-4 days we hiked back to the exact spot and collected habitat characteristics and use data. We placed a 1 m^2 circular plot to include plants that had been eaten, identified all plants to within the plot and cut all herbaceous species to ground level, weighed them by species and preserved them in paper bags. This procedure was performed five times for each use site, and then five samples were collected randomly. A

20 gram sample of all woody plant species that showed bite marks was also gathered. Samples were separated by species, weighed and retained for further analysis. Fresh bighorn sheep fecal samples were collected from each foraging location and were labeled based on sex (ewe, lamb, or ram). After collection, each plant and fecal sample was dried at 60°C for 24 hours and percent dry matter was determined (Flinders and Hansen 1972). Plant species were identified using the dichotomous key, *A Utah Flora* (Welsh et al. 2003) as well as from consultation from botanists and range scientists at Brigham Young University.

Mass Spectrometry Procedures

Plant and fecal samples were ground using a 0.4 mm mill (Mini-Mill, Wiley, Swedesboro, NJ). Tissue from the same species from each sample day was ground simulataneously. From each fecal and forage sample a 600-700µg subsample was weighed in a tin capsule and analyzed for $\delta^{13}C$ and $\delta^{15}N$ using a combustion elemental analyzer (Costec 4110) coupled to a continuous flow mass spectrometer (Delta V, Thermo Scientific, Waltham, Maryland). The values from individual species were then combined into plant family groups.

Diet Reconstruction

The C and N isotope values for the forage and fecal samples obtained from the mass spectrometer were then entered into IsoSource© (Phillips and Gregg 2003). IsoSource© is a computer model that determines the percent contribution of the isotope signatures of the different plants (sorted and combined by family or photosynthetic pathway) to the isotopic signature of the fecal sample and by determining the most likely combination of sources (Phillips and Gregg 2003). Results are expressed as a percent contribution of each plant family to the total diet.

Electivity Indices

Data collected on forage samples from each site included total cover, percent use of each plant and percent of individual plants showing use. This information was then used to construct electivity indices based on Ivlev's methods (Ivlev 1961). We constructed two types of electivity indices. One was based on estimated percent of a forage species consumed versus what was available in the sample area. The second index was based on the number of individual plants showing use from bite marks compared to the total number of plants of that species available within the samples. For example, in one sample bluebunch wheatgrass had bite marks. We estimated the percent of the bluebunch wheatgrass eaten, then, we counted the number of individual bunches within the sample area and then calculated the percent of those individuals that showed bighorn sheep use.

A species that occurs rather infrequently but is used regularly would show an electivity value approaching 1.0 while a common species used infrequently would receive a value nearer to -1.0. Use is determined by visual observation of bighorn sheep foraging and then estimated biomass consumed and noting the percent of individuals that were used.

RESULTS

Study Areas

Diet reconstruction was performed for both rams and ewes on Antelope Island. On each of the other sites, however, diets were only reconstructed for ewes, as the rams were not radio collared and therefore difficult to find and follow. Due to restrictions on the number of inputs IsoSource© can accommodate plant species were combined into family groups. Tables 1 through 4 present the isotope ratios of C and N from the different plant species. Fecal isotope ratio values are presented in Table 5. No fecal values were determined for the Mount Timpanogos herd because the samples were lost. These values were then entered into IsoSource © to reconstruct the diets based on plant and fecal data for each site.

Table 1. Mean δ13C and δ15N values for plant species from Antelope Island.

	δ13C	δ15N
Asteraceae	-27.6	-0.4
C_3 Poaceae	-27.7	-4.5
C_4 Poaceae	-14.1	-2.9
Chenopodiaceae	-15.1	2.1
Geraniaceae	-13.7	-1.8
Onagraceae	-27.3	-0.2
Polygonaceae	-29.1	-0.2
Scrophulariaceae	-28.9	0.5

Table 2. Mean δ13C and δ15N values for plant species from Provo Peak.

	δ13C	δ15N
Pseudoroegneria spicata	-28.0	-4.3
Asteraceae species	-27.2	-2.1
Bouteloa dactyloides	-27.4	-11.8
Bromus tectorum	-25.4	-4.9
Erodium cicutarium	-28.8	1.8
Poa secunda and fendleriana	-28.1	-3.5
Quercus gambelii	-27.7	-3.3
Verbascum virgatum	-27.1	-2.6

Table 3. Mean δ13C and δ15N values for plant species from Mount Nebo.

	δ13C	δ15N
Pseudoroegneria spicata	-28.1	-3.6
Asteraceae	-27.6	-2.0
Brassicaceae	-27.8	-1.7
Fagaceae	-26.8	-3.4
Loasaceae	-27.6	-1.5
Poaceae	-26.9	-2.1
Rhamnaceae	-27.5	-1.3
Rosaceae	-26.9	-14.5
Unknown[a]	-26.8	-3.2

Table 4. Mean δ13C and δ15N values for plant species from Mount Timpanogos.

	δ13C	δ15N
Pseudoroegneria spicata	-28.1	-3.6
Bromus tectorum	-28.9	-2.3
Ceanothus velutinus	-26.8	-1.2
Chrysothamnus nauseosus	-27.0	-1.6
Elymus trachycaulus	-27.0	0.0
Erodium spp	-27.5	0.6
Gutierezzia sarothrae	-26.2	-4.0
Poa fendleriana	-27.2	-1.3
Poa secunda	-28.0	-3.2
Poa, unknown[a]	-26.8	-2.9
Quercus gambelii	-26.4	-2.2
Sambucus racemosa	-26.2	1.3
Sporobulus cryptandrus	-28.4	-1.8
Triticeae	-28.1	0.0
Unknown[a]	-27.1	-1.2

[a]Unknown species are forbs that were not keyed due to lack of suitable specimens or sample sizes.

Table 5. Mean δ13C and δ15N values for feces collected from bighorn sheep survey sites.

	δ13C	δ15N
Antelope Island, Ewes	-28.4	3.4
Antelope Island, Rams	-27.5	3.4
Provo Peak, Ewes	-27.9	0.5
Mount Nebo, Ewes	-27.3	1.5
Mount Timpanogos, Ewes	**N/A**	**N/A**

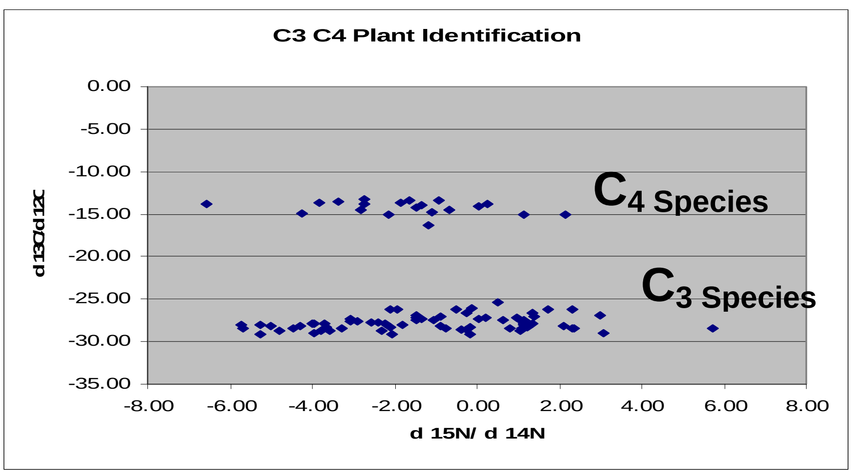

Figure 2. The difference in carbon ratios between C_3 and C_4 plants collected at Antelope Island, Mount Nebo, Mount Timpanogos and Provo Peak

The data represented is a culmination across all data site samples. C_4 plants generally have values around -15 while C_3 plants average between -25 and -30. The difference is due to the different photosynthetic pathways and carbon handling of the two plant types. C_3 plant species also differ amongst themselves in their ability to assimilate ^{13}C, however, individual species assimilate at similar rates..

Plant values from Tables 1 through 4 were entered into IsoSource© in conjunction with corresponding fecal values from Table 5 for diet reconstruction. The diets were reconstructed and the results are shown in Figures 3, 4, 6, 7, 9, and 10.

Antelope Island

Antelope Island is the only location where ewe and ram comparisons were made (Figures 3 and 4). For both ewes and rams, the buckwheat (*Polygonaceae*) and figwort (*Scrophulariaceae*) families made up the largest percentage of the diet. This is further illustrated in Figure 4 where the ewes' diets consisted of approximately 90% forbs and 10% grasses and rams' diets are nearly 80% forb and 19% grasses. Use by forage group was not significantly different between ewes and rams on Antelope Island at the $\alpha \leq 0.05$. Crispleaf buckwheat (*Eriogonum divergens*) was the single most important forb species in both ram and ewe diets. It was the sole representative of the buckwheat family and accounted for 41% and 25% of ewe and ram diets, respectively. Rams and ewes did not differ significantly in their use of the available plant families. Compared to other bighorn sheep populations the Antelope Island herd consumed more forbsthan any other population within the study and had a diet most similar to populations of California bighorn sheep in California, USA (Jones 1950).

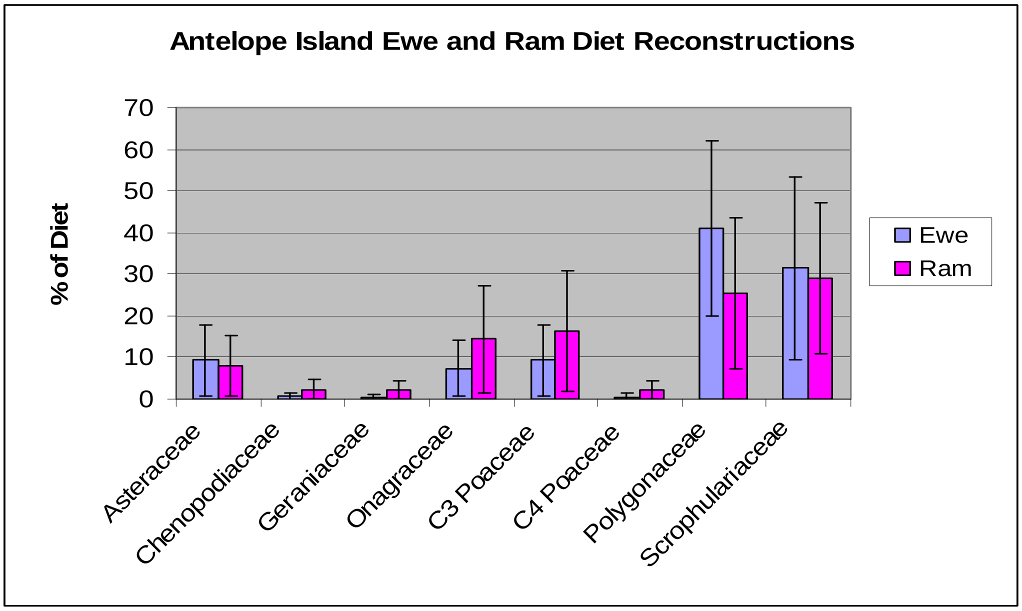

Figure 3. Comparison of ewe and ram diets from Antelope Island, summer 2006.

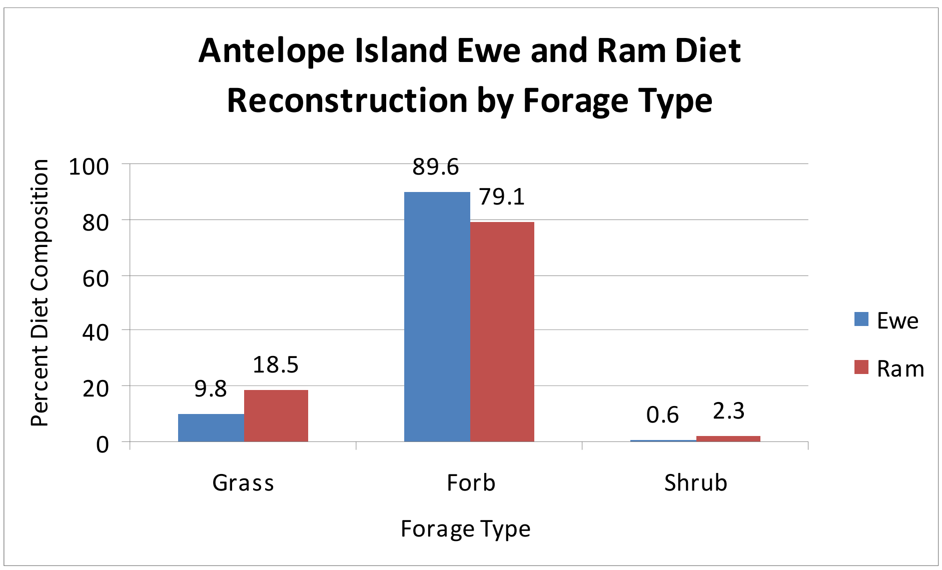

Figure 4. Comparison and reconstruction of diets by forage type from Antelope Island, 2006.

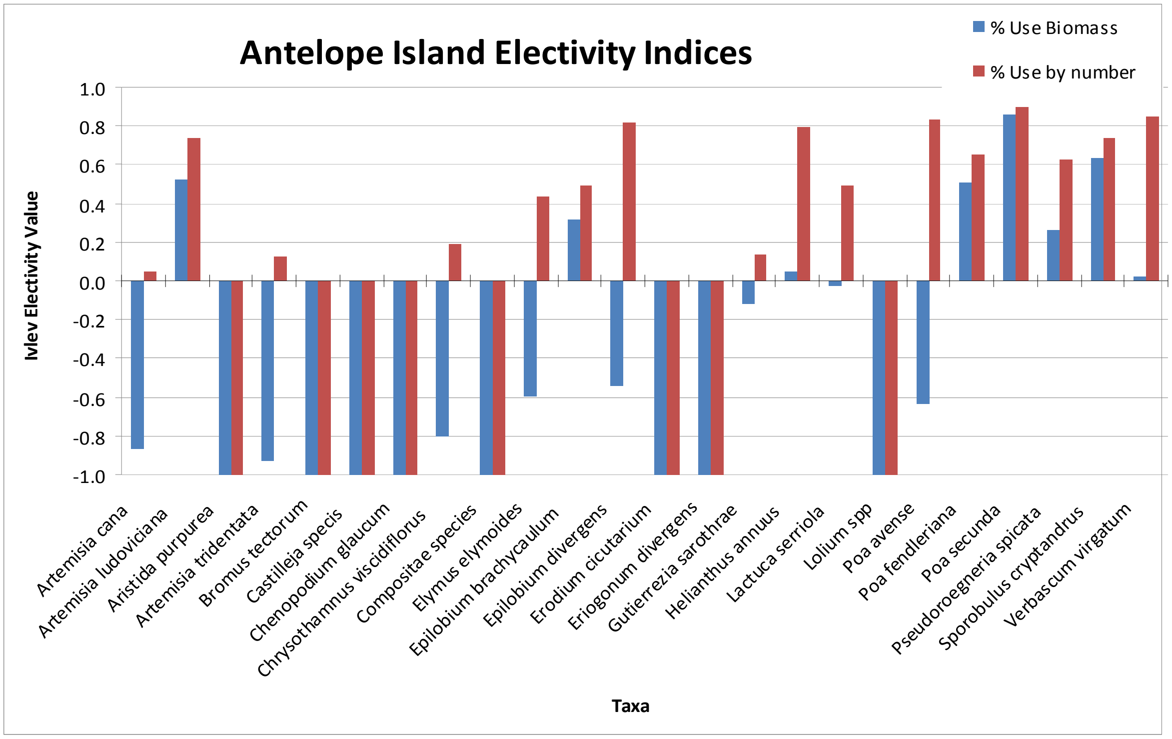

Figure 5. Electivity indices of forages found and selected for by ram and ewe bighorn sheep on Antelope Island, 2006.

Many grasses were selected for by bighorn on Antelope Island by both rams and ewes (Figure 4). Many of the forbs, such as sunflower (*Helianthus* annuus) and wand mullein (*Verbascum* virgatum) were gleaned of their leaves and tender parts. Such use leads to electivity values that differ between the biomass index and that based on the number of individuals showing use. Plant species that were selected for included white sagebrush (*Artemisia ludoviciana*), tall annual willowherb (*Epilobium brachycarpum*), sunflower, mutton bluegrass (*Poa fendleriana*), Sandberg bluegrass (*Poa secunda*), bluebunch wheatgrass, and wand mullein. All of the aforementioned species were selected for by number and biomass, with at least one of those categories having a value of 0.5 or greater.

Provo Peak

The forage species consumed by the Provo Peak herd (Figure 6) were storksbill (*Erodium cicutarium*) at 23.8% of the diet and a combination of grass species (*Poa* species and *Pseudoroegneria spicata*) that combined to provide 33% of the overall diet. When comparing grasses, forbs and shrubs, isotope analysis determined the diet consisted of 47.1, 40.3 and 12.7% grasses, forbs and shrubs repectively (Figure 7).

Electivity indices showed the species selected for by biomass and number (Figure 8), with at least one of those values being 0.5 or greater, including white sagebrush, a milkweed (*Asclepias* species), mutton bluegrass, and bluebunch wheatgrass. Storksbill was very prolific in this area and contributed nearly a quarter of the bighorn sheeps' diet. At the same time, the electivity value for storksbill was -1.0 because it was so prolific as a ground cover.

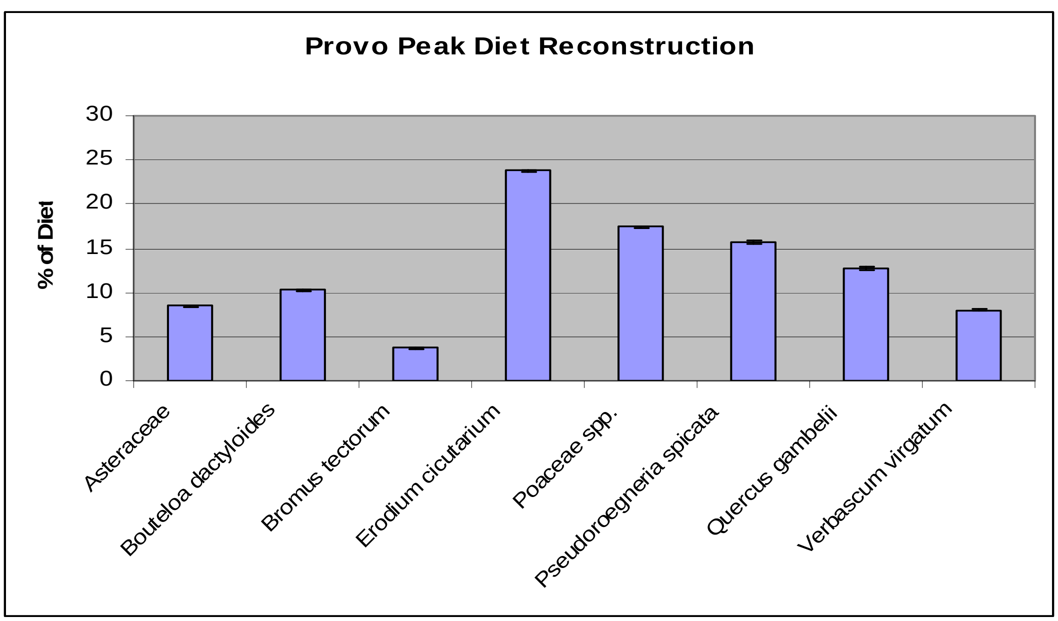

Figure 6. Provo Peak herd diet reconstruction, summer 2006.

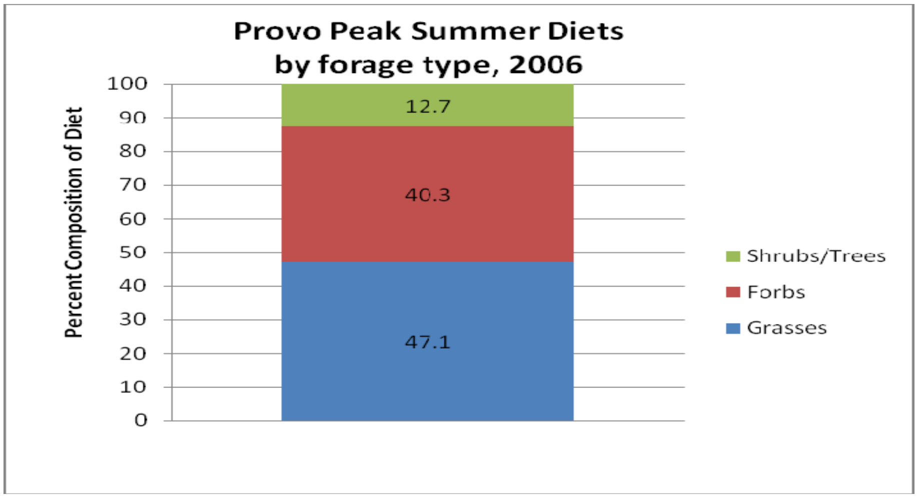

Figure 7. Provo Peak herd diet reconstruction, by forage type, summer 2006.

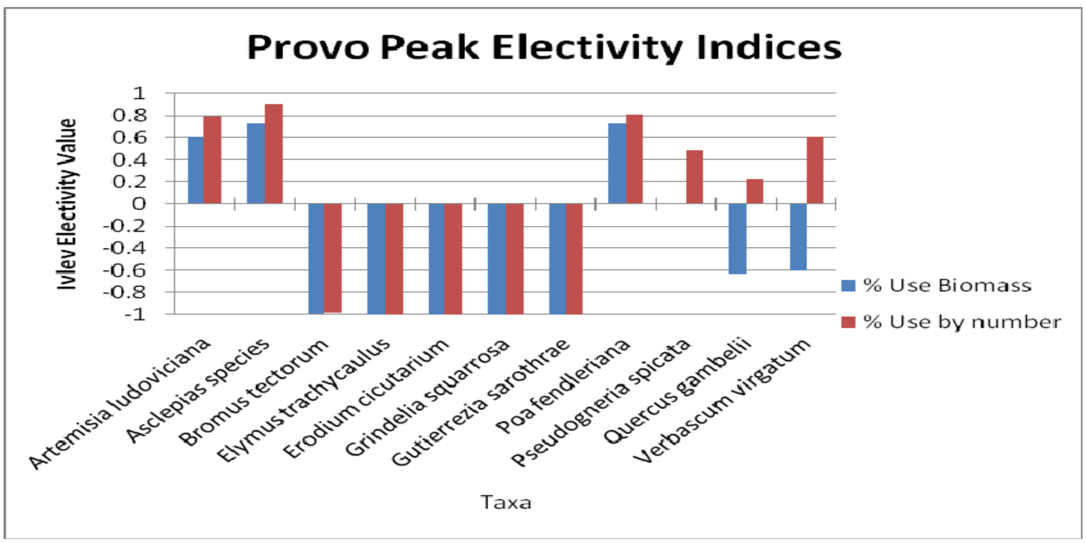

Figure 8. Electivity indices for the Provo Peak herd, for summer of 2006.

Mount Nebo

The Mount Nebo herd had a very balanced diet between the different plant families (see Figure 9), Poaceae represented 22% of the overall diet while all other plant families represented 11%. Of the 22% represented by Poaceae half of that (11%) was from bluebunch wheatgrass. Forbs, however were the predominant species at 44% including storksbill, prickly lettuce, yellow salsify (*Tragopogon spp.*), and showy goldeneye (*Viguiera multiflora*). Shrub consumption was the highest of the three populations where isotope analysis was used; making up 33% of the diet. The shrub species included true mountain mahogany (*Cercocarpus montanus*), rubber rabbitbrush, and Gambel oak. Stickyleaf low rabbitbrush (*Chrysothamnus viscidiflorus*) is also found on this site but receives little to no use from bighorn sheep. The Provo Peak herd consumed grasses, forbs and shrubs at levels comparable to Rocky Mountain bighorn sheep found in Montana at 41% grasses, 39% forbs, and 19% shrubs (Scahllenberger 1966; Constan 1972; Erickson 1972; and Stewart 1975).

Species selected for based on the electivity indices include intermediate wheatgrass (*Thinopyrum intermedium*), prickly lettuce (*Lactuca serriola*), and bulbous bluegrass (*Poa bulbosa*) Based on visual observations this site was the most productive, in terms of biomass and had the largest variety of species of the four study sites.

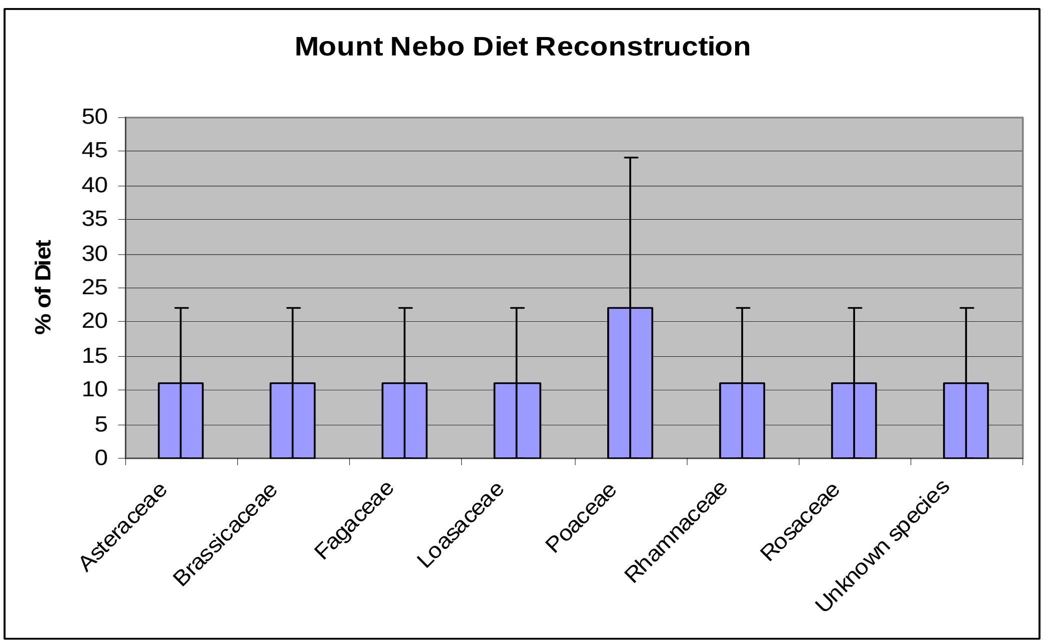

Figure 9. Mount Nebo diet reconstruction, summer 2006.

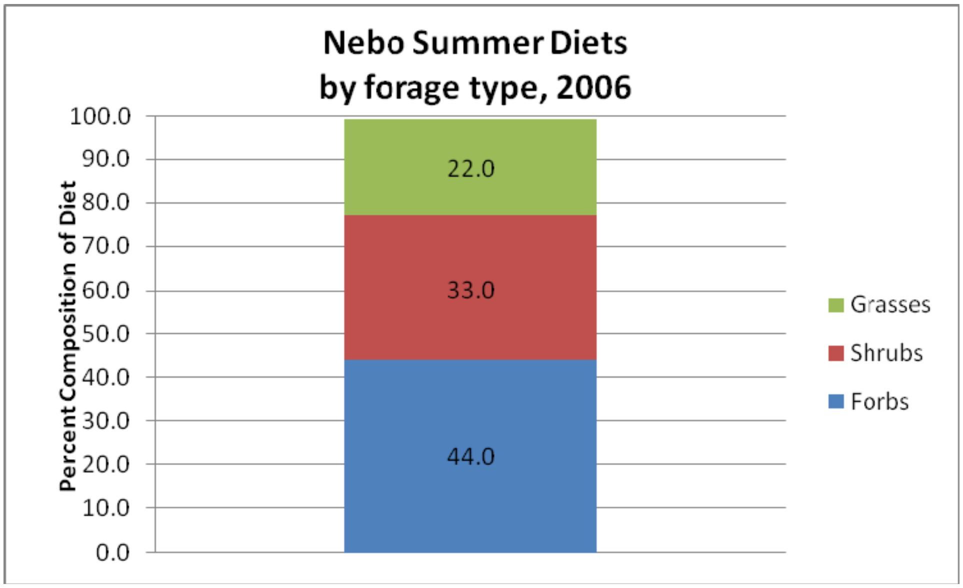

Figure 10. Mount Nebo diet reconstruction by forage type, summer 2006.

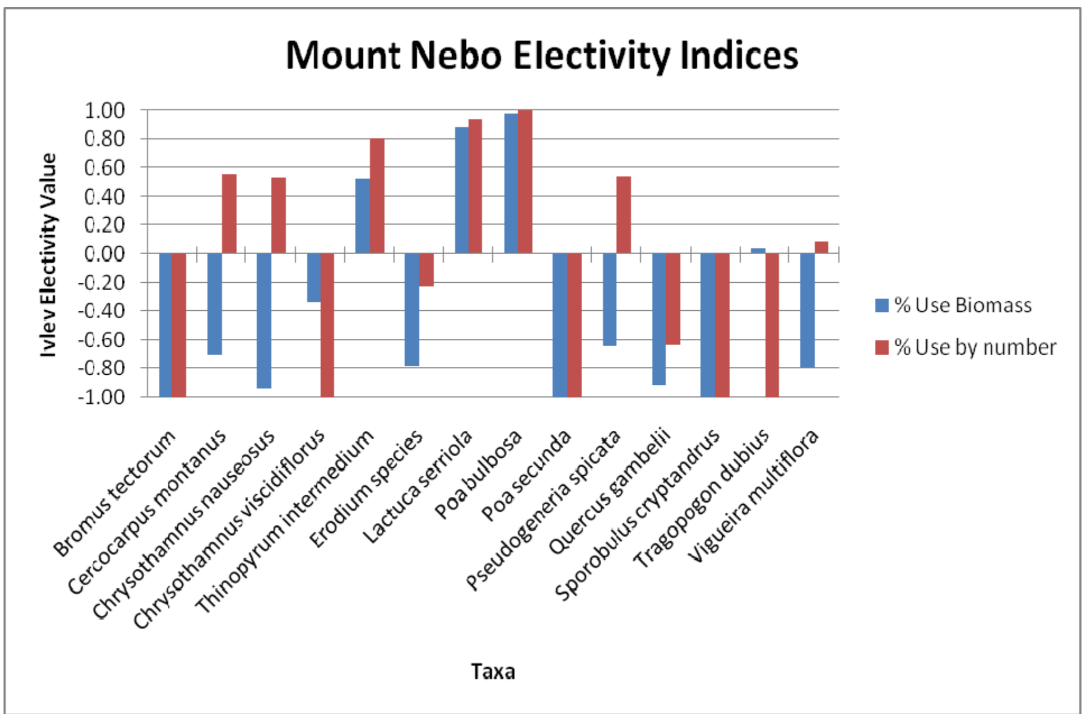

Figure 11. Electivity indices for the Mount Nebo herd.

Mount Timpanogos

Fecal samples for the Mount Timpanogos herd were lost, so only the electivity index was used. The electivity index showed this population selecting for bluebunch wheatgrass, sand dropseed, and Gambel oak. The negative electivity value based on percent use of biomass for Gambel oak is due to bighorn sheep use being limited to leaves and new growth.

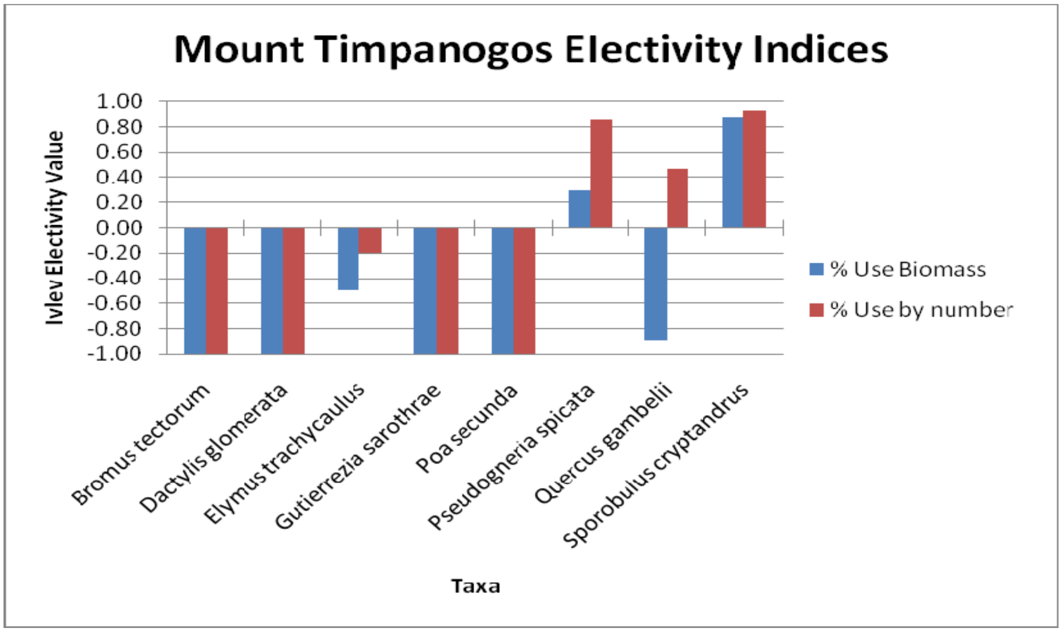

Figure 12. Electivity indices for the Mount Timpanogos herd.

DISCUSSION

The variation in diets over these four study areas is consistent with dietary variation reported for bighorn sheep populations across the west (Shackleton 1992). Forbs were the dominate forage for the Antelope Island herd and Mount Nebo ewes followed by grasses and shrubs, but Provo Peak bighorn ewes preferred grasses followed by forbs and shrubs. Shrubs were a small component in all of the survey areas except Mount Nebo where it comprised more of the diet than in any other location.

Electivity indices indicate the preferred use of a plant species based on its availability. The purpose in creating an index based on the percent use of biomass gives a good idea as to how much is used. The index based on the percent of individuals used helps determine how many of the available plants within the sample are consumed. The percent of individuals used also helps denote higher use of plant species that have woody growth or are gleaned for leaves and tender new growth such as Gambel oak, annual sunflower, and wand mullein. An understanding of the physical properties of the different forage species available helps to fill in the picture sketched by the numerical data.

Antelope Island

Antelope Island is a unique area in that it is a state park and is intensely managed. Antelope Island is an arid grass-shrub steppe dominated by cheatgrass and stickyleaf rabbitbrush (*Chrysothamnus viscidiflorus*). There are stands of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and perennial grasses that provide good foraging opportunities, as well as scattered forbs. No significant threats exist from predators; the only predators of capable of harassing bighorn are coyotes (*Canis latrans*) and possibly bobcats (*Lynx rufus*) and golden eagles. No grazing from domestic livestock occurs on the island. The island's bison (*Bison bison*) herd is managed for sustainable use and range improvement projects are conducted regularly so competition between these two populations is minimized and forage production is adequate to maintain all ungulate populations. Other species present on the island include pronghorn (*Antilocapra americana*) and mule deer (*Odocoileus hemionus*), but generally these populations are small and scattered enough to minimize competition.

The lack of predators likely allows ewes and lambs to move out farther from escape terrain as they take advantage of more abundant and higher quality forage. Park management may also minimize competition for forage resources between ungulate species as biologists control herd numbers and perform numerous habitat improvement projects. Management practices at Antelope Island State Park include culling bison herds, transplanting bighorn sheep and treating and seeding habitat.

Many grasses were selected on Antelope Island by both rams and ewes (Figure 4). Many the forbs, such as sunflower and wand mullein were gleaned of their leaves and tender parts so the electivity index for biomass is near zero or a negative value while the electivity value for the number of plants is high. Although the biomass from these species is not particularly high they reflect the importance of using electivity indices or visual observation in companion to stable isotope techniques to find how different plant species are used.

Provo Peak

The Provo Peak population roams the mountains directly east of Provo and Orem down to Springville, Utah. The range begins on the east bench of the city right down to the urban interface. This area dominated by steep hillsides, rockslides, cliffs and is crossed by hiking trails, parks and rock climbing areas. The predominant vegetation is Gambel oak with a grass/forb understory. Unlike Antelope Island, the Provo Peak herd is not without predators and other herd limiting issues. Cougar predation is a problem in this herd area, as are sheep/vehicle collisions in nearby Provo Canyon. Interactions with domestic sheep are limited due to the absence of grazing permits in the area.

Bluegrass species, including bluebunch wheatgrass, were shown by this research to be the most important forage for this population (47.1%), followed by forbs (40.3%) and then shrubs (12.7%) (Figure 7). The average electivity value for percent of forb species was -0.1 and for bluegrass species was 0.1. The bluegrass species, including bluebunch wheatgrass, mutton bluegrass and some Sandberg bluegrass, were selected for more than the forbs. Mutton bluegrass and bluebunch wheatgrass are selected for in their diets. Favored forbs are white sagebrush, a milkweed species, and wand mullein. Within the electivity indices wand mullein shows preferential use by number only and a negative preference in biomass. This is due to the bighorn sheep gleaning leaves and the tender tips while leaving the stalk and basal rosette untouched. This population also made use of Gambel oak (*Quercus gambelii*) at 12.7% of their diet and the electivity indices follows that of wand mullein. The Provo Peak herd consumed grasses, forbs and shrubs at levels comparable to Rocky Mountain bighorn sheep found in Montana at 41% grasses, 39% forbs, and 19% shrubs (Scahllenberger 1966; Constan 1972; Erickson 1972; and Stewart 1975).

Mount Nebo

The Mount Nebo herd predominantly uses the western slopes of Mount Nebo east of Mona, Utah. The primary areas that bighorn used during this study were steep canyons and hillsides. Rarely were sheep found in canyon bottoms or on ridges. There are a few well-developed stands of various evergreen tree species and sheep used these areas only when in transit. As we actively tracked bighorn through evergreen stands we rarely saw signs of foraging. Predation by mountain lions is a concern in this area, as is contact with an occasional stray domestic sheep that has escaped from farms in nearby towns or from herds trailed along the Skyline Trail to the distant northwest.

The Mount Nebo herd's diet is the typified by mostly forbs and grasses with a minimum of shrubs (Figure 10). Preferred grass species include intermediate wheatgrass, bulbous bluegrass, and bluebunch wheatgrass. The preferred forb is prickly lettuce. True mountain mahogany and rubber rabbitbrush are the preferred shrub species (Figure 11). This herd had the highest shrub usage at 22.0%. A possible reason for the shrub component being so high for this herd when compared to others is that the herd spends more time in higher elevation mountain brush communities than the lower lying sagebrush. Nevertheless, the Mount Nebo herd's diet compares with the Rocky Mountain bighorn sheep herds found in Montana (Scahllenberger 1966; Constan 1972; Erickson 1972; and Stewart 1975), and has a diet similar to the Provo Peak herd within our own study. The high use of the shrub communit, while high within our study areas, is not incommon in other populations.

Mount Timpanogos

The Mount Timpanogos herd roams the lower limits of Mount Timpanogos near Alpine and Highland, UT. They occasionally roam into the yards of nearby homes. This herd also makes heavy use of a golf course found near the mouth of American Fork Canyon. The golf course is located on the west aspect south of American Fork Canyon and provides large areas of green grass (*Poa spp.*) with minimal human disturbance during the fall and winter. The terrain above the golf course is steep (>30% slope) and provides adequate escape terrain for bighorn. The entire range is steep and has numerous rock slides. The highest elevation a sample was taken atop a ridge during movement of the herd from a valley that led into American Fork Canyon to the face of Mount Timpanogos. This area was similar to the Provo Peak habitat in that Gambel oak was the predominant browse.

Electivity indices (Figure 12) illustrate that the most selected for species consumed were bluebunch wheatgrass, sand dropseed, and Gambel oak. Bluebunch wheatgrass may be more important in diets during the winter as it is still available after forb species have senesced and deciduous shrub and tree species have shed their leaves. Bluebunch wheatgrass and sand dropseed are the predominant grass species found in this habitat, with other species occurring infrequently in small patches whereas bluebunch and sand dropseed are larger and have developed small stands. Gambel oak is the most common woody species on the mountain and was found in adjacent to or in sample areas.

The biggest differences in diet between the study populations was the dominance of forbs in the Antelope Island diets, forbs provided 90% and 79% of ewe and ram diets, respectively. The Provo Peak herd, which had the next highest use of forbs, did not use forbs half as much (40%). Part of the reason for this may be more availability on Antelope Island and less need to remain close to escape terrain. The Antelope Island herd consumed a higher percentage of forbs than any of the other herds we looked at and those outlined in Table 1. The Antelope Island bighorn consumed less grass than any other population in the study or in the literature at 10% of ewe diets and 19% of ram diets. Shrub use by the Antelope Island herd was minimal. This does mirror the diets of bighorn sheep in California as found by Jones (1950) and Wikeem and Pitt (1992) where sagebrush was the most common shrub on site providing 1% of the diet.

The Mount Nebo and Provo Peak herd diets were consistent line with diets reported within the literature. Table 1 of the accompanying literature review shows grass use ranged from 31% to 76% of the diets of various bighorn sheep populations across western North America. Forbs ranged from 7% to 67% and shrubs from 0% to 59%.

CONCLUSION

A comparison of the diet reconstruction from the isotope data with electivity indices (Figure 5) shows the bighorn sheep population on Antelope Island preferred forage species included: Grasses- bluebunch wheatgrass, Sandberg bluegrass, and sand dropseed; Forbs- white sagebrush, tall willowherb, a buckwheat species, sunflower, and wand mullein. Forbs made up the greatest percent of the diet in both sexes focused on the species in the evening primrose, buckwheat and figwort families

As documented by Dibb and Quinn (2000), bluebunch wheatgrass is an important grass species for all bighorn herds, however, bighorn diets reflect availability as well. When electivity indices are compared, the one species that was selected for across all populations was bluebunch wheatgrass. According to Shackleton et al. (1999) citing Wikeem and Pitt (1992), bluebunch wheatgrass is generally selected for less than it is available in populations in Canada and the United States even though it is an important component of their diet. A positive aspect of bluebunch wheatgrass is the range of habitats that it can grow in, from lower elevation valleys to higher elevation ridges and slopes, it is widespread and available throughout the year. Other species that were selected for, on sites where they occurred, were sand dropseed, wand mullein, mutton bluegrass, white sagebrush, and prickly lettuce. White sagebrush has been selected for in other populations of Rocky Mountain bighorn sheep near Rosebud and Stillwater, Montana (Stewart 1975).Forbs are among the most important contributors to overall diet in every site, although the forb species differs over the different sites from storksbill to woolly mullein. The forb component is more limited by elevation and plant community than the grass species were. This information is useful to develop seed mixes and to determine which treatments would improve bighorn sheep habitat. As the UDWR continues working to improve the condition of its bighorn sheep herds this information will help make these decisions.

All reseeding projects should focus on the local plant species selected by bighorn and be located near escape terrain and lambing areas. Since the survival of young and their recruitment, or their addition to the breeding population, is of vital importance to the sustainability and growth of bighorn sheep herds, increasing the vigor of lambs without having to forage far from escape terrain will alleviate predation, thus helping them to stabilize and grow.

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