DIET, NUTRITION, AND REPRODUCTIVE SUCCESS OF ROOSEVELT ELK IN MANAGED FORESTS OF THE OLYMPIC PENINSULA, WASHINGTON

by

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ABSTRACT

Diet, nutrition, and reproductive success of Roosevelt elk in managed forests of the Olympic Peninsula, Washington

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The relationship between reproductive success, vegetation types in the home range, and diet composition and nutritional quality was examined in female Roosevelt elk on the Olympic Peninsula, Washington. Nine elk herds were radio-tracked during 2001 to quantify reproductive success (as calf:cow ratio), home range size and location, and vegetation types used. I measured diet composition from fecal samples, and collected plant samples of forages found in the diet. I analyzed plant samples for nutritional quality (protein content, digestibility, and energy).

Herds were grouped into highly productive (December calf:cow ratio > 0.30) and less productive (December calf:cow ratio < 0.30). Highly productive herds had more 2 – 9 year old timber ($P = 0.03$) and less 11 – 24 year old timber ($P = 0.03$) available in the home range than less productive herds. Highly productive herds consumed more grasses ($P = 0.008$) and less shrubs ($P = 0.02$) and ferns ($P = 0.02$) than less productive herds. In addition, I found negative correlations between percentage grass or forb in the diet and percentage shrub or fern in the diet. Percentage shrub in the diet was positively correlated to percentage 20 – 24 year old timber, and negatively correlated to percentage 2 – 9 year old timber available in the home range.

Grasses and forbs were high in protein (> 12%), digestibility (> 55%), and digestible energy (> 2.1 Kcal/g). Ferns and shrubs were lower in protein except during spring when *Athyrium felix-femina* and *Equisetum* had protein content greater than 17%. Ferns and shrubs were less digestible (< 46%), and had lower digestible energy (< 1.7 Kcal/g) than grasses and forbs.

Regression and correlation analyses were used to investigate relationships between home range size, vegetation types used, vegetation types available, diet, and reproductive success. For highly productive herds, there was no change in calf survival as home range size increased. However, for less productive herds, calf survival decreased and mean calf:cow ratio increased with increasing home range size. Less productive herds could increase home range size to include more forage, but the higher cost of travel and predation risk may have lowered calf survival. Highly productive herds had areas of high quality forage (high protein and digestible energy) within their home range, therefore did not have to increase home range size to provide adequate nutrition.

Available marsh, riparian, and pasture in the home range, as well as used and available 2 – 9 year old timber in the home range, were positively related to reproductive success of female elk ($P < 0.05$). 20 – 24 year old timber used by herds was negatively related to reproductive success ($P < 0.05$). The amount of grasses, sedges, and forbs in the diet, all forages that were high in protein and digestible energy, were positively related to reproductive success ($P < 0.001$). Elk herds with home ranges that included riparian, pasture, and some young timber had access to abundant, good nutritional quality forages, allowing for high reproductive success regardless of home range size. Elk herds

with home ranges that consisted of expanses of maturing timber did not have access to as much high quality forage, and therefore had lower reproductive success.

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INTRODUCTION

Roosevelt elk (*Cervus elaphus roosevelti*) occur along the Pacific Coast from northern California, through western Oregon and Washington, to Vancouver Island, British Columbia, Canada (Dasmann 1975). Populations in the northern parts of this range were increasing or stable until the 1980's (Ferry et al. 2001). Populations of Roosevelt elk on Washington's Olympic Peninsula, excluding Olympic National Park, have declined since the 1980's (Ferry et al. 2001). Possible causes for the decline in elk numbers include mortalities from hunting and predation (leading to skewed sex ratios and decreased numbers of mature bulls) and decreased reproductive success due to diet, nutrition and vegetation changes arising from forest management practices (Noyes et al. 1996, Cook et al. 2004). There is a need to understand the causes of the population decline on the Olympic Peninsula, enabling land and wildlife managers to develop a management plan that will benefit the elk population.

In February 2000, the Makah Tribe initiated a study of non-migratory Roosevelt elk on the Hoko Game Management Unit (hereafter Hoko GMU), Clallam County, Washington. The goals of the tribe's study included an elk population estimate for the Hoko GMU, as well as identification of factors influencing size and health of elk populations on the Olympic Peninsula. The management goal was to restore elk populations to sustainable numbers and allow for cultural, subsistence, and recreational hunting needs. The project began in 2000, by examining the effects of human

disturbance on elk movements and mortality (J. Storlie, 2005, Humboldt State University, personal communication). In 2001, I began an investigation of the influences of timber stand age, vegetation type, diet, and nutritional quality of forage on elk reproductive success in managed coastal forests.

Reproductive success has been defined as the number of offspring of an individual surviving at a given time (Lincoln et al. 1998). In ungulates, reproductive success was previously quantified as total number of calves produced within a herd or group, or number of calves per cow (Post and Klein 1999, Cook et al. 2001). Reproductive success of elk is influenced by a number of proximal factors, including the health of the cow (Thorne et al. 1976, Cook et al. 2004), breeding bull age (Noyes et al. 1996, Cook et al. 2004), or predation (Bergerud and Elliot 1998, Hebblewhite et al. 2002, Lawrence et al. 2004).

The health of cow elk affects pregnancy rates and the health of calves at parturition, and therefore influences reproductive success (Thorne et al. 1976, Cook et al. 2001, Cook et al. 2004). Cow health is influenced by the nutritional quality (amount of protein and energy in forage) of the diet. Good nutritional quality forage has high protein content, high digestibility, high digestible energy, and small amounts of secondary compounds such as tannins. Decreased body weight of cow elk due to poor nutritional quality and less abundant food during gestation can negatively effect reproductive success (Thorne et al. 1976, Cook et al. 2004). Calves born to cows with access to great quantities of high quality forage during gestation and lactation had higher survival than calves of cows with access to smaller amounts of poor-quality food (Thorne et al. 1976).

Similarly, high quality habitat (vegetation types that provide abundant, high-quality forage) has been linked to high pregnancy and birth rates, increased calf survival, and a larger proportion of young cows breeding (Trainer 1971, Cook et al. 2004). Gestation, lactation, and calf growth have been shown to be energetically demanding, and require large amounts of high quality forage for successful recruitment (Albon et al. 1983, Oftedal 1985, Clutton-Brock et al. 1988, Cook et al. 1996). Generally, a herd consuming a high quantity and quality diet will have healthier cows with higher reproductive success and the herd will be subject to fewer losses from starvation, disease, and predation (Nelson and Leege 1982).

In coastal forests of the Olympic Peninsula, the link between land management and elk reproductive success is poorly understood. Few studies have identified relationships between vegetation type or timber stand age, and reproductive success of elk (Iason et al. 1986, Merrill and Boyce 1991), particularly in managed forests. This may be due to an unsupported assumption that timber harvesting will result in landscapes with ample amounts of elk forage from increased vegetative productivity. Timber management practices can alter the abundance and arrangement of vegetation types and timber stand ages across large areas. Elk forage production, particularly grasses and forbs, may be increased for approximately 15 - 20 years after the timber harvest (Hanley 1984). However, as timber stand age reaches approximately 15 or 20 years, available forage declines and remains low until the next timber harvest (Alaback 1982). Therefore, timber harvest practices influence the availability of elk forage and consequently elk diets over long time frames (Irwin and Peek 1983, Jenkins and Starkey 1993, Jenkins and

Starkey 1996). This association of timber harvest and forage has been further complicated because the great quantities of forage generated after timber harvest can also be of poor nutritional quality due to high levels of secondary plant compounds such as tannins, especially in shrubs (Robbins et al. 1987, Happe et al. 1990). Increased sun exposure after timber harvest has been shown to elevate tannin levels in shrubs (Robbins et al. 1987), a concern for Roosevelt elk because shrubs make up the greatest proportion of the diet (Jenkins and Starkey 1991). Therefore forage quality, not simply abundance, may influence cow elk health and limit elk reproductive success in managed coastal forests.

Elk diet and nutritional quality of elk forages have been investigated for Pacific coast old-growth (Leslie et al. 1984, Jenkins and Starkey 1993), Pacific coast managed forests (Jenkins and Starkey 1993), and the Rocky Mountain region (Hobbs et al. 1981, Hobbs et al. 1982). Furthermore, recent studies on the effects of diet and nutrition on reproductive success of captive elk have established a positive relationship between high quality forage, pregnancy rates, and calf survival (Cook et al. 1996, Cook et al 2001, Cook et al. 2004). However, effects of diet and nutrition on reproductive success of free-ranging elk have not been investigated. Some authors have argued that spring and summer diet and nutrition has little affect on elk reproductive success due to the abundance of forage during these times (Nelson and Leege 1982, Unsworth et al. 1998). However, some recent studies found significant influences of nutrition during summer and early autumn on ungulate reproductive success (Hudson and Adamczeweski 1990, Cook et al. 1996, Post and Klein 1999, Cook et al. 2004). Furthermore, nutritional

deficiencies have been reported for summer and fall, potentially limiting weight gain of cows and calves, leading to decreased winter survival and reproductive success (Merrill and Boyce 1991, Alldredge et al. 2002).

Food availability, in the form of vegetation types and plant species available, has also been shown to relate to female mammal home range size (Boutin 1990). Home range size of small mammals has been found to decrease (Boutin 1990), and reproductive success increase (Jonsson et al. 2002) with supplemental food. However, decreased food quality, and lower reproductive success, has also been found to have no effect on home range size of voles (Fortier et al. 2001). In caribou (*Rangifer tarandus*), herds with access to smaller areas of preferred vegetation types were found to have smaller home ranges and lower calf survival (Stuart-Smith et al. 1997). The relationship between home range size and reproductive success of elk herds in the Hoko GMU may depend on food quantity and quality, and therefore on abundance of particular vegetation types available to the herds.

While many studies have investigated the link between vegetation types, diet, nutrition, and reproductive success of ungulates, most have been with captive animals (Thorne et al. 1976, Cook et al. 1996, Cook et al. 2001*b*, Cook et al. 2004). Studies using wild populations were limited by small sample size (Post and Klein 1999) or by use of indirect measures of diet and nutrition (Merrill and Boyce 1991). Hence, to determine if there was a relationship between vegetation type, diet composition, and reproductive success of Roosevelt elk on the Hoko GMU, I compared calf:cow ratios of nine elk herds to diet and vegetation type used by the free-ranging herds. Calf:cow ratio has been a

common method of quantifying reproductive success in ungulates (Merrill and Boyce 1991, Post and Klein 1999, Phillips and Alldredge 2000, White et al. 2001). Herd differences were used to avoid problems of pseudoreplication in diet composition and home range at the scale of individual cows. My objectives were: 1) determine reproductive success of each herd using calf:cow ratios; 2) identify vegetation types used and available to each herd; 3) quantify diet of each herd; 4) determine nutritional quality of forage species found in the diet; 5) identify relationships between home range size and reproductive success; 6) identify correlations between vegetation types used and available, diet, nutrition and reproductive success.

Thus, it was predicted that reproductive success would be positively related to vegetation types containing abundant elk forage (timber less than 10 years old, riparian, pasture), and negatively related to vegetation types with sparse forage (timber over 20 years old). I also predicted that reproductive success would be positively related to the percentage of high quality forage species in the diet, and negatively related to the percentage of forage species with low nutritional quality in the diet. High nitrogen content grass in the diet, as well as availability of meadows for foraging, have been found to be positively related to elk cow reproductive success (Iason et al. 1986). Similarly, Cook et al. (2004) found that pregnancy rates of cows, calf growth, and overwinter survival were positively influenced by digestible energy content of forage.

STUDY AREA

The Hoko Game Management Unit (GMU) is located in the extreme northwest portion of the Olympic Peninsula, Clallam County, Washington. The study area was approximately 233 km^2, bounded to the north by the Makah Reservation and the Straight of Juan de Fuca, on the southeast by the Hoko-Ozette road, and on the west by Olympic National Park and the Pacific Ocean (Figure 1). The Hoko GMU is comprised of privately owned timberlands that are harvested every 50-70 years. Throughout the 1970's and 1980's, the Hoko GMU was subject to extensive timber harvesting, resulting in widespread second growth stands (Olympic Peninsula State-Tribal Elk Working Group 1999). Timber over 100 years old existed west of the Hoko GMU in Olympic National Park, and on the southwest portion of the Makah Reservation. Private homes and ranching operations were interspersed along the perimeter of the study area.

Elevations in the Hoko GMU range from sea level to just over 600 m at ridgelines. Climate is maritime, characterized by cool, relatively dry summers and mild, wet winters. Annual precipitation averages 140 cm (inland) to 250 cm (coast), most occurring as rain from October to March. Year round temperatures are mild with snow occurring occasionally at elevations above 100 m (Makah Forestry 1999).

Dominant overstory species within the Hoko GMU included western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), and Western red cedar (*Thuja plicata*) . Major understory species included salal (*Galtheria shallon*), *Vaccinium* spp., *Rubus* spp., red elderberry (*Sambucus*

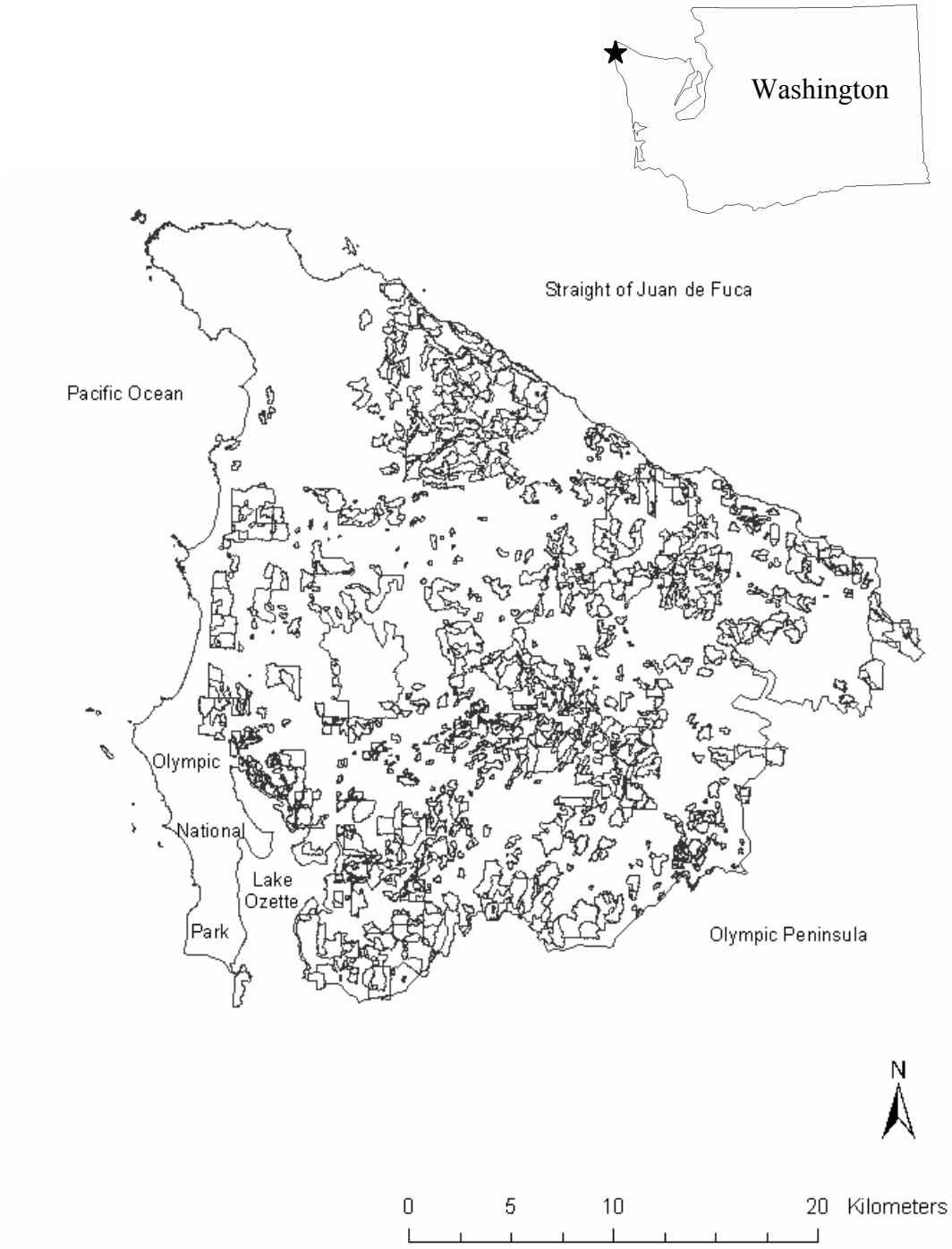

Figure 1. Study area of Roosevelt elk diet and reproductive success, Hoko Game Management Unit, Washington, 2001. Star indicates location of Hoko GMU within Washington. Polygons represent timber harvest within study area since 1976.

racemosa), swordfern (*Polystichum munitum*), and lady fern (*Athyrium felix-femina*). Common riparian species included red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*) and *Salix spp*. Herbaceous understories were dominated by a variety of grasses and forbs.

METHODS

Elk Capture, Telemetry and Locations

Elk were radio-collared (1,000 g radiocollar, Model 2-9D, Advanced Telemetry Systems, Isanti, MN) to uniquely identify herds and extent of herd home ranges. Radiocollars included a mortality-mode switch to facilitate the later detection of dead elk. Nine distinct elk herds were identified on the Hoko GMU prior to this study. In March 2000, 12 cow elk (from seven herds) were captured and radio-collared. In March 2001, seven additional cow elk (two additional herds) were captured and radio-collared. Darts (3-4 mg Carfentanil citrate, Wildlife Pharmaceuticals, Fort Collins, CO) were projected from a helicopter to immobilize elk.

Twice per week, from March to December 2001, I located radio-collared elk with a portable radio-receiver (Model R-1000, Communications Specialist, Inc., Orange, CA), a hand-held, 2-element yagi antenna (Model RA-14, Telonics Telemetry-Electronic Consultants, Mesa, AZ), and an omni directional vehicle-mounted antenna. I triangulated on the strongest signal to locate elk (Springer 1979). The time between triangulation bearings (3-5) was always less than 30 minutes. Universal Transverse Mercator (UTM) coordinates were assigned to all locations and plotted on USGS 1:24000 quadrangle maps in the field, and later entered into a Geographical Information System (GIS; ArcView 3.2 and ArcGIS 8.1; Environmental Systems Research Institute, Inc., Redlands, CA). Time of day, weather conditions, and location of elk were recorded. To maximize temporal

independence, I allowed at least 24 hours between successive locations for each collared elk (Swihart and Slade 1985, Grenier et al. 1990).

To estimate telemetry error I conducted blind tests in the field. Each field technician located a hidden test collar using the same methods used for locating collared elk. Each technician completed between 15 and 20 test locations. Actual test collar location and triangulated test collar location (in UTM) were plotted in a GIS. I measured error distance (in m) between actual and triangulated points, and used the average as a measure of location error for radio-located elk (Zimmerman and Powell 1995).

To identify elk herds, I used a coefficient of association (CA) to quantify associations between individual radio-collared elk (Cole 1949, Galea 1990). CA values were calculated for each possible collared elk pair using the formula:

$$CA = 2h / (a + b)$$

where h was the number of locations when elk a and b were found together, a was the total number of locations for animal a, b was the total number of locations for animal b. The resulting CA values represented a percentage of locations where each elk was located with any other elk. CA values ranged from 0 (no association) to 1 (perfect association). To minimize spatial pseudoreplication, elk were considered to be associated if CA was greater than or equal to 0.5. Associated elk were considered to belong to a single herd. Duplicate locations for elk of one herd on a given day were used only once in analysis. For all subsequent data collection and analyses (reproductive success, herd home range, diet, forage), the herd represented the sampling unit regardless of the

number of radio-collared or associated elk in the herd. All elk seen with radio-collared elk were also considered part of the same herd.

When a collared elk was located by telemetry and at least one elk was observed, I recorded that location as a visually-confirmed location. For each visual location, time, location, number of animals seen, herd composition (number of cows, calves, yearling males, bulls), vegetation type (meadow, roadside, riparian, timber harvest and stand age, Appendix A), and elk activity (foraging, bedded, walking/running) were recorded. When elk were seen foraging I used 8 X 42 binoculars to observe plant species and plant part consumed (flowers, leaves, bark, twigs, entire plant) by elk (15 min to 1.5 hr observations). After elk moved away from the foraging location, I visited the exact site where the elk had been seen and recorded additional plant species present. All elk locations were determined during daylight hours.

Reproductive Success

Calf:cow ratios were used to quantify reproductive success of elk herds for analytical comparisons with diet and vegetation use. I determined calf:cow ratios from herd composition counts for June through December 2001. Elk cows typically give birth from mid-May to the end of June (Franklin et al. 1975). Dense spring vegetation can make seeing calves difficult, particularly when animals lay down. Therefore, I used helicopter surveys beginning in May 2001 to maximize the chance of counting all calves. Helicopter surveys occurred once a month from the last week of May 2001 through August 2001. The helicopter surveys were conducted by three observers: one observer

counted calves and cows, one observer counted antlered elk and total animals, one person recorded data. The helicopter had an external antenna to find radio-marked individuals and the associated herd, and circled each herd at approximately 300 ft elevation for 2 - 3 minutes to complete each count.

In addition to helicopter surveys I opportunistically conducted at least one herd composition count per herd per month from the ground. Between May and December, when herds were visually located in an open location (meadow, 0-9 year-old timber, or non-forested marsh) I recorded numbers of cows, calves, yearling males, and bulls. When located in a partially obscured location (riparian or 40+ year-old timber) the count was recorded as partially complete. I used these partial counts as indexes of calf:cow ratios. When a herd was located in a closed location (8-35 year-old timber, forested marsh) herd counts were not possible. If there was more than one ground count per herd per month, the most complete count (from open location when possible) was used as the calf:cow ratio representative of that month.

Five variables were used to assess herd reproductive success. First, birthrate was calculated as the calf:cow ratio for each herd in July. July data was used to calculate birthrate because of extremely poor herd visibility in June. Herds were scattered during the calving season from mid-May through early July, making June herd counts difficult. Second, I calculated percent calf survival (hereafter survival) as December calf:cow ratio divided by the highest calf:cow ratio for each herd. Third, mean calf:cow was the mean for each herd from June to December. Forth, December calf:cow ratio represented reproductive success in early winter. Finally, I used relative productivity as an index to

rank herds on overall reproductive success. The productivity index was the rank of the sum of each herd's rank for birthrate, survival, mean calf:cow, and December calf:cow. The productivity index ranged from 1 (low reproductive success) to 9 (high reproductive success).

To test for a visibility bias of cows or calves for each herd, I used simple regression (Zar 1999) of number of cows seen with calf:cow ratio. If I found a significant relationship, I used the most complete cow count to determine calf:cow ratios and correct for visibility problems. I used a Kruskal-Wallis Test of Ranks and Tukey-Kramer Multiple Comparisons to test for differences in mean calf:cow ratios between herds over the entire year (Zar 1999). All statistical analyses were completed using Number Cruncher Statistical System (Hintze 2001). For purposes of comparing vegetation types used and available, home range size, and diet between high and low reproductive success herds, I separated the herds into highly productive (December calf:cow > 0.30) or less productive (December calf:cow < 0.30) groups.

Vegetation Type Used and Available

To determine vegetation types used by and available to elk, a vegetation type and timber stand age map of the study area was generated for analysis with radio-telemetry data. To generate the vegetation map, existing landform data (rivers, roads, non-forest areas, lakes, Olympic National Park) were combined with timber stand age data digitized by the Makah Wildlife Division Manager. Timber stand age data were digitized from Landsat images and orthophotos from 1976 to 2001 (R. McCoy, Makah forestry, personal

communication). Riparian areas of varying width (50 m-100 m wide) were identified around streams and rivers. Small tributary streams were not included in the analysis. Road areas of varying width (2 m-12 m wide) were identified by road type (paved road, primary, secondary, and tertiary timber roads). Roads were classified by observations of use; primary timber roads were used daily by logging trucks, secondary timber roads were used weekly, and tertiary roads were rarely used. I identified 28 distinct vegetation types or timber stand ages (Appendix A). Random UTM locations were generated that were verified in the field ("groundtruthed") for classification accuracy.

To identify vegetation type used by elk herds, each radio-location and visually confirmed location were assigned the vegetation type at that location. To assign non-visual locations a vegetation type, mean telemetry error (± 2 SD) was used to create a 95% confidence radius (hereafter circle) around each radio-location. I determined the percentage of each vegetation type within each circle (area of each vegetation type divided by the area of the circle). Because the majority of the study area consisted of mature second-growth timber greater than 25 years old, this vegetation type often dominated the circle. In addition, although riparian areas made up a minor percentage of the study area, elk were regularly observed within these riparian areas. Therefore, two criteria were used to assign each circle a vegetation type. First, if a riparian area bisected the circle it was classified as riparian. Second, if not classified as riparian, the circle was assigned the greatest percentage vegetation type within the circle. Percentage use of each vegetation type was calculated for each herd (number of locations in each vegetation type divided by total locations, Otis and White 1999).

To identify vegetation types available to each herd I calculated the percentage of each vegetation type within each herd's home range. To determine the extent of each herd's home range (minimum convex polygon, MCP, Hayne 1949), all locations were used in a home range program (Animal Movement extension 2.0, Hooge and Eichenlaub 2000, and ArcView 3.2, ESRI, Redlands, CA). To determine the number of elk locations necessary to correctly estimate home range for each herd, the number of locations was plotted against home range area. I identified the minimum number of locations after which home range area did not increase by more than 1% per 1 location added (Odum and Kuenzler 1955). A Paired T-Test (Zar 1999) was used to test for shifts in home range size between the years 2000 (J. Storlie, Humboldt State University, personal communication) and 2001. A shift or shrinkage of home ranges may reflect utilization of new forage areas (Irwin and Peek 1983). Home range size stability between years was necessary to apply conclusions concerning diet and reproductive success across years. Percentage available vegetation type was calculated for each herd (area of each vegetation type in the home range divided by total home range area). If a vegetation type did not occur within a herd's home range it was considered unavailable to that herd.

While percentage vegetation type within each home range was not an exact measure of available forage species, it was an adequate measure for comparing general vegetation differences between home ranges (Jenkins and Starkey 1993). Vegetation sampling to quantify available forage species within each home range was completed in June 2004 as part of a continuing study, but was not reported here.

The 28 vegetation types and timber stand ages were collapsed into 10 biologically relevant vegetation categories for statistical analysis purposes (Appendix A). A Mann-Whitney U corrected for ties (Zar 1999) was used to test for differences in percentage vegetation category available between highly productive and less productive herds. A Chi-square goodness-of-fit (Neu et al. 1974, Zar 1999) was used to test vegetation category used verses available within the home range for each herd. The 10 vegetation categories were condensed into 5 vegetation groups to maximize expected values for Chi-square analysis (Appendix A). Very rare vegetation groups could not be included in the Chi-square analysis due to low expected values. Trends in use for the rare vegetation categories or groups are descriptively portrayed as figures.

Diet Analysis

Differences in diet were quantified between herds. Fecal samples were collected during six sampling periods from March 2001 to February 2002. Sampling periods were: March to April, May to June, July to August, September to October, November to December 2001, and January to February 2002.

When herds were visually located 6 to 10 pellets were collected from 15 to 20 distinct fecal piles for each herd during each sampling period. If herds were not visually located, fecal samples were collected from areas where elk were radio-located while the herd was known to be nearby (through smell or auditory cues). Fecal samples collected in this manner were assumed to be fresh due to color and temperature (warm to the touch) of feces. A composite fecal sample (Leslie et al. 1983) was created from the 15 to 20

pellet groups collected for each herd during each sampling period. Plant species in elk diets were determined to species through microhistological analysis of fecal samples at the Wildlife Nutrition Lab, Washington State University, Pullman, WA (Nelson and Davitt 1982). Differential digestion of plant species has been a potential problem of this method (Nelson and Davitt 1982), resulting in increased percentages of less digestible plant species and decreased percentages of highly digestible species in the feces. It was assumed that all herds in this study had similar digestion rates of plant species, therefore an equal digestibility bias. Fecal samples were stored frozen prior to analysis.

To identify general trends in diet differences between herds and sampling periods, forage plant species were combined into forage classes. Forage classes were groups of related plant species: grass, forb, fern, sedge/rush, shrub, conifer. Kruskal-Wallis test of ranks with Bonferroni inequality correction factor and Tukey-Kramer multiple comparisons (Zar 1999) was used to test for differences in mean percentage of each forage class in the diet of all herds between sampling periods, and between herds over the entire year. A two-way ANOVA with sampling period and herd as factors could not be used because there were no replicates in the data (data were pooled). Therefore, I could not test for interactions between herd and sampling period, but significant differences identified using each factor independently can be statistically acceptable (Zar 1999). A Mann-Whitney U corrected for ties (Zar 1999) was used to test for differences in mean percentage forage class in the diet between high and low reproductive success herds.

Pearson's correlation matrix was used to identify correlated plant species ($r \geq 0.7$) for each sampling period (Hintze 2001). Forage species with strong positive correlations

could indicate forage plant groups associated with particular vegetation types. These plants could have been subject to incidental take by elk when elk were consuming particular species. Also, forage species with strong negative correlations could indicate variable availability of those species or vegetation types between herds. Hence, negative correlations may indicate consumption of a forage species in the absence of another species.

Nutritional Analysis of Forage Plants

Nutritional quality was determined by analysis of forage plant samples collected during the same six sampling periods from March 2001 to February 2002 that were used for diet composition. Three scales of elk foraging behavior were considered when collecting plant samples. The first scale described herd foraging location, defined as an area where a herd was radio-located and seen foraging at a specific point in time. The second scale of elk foraging behavior described the plant species consumed by elk. Because I collected plant samples concurrently with fecal samples, and therefore did not have diet composition results available, the elk diet reported by Jenkins and Starkey (1991) for the Olympic Peninsula was used to list known forage species. This list was modified to include additional forage species that I saw elk consume. A sample of each plant species on this list (equivalent to 20g dry) was collected from one foraging location for each sampling period.

The third scale of elk foraging selection described plant part consumed by elk. Elk foraging observations were used to establish a protocol for plant part collection: grasses

and forbs were taken from just above ground, shrubs were collected as leaves and twigs, ferns were collected as 75% of frond, conifers were collected as new or young growth. This collection method reflected observer bias, and may not accurately reflect elk selection of particular plants or plant parts. Grazing animals are known to select forage higher in quality than what is available (Van Dyne et al. 1980), whereas I collected plant samples from random plants at a foraging location. All plant samples were air dried (18-22°C) for 2 to 5 days until brittle, and stored in paper bags.

A subset of the collected plant samples was selected for nutritional analysis. The selection of the subset of plant samples was based on the diet results from fecal analysis. Every forage plant species found in the diet could not be analyzed. Two criteria were used to reduce the list of plant species to a feasible number of plants (6 to 7) for each sampling period. First, I selected the three or four plant species that made up the greatest percentage of the diet across all herds for each sampling period. Second, I selected three or four plant species that made up the greatest percent of the diet for only a few herds for each sampling period. Combining these two criteria I attempted to analyze the three plant species that made up the greatest percentage of each herds' diet for each sampling period.

Each plant species was analyzed for crude protein, in-vitro dry matter digestibility (hereafter digestibility), and gross available energy. All plants were ground to 1 mm screen size in a Wiley Mill (Model 3383L20, Thomas Scientific, Swedesboro, NJ). The Wildlife Nutrition Lab at Washington State University completed the dry-weight protein (Kjeldahl method) and digestibility analysis (Tilley and Terry 1963). Laboratory analysis

of digestibility was not an exact measure of digestibility in wild elk, but these analyses provide an accurate ranking of digestibility for different forage species (Robbins 1993). Bomb calorimetry (Model 1266, Parr Instrument Company, Moline, IL) was used to measure ash-free gross available energy (Gessaman 1987, Appendix B). For all plant samples, variation between replicates was less than 5%. Digestibility was multiplied by gross available energy to calculate digestible energy for each plant species.

Statistical Analysis

Linear regression (Hintze 2001) was used to investigate the relationship between home range size and the five measures of reproductive success. Km^2 per elk was used as the measure of home range size in regression analyses to weigh for variation in herd size.

Multiple regression (Zar 1999) was used to identify relationships between percentage used vegetation category (hereafter used), percentage available vegetation category (hereafter available), percentage of forage species in the diet, and the five measures of reproductive success. Because vegetation category used and available was a static measure, and diet was measured over six sampling periods during 2001 and 2002, I did not combine these into one regression analysis. However, Pearson's correlation matrix was used to investigate relationships between mean percentage forage class in each herd's diet and vegetation category available.

Vegetation category

Principal Components Analysis (Zar 1999) was used to reduce the number of vegetation categories used or available to three or four principal components. As a result,

the principal components combined several correlated vegetation categories and eliminated the problem of multicollinearity and non-independence in the independent variables. Vegetation category used and available were not combined into one principal components analysis because this analysis required large numbers of replicates (herds) relative to variables (vegetation category). To facilitate interpretation of each principal component, Pearson's correlation analysis (Hintze 2001) of principal components and vegetation category was used. A vegetation category with high correlation ($r > 0.55$) to a principal component was incorporated into the interpretation of that principal component.

Multiple regression (Zar 1999) of principal components and calf:cow ratios, using all-possible regression and variable selection methods to select independent variables, was used to model the relationship between vegetation category used, available, and the five measures of reproductive success. The five calf:cow measures were used as the dependent variables in separate regression analyses.

Diet

Principal Components Analysis (Zar 1999) was used to identify plant species that were consumed with other plants and to combine the correlated plant species into eight principal components. The principal components eliminated the problem of multicollinearity in the independent variables, and allowed me to include more plant species in the analysis. Because principal components analysis is sensitive to outliers, and requires a high number of replicates relative to the number of variables, all 80 forage plant species could not be included in the analysis. Therefore, the subset of forage plant species analyzed for nutritional quality was used in the principal components analysis. I

used Pearson's correlation analysis (Hintze 2001) of principal components and forage plant species to facilitate interpretation of each principal component.

Multiple regression (Zar 1999) of principal components and calf:cow ratios, using all-possible regression and variable selection methods to select independent variables, was used to model the relationship between elk diet and the five measures of reproductive success. The 5 calf:cow measures were used as the dependent variables in separate regression analyses. Diet data through June 2001 was used in multiple regression with birthrate, and diet data through December 2001 was used with survival, mean calf:cow, December calf:cow, and productivity index. Because the diet data were collected from March 2001 to February 2002, and all calf:cow measures were collected in 2001, I assumed little change in elk diet between years to apply the January/February diet to the analysis. To investigate the potential effects of January/February diet, assuming little change in diet between years, I also completed the five regression analyses with all diet data (March 2001 - February 2002).

To identify the influence of forage plants used at particular times of the year on reproductive success, sampling period was included as a dummy variable (Zar 1999) in the multiple regression analysis. The March/April sampling period was used as the reference group, and five dummy variables were added for the other five sampling periods. A significant dummy variable in the regression indicated a greater effect (positive or negative) of diet during that sampling period on reproductive success. If no dummy variables were significant, then the March/April sampling period (reference group) had the largest effect of diet on reproductive success.

When outliers and non-constant variance were identified as problems in the data, weighted regression using Huber's method (Affifi et al. 2004) was used. Outliers were not removed from the data because I did not want to lose any information from the nine herds.

When multiple regression analyses resulted in identification of one plant species or forage class as important for reproductive success, the relationship between that forage plant and reproductive success was investigated using linear regression (Zar 1999). The mean percentage use of the important forage for each herd was used in regression with reproductive success. The mean percentage for the year was calculated using March to December diet data.

RESULTS

Elk Telemetry and Locations

Nineteen individual cow elk were located at least twice weekly from March – December 2001, for a total of 1016 locations. 395 (39%) radio-locations were visually-confirmed. Fifty-five test collar locations were used to estimate telemetry error. Telemetry error was 126 ± 106 m. Visual locations had no telemetry error.

Six cow groups were identified, each group had two collared cows with coefficient of association ≥ 0.5 (Appendix C). One additional group of 3 collared cows had coefficient of association ≥ 0.4 and complete home range overlap. Two collared cows had coefficient of association ≤ 0.15 and were not grouped with any other collared cows. This totaled nine groups that corresponded to nine herds (arbitrarily numbered one through nine) identified in the field. Sixty to 86 locations were collected for each herd. The number of visual locations for each herd ranged from 6 - 40 (9 - 59%, Appendix C). Two collared cows were not grouped into a herd, and were not used for calf:cow counts or fecal collections due to collar failure and association with more than one herd.

Reproductive Success

Herd composition counts were obtained for eight of the nine herds from July – December 2001. The herd without good composition counts (herd 9) was difficult to visually locate due to dense vegetation throughout most of the herd's home range. There were approximately 20 cow elk total in herd 9, but the entire herd was never observed at

one time for a complete calf count. There was a significant negative relationship (r^2 = 0.83, P = 0.03, Figure 2) between number of cows seen and calf:cow ratio. This relationship indicated that the highest calf:cow ratio was observed when the fewest cows were visible. Counts were standardized to 20 cows to calculate calf:cow ratios for herd 9. Constant cow survival was assumed for all herds because no radio-collared elk were lost in 2001, and the same number of cows were repeatedly counted for 7 of the nine herds.

Five herds had mean calf:cow ratios greater than 0.43, significantly greater than two herds with the lowest mean calf:cow ratios (H = 38.1, n = 9, P < 0.001, df = 8, Table 1). Five of nine herds had December calf:cow ratio greater than 0.3, were in the highly productive group, and had productivity indices of 5 to 9 (Table 1). Of the five herds in the highly productive group, three had at least 75% calf survival and December calf:cow ratio of at least 0.45 (Table 1). Four of nine herds had December calf:cow ratios less than 0.3, were in the less productive group, and had productivity indices of 1 to 4 (Table 1).

Vegetation Type Used and Available

Vegetation type was correctly classified for 94.4 % of groundtruth points, and timber stand age was correctly classified for 97.7% of groundtruth points (n = 36). The 95% probability circles around each radio-location had a radius of 338m. Average home range size was 29.3 ± 7.6 km^2 (15 to 50 locations for each herd; Appendix D). Home range size was not different between years 2000 (24.4 ± 4.8 km^2) and 2001 (33.7 ± 9.1 km^2, t = 1.94, P = 0.1, n = 7). There was no home range overlap in five of nine herds, and two pairs of herds had small areas of home range overlap.

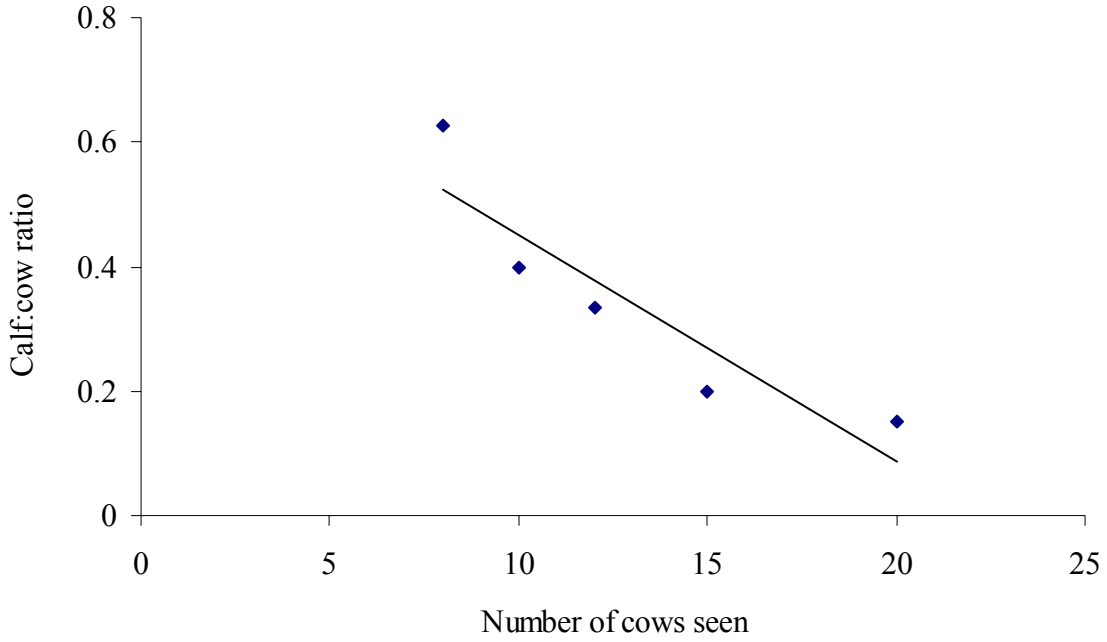

Figure 2. Number of cows seen and calf:cow ratio for elk herd number 9, Hoko GMU, Washington, June – December 2001. Equation for line was: y = 0.82 + (-3.65 * number of cows).

Table 1. Reproductive success of nine elk herds in the Hoko GMU, Washington, 2001. Herds are listed in decreasing order of mean calf:cow ratio. Mean calf:cow was calculated from n = 7 counts per herd, 1 per month from June through December 2001. If more than 1 count was completed per herd per month, the most accurate count was used. Birthrate was calf:cow ratio in July. Productivity index was a rank derived from mean calf:cow, birthrate, December calf:cow, and survival.

	Calf:Cow ratio				
Herd	$\bar{x} \pm SE$	Birthrate	December	Calf survival (%)	Productivity index
1	0.48 ± 0.03	0.63	0.47	75	9
3	0.48 ± 0.01	0.50	0.45	90	8
4	0.46 ± 0.01	0.50	0.45	90	7
2	0.46 ± 0.03	0.59	0.38	64	6
6	0.44 ± 0.03	0.52	0.29	51	4
5	0.38 ± 0.02	0.46	0.41	89	5
8	0.35 ± 0.05	0.62	0.24	39	2
9	0.30 ± 0.02	0.33	0.25	68	1
7	0.23 ± 0.01	0.24	0.25	100	3
Average	0.40 ± 0.03	0.49 ± 0.04	0.35 ± 0.03	74 ± 6.8	

Five of the nine herds used vegetation groups (excluding riparian/marsh) significantly different than expected ($P < 0.001$, Table 2). However, no particular vegetation group was used more or less than expected by a majority of herds (Table 3). The riparian/marsh vegetation group was excluded from Chi-square analysis due to low expected values. However, herds used riparian, marsh and pasture more than expected when available (Figure 3). The pasture class available to herd 6 was unlike other pastures, having conifer encroachment and interspersed shrubs, and may have been better classified as prairie.

Highly productive herds had significantly more available timber aged 2 – 9 years than less productive herds (Table 4). Highly productive herds also had significantly less available timber aged 11 – 24 years than less productive herds (Table 4). Availability of timber over 26 years was not different between the two herd types.

Diet Analysis

The total number of plant species and plant parts (seed, thorn) identified in the diet ranged from 40 in January/February to 78 in July/August (Appendix F). Across all herds, grass consumption from March through June and September through December was higher than during July/August and January/February (Figure 4, $H = 27.4$, $n = 9$, $P < 0.001$). Herds consumed more forbs from May through October than from November through April (Figure 4, $H = 43.6$, $n = 9$, $P < 0.001$). Herds consumed more ferns from September through February (Figure 4, $H = 29.2$, $n = 9$, $P < 0.001$), and more conifers from January through February (Figure 4, $H = 19.5$, $n = 9$, $P = 0.002$) than in spring and

Table 2. Chi-square goodness-of-fit for used and available vegetation groups for nine elk herds, Hoko GMU, Washington, March – December 2001. Vegetation used and available data in Appendix E.

Herd	n	x^2	df	*P*
1	55	229.81	3	<0.001
1[a]	27	17.65	2	<0.001
2	47	7.05	3	0.07
3	36	36.69	3	<0.001
4	42	1.76	3	0.62
5	58	23.33	3	<0.001
6	38	33.60	3	<0.001
7	51	24.97	3	<0.001
8	56	4.92	3	0.18
9	47	2.12	3	0.55

n number of locations (excluding riparian) per herd
[a] herd 1 Chi-square results excluding non-forest

Table 3. Vegetation groups used less than, equal to, or greater than expected from Chi-square goodness-of-fit analysis. Riparian/marsh vegetation group was excluded due to low expected values. Data presented were from nine elk herds in the Hoko GMU, Washington, 2001. Used and available vegetation group data is presented in Appendix E.

	Use Compared to Expected		
Vegetation Group	Less Than	Equal To	Greater Than
Timber aged 2 – 9 years		5	4
Timber aged 11 – 24 years	1	7	1
Timber over 26 years	3	6	
Non-forest		8	1

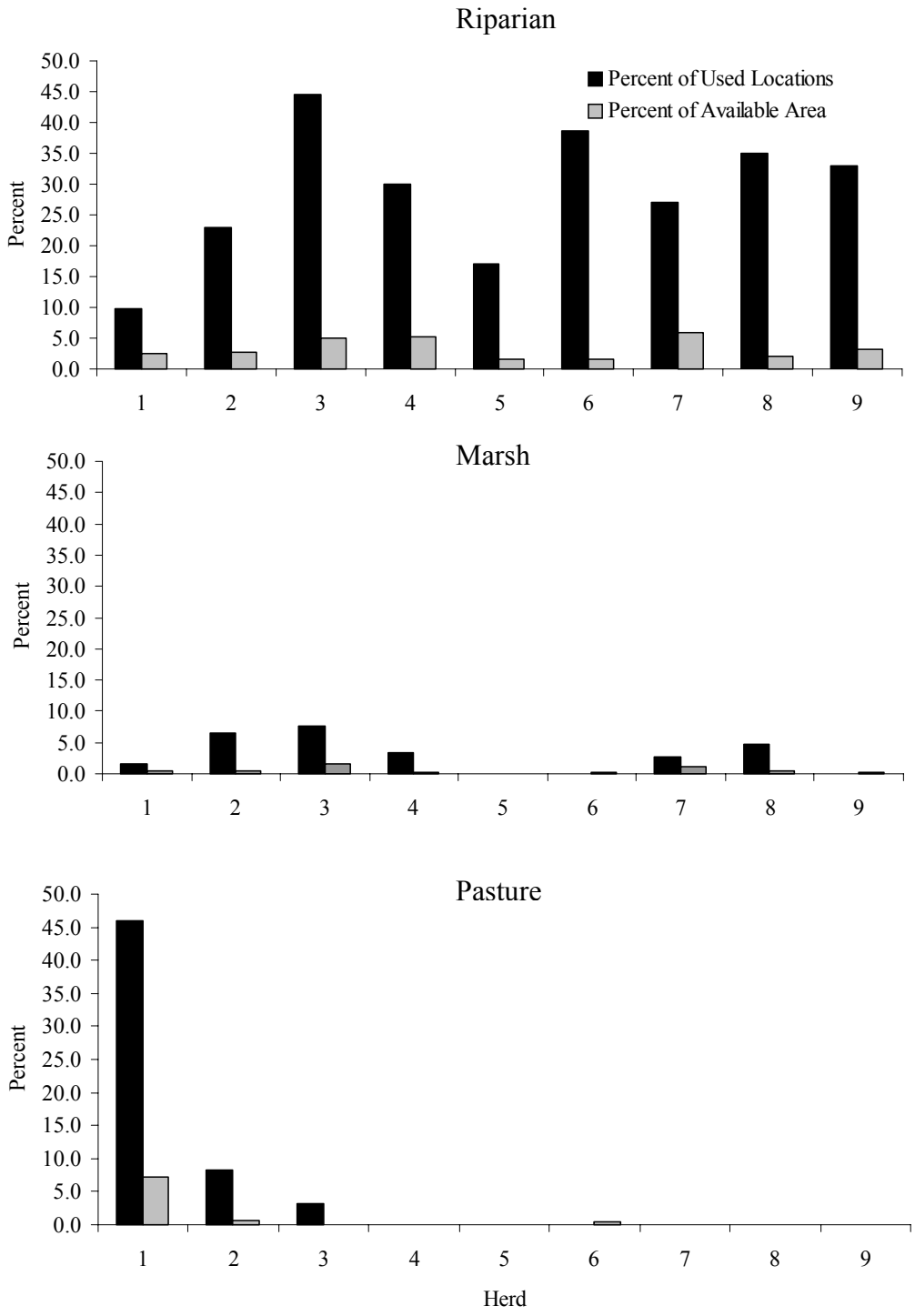

Figure 3. Percentage used and available riparian, marsh, and pasture vegetation categories for nine elk herds, Hoko GMU, Washington, March – December 2001. Pasture available to herd 3 was less than 0.1% of the home range.

Table 4. Results of Mann-Whitney U test for differences in median available vegetation category (%) between highly productive and less productive elk herds, Hoko GMU, Washington, 2001. Vegetation categories were those used in Chi- square analysis, and that were available to all herds.

	Highly Productive Herds (n = 5)		Less Productive Herds (n = 4)			
Variable	median (%)	U	median (%)	U	Z	P
Available Timber aged 2-9 years	28.1	18	5.9	2	-1.96	0.03
Available Timber aged 11-24 years	6.9	2	23.4	18	1.96	0.03
Available Timber over 26 years	52.4	6	60.4	14	0.98	0.21

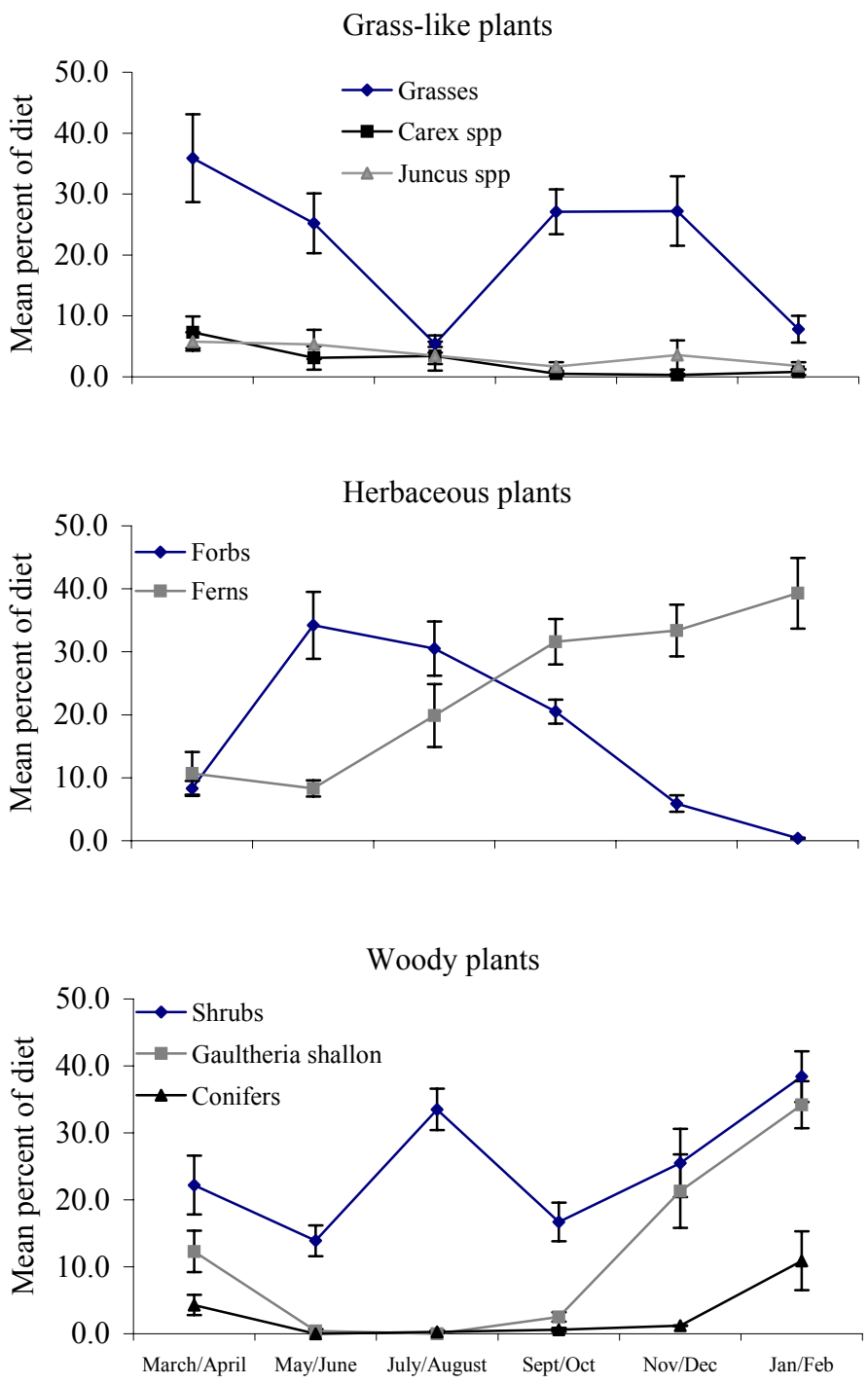

Figure 4. Mean percentage of each forage class in diets of nine elk herds, Hoko GMU, WA, March 2001 – February 2002. All forage classes were significantly different ($P < 0.005$) between sampling periods except Juncus spp. *G. shallon* was included to show contribution to mean shrub percentage from November – February. Error bars = ± 1 SE.

summer months. Shrub consumption from July to August and January to February was higher than in spring and fall months (Figure 4, $H = 21.8$, $n = 9$, $P < 0.001$). January to February shrub use was primarily *Gaultheria shallon*, an evergreen shrub (Figure 4).

Throughout the year, one herd consumed more grasses than two other herds, and equally with six herds ($F = 2.52$, $n = 9$, $P = 0.024$, $df = 8$, Table 5). Mean use of forbs, ferns, and shrubs was not significantly different between individual herds ($P > 0.05$, Table 5). However, when grouped, highly productive herds had significantly higher mean percentage grass in the diet, and percentage grass in the March/April diet, than less productive herds (Table 6). Highly productive herds had significantly lower mean percentage shrub in the diet, mean percentage fern in the diet, and percentage shrub in the March/April diet than less productive herds (Table 6). There was no difference in mean or March/April percent forb in the diet between herd types ($P > 0.05$).

Furthermore, percentage grasses and forbs in the diet were negatively correlated to percentage shrubs or ferns in the diet during five of six sampling periods. Grasses were negatively correlated to shrubs during March/April, September/October, and November/December (Figure 5). Specifically, grasses were negatively correlated to *Gaultheria shallon* during March/April and November/December (Figure 6). In May/June, grasses and forbs were negatively correlated (Figure 7). In July/August, forbs were negatively correlated to ferns (Figure 7).

Table 5. Mean use (% of diet) of forage classes for nine elk herds, Hoko GMU, Washington. Mean (± 1 SE) was calculated from March 2001 – February 2002 diet data.

	Forage Class			
Herd	Grass	Forb	Fern	Shrub
1	42.1 ± 9.4	15.0 ± 7.0	18.9 ± 3.5	18.0 ± 6.0
2	30.3 ± 9.9	17.3 ± 7.0	21.3 ± 7.5	25.5 ± 6.2
3	23.1 ± 5.9	21.5 ± 7.8	11.6 ± 3.0	23.5 ± 6.1
4	22.7 ± 6.6	18.8 ± 7.2	17.5 ± 6.1	18.7 ± 5.1
5	22.3 ± 6.0	11.7 ± 3.5	28.2 ± 5.6	22.0 ± 4.8
6	16.0 ± 4.1	13.7 ± 4.0	30.6 ± 8.5	27.7 ± 5.0
7	14.8 ± 2.7	18.3 ± 6.7	28.3 ± 10.9	24.2 ± 2.9
8	12.7 ± 5.0	14.7 ± 5.3	25.8 ± 5.2	34.4 ± 6.5
9	9.0 ± 3.7	18.8 ± 9.5	32.7 ± 6.4	31.2 ± 7.1

Table 6. Differences in median forage class (%) in the diet between highly productive and less productive elk herds, Hoko GMU, Washington, 2001. Mean forage class for each herd was the percent of the diet averaged over the time period March 2001 – February 2002 (Table 5).

	Highly productive herds (n = 5)		Less productive herds (n = 4)			
Variable	median (%)	U	median (%)	U	Z	P
Mean grass	23.1	20	13.8	0	-2.45	0.008
Mean forb	17.3	11.5	16.5	8.5	-0.25	0.4
Mean shrub	22.0	1	29.5	19	2.2	0.02
Mean fern	18.9	1	29.5	19	2.2	0.02
March/April grass	44.9	20	16.0	0	-2.45	0.008
March/April forb	5.7	4	11.2	16	1.47	0.9
March/April shrub	12.2	0	36.8	20	2.45	0.008
March/April fern	3.2	7	8.6	13	0.65	0.27

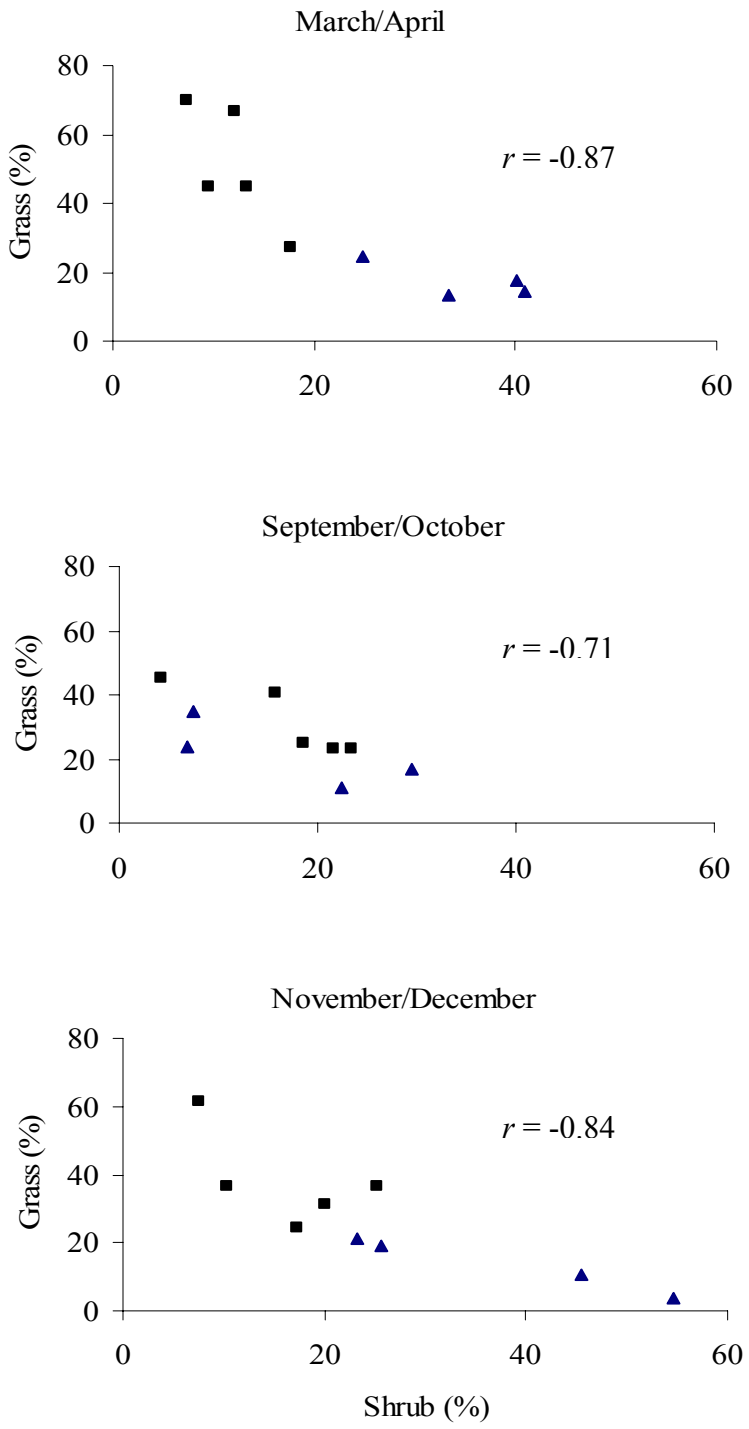

Figure 5. Correlations of relative percentages of grass and shrub in the diet of nine elk herds during three sampling periods in 2001, Hoko GMU, Washington. Squares represent highly productive herds. Triangles represent less productive herds.

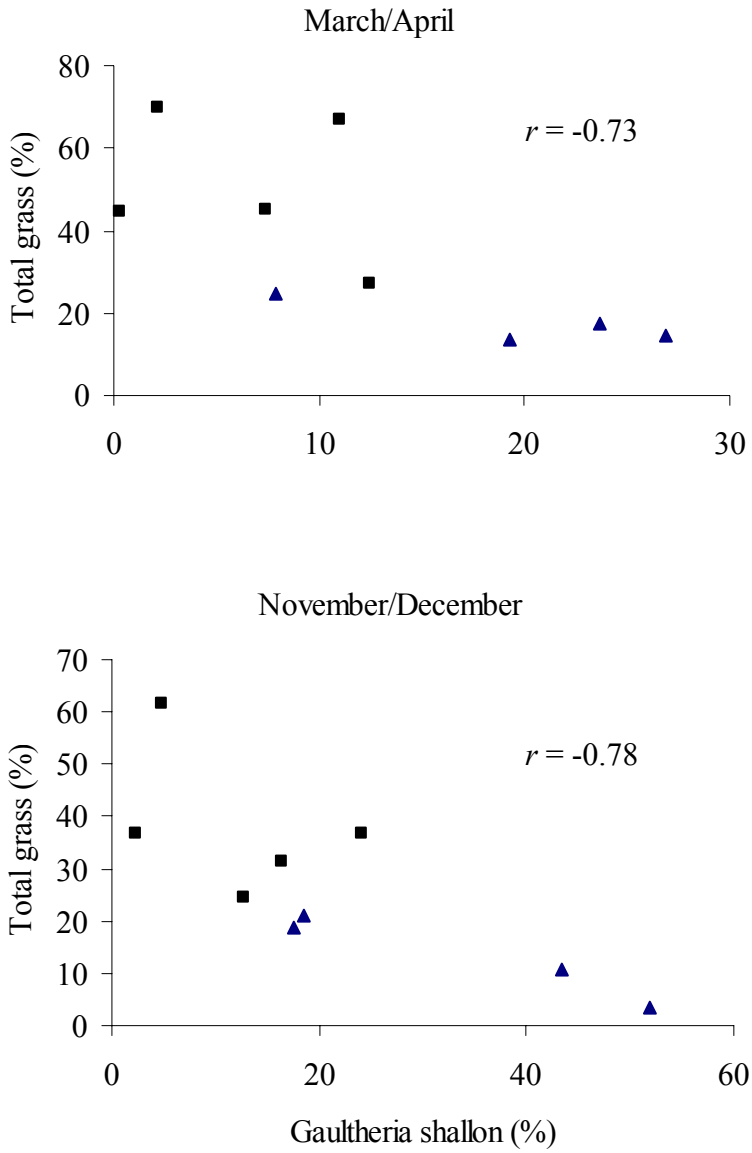

Figure 6. Correlations of relative percentages of grass and *G. shallon* in the diet of nine elk herds during two sampling periods in 2001, Hoko GMU, Washington. Squares represent highly productive herds. Triangles represent less productive herds.

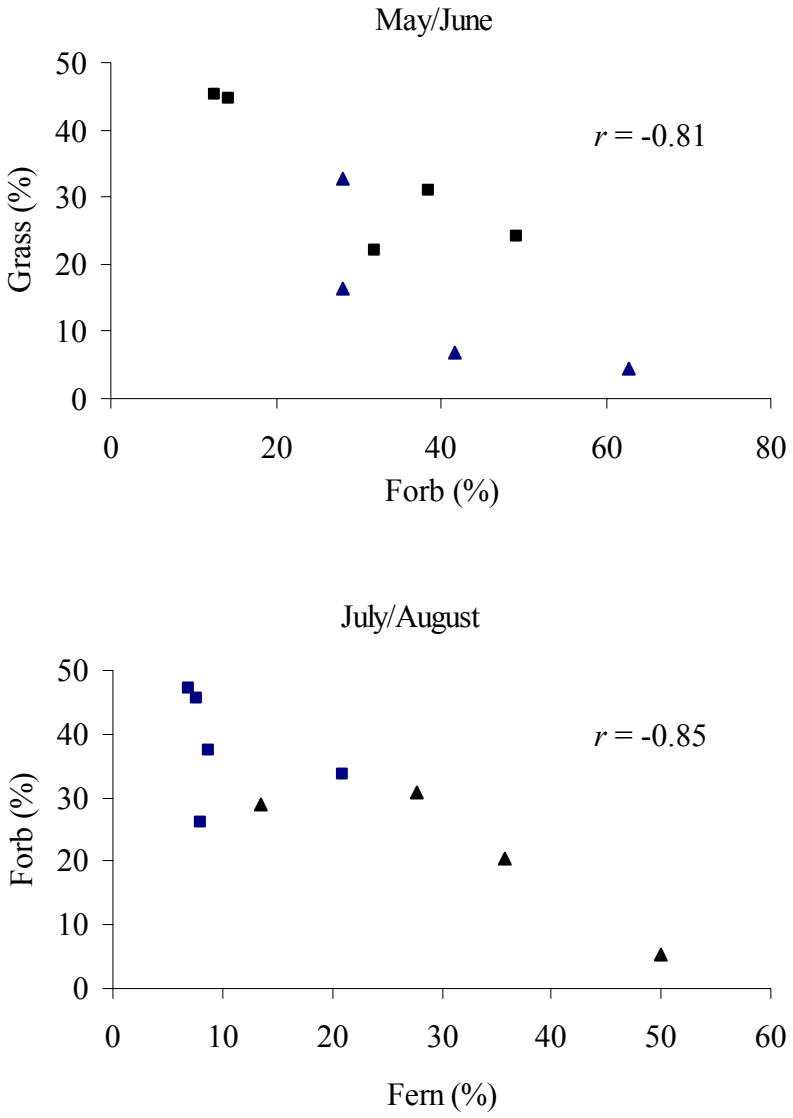

Figure 7. Correlations of relative percentages of two diet constituents for nine elk herds during two sampling periods in 2001, Hoko GMU, Washington. Squares represent highly productive herds. Triangles represent less productive herds.

Nutritional Analysis of Forage Plants

Forty forage plant samples, comprised of twenty-one different species (six to eight plant species per sampling period), were selected for nutritional analysis. The total percentage of each herd's diet analyzed for nutritional quality ranged from 16.5% to 92.6% (Appendix G).

Crude protein content in grasses and forbs ranged from 12 – 28% throughout the year (Figure 8). Early spring (March to April) grasses had greater than 23% protein, and summer forbs had greater than 18% protein. Protein ranged from 6 – 33% in ferns. *Athyrium-felix femina* had greater than 18 % protein in spring and summer, and *Equisetum* had greater than 17% protein in spring. Other ferns had protein content below 13% throughout the year. Protein content of shrubs ranged from 7 – 26%. *Sambucus racemosa* had greater than 20% protein from July through October. *Gaultheria shallon* had less than 9% protein in spring and winter.

Digestibility of forage species was variable throughout the year (Figure 9). Digestibility of grasses, forbs, and *Sambucus racemosa* was high and ranged from 55 – 76% throughout the year (Figure 9). Ferns, conifers, and shrubs had lower digestibility of 23 – 46%.

Gross available energy (Kcal/g) of forage species was relatively stable throughout the year, ranging from 4.0 – 4.7 Kcal/g (Figure 10). *Equisetum* was the only plant with a notably low energy content of 3.7 Kcal/g in fall and winter. Digestible energy (Kcal/g) was more variable than gross available energy (Figure 11). Grasses, forbs, and *Sambucus racemosa* had digestible energy ranging from 2.1 – 3.3 Kcal/g throughout the year

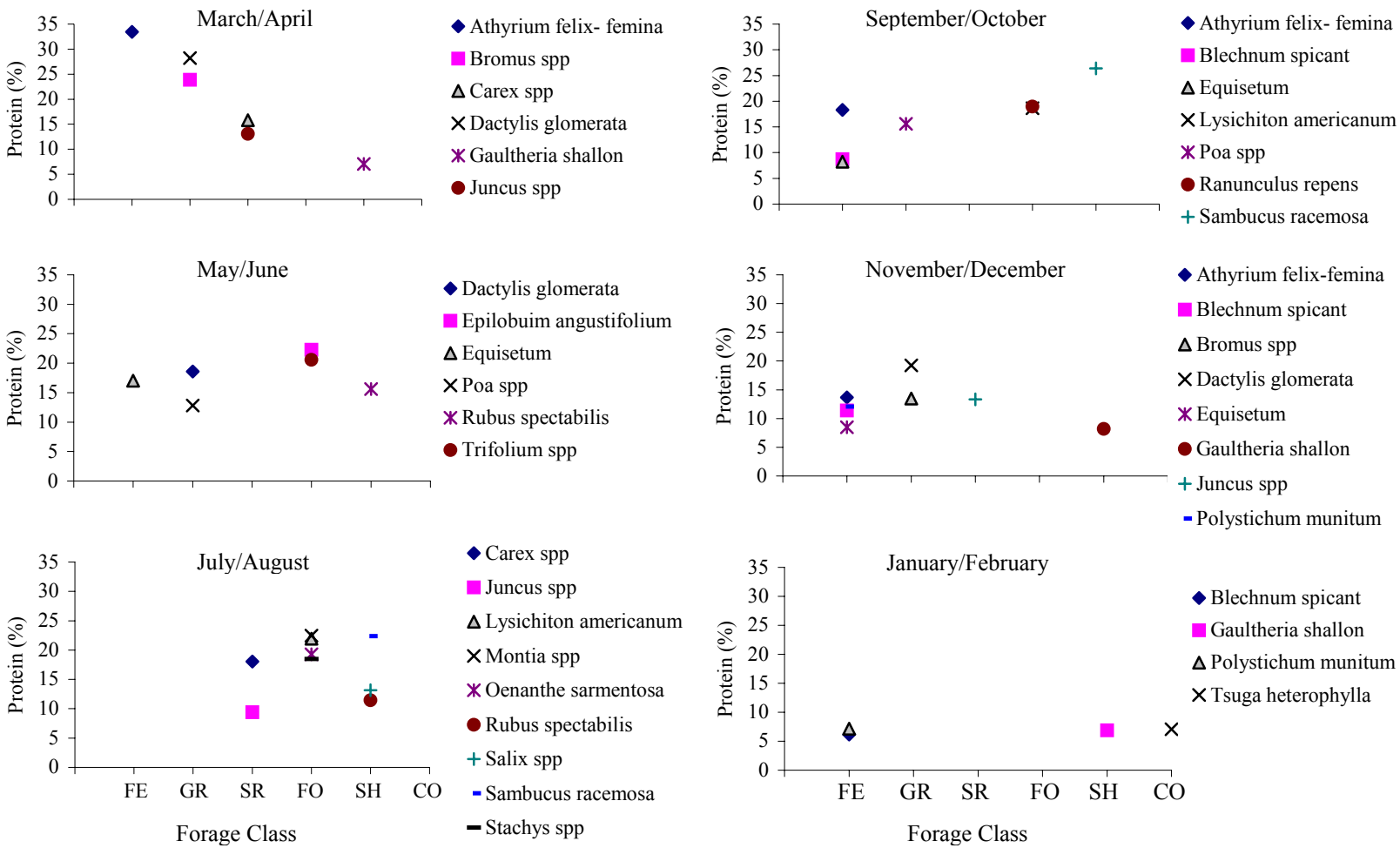

Figure 8. Mean crude protein content (%) for 21 elk forage plant species from March 2001 – February 2002. Means are dry-weight values. Range of protein values was within 1% of mean. Forage class: FE = fern, GR = grass, SR = sedge/rush, FO = forb, SH = shrub, CO = conifer.

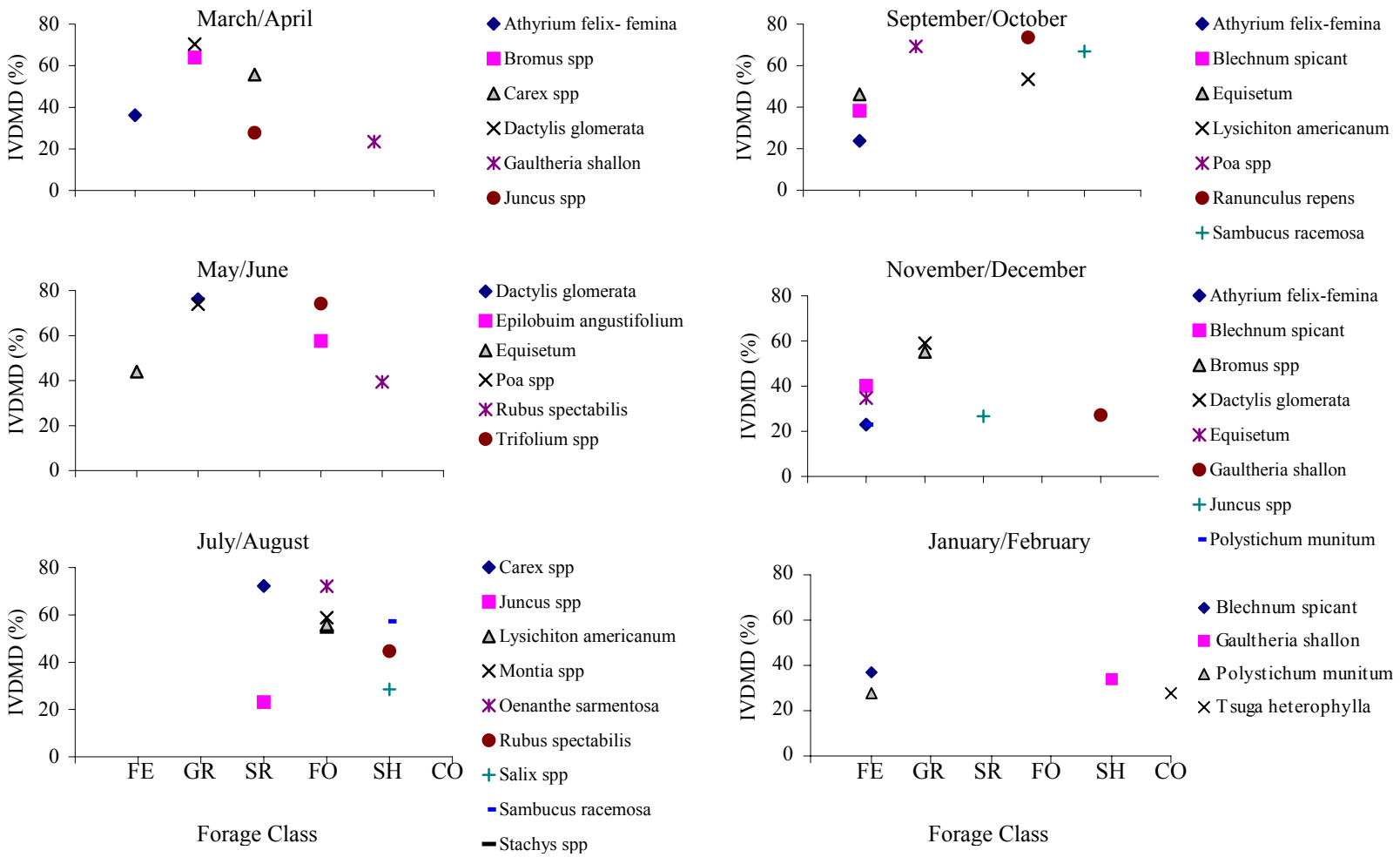

Figure 9. Mean percentage in-vitro dry matter digestibility (IVDMD) for 21 elk forage plant species from March 2001 – February 2002. Means are dry-weight values. Range of digestibility values was within 5 % of mean. Forage class: FE = fern, GR = grass, SR = sedge/rush, FO = forb, SH = shrub, CO = conifer.

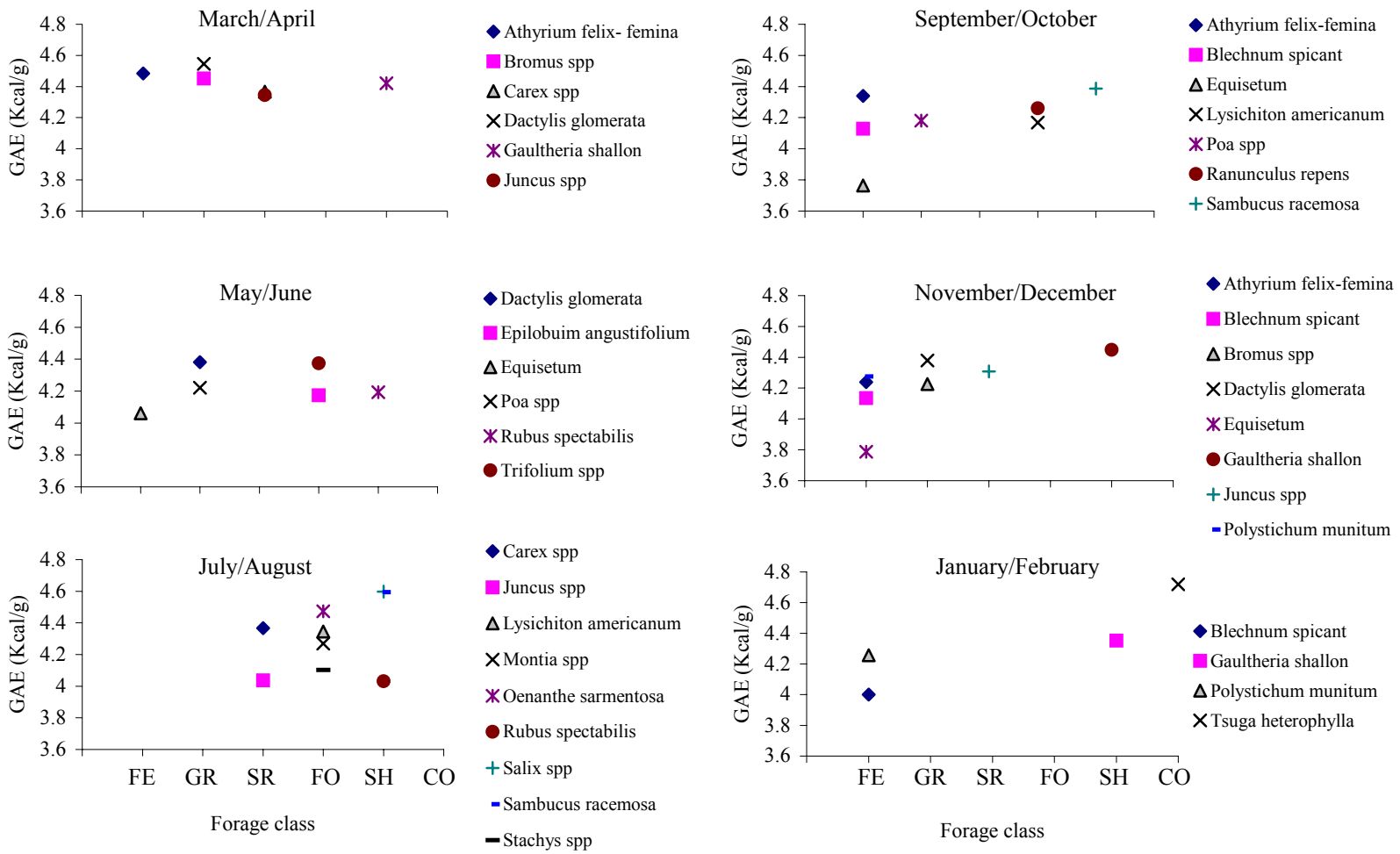

Figure 10. Mean gross available energy (GAE) for 21 elk forage plant species from March 2001 – February 2002. Means are reported as ash-free values. Standard error ranged from 0.01 – 0.03. Forage class: FE = fern, GR = grass, SR = sedge/rush, FO = forb, SH = shrub, CO = conifer.

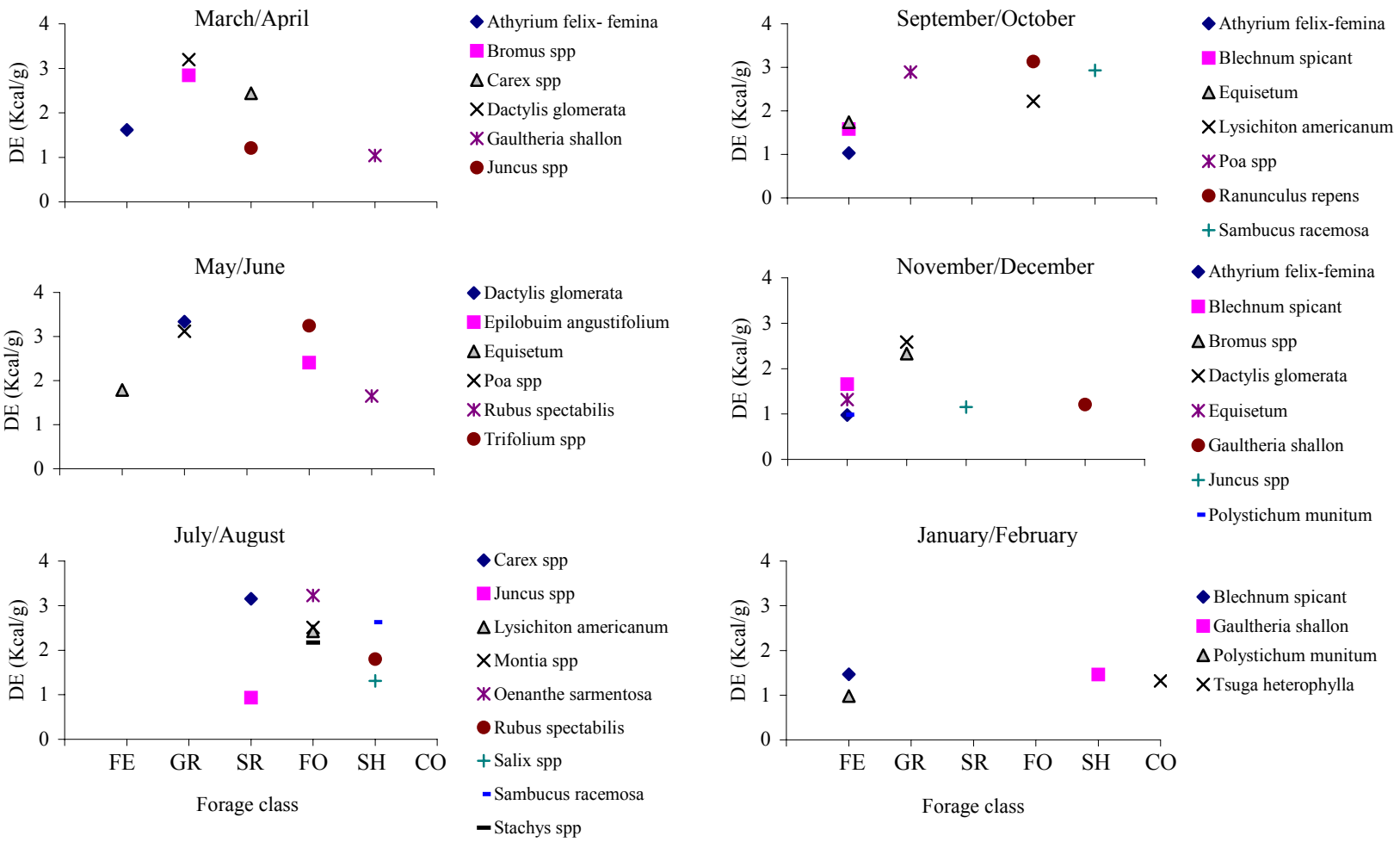

Figure 11. Mean digestible energy (DE) for 21 elk forage plant species from March 2001 - February 2002. Means are reported on an ash-free, dry-weight basis. Standard error ranged from 0.003 - 0.009. Forage class: FE = forbs, GR = grasses, SR = sedge/rush, FO = forbs, SH = shrubs, CO = confers.

(Figure 11). Ferns, shrubs, and conifers had low digestible energy ranging from 0.9 – 1.7 Kcal/g (Figure 11).

Effects of home range, vegetation category, and diet on reproductive success

Home range size was significantly negatively related to mean calf:cow ratio for highly productive herds (Figure 12). The influence of one outlier may have exaggerated this relationship. There was no relationship between home range size and calf survival for highly productive herds. However, for less productive herds, calf survival decreased (nearly significant, $P = 0.07$) and mean calf:cow increased, but not significantly, with increasing home range size (Figure 12).

The mean percentage shrub in the diet was negatively correlated to the percent of 2 – 9 year old timber available in the home range, and positively correlated to the percent of 20 – 24 year old timber available in the home range (Figure 13). Highly productive herds had low percentage shrub in the diet, high 2 – 9 year old timber, and low 20 – 24 year old timber in the home range (Figure 13).

Vegetation category

Seven principal components represented 81% of the variation in vegetation category used by the herds, and 82% of the variation in vegetation category available to the herds (Appendix H). Principal components 1 – 3 combined eight classes of vegetation category used by herds within their home ranges into 3 principal components (Table 7). Principal components 4 – 7 combined eight classes of vegetation category available to herds within their home ranges into 4 principal components (Table 7).

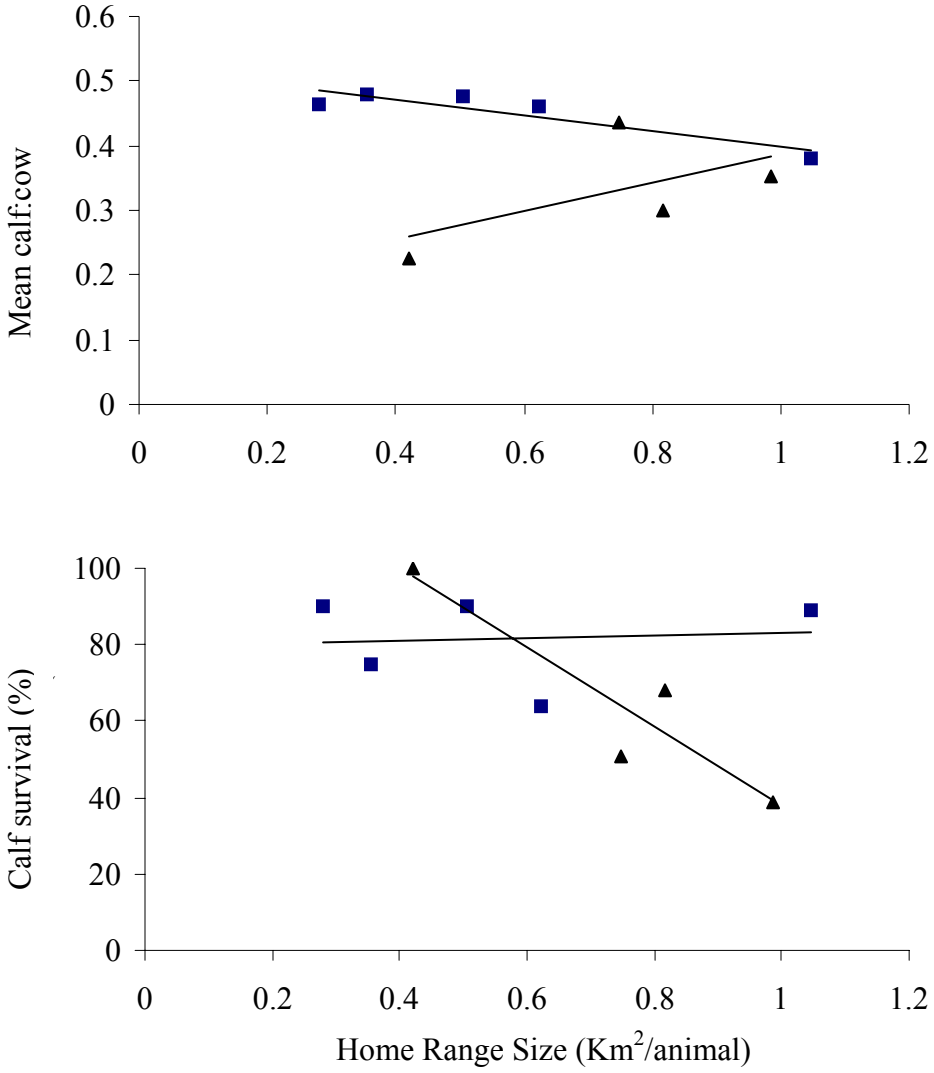

Figure 12. Mean calf:cow ratio, calf survival, and home range size of nine elk herds, Hoko GMU, Washington, 2001. Squares represent highly productive herds, with mean calf:cow $r^2 = 0.81$, $P = 0.04$, and calf survival $r^2 = 0.006$, $P > 0.05$. Triangles represent less productive herds, with mean calf:cow $r^2 = 0.35$, $P > 0.05$, and calf survival $r^2 = 0.86$, $P > 0.05$.

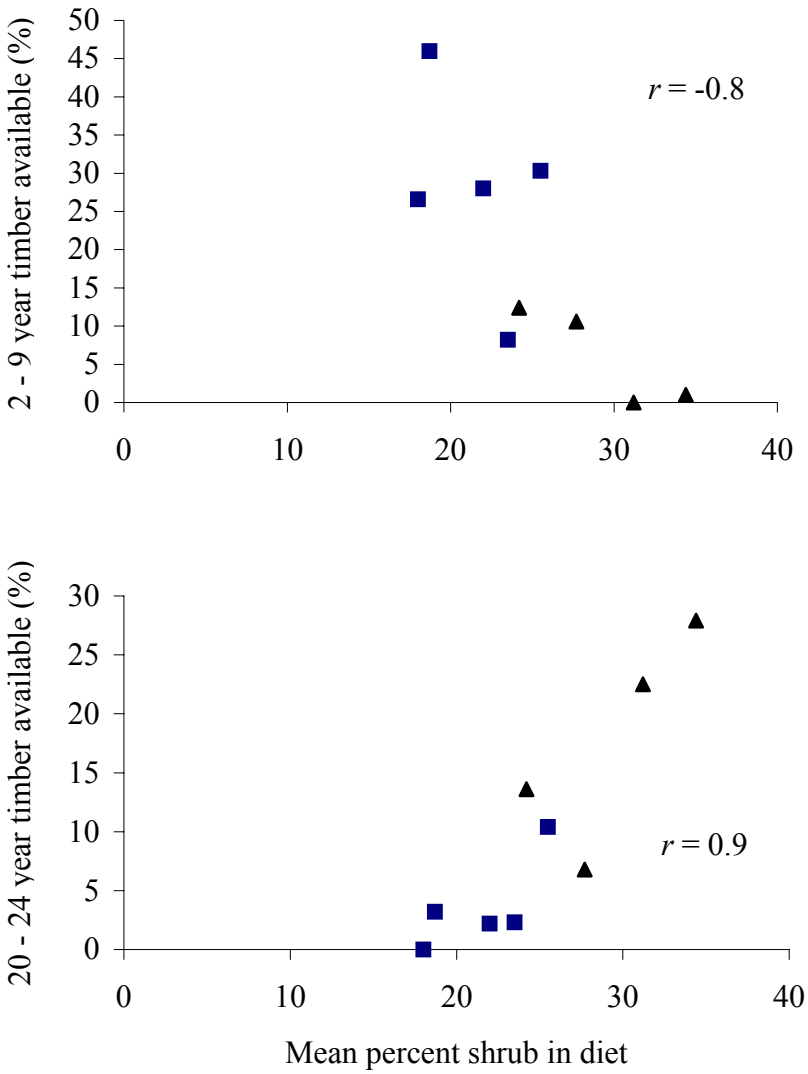

Figure 13. Correlations of mean percent shrub in the diet of nine elk herds and percent 2 – 9 year old timber or 20 – 24 year old timber available in the home range, Hoko GMU, Washington, 2001. Squares represent highly productive herds, triangles represent less productive herds.

Table 7. Summary of principal components 1 - 7, representing vegetation category within the home range of nine elk herds. Sign of correlation represents the sign (+ or -) of *r* for that vegetation category type and principal component. Values of *r* are reported in Appendix H. Used and available vegetation category data were for nine elk herds and home ranges from March – December 2001, Hoko GMU, Washington.

	Vegetation category	Sign of correlation (+/-)
Principal component 1	Used timber aged 11 - 17 years	+
	Used pasture	+
	Used riparian	-
Principal component 2	Used timber aged 2 - 9 years	+
	Used timber aged 20 - 24 years	-
	Used timber over 26 years	-
Principal component 3	Used timber over 26 years	-
	Used marsh	-
	Used timber in Olympic National Park	+
Principal component 4	Available timber aged 11 - 17 years	-
	Available pasture	-
	Available roads	-
Principal component 5	Available timber aged 2 - 9 years	+
	Available timber over 26 years	-
Principal component 6	Available timber aged 11 - 17 years	-
	Available marsh	+
	Available riparian	+
Principal component 7	Available timber aged 2 - 9 years	-
	Available timber aged 20 - 24 years	+
	Available pasture	-

Survival was positively related to available marsh and riparian vegetation categories (Principal component 6, Table 8). Mean calf:cow, December calf:cow, and productivity index were positively related to used timber aged 2 – 9 years, available timber aged 2 – 9 years and pasture (Principal components 2 and 7, Table 8). Mean calf:cow, December calf:cow, and productivity index were negatively related to used timber aged 20 – 24, used timber over 26 years, and available timber aged 20 – 24 years (Principal components 2 and 7, Table 8). Birthrate was not significantly related to any vegetation category principal component.

Diet

Eight principal components represented 76% of the variation in use of 21 forage plant species (Table 9, Appendix K). Generally, diet principal components combined plant species into groups similar to forage class (Table 9).

Birthrate, mean calf:cow, December calf:cow, and productivity index were all positively related to the amount of grass in the diet, for 2001 data as well as 2002 (Principal component 2d, Table 9, 10, 11). Calf survival was positively related to sedges and rushes in the diet, for 2001 data as well as 2002 (Principal component 3d, Table 9, 10, 11). Mean calf:cow, December calf:cow, and productivity index were positively related to the forbs *Oenanthe sarmentosa*, *Stachys* spp, and *Sambucus racemosa* (Principal component 5d, Table 9, 10). In addition, December calf:cow and productivity index were positively related to *Ranunculus repens* (Principal component 8d, Table 9, 10, 11).

Table 8. Summary of multiple regression analyses of reproductive success of nine elk herds and vegetation category principal components. Vegetation data was from elk locations in the Hoko GMU, Washington, March - December 2001. Only principal components with coefficients significantly different from zero are included. Additional statistical values are shown in Appendix I and Appendix J.

Dependent variable	Independent variable	Sign (+/-) of regression coefficient	P
Survival	Principal component 6	+	0.046
Mean calf:cow	Principal component 2	+	0.011
	Principal component 7	-	0.032
December calf:cow	Principal component 2	+	0.030
	Principal component 7	-	<0.001
Productivity index	Principal component 2	+	0.026
	Principal component 7	-	0.001

Table 9. Summary of plant species making up principal components 1d – 8d. The nomenclature 1d – 8d distinguishes principal components that summarized elk diet from principal components of vegetation category. Sign of correlation represents the sign (+ or -) of *r* for that vegetation category and principal component. Values of r are shown in Appendix K.

	Plant species	Forage class	Sign (+/-) of correlation
Principal component 1d	Athyrium felix-femina	fern	+
	Blechnum spicant	fern	+
	Polystichum munitum	fern	+
	Rubus spectabilis	shrub	-
Principal component 2d	Bromus spp	grass	-
	Dactylis glomerata	grass	-
	Poa spp	grass	-
Principal component 3d	Carex spp	sedges	-
	Juncus spp	rushes	-
Principal component 4d	Epilobium angustifolium	forb	-
	Montia spp	forb	-
	Trifolium spp	forb	-
Principal component 5d	Oenanthe sarmentosa	forb	+
	Stachys spp	forb	+
	Sambucus racemosa	shrub	+
Principal component 6d	Lysichiton americanum	forb	+
Principal component 7d	Salix spp	shrub	+
Principal component 8d	Ranunculus repens	forb	+

Table 10. Summary of multiple regression analyses of reproductive success and elk diet principle components. Elk diet data were for nine herds in the Hoko GMU, Washington, March – December 2001. Only principal components with coefficients significantly different from zero were included. Additional statistics are shown in Appendix L.

Dependent variable	Independent variable	Sign (+/-) of regression coefficient	P (model)
Birthrate	Principal component 2d	-	<0.001
	Principal component 7d	-	
Survival	Principal component 3d	-	0.033
Mean calf:cow	Principal component 2d	-	<0.001
	Principal component 5d	+	
December calf:cow	Dummy variable 3 (Sept/Oct)	-	
	Principal component 2d	-	<0.001
	Principal component 5d	+	
	Principal component 8d	+	
Productivity index	Dummy variable 3 (Sept/Oct)	-	
	Principal component 2d	-	<0.001
	Principal component 5d	+	
	Principal component 8d	+	

Table 11. Summary of multiple regression analyses of reproductive success and elk diet principal components. Elk diet data were for nine herds in the Hoko GMU, Washington, March 2001 – February 2002. Only principal components with coefficients significantly different from zero were included. Additional statistics are shown in Appendix M.

Dependent variable	Independent variable	Sign (+/-) of regression coefficient	P (model)
Birthrate	Principal component 2d	-	<0.001
	Principal component 3d	+	
	Principal component 6d	-	
Survival	Principal component 3d	-	0.023
Mean calf:cow	Principal component 2d	-	<0.001
	Principal component 6d	-	
December calf:cow	Dummy variable 3 (Sept/Oct)	-	<0.001
	Principal component 2d	-	
	Principal component 5d	+	
	Principal component 8d	+	
Productivity index	Dummy variable 3 (Sept/Oct)	-	<0.001
	Principal component 2d	-	
	Principal component 5d	+	
	Principal component 8d	+	

Birthrate was negatively related to *Salix* spp in the 2001 diet (Principal component 7d, Table 9, 10), and negatively related to sedges, rushes, and *Lysichiton americanum* when the 2002 diet was included (Principal components 3d and 6d, Table 9,11). Mean calf:cow was negatively related to *Lysichiton americanum* when 2002 diet data was included (Principal component 6d, Table 9, 11).

The reference dummy variable (March/April sampling period) had the strongest effect on birthrate, survival, and mean calf:cow. Dummy variable number 3 (September/October sampling period), had a significant, negative effect on December calf:cow and productivity index (Table 10).

There was a significant positive relationship between mean percent grass in the diet from March through December and productivity index, December calf:cow, and mean calf:cow (Figure 14). A positive trend between mean percent grass in the diet and birthrate was not significant ($P = 0.08$).

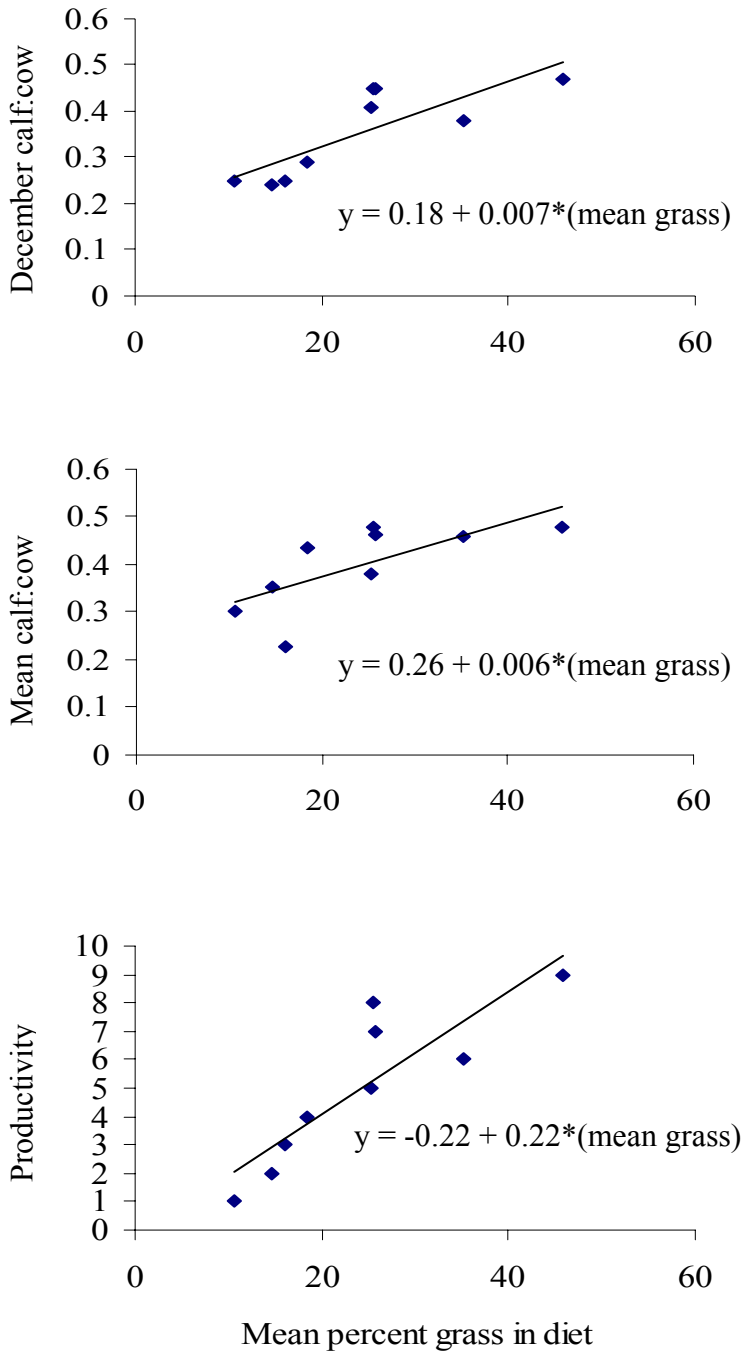

Figure 14. Regressions of reproductive success (December calf:cow $R^2 = 0.65$, P = 0.009, Mean calf:cow $R^2 = 0.5$, P = 0.03, Productivity index $R^2 = 0.76$, P = 0.002) and mean percent grass in the diet of nine elk herds, March – December 2001, Hoko GMU, Washington. Regression of birthrate was not significant ($R^2 = 0.37$, P = 0.08, y = 0.31+0.007*mean grass).

DISCUSSION

Highly productive herds in the Hoko Game Management Unit had calf:cow numbers similar to those reported as adequate for stable or growing populations (at least 33 calves per 100 cows, Clutton-Brock et al. 1988, Coughenour and Singer 1996, Post and Klein 1999). Less productive herds in the Hoko GMU had calf:cow numbers similar to those reported as low calf recruitment or poor reproductive success (less than 26 calves per 100 cows, Bomar et al. 2000, Post and Klein 1999). The mean calf:cow ratio on the Olympic Peninsula during the late 1970's, excluding Olympic National Park, was 45.6 calves to 100 cows (Smith 1980), higher than all less productive herds in my study. The difference in reproductive success between highly productive and less productive herds was related to the available and used vegetation type, forage species in the diet, and nutritional quality of forages in the diet of the elk herds.

Highly productive herds in the Hoko GMU had significantly greater percentages of available young timber in their home ranges than less productive herds. Young clear cuts had high primary productivity, and therefore high biomass, until approximately 15 – 20 years old, when biomass production decreased due to canopy closure (Hanley 1984, Irwin and Peek 1983). High plant biomass, and therefore large amounts of available elk forage, has been found to increase elk recruitment and survival (Coughenour and Singer 1996). Less productive herds in the Hoko GMU had significantly greater percentages of available maturing timber in their home ranges than highly productive herds. Therefore, less productive herds had less available forage biomass than highly productive herds.

The high percentage of maturing timber in less productive herds' home ranges coincided with limited availability of other, preferred vegetation categories. Riparian and marsh vegetation categories were rare but highly used in all home ranges. In addition, herds regularly used clear cuts 2 - 9 years of age and pasture when available within the home range. Mesic areas (Hanley 1984), young clear cuts (Irwin and Peek 1983, Witmer and deCalesta 1983), and wet meadows (Collins and Urness 1983) have been identified as preferred elk foraging areas. However, availability of these vegetation categories was limited for the less productive herds, possibly limiting preferred forages. Less productive herds were observed using low-lying mesic areas within the maturing timber stands, which provided the herds with small areas of preferred forages within the larger area of maturing timber. There was often standing water within mesic areas, and understory species included *Lysichiton amricanum*, *Carex* spp, and *Salix* spp. Maturing timber stands normally had little or no understory, and typical understory species were *G. shallon* or ferns. Classifying these mesic areas within the maturing timber using GIS was not possible, due to the small size and little difference in canopy cover.

Vegetation categories available to elk herds influenced the plant species in their diet. The availability of maturing timber in the home range was positively correlated to the mean percentage of shrubs in the diets (Figure 13). In addition, the availability of 2 – 9 year old timber in the home range was negatively correlated to the mean percentage of shrubs in the diet. Thus, less productive herds, with large expanses of maturing timber in their home range, likely had fewer forage options than highly productive herds and were consuming more poor-quality evergreen shrubs (Alaback 1982, Cook et al. 2001*a*). High

consumption of evergreen shrubs, with relatively low protein and digestible energy content throughout the year, likely contributed to the poor reproductive success of less productive herds.

Forage species availability was not measured, but changes in elk diet throughout the year appeared to reflect seasonal availability of forage species. Winter diets were predominantly evergreen shrubs, ferns, and conifers. Elk switched to grasses in spring, then deciduous shrubs and forbs in summer (Figure 4). Fall diets varied from predominantly grass to mostly shrubs and ferns. These results suggested that while many plants were available year-round (*Gaultheria shallon*, some ferns, conifers), elk only used these species when grasses and forbs were not available. Therefore, less productive herds had less availability of grasses in spring and fall or forbs in summer, as evidenced by their greater use of ferns and shrubs during these seasons (Figure 5, 6, 7). This timing and abundance of grass and forb use differentiated highly productive from less productive herds. Herds that used shrubs and ferns in spring and fall were those with the lowest productivity indices, consistent with Merrill and Boyce (1991), who found that the availability of high-quality forage early in spring and late in fall increased calf recruitment and survival.

During three of six sampling periods, highly productive herds had more grasses or forbs in the diet than less productive herds (Figures 5, 6, 7). Grasses and forbs were relatively high in protein and digestible energy (Figures 8 – 11), resulting in high reproductive success. The diet difference was absent during September/October (Figure 5) and May/June (Figure 7). During September/October, elk consumed primarily

deciduous shrubs such as *S. racemosa*. Unlike *G. shallon, S. racemosa* had protein and energy content comparable to grasses and forbs, thus all herds had diets similar in nutritional quality in early fall. Similarly, during May/June, there was no pattern of grass and forb use that distinguished between highly productive and less productive herds (Figure 7). Again, grasses and forbs had relatively good nutritional quality (Figures 8 – 11), and therefore all herds were supplied with adequate nutrition during May and June.

Percentage grass was negatively correlated to percentage *Gaultheria shallon* in the diet during March/April and November/December sampling periods. Also, percentage forb was negatively correlated to percentage fern in the diet during summer. In both cases, the herds with greater percentages of grasses or forbs in the diet were highly productive herds (Figures 6, 7). A lack of nutritious grasses replaced by poor nutritional quality *G. shallon* negatively affected cow condition prior to parturition, and therefore calf survival after birth (Thorne et al. 1976). Additionally, poor nutrition during summer and fall limited calf growth (Cook et al. 1996), and juvenile body size at the onset of winter effected survival where winter weather or nutritional conditions were harsh (Hobbs 1989). The Hoko GMU had mild winter weather, but some home ranges (less productive herds) were subject to "harsh" nutritional conditions due to the large area of maturing timber within them. Therefore, herds with poor nutrition likely had small calves at parturition, and poor calf survival over the winter. However, grasses and *G. shallon* account for only approximately 40% of some herds' diets, particularly those herds with low reproductive success. The remainder of the diet was primarily average or low-quality forage such as rushes, ferns, conifers, and other shrubs (Appendix H).

Therefore, low percentages of grass in the diet were not being supplemented with other highly nutritious forage such as forbs.

Several forage species identified as preferred in other studies were not present, or were rarely found in elk diets on the Hoko Game Management Unit. In Oregon's Cascade range, Cook et al. (2001*a*) reported that elk tended to avoid grasses, evergreen shrubs, conifers, and most ferns; these elk selected forb and deciduous shrub species such as Oregon oxalis, huckleberry, vine maple, big leaf maple, cascara, and snowberry. Of these forages, only oxalis and huckleberry were relatively abundant on the Hoko GMU. The extremely low use of these forages by herds in my study suggests limited availability in the Hoko GMU. Hence, it would appear that grasses and other forbs such as *Trifolium* or *Stachys* spp. become more critical for adequate nutrition of elk herds in the Hoko GMU. This may be true for other coastal areas in Washington and Oregon.

Grasses and forbs averaged higher than shrubs and ferns in protein, digestibility, and digestible energy content throughout the year (Figures 8, 9, 11). Highly productive herds had significantly higher mean percentage grass in the diet than less productive herds. Highly productive herds also had significantly lower mean percentage shrub and fern in the diet than less productive herds. Less productive herds may have had decreased weight gain during spring and summer, and higher weight loss during fall and winter, relative to Highly productive herds, due to higher use of shrubs and ferns. Poor weight gain and high weight loss are both factors known to contribute to poor reproductive success (Cook et al. 1996, Cook et al. 2004).

Overall, the crude protein of forages in the Hoko GMU was comparable to levels reported for captive feeding trials (Mould and Robbins 1981) and old-growth forests in Washington (Leslie et al. 1984). One exception, *Rubus spectabilis* in old-growth forests had higher spring and summer crude protein (24.3, 15.3, respectively, Leslie et al. 1984) than *R. spectabilis* in the Hoko GMU (16, 11, respectively). The low protein content of shrubs, particularly *Rubus* spp, in the Hoko GMU may have been due to secondary plant compounds, particularly tannins. Tannins reduce the protein content of forages by decreasing digestible protein (Robbins et al. 1987). Digestible protein was higher in shrubs from old-growth timber stands than from clear cuts (Happe et al. 1990). Conversely, grasses and forbs do not have high levels of secondary plant compounds. Therefore, herds that supplemented their diet with forbs or grasses may have had higher reproductive success. Roosevelt elk are traditionally viewed as browsers (Skinner 1936), and grass has not been identified as an important forage for them. However, grasses may become critical in areas where tannin levels in shrubs are high.

Digestibility and digestible energy appeared to differ more between forage classes and plant species than between seasons (Figure 9, 11). During spring, summer, and early fall only grasses, forbs, *Carex* spp, and *S. racemosa* had digestible energy at or above 2.6 Kcal/g of forage. No winter forages measured were near this level of digestibility. Digestible energy over 2.6 Kcal/g of forage, particularly in summer and fall, has been identified as important for calf growth, calf winter survival, and high pregnancy rates in cow elk (Cook et al. 1996, Cook et al. 2001*a*, Cook et al. 2004). All of these factors affect overall reproductive success. This suggests that less productive cows may not have

been able to gain adequate weight in spring and summer, had low pregnancy rates, and their calves may not have gained enough weight prior to fall for winter survival (Cook et al. 2004). Additionally, in ungulates, the size of the digestive tract limits the amount of low digestibility forage they can consume (Ammann et al. 1973, Montgomery and Baumgardt 1965). As a result, ungulates that consumed a diet low in digestible energy could not increase forage intake enough to compensate (Gray and Servello 1995). This suggests that less productive herds, with high percentages of low-digestibility ferns and shrubs in their diet, could not consume the same amount of digestible energy in forage as highly productive herds.

All diet constituents were not analyzed for nutritional quality, yet all forages in the diet contributed to the nutritional status of the herds. However, methods of extrapolating nutritional quality to greater percentages of a diet exists. First, species in the same forage class often follow similar trends in nutritional quality (Hobbs et al. 1982, Leslie et al. 1984). Second, nutritional quality can be extrapolated across sampling periods for forage species. For example, *D. glomerata* nutrition during summer can be derived from spring and fall nutritional quality. Therefore, although the regression analyses included only the 21 forage species analyzed for nutritional quality, the overall correlations identified were applicable for larger percentages of plant species in the diet.

Unexpected diet constituents could not be analyzed for nutritional quality because samples were not collected. For example, lichen occurred as 7 – 18% of 5 herds' diets in May/June. Lichen has not been identified previously as a primary forage for Roosevelt elk (Jenkins and Starkey 1991). Therefore lichen was not included as a potential forage

item for sample collection. Lichen has been identified as an important autumn and winter forage item for caribou in Northeastern Washington (Rominger et al. 1996, Rominger et al. 2000). During winter, dry matter digestibility was high (82%, Rominger et al. 1996). Lichen available in mature timber stands, as opposed to clear cuts, also provided additional crude protein, but overall protein was low for lichens (< 4.3%, Rominger et al. 2000). Elk in the Hoko GMU may have consumed lichen as a highly digestible food source during spring.

The relationship between weighted home range size and reproductive success was different for highly productive and less productive herds. For highly productive herds, there was no relationship between calf survival and home range size, and mean calf:cow ratio decreased slightly with increased home range size (Figure 12). However, the latter relationship was strongly influenced by one herd. Without the outlier herd, there would have been no relationship between mean calf:cow ratio and home range size. Highly productive herds had preferred forage areas, such as pasture, marsh, or 2 – 9 year timber, within their home ranges. Thus, highly productive herds did not have to increase their home range size to gain access to abundant, high quality forage. For less productive herds, mean calf:cow increased and calf survival decreased with increased home range size. These relationships were not significant, likely due to the small sample size. Less productive herds increased home range size to include more preferred foraging areas, but this increased the amount of travel. The increase in travel contributed to decreased calf survival (Figure 12), due to increased energetic costs and exposure to predation. Thus, there was a tradeoff between a small, poor quality home range that promoted high calf

survival but few calves overall, and a larger, poor quality home range that had a higher mean calf:cow ratio, but lower calf survival. However, when areas of dense forage were available, as with pasture or wetlands, herds did not require as large a home range to have high reproductive success. This follows the patterns identified with small mammal food supplementation studies (Jonsson et al. 2002), but in the case of elk herds in the Hoko GMU, the presence of a pasture or wetland provided a dense food source around which a smaller home range was centered.

High plant productivity (Coughenour and Singer 1996), plant biomass (Merrill and Boyce 1991), and amount of herbaceous forage (Post and Klein 1999) have been linked to ungulate population growth or stability. Positive relationships were found between the percentage of 2 – 9 year timber used and available and three measures of reproductive success (mean calf:cow, December calf:cow, and productivity index) of elk on the Hoko GMU. In addition, maturing timber greater than 20 years old, both percentage used and available, was negatively related to reproductive success of elk. High primary productivity after timber harvest, followed by decreases in forage plant biomass as timber matures, explained this pattern.

Percentage pasture available in the home range was positively related to mean calf:cow, December calf:cow, and productivity index. Similarly, Iason et al. (1986) found reproductive success of red deer hinds was positively related to both area of grass pasture available and the extent to which hinds used the pastures. Marsh and riparian vegetation categories available in the home range were positively related to survival. Grasses, sedges, and forbs were typical forage plants found in pasture, marsh, and

riparian areas in the study area. These forage plants were high in protein and digestible energy (Figure 8, 11), and likely contributed to the higher reproductive success associated with these vegetation categories.

Vegetation categories used or available were not strongly related to birthrate. This may have been due to difficulties obtaining accurate calf:cow ratios in June. In addition, both herds 5 and 6 had calves born late in the year, with young calves (with spots in the coat) seen as late as October 2001. This suggested a prolonged parturition for some herds, which may have created inaccuracies in birthrate estimates. Prolonged parturition could increase calf mortality via small calf size at the onset of winter (Hobbs 1989), or increased predation risk (Estes 1976). Birthrate values could reflect some mortality due to predation.

Regression analyses of elk diet constituents identified positive relationships between percentage grasses, forbs, and *S. racemosa* in elk diets and all measures of reproductive success except survival. Interestingly, *S. racemosa* was a shrub species with relatively good nutritional quality, comparable to grasses and forbs during spring, summer, and fall (Figures 8 – 11). In addition, grasses and forbs were typical forages found in young clear cuts, riparian areas, and pastures within the Hoko GMU, all of which were vegetation categories positively related to reproductive success. Furthermore, percentage sedges and rushes in elk diets were positively related to survival. Sedges and rushes were typical riparian and marsh plant species, and these vegetation categories were also positively related to survival. Consistent with previous studies of nutrition and reproductive success (Cook et al. 1996, Post and Klein 1999, Cook et al

2004), highly nutritious forage plants in the diet of elk on the Hoko GMU allowed for higher reproductive success.

When 2002 winter diet data were included in the regression analyses, sedges and rushes were again positively related to survival, but negatively related to birthrate. This may be explained if survival was primarily linked to the riparian and marsh vegetation category as protection from lion predation, with the amount of sedge and rush in the diet a result of herds using this vegetation category. Moreover, *L. americanum* was negatively related to birthrate and mean calf:cow. *L. americanum* was at or below 2.6 kcal/g of digestible energy needed for maintenance during summer and early fall, which may have been low enough to contribute to poor reproductive success. In addition, *L. americanum* was found in marsh-like maturing timber stands, where less productive herds were often located. These wider influences on the reproductive success of elk herds in the study area contributed to the influence of grasses and forbs previously identified.

The significance of the September/October sampling period in the December calf:cow and productivity index models suggested that September/October may have been a period that influenced reproductive success for all herds, possibly resulting from decreased plant productivity due to seasonally dry conditions. Cook et al. (2004) also identified summer and autumn diet and nutrition as important factors in elk reproductive success. Summer and autumn diets dominated by poor quality forage was particularly important (Cook et al. 2004), as was the case with less productive herds which had large percentages of ferns in the diet during summer. Conversely, highly productive herds had

large amounts of forbs in the summer diet. My results were consistent with Cook et al. (2004), but also suggested the importance of spring diet, in particular the early availability of grasses to highly productive herds. Highly productive herds were able to switch from shrubs to grasses as much as two months prior to less productive herds.

Conclusions

Reproductive success of elk was influenced by many factors, not all of which were addressed in this study. However, the vegetation types available to herds, home range size, diet, and nutritional quality of forage plants were related to all five measures of reproductive success. While diet, vegetation type, and nutritional quality each independently affect reproductive success of elk, the relationships between each of the influencing factors also need to be considered. Diet composition and nutritional quality of forage were influenced by vegetation category within the home range. The availability of young timber and pasture, and subsequent increase of good nutritional quality grasses and forbs in the diet, coincided with higher reproductive success. In addition, home range size was related to reproductive success via the influence of diet and vegetation category availability. Herds with large areas of maturing timber in the home range, and therefore large amounts of poor nutritional quality shrub and fern in the diet, could improve their overall reproductive success with a larger home range. The larger home range increased access to forage, but also increased energetic costs of travel and decreased calf survival. However, if herds had areas within the home range that produced abundant, highly nutritious forage, high reproductive success was possible

regardless of home range size. Therefore, heterogeneous landscapes with patches of good nutritional quality forage resulted in increased reproductive success.

MANAGEMENT IMPLICATIONS

Better availability of forage species high in nutritional quality (grasses and forbs) could potentially increase elk productivity in managed coastal forests. Although I did not directly measure species composition across vegetation types, personal observations and additional studies (K. Boyd, Humboldt State University, personal communication) suggest these plant species were most commonly found in riparian areas, meadows, and young (less than 15 year-old) clear cuts. As clear cuts age and fill with larger shrubs, and eventually approach maturity, their value as a foraging area to elk decreased. My findings of vegetation types used by elk and available to elk also support these conclusions. Elk productivity could potentially benefit by leaving larger riparian buffers around rivers and streams, using fire or other methods to increase open meadows, or spatially distributing new timber harvests to ensure large tracts of land that do not approach maturity at the same time.

Concern over poor elk productivity in the Pacific Northwest, particularly in coastal Oregon and Washington is valid in areas with large, contiguous expanses of maturing timber. Nine collared elk mortalities have occurred in the Hoko GMU since 2001. Three of these have been attributed to malnutrition (R. McCoy, Makah Forestry, personal communication), all of which were cows in less productive herds. Of the other six mortalities, two were hit by vehicles, two were lion kills, and two were from unknown causes. These mortalities suggest that nutrition and forage quality affected survival of adult elk, as well as calves, in the Hoko GMU.

However, it is possible to have relatively high herd productivity in coastal areas where timber harvest has left a mosaic of variable aged timber stands, as well as riparian areas around rivers and streams. Previous studies have also suggested that mosaics of mature and regenerating forests provide better year-round foraging habitat (Happe et al 1990). Timber harvesting does change the quality of forage, and the value of harvested lands to elk nutrition changes with time. Thus, managers could include prairie or mesic meadow in long-range land-use plans to counteract the potential effects of secondary compounds in shrubs as recently harvested areas age.

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APPENDICES

Appendix A. Vegetation types and stand ages identified within the Hoko Game Management Unit, Washington, 2001. Vegetation type and stand ages were grouped into vegetation category or vegetation group for statistical purposes.

Vegetation type	Stand Age (years)	Description of dominant vegetation	Vegetation category	Vegetation group
timber	0	western hemlock, Douglas-fir	timber aged 0 years	non-forest
timber	1-2	western hemlock, Douglas-fir	timber aged 2-9	timber aged 2-9
timber	3	western hemlock, Douglas-fir	timber aged 2-9	timber aged 2-9
timber	4-5	western hemlock, Douglas-fir	timber aged 2-9	timber aged 2-9
timber	6	western hemlock, Douglas-fir	timber aged 2-9	timber aged 2-9
timber	7	western hemlock, Douglas-fir	timber aged 2-9	timber aged 2-9
timber	8-9	western hemlock, Douglas-fir	timber aged 2-9	timber aged 2-9
timber	10-11	western hemlock, Douglas-fir	timber aged 11-17	timber aged 11-25
timber	12-14	western hemlock, Douglas-fir	timber aged 11-17	timber aged 11-25
timber	15-17	western hemlock, Douglas-fir	timber aged 11-17	timber aged 11-25
timber	18-20	western hemlock, Douglas-fir	timber aged 18-25	timber aged 11-25
timber	21-23	western hemlock, Douglas-fir	timber aged 18-25	timber aged 11-25
timber	24-25	western hemlock, Douglas-fir	timber aged 18-25	timber aged 11-25
timber	26+	western hemlock, Douglas-fir	timber over 26 years	timber over 26 years
timber	80+	western hemlock, Douglas-fir	timber over 26 years	timber over 26 years
pond	n/a	water	non-forest	non-forest
lake	n/a	water	non-forest	non-forest
slide	n/a	hillside slide area, mud, earth	non-forest	non-forest
quarry	n/a	gravel	non-forest	non-forest
pasture/prairie	n/a	grass	pasture	non-forest
marsh	n/a	skunk cabbage, willow, sedge	marsh	riparian/marsh
residential	n/a	houses, yards	non-forest	non-forest

Appendix A. Vegetation types and stand ages identified within the Hoko Game Management Unit, Washington, 2001. Vegetation type and stand ages were grouped into vegetation category or vegetation group for statistical purposes. (continued)

Vegetation type	Stand Age (years)	Description of dominant vegetation	Vegetation category	Vegetation group
highway	n/a	paved	non-forest	non-forest
primary logging road	n/a	gravel	non-forest	non-forest
secondary logging road	n/a	gravel	non-forest	non-forest
tertiary logging road	n/a	gravel with some forb	non-forest	non-forest
developed	n/a	non-residential building site	non-forest	non-forest
Olympic National Park	100+	timber 100+ years	Olympic National Park	timber over 26 years
riparian	100+	timber around larger rivers and streams	riparian	riparian/marsh

Appendix B. Bomb Calorimetry laboratory methods for analysis of plant species in the diet of nine elk herds, Hoko GMU, Washington, 2001.

Forty forage plant samples were analyzed for energy content using bomb calorimetry. I determined the energy content of three or four, 0.90 – 1.0 g subsamples of each ground forage plant. Each subsample was pressed into a cylindrical pellet and combusted using a Parr adiabatic bomb calorimeter (Model 1266, Parr Instrument Company, Moline, IL). The bomb calorimeter was equipped with a computer system that calculated corrections for fuse wire for each subsample. I combusted 1.0 g of each plant sample in a muffle furnace at 600° C for four hours to quantify ash content of each plant sample. I corrected all bomb calorimetry results to be reported on an ash-free basis.

Appendix C. Coefficient of Association (CA), number of collared cows, total number of herd locations, and total number of herd visual locations for nine elk herds, Hoko GMU, Washington, March – December 2001. Visual locations were a subset of total locations.

Herd	CA	Number of collared cows	Total number of locations	Number of visual locations	Percent visual locations
1	0.9	2	61	36	59
2	n/a	1	61	26	43
3	0.72	2	65	24	37
4	n/a	1	60	23	38
5	0.79	2	70	40	57
6	0.75	2	62	19	31
7	0.88	2	70	21	30
8	0.42-0.67	3	86	23	27
9	0.57	2	70	6	9
Total		17	605	218	36%

Appendix D. Minimum Convex Polygon (MCP) home range size from radio-telemetry locations for nine elk herds, Hoko GMU, Washington, 2001. Individual elk have been combined into herds and duplicate locations omitted. The number of locations reported reflects stable home range size.

		MCP		
Herd	Number of days monitored	Date of last location used	Number of locations	Area (Km^2)
1	245	10/2/2001	40	9.2
2	254	10/2/2001	40	25.5
3	246	7/21/2001	30	17.2
4	246	9/10/2001	30	15.1
5	250	5/1/2001	15	78.5
6	259	8/10/2001	35	38.2
7	249	8/24/2001	40	10.1
8	249	7/28/2001	40	49.3
9	258	11/2/2001	50	20.4

Appendix E. Percentage of each vegetation category used and available to elk herds in the Hoko GMU, Washington, March – December 2001. Percent used was the percent of all herd locations within each vegetation category. Percent available was the percent of each vegetation category within the home range of that herd.

	Herd																	
	2		5		4		1		3		6		9		8		7	
Vegetation category	used	available	used	available	used	available	used	available	used	available	used	available	used	available	used	available	used	available
Timber aged 0 years	1.6	5.8	1.4	5.3	0.0	1.4	0.0	1.3	0.0	0.6	0.0	3.8	0.0	0.0	1.2	3.9	0.0	0.7
Timber aged 2-9 years	31.2	30.3	47.1	28.1	38.4	46.1	16.4	26.6	18.5	8.3	24.2	10.7	0.0	0.0	0.0	1.1	22.9	12.4
Timber aged 11-17 years	4.9	12.2	2.9	3.5	1.7	3.7	6.6	9.0	1.5	3.8	3.2	9.6	5.7	8.0	2.4	5.1	1.4	2.7
Timber aged 20-24 years	3.2	10.5	0.0	2.2	1.7	3.2	0.0	0.0	6.1	2.3	3.2	6.8	21.4	22.4	26.8	27.9	20.0	13.6
Timber over 26 years	27.9	36.5	31.4	58.1	28.3	39.5	21.3	52.4	26.2	78.9	16.1	57.5	38.6	65.4	34.9	57.2	27.1	53.0
Non-forest	0.0	1.5	0.0	1.1	0.0	1.0	0.0	1.0	0.0	0.9	0.0	3.3	0.0	1.0	0.0	2.8	0.0	6.6
Pasture	8.2	0.5	0.0	0.0	0.0	0.0	45.9	7.1	3.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Marsh	6.5	0.5	0.0	0.0	3.3	0.3	1.6	0.6	7.7	1.6	0.0	0.2	0.0	0.1	4.7	0.4	2.8	1.2
Olympic National Park	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.5	6.2	1.4	0.0	0.0	0.0	1.4	5.0
Riparian	16.4	2.2	17.1	1.6	26.7	4.9	8.2	2.0	36.9	3.5	38.7	1.5	32.9	3.0	30.2	1.7	24.3	4.7

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods.

March/April 2001

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Achillea lanulosa	0.0	0.0	1.0	0.4	0.0	1.6	1.2	0.0	0.0
Anaphalis margaritacea	0.4	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Epilobium angustifolium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.6
Geranium spp.?	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Heracleum lanatum	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.4	1.6
Lactuca muralis	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Lotus/Lupinus spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lysichiton americanum	0.0	0.0	1.0	0.0	0.0	0.0	1.2	0.0	0.0
Montia spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Oenanthe sarmentosa	0.0	0.3	0.8	0.0	2.1	0.0	0.0	0.6	0.0
Petasites palmatus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.8
Plantago spp.	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.4	0.0
Ranunculus repens	0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.1	0.0
Rumex spp.	0.0	0.0	1.3	0.0	0.8	0.0	0.0	0.0	0.0
Stachys spp.	0.0	0.0	1.0	0.6	0.8	5.1	1.8	1.5	1.6
Tiarella trifoliata	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.9	0.0
Trifolium spp.	0.0	1.4	2.3	1.2	0.0	0.0	0.0	0.0	0.0
Composite family hair	1.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Flower	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Other Forb stem	0.0	0.0	0.7	0.0	1.2	0.0	0.0	0.0	0.0
Other Forbs	3.6	0.3	2.9	3.3	0.4	3.9	2.1	2.8	5.8
Athyrium felix-femina	14.1	4.6	0.0	2.0	0.0	0.0	0.8	5.3	2.1
Blechnum spicant	5.3	3.9	2.0	0.0	0.0	0.0	0.0	1.5	0.0
Equisetum spp.	8.5	1.1	1.0	0.0	0.8	2.8	0.4	1.5	0.0
Polystichum munitum	2.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.8
Pteridium aquilinum	0.4	0.0	0.0	0.0	1.2	0.0	0.0	0.8	0.8
Fern rhizome	1.2	7.4	0.0	1.2	0.0	0.8	1.2	4.5	14.8
Agrostis spp.	0.8	2.5	2.6	3.9	2.1	2.0	2.9	1.5	0.0
Anthoxanthum odoratum	0.0	1.8	1.0	0.0	1.2	0.0	0.0	0.0	0.0
Bromus spp.	5.3	17.3	11.4	16.4	9.9	7.5	1.6	5.3	2.9
Calamagrostis spp.	0.8	0.0	0.7	0.0	0.0	0.0	0.0	0.0	1.6
Dactylis glomerata	8.1	32.2	6.8	22.7	12.7	10.3	4.9	2.3	3.3
Danthonia spp.	1.2	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Deschampsia cespitosa	0.0	3.9	1.0	4.3	7.0	0.0	1.2	0.8	0.0
Festuca spp.	0.0	0.0	0.0	1.6	0.0	1.6	0.0	0.0	0.0
Glyceria spp.	0.0	0.0	8.8	0.0	0.4	0.0	1.2	0.0	3.3
Holcus lanatus	2.8	0.7	2.6	6.6	0.0	0.0	1.2	2.6	0.0
Lolium spp.	0.8	1.4	2.9	0.8	2.1	0.0	0.0	0.0	0.0
Poa spp.	6.5	8.5	5.5	8.6	2.5	3.2	1.6	0.0	2.5
Other Grasses	0.8	1.4	1.3	1.9	3.3	0.0	2.9	1.9	0.0
Carex spp.	2.0	0.7	1.6	1.9	11.9	24.5	10.2	2.3	10.3
Juncus spp.	5.2	2.5	10.8	0.0	11.1	10.7	8.2	1.1	2.5
Pseudotsuga menziesii	0.0	0.0	0.0	0.0	1.2	0.0	0.8	0.0	0.0
Thuja plicata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Tsuga heterophylla	7.7	0.0	0.0	0.0	4.1	0.0	4.5	9.8	7.8
Conifer bark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
Acer circinatum leaf	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus rubra leaf	0.0	0.0	6.5	0.0	0.4	0.8	2.9	0.0	0.0
Amelanchier alnifolia leaf	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0
Cornus canadensis leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gaultheria shallon leaf	12.5	2.1	0.3	11.0	7.4	7.9	23.7	26.9	19.3
Rosa spp. leaf	0.0	0.0	0.0	0.0	0.0	1.2	2.5	0.0	0.0
Rubus discolor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Rubus spectabilis leaf	1.0	1.6	1.6	0.6	1.0	3.5	0.4	7.8	5.5
Rubus ursinus leaf	0.2	2.3	0.0	0.4	0.0	0.0	5.3	0.8	0.0
Rubus spp. leaf	2.0	1.1	2.9	0.2	0.0	3.1	2.5	2.3	0.0
Rubus spp. stem	0.8	0.0	0.0	0.0	0.0	1.6	0.0	0.0	2.5
Salix spp. leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.8
Sambucus racemosa leaf	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Spiraea douglasii stem	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
Vaccinium spp. leaf	0.8	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0
Vaccinium spp. stem	0.0	0.0	2.0	0.0	0.0	0.0	2.1	0.0	1.6
Other Shrub leaf	0.0	0.0	0.0	0.0	0.8	0.0	0.8	0.7	0.0
Other Shrub stem	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Lichen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moss	0.8	0.7	12.9	10.4	6.6	0.8	6.3	1.1	0.4
Seed/Nut	0.0	0.0	1.3	0.0	2.9	0.0	1.2	3.8	0.0
Insect	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

May/June 2001

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Achillea lanulosa	1.0	0.0	0.0	1.5	1.5	0.3	2.0	1.6	1.7
Epilobium angustifolium	0.0	1.9	1.6	0.9	10.1	14.6	4.3	3.2	13.9
Geranium spp.?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.4
Heracleum lanatum	0.3	1.5	0.7	3.1	1.9	0.3	0.0	0.0	0.0
Lactuca muralis	0.0	0.0	0.0	1.3	1.2	0.6	0.0	1.4	2.3
Lotus/Lupinus spp.	0.0	0.0	0.0	5.3	0.0	0.0	1.3	0.0	0.0
Lysichiton americanum	0.0	0.0	0.0	0.0	3.5	0.0	1.1	0.0	3.8
Montia spp.(Claytonia)	0.0	0.0	0.0	1.3	1.2	1.2	1.4	0.5	5.3
Oenanthe sarmentosa	0.0	0.9	5.4	2.0	0.2	0.0	1.4	0.0	0.0
Petasites palmatus	0.0	0.0	1.0	1.7	1.2	0.0	0.0	0.5	0.0
Plantago spp.	0.3	1.5	0.0	1.7	0.0	0.0	0.0	1.4	0.4
Ranunculus repens	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
Rumex spp.	0.0	0.4	0.0	0.0	5.0	0.3	0.0	0.0	7.2
Saxifraga spp.	0.3	0.0	0.0	0.0	0.0	2.4	1.4	0.0	2.6
Solidago canadensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stachys spp.	1.2	0.0	3.7	3.1	0.8	2.8	1.1	2.7	0.0
Tiarella trifoliata	0.3	0.0	0.3	0.4	5.4	0.6	1.8	3.2	0.0
Trifolium spp.	0.0	0.2	5.2	7.9	2.9	9.0	5.0	2.3	10.5
Composite family hair	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.4
Flower	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0
Lily family	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.9
Monocot Forb	0.0	3.8	4.5	2.6	3.1	0.6	2.5	0.0	0.0
Other Forb stem	1.7	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Other Forbs	7.6	3.8	8.1	5.7	9.7	9.1	4.7	7.3	12.4
Athyrium felix-femina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blechnum spicant	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0
Equisetum spp.	10.6	7.5	3.6	7.0	1.2	0.3	1.8	4.1	7.9
Polystichum munitum	0.0	0.0	0.0	2.2	0.0	0.0	1.1	0.0	0.0
Pteridium aquilinum	0.7	1.5	0.0	0.0	0.4	2.1	0.0	2.7	0.4
Fern rhizome	4.0	3.0	0.0	0.0	0.8	3.4	4.3	0.0	2.3
Fern capsule	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agrostis spp.	5.0	8.7	3.6	2.2	0.8	0.3	1.1	0.9	0.8
Anthoxanthum odoratum	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0
Bromus spp.	9.6	7.2	3.2	8.3	3.9	0.3	7.9	1.8	1.1
Calamagrostis spp.	0.7	2.6	1.9	0.0	1.9	0.0	1.8	4.1	0.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Dactylis glomerata	13.6	5.3	3.2	6.6	16.3	3.7	8.3	4.6	1.5
Danthonia spp.	3.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Deschampsia cespitosa	3.3	4.1	0.3	0.0	0.0	0.0	2.5	0.0	0.0
Festuca spp.	0.0	0.4	3.6	2.6	0.0	0.0	3.6	0.0	0.0
Glyceria spp.	3.0	0.0	2.3	1.7	0.0	0.0	2.1	1.8	0.0
Holcus lanatus	0.7	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Lolium spp.	0.0	0.0	0.0	2.6	0.0	1.5	0.0	0.0	0.0
Poa spp.	4.0	13.9	1.6	5.7	0.0	0.9	3.9	2.3	0.0
Other Grasses	1.7	2.3	0.7	0.0	0.8	0.0	1.4	0.9	1.1
Carex spp.	0.0	4.5	4.9	0.9	0.8	17.1	0.4	0.0	0.0
Juncus spp.	1.0	3.4	20.8	3.1	0.0	13.4	2.9	3.2	0.0
Acer circinatum stem	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Alnus rubra leaf	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Amelanchier alnifolia leaf	0.0	1.5	0.0	1.3	0.0	0.9	0.0	0.9	0.0
Cornus canadensis leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gaultheria shallon leaf	2.3	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
Ledum groenlandicum leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Physocarpus capitatus	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Rosa spp. leaf	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0
Rubus spectabilis leaf	4.1	6.2	1.3	2.0	3.5	0.9	4.5	11.6	2.3
Rubus ursinus leaf	1.7	5.1	0.7	0.4	2.7	0.3	2.1	0.9	1.7
Rubus spp. leaf	0.0	0.0	2.3	2.2	2.7	2.8	2.5	5.0	4.1
Rubus spp. stem	0.0	0.0	0.0	0.0	0.0	1.8	0.0	6.8	0.0
Salix spp. leaf	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix spp. stem	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Sambucus racemosa leaf	3.0	3.4	0.0	0.0	0.0	4.6	0.0	0.0	2.6
Spiraea douglasii stem	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vaccinium spp. leaf	0.0	0.0	0.0	2.2	1.1	0.0	0.4	0.0	0.0
Vaccinium spp. stem	0.0	0.8	0.0	0.9	1.1	0.6	0.0	0.0	0.0
Thorn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Shrub leaf	0.0	0.7	0.0	0.0	0.0	0.0	0.0	3.2	0.7
Other Shrub stem	0.0	0.0	0.0	2.2	0.0	0.6	0.0	0.0	0.7
Lichen/Mushroom	12.0	2.6	7.5	2.6	9.7	2.1	17.9	15.1	7.7
Moss	0.3	0.0	4.2	2.6	0.0	0.0	0.0	0.5	2.3
Seed/Nut	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Insect	0.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

July/August 2001

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Achillea lanulosa	1.2	0.0	0.0	0.7	1.5	3.7	0.8	2.4	0.0
Anaphalis margaritacea	6.4	0.8	1.1	0.0	1.1	0.0	0.0	0.0	0.0
Astragalus?	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Epilobium angustifolium	1.3	9.2	6.9	3.7	1.8	0.0	0.4	3.8	0.0
Heracleum lanatum	1.3	1.0	2.6	1.7	0.7	0.0	0.4	0.8	0.0
Hypochaeris radicata	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0
Lactuca muralis	1.0	3.2	1.9	0.7	1.5	0.0	0.0	1.1	0.0
Lotus/Lupinus spp.	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0
Lysichiton americanum	0.0	0.0	0.0	4.3	7.4	2.5	0.8	5.3	0.7
Montia spp.(Claytonia)	0.0	10.5	0.7	0.0	0.0	2.1	0.0	0.0	0.0
Oenanthe sarmentosa	2.7	3.2	7.0	0.0	0.4	0.0	0.4	0.0	0.0
Petasites palmatus	1.7	0.4	4.1	1.0	2.6	0.0	2.0	0.0	0.0
Plantago spp.	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Potentilla?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	1.0
Rumex spp.	0.0	0.0	0.7	3.0	3.3	0.0	1.2	0.8	0.7
Saxifraga spp.	0.0	0.0	0.0	0.0	0.4	0.0	0.8	0.0	0.0
Stachys spp.	2.0	2.0	11.1	1.5	6.6	7.4	3.8	2.1	0.8
Tiarella trifoliata	0.0	1.6	0.0	0.0	0.0	0.8	0.0	0.4	0.0
Tolmiea menziesii	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trifolium spp.	1.7	1.8	0.0	0.0	0.7	2.1	0.8	0.2	0.2
Viola?	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0
Composite family hair	0.0	3.0	0.7	0.6	0.0	0.0	0.2	0.4	0.0
Flower	0.0	0.8	0.0	0.0	1.5	0.0	1.2	1.5	0.0
Lily family	0.0	0.0	0.0	6.7	0.0	0.8	0.0	0.0	0.0
Monocot Forb	1.7	0.0	1.5	0.0	0.0	0.8	1.2	0.0	0.0
Other Forb stem	0.0	2.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Other Forbs	5.0	4.0	6.3	7.7	3.7	8.6	6.4	9.4	2.0
Athyrium felix-femina	0.0	0.0	3.3	0.0	1.5	0.4	5.2	0.0	9.9
Blechnum spicant	1.7	0.0	0.0	0.0	0.0	2.1	3.6	3.4	3.7
Equisetum spp.	4.3	7.6	3.3	7.7	18.4	9.4	14.7	12.8	21.0
Polystichum munitum	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.4	1.4
Pteridium aquilinum	0.3	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Fern rhizome	0.7	0.0	0.0	0.0	0.0	0.0	0.8	2.6	1.4
Fern capsule	1.0	0.0	0.4	1.0	1.1	0.8	10.3	8.6	12.6
Agrostis spp.	0.0	1.6	1.1	0.0	1.5	2.1	0.0	0.0	0.0
Bromus spp.	0.0	2.0	0.0	1.0	0.0	5.3	2.4	0.0	0.0
Calamagrostis spp.	2.3	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Dactylis glomerata	2.0	0.0	0.0	0.0	1.1	1.2	0.0	0.0	0.0
Danthonia spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Deschampsia cespitosa	0.0	3.6	0.0	0.0	1.1	0.8	0.0	0.8	0.0
Poa spp.	0.0	0.0	0.0	0.0	0.0	0.0	2.4	1.1	0.0
Other Grasses	0.7	1.2	0.0	0.3	0.7	3.7	4.0	2.3	0.0
Carex spp.	22.7	0.8	0.0	0.0	1.1	1.2	2.8	1.1	0.7
Juncus spp.	12.7	5.2	1.1	2.7	0.7	6.2	3.2	0.0	0.0
Scirpus?	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Tsuga heterophylla	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Conifer bark	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
Acer circinatum stem	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Alnus rubra leaf	0.0	0.8	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Amelanchier alnifolia leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cornus canadensis leaf	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0
Mahonia nervosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0
Myrica gale	0.3	1.2	0.0	1.7	0.7	0.8	0.0	0.0	0.0
Ribes spp. stem	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0
Rosa spp. leaf	0.0	0.0	3.3	0.0	0.0	0.0	0.0	1.5	0.0
Rubus spectabilis leaf	1.0	3.4	1.1	0.0	8.1	2.3	2.2	1.5	0.0
Rubus ursinus leaf	0.7	1.0	1.9	1.0	4.8	0.4	0.0	1.1	0.0
Rubus spp. leaf	0.0	0.0	0.0	6.3	5.9	4.9	6.0	8.6	2.0
Rubus spp. stem	0.0	0.0	0.0	0.0	0.0	1.2	1.2	0.0	1.0
Salix spp. leaf	0.0	5.2	0.0	13.7	0.4	7.4	1.2	3.9	23.8
Salix spp. stem	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.7	2.4
Salix spp. catkin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	6.5
Sambucus racemosa leaf	17.7	18.1	34.1	25.7	4.4	6.6	5.2	3.0	6.8
Spiraea douglasii stem	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0
Vaccinium spp. leaf	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.0	0.0
Vaccinium spp. stem	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
Viburnum edule	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0
Other Shrub leaf	0.0	0.0	0.0	0.0	0.0	2.5	0.8	3.0	0.0
Other Shrub stem	0.0	0.8	0.0	0.0	3.0	1.6	1.2	1.1	1.4
Lichen/Mushroom	5.2	0.0	1.1	0.3	5.2	1.6	2.0	4.1	0.0
Moss	0.0	0.0	0.0	1.0	0.0	2.1	0.0	0.0	0.0
Seed/Nut	0.7	0.8	0.7	0.0	4.8	0.0	0.0	0.0	0.0
Insect	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

September/October 2001

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Achillea lanulosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
Anaphalis margaritacea	0.0	0.7	0.0	0.0	0.0	0.0	5.0	1.9	0.0
Epilobium angustifolium	2.9	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.0
Heracleum lanatum	0.8	0.7	0.9	1.6	0.0	1.4	0.0	0.0	0.7
Lotus/Lupinus spp.	0.0	0.0	0.0	0.0	0.0	0.4	0.2	1.9	0.0
Lysichiton americanum	0.0	1.1	1.3	0.0	2.1	14.3	0.7	0.8	8.8
Montia spp.	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0
Oenanthe sarmentosa	0.0	1.1	5.6	0.8	0.0	0.0	0.0	0.0	0.0
Plantago spp.	0.2	0.0	0.0	0.0	1.1	0.7	0.2	0.0	0.6
Ranunculus repens	0.8	7.1	1.4	2.6	7.1	2.1	1.6	1.4	1.0
Rumex spp.	0.0	2.1	1.3	0.0	1.1	0.4	0.0	0.0	2.6
Saxifraga spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Solidago canadensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Stachys spp.	1.4	0.0	1.6	1.8	6.6	0.9	0.5	4.6	1.3
Tiarella trifoliata	1.2	0.7	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Trifolium spp.	1.4	4.1	0.0	3.2	2.4	0.4	0.4	1.2	0.7
Composite family hair	0.4	0.0	0.2	0.0	0.0	0.0	1.1	0.0	0.0
Flower	0.0	0.0	0.0	0.0	1.0	0.0	0.7	0.0	0.0
Monocot Forb	0.0	0.0	0.0	0.0	5.8	1.4	0.0	0.0	0.0
Other Forbs	5.4	5.3	4.0	6.9	2.4	3.9	3.2	3.9	4.2
Athyrium felix-femina	12.1	4.3	2.2	7.4	0.5	2.1	11.0	16.2	15.3
Blechnum spicant	4.7	10.3	2.7	4.8	2.6	10.7	21.3	7.4	2.3
Equisetum spp.	19.1	8.9	23.3	9.0	3.2	10.0	12.8	6.6	9.6
Polystichum munitum	2.3	2.8	1.3	1.1	1.6	0.4	3.6	1.5	5.9
Fern rhizome	0.0	0.0	0.0	0.0	3.7	0.0	1.1	4.6	1.0
Fern capsule	0.4	0.4	0.0	0.5	3.7	2.5	2.5	1.5	2.0
Agrostis spp.	1.9	4.6	0.0	4.8	1.6	1.8	3.6	3.1	0.0
Anthoxanthum odoratum	0.0	1.1	0.0	0.0	0.0	0.0	1.1	0.0	0.0
Bromus spp.	4.7	8.9	8.5	9.5	5.3	1.4	2.1	13.9	10.4
Calamagrostis spp.	0.0	0.7	0.0	2.6	2.6	1.8	0.0	0.0	0.0
Dactylis glomerata	5.4	16.4	2.2	6.3	4.2	1.8	0.7	2.3	1.6
Deschampsia cespitosa	0.0	2.5	5.8	4.8	1.1	6.1	0.0	0.0	0.6
Festuca spp.	3.1	0.4	0.9	0.0	4.7	1.1	1.4	2.3	0.0
Glyceria spp.	0.0	0.0	0.0	2.1	0.5	0.0	0.0	0.0	0.0
Holcus lanatus	3.5	0.0	3.1	2.6	0.0	0.0	0.0	6.6	0.0
Lolium spp.	0.0	3.6	0.0	0.0	0.0	0.0	0.0	1.2	0.0
Poa spp.	4.7	5.0	0.9	6.9	1.6	1.8	1.4	3.9	10.7

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Other Grasses	1.5	1.8	1.8	1.1	1.6	1.1	0.7	1.5	0.6
Carex spp.	2.3	0.7	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Juncus spp.	1.2	0.0	3.6	0.0	4.7	0.7	0.0	0.0	5.2
Thuja plicata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Tsuga heterophylla	0.0	0.0	1.3	0.0	2.6	0.0	0.0	0.0	0.0
Conifer bark	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.6
Acer circinatum leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0
Alnus rubra leaf	0.0	0.0	3.1	1.1	0.0	0.0	0.0	0.0	0.0
Amelanchier alnifolia leaf	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Cornus canadensis leaf	0.0	0.0	0.5	0.5	0.0	1.8	0.0	0.0	0.0
Gaultheria shallon leaf	3.1	1.4	7.6	3.7	1.6	0.7	0.4	1.9	2.0
Ledum groenlandicum leaf	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0
Ribes spp. leaf	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Rubus laciniatus hair	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Rubus spectabilis leaf	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.4	0.0
Rubus ursinus leaf	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0
Rubus spp. leaf	0.0	0.0	1.8	0.0	5.3	5.3	1.4	0.0	1.3
Salix spp. leaf	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sambucus racemosa leaf	10.9	0.4	0.0	10.0	5.3	16.0	18.5	3.9	2.0
Vaccinium spp. leaf	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Vaccinium spp. stem	2.3	1.1	0.9	0.0	1.1	3.2	0.0	0.0	0.6
Thorn	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0
Other Shrub leaf	2.3	0.0	0.5	0.0	2.1	2.1	0.7	0.0	1.0
Other Shrub stem	0.0	0.0	0.0	0.5	0.0	0.3	0.0	0.0	0.0
Lichen	0.0	0.0	0.5	1.1	0.0	1.1	0.0	0.0	0.0
Moss	0.0	0.0	0.0	1.1	2.1	0.3	0.0	3.1	0.0
Insect	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1.2	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

November/December 2001

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Achillea lanulosa	1.0	0.0	0.0	2.0	1.1	0.0	0.0	0.4	2.9
Anaphalis margaritacea	0.0	0.0	0.8	0.6	0.0	0.0	3.5	0.0	0.0
Heracleum lanatum	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lotus/Lupinus spp.	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Lysichiton americanum	0.8	0.0	0.0	0.0	0.7	0.0	1.3	0.0	0.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Oenanthe sarmentosa	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Plantago spp.	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.1	0.0
Ranunculus repens	1.0	4.9	0.9	0.0	3.7	0.7	1.3	0.0	1.1
Rumex spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Stachys spp.	2.5	0.3	0.6	0.1	1.9	0.0	0.0	0.0	0.0
Tiarella trifoliata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
Trifolium spp.	0.0	0.0	0.0	1.0	0.0	0.7	0.0	0.1	0.0
Composite family hair	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Other Forb stem	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0
Other Forbs	4.1	0.0	0.8	0.0	2.1	0.0	2.2	0.4	0.5
Athyrium felix-femina	14.0	11.0	27.1	14.8	2.2	13.1	15.1	17.6	12.2
Blechnum spicant	7.0	3.6	0.4	10.3	2.2	21.7	4.3	8.3	6.6
Equisetum spp.	19.8	3.2	8.4	2.0	3.4	5.8	10.8	3.9	1.9
Polystichum munitum	2.1	1.9	0.4	4.0	1.9	6.5	1.7	7.0	12.0
Pteridium aquilinum	0.0	0.0	0.0	0.0	1.1	0.7	1.3	0.6	0.0
Fern rhizome	0.0	0.0	1.1	0.0	0.0	2.8	0.0	0.0	0.0
Fern capsule	0.4	0.0	1.1	0.8	0.0	1.7	0.9	0.2	0.0
Agrostis spp.	0.0	6.8	0.4	3.7	3.0	0.7	7.8	0.0	2.4
Anthoxanthum odoratum	0.0	0.0	0.8	6.0	1.1	0.0	0.0	0.0	0.0
Bromus spp.	14.4	19.1	17.9	4.8	4.5	7.6	3.9	3.1	2.4
Calamagrostis spp.	2.1	1.6	0.8	0.0	0.7	2.7	0.0	0.0	0.0
Dactylis glomerata	2.9	19.1	9.5	5.4	12.3	1.4	2.2	0.4	1.9
Deschampsia cespitosa	1.7	4.2	4.2	3.7	1.5	0.0	2.6	0.0	0.3
Festuca spp.	0.0	1.0	0.0	1.1	1.1	0.0	1.7	0.0	0.0
Glyceria spp.	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0
Holcus lanatus	0.0	1.6	1.1	0.0	0.0	2.7	1.3	0.0	1.1
Lolium spp.	0.0	0.0	0.0	1.4	0.0	0.7	0.0	0.0	0.0
Poa spp.	2.1	7.4	0.0	10.0	3.4	2.1	0.0	0.0	1.6
Other Grasses	1.2	0.7	1.9	0.6	1.9	1.0	1.7	0.0	1.1
Carex spp.	1.2	0.0	0.8	0.0	0.0	1.0	0.0	0.0	0.0
Juncus spp.	1.6	1.6	1.9	0.0	22.3	0.7	3.9	0.4	0.0
Pseudotsuga menziesii	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Thuja plicata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Tsuga heterophylla	0.0	2.6	0.8	0.0	0.0	0.0	0.0	0.4	0.8
Conifer bark	0.0	0.0	0.0	0.6	0.0	0.0	0.9	1.7	0.0
Alnus rubra leaf	0.8	1.6	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Amelanchier alnifolia leaf	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Cornus canadensis leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8
Gaultheria shallon leaf	12.8	4.9	2.3	24.2	16.4	17.5	18.6	51.9	43.4
Rubus discolor	0.0	0.0	0.0	1.1	0.0	0.0	0.2	0.0	0.0
Rubus laciniatus hair	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Rubus ursinus leaf	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rubus spp. leaf	0.0	0.0	1.1	0.0	3.0	0.0	1.9	0.0	0.3
Salix spp. stem	0.0	0.0	1.5	0.0	0.7	0.0	0.0	0.0	0.0
Sambucus racemosa leaf	1.6	0.0	1.9	0.0	0.0	0.7	1.7	0.0	0.0
Spiraea douglasii stem	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0
Vaccinium spp. leaf	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vaccinium spp. stem	0.0	0.0	0.0	0.0	0.0	1.0	0.0	2.3	0.5
Thorn	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Shrub leaf	0.0	1.0	2.7	0.0	0.0	1.4	0.0	0.0	0.5
Other Shrub stem	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0
Lichen	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	1.9
Moss	2.5	1.9	6.1	0.6	5.2	0.0	4.8	0.6	0.8
Insect	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

January/February 2002

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Achillea lanulosa	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lysichiton americanum	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Saxifraga spp.	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Solidago canadensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stachys spp.	0.1	0.0	0.1	0.0	0.2	0.0	0.0	0.1	0.0
Tiarella trifoliata	0.0	0.0	0.6	0.0	0.5	0.0	0.0	0.0	0.0
Other Forbs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Athyrium felix-femina	16.0	13.3	8.4	18.6	5.5	27.7	24.7	17.5	24.2
Blechnum spicant	3.9	6.5	1.2	9.6	1.6	19.2	8.0	5.7	8.0
Equisetum spp.	5.4	2.7	11.5	14.2	5.3	10.1	13.2	6.6	13.7
Polystichum munitum	5.3	7.8	1.7	9.2	1.1	5.3	0.5	0.4	2.1
Pteridium aquilinum	0.0	0.0	0.0	0.0	0.2	1.1	0.3	0.1	0.0
Fern rhizome	1.2	0.1	0.0	0.6	1.8	4.5	2.8	0.4	0.0
Fern capsule	0.6	0.0	0.6	0.0	0.7	1.2	1.1	0.3	0.0
Agrostis spp.	1.4	2.8	0.6	0.0	0.5	0.0	1.0	0.3	0.0

Appendix F. Diet of nine elk herds in the Hoko Game Management Unit, Washington, March 2001 – February 2002. Values for each plant species are percent of the diet for each of six sampling periods. (continued).

	Herd								
Plant species	5	1	4	2	3	7	6	8	9
Anthoxanthum odoratum	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Bromus spp.	2.4	8.7	1.7	1.1	2.8	2.8	0.9	0.6	0.0
Calamagrostis spp.	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dactylis glomerata	0.7	3.0	1.4	1.6	3.7	3.4	1.4	0.4	0.0
Deschampsia cespitosa	0.0	3.4	0.0	2.1	0.0	0.0	0.0	0.0	0.0
Festuca spp.	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Glyceria spp.	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Holcus lanatus	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0
Lolium spp.	0.4	0.4	0.0	0.0	1.4	0.0	0.0	0.0	0.0
Poa spp.	1.7	4.2	1.6	0.0	0.9	2.0	0.9	0.0	0.0
Other Grasses	0.0	0.0	0.0	0.4	1.1	0.3	0.0	0.5	0.9
Carex spp.	0.0	0.0	4.7	0.9	0.5	0.0	1.1	0.0	0.3
Juncus spp.	3.4	3.1	5.4	1.8	1.2	1.4	0.0	0.0	0.0
Scirpus?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudotsuga menziesii	0.0	0.0	0.6	0.0	0.7	0.0	0.3	0.9	0.0
Thuja plicata	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.5	0.0
Tsuga heterophylla	11.0	1.1	34.3	0.3	18.0	0.0	0.0	22.3	4.7
Conifer bark	0.0	0.0	1.0	0.4	0.0	0.0	0.0	0.5	0.3
Cornus canadensis leaf	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gaultheria shallon leaf	41.2	33.6	14.6	35.3	42.1	18.8	40.9	37.2	44.4
Ledum groenlandicum leaf	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
Linnaea borealis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Myrica gale leaf	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Ribes spp. stem	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rubus ursinus leaf	0.0	0.2	0.2	0.0	0.7	0.2	0.0	0.0	0.0
Rubus spp. leaf	0.0	0.0	1.7	0.8	0.5	0.3	0.8	0.4	0.3
Rubus spp. stem	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix spp. leaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Salix spp. stem	0.0	0.8	0.0	0.0	0.4	0.0	0.3	0.3	0.0
Salix spp. catkin	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
Vaccinium spp. leaf	0.0	0.0	0.0	0.4	0.5	0.0	0.9	0.4	0.0
Vaccinium spp. stem	3.2	4.4	0.8	1.4	4.4	0.0	0.3	2.5	0.0
Thorn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Shrub leaf	0.9	0.0	0.0	0.5	0.0	0.0	0.6	0.0	0.0
Other Shrub stem	0.4	0.0	2.3	0.6	0.4	0.0	0.0	0.3	0.0
Lichen/Mushroom	0.0	0.3	0.0	0.1	0.9	0.1	0.0	0.1	0.0
Moss	0.4	0.8	1.7	0.1	0.4	0.8	0.0	0.1	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix G. Total percentage of nine elk herd diets analyzed for nutritional quality in the Hoko GMU, Washington, March 2001 – February 2002. Superscripts indicate forage species which were not analyzed but were large percentages of the diet, therefore influencing the total.

	Sampling Period					
Herd	March/April	May/June	July/August	Sept/Oct	Nov/Dec	Jan/Feb
1	59.4	35.0	48.4	37.1	64.4	49.0
2	54.0	30.1	47.9	40.7	65.5	54.4
3	53.0	34.0	29.1	22.4[d]	65.2	62.8
4	30.9[a]	16.5[b]	55.1	31.8	67.9	51.8
5	47.2	32.3	58.8	52.3	74.6	61.4
6	49.4	27.8	19.6[c]	67.3	60.5	49.4
7	60.9	29.4	35.7	57.0	74.3	43.3
8	43.2	28.1	16.9[c]	40.2	92.6	65.6
9	40.4	36.1	32.8	49.7	80.4	59.2

[a] miscellaneous other grasses

[b] lichen, other forbs

[c] other forbs, Rubus spp, unidentified fern capsule

[d] Rubus spp, other forbs

Appendix H. Correlations between percentage vegetation category used or available and principal components 1 – 7. Pearson correlations greater than 0.5 are included in the interpretation of the principal component. Vegetation data was for locations and home ranges of nine elk herds, Hoko GMU, Washington, March – December 2001.

	Principal Component						
Vegetation category (Percent Used)	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Timber aged 2 - 9 years		0.90					
Timber aged 11 - 17 years	0.87						
Timber aged 20 - 24 years		-0.90					
Timber over 26 years		-0.66	-0.57				
Pasture	0.90						
Marsh			-0.62				
Olympic National Park			0.93				
Riparian	-0.79						
Vegetation category (Percent Available)							
Timber aged 2 - 9 years					0.77		-0.63
Timber aged 11 - 17 years				-0.74		-0.50	
Timber aged 20 - 24 years							0.92
Timber over 26 years					-0.93		
Pasture				-0.64			-0.62
Marsh						0.85	
Olympic National Park							
Riparian						0.84	
Roads				-0.89			

Appendix I. Multiple regression analyses of reproductive success and principal components of vegetation category used by elk. Only principal components with coefficients significantly different from zero were included. Vegetation data was from elk locations in the Hoko GMU, Washington, March – December 2001. No principal component was related to birthrate or survival.

Dependant Variable	Independant variables	Regression coefficient (Bi)	SE	P	F	n	R^2
Mean calf:cow	Intercept	0.417	0.016	<0.001			
	Principal component 2	0.055	0.016	0.011			
	Model*			0.011	11.9	9	0.63
December calf:cow	Intercept	0.354	0.024	<0.001			
	Principal component 2	0.07	0.025	0.03			
	Model			0.03	7.4	9	0.51
Productivity index	Intercept	5	0.668	<0.001			
	Principal component 2	1.998	0.708	0.026			
	Model			0.026	8.0	9	0.53

* Weighted Regression using Huber's method

Appendix J. Multiple regression analyses of reproductive success and principal components of vegetation category available to elk. Only principal components with coefficients significantly different from zero were included. Vegetation data were from elk home ranges in the Hoko GMU, Washington, March – December 2001. No principal component was related to birthrate

Dependant Variable	Independent variable	Regression coefficient (Bi)	SE	P	F	n	R^2
Survival	Intercept	0.740	0.053	<0.001			
	Principal component 6	0.137	0.057	0.046			
	Model			0.046	5.9	9	0.46
Mean calf:cow	Intercept	0.398	0.022	<0.001			
	Principal component 7	-0.063	0.024	0.032			
	Model			0.032	7.2	9	0.51
December calf:cow	Intercept	0.354	0.013	<0.001			
	Principal component 7	-0.090	0.014	<0.001			
	Model			<0.001	42.1	9	0.86
Productivity index	Intercept	5.000	0.43	<0.001			
	Principal component 7	-2.460	0.45	0.001			
	Model			0.001	29.2	9	0.81

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Appendix K. Correlations between percentage forage species in elk diets and principal components 1d – 8d. Pearson correlations greater than 0.5 were included in the interpretation of the principal component. Elk diet data was from nine elk herds, Hoko GMU, Washington, March 2001 – February 2002.

Forage class	Forage species	Principal Components							
		PC1d	PC2d	PC3d	PC4d	PC5d	PC6d	PC7d	PC8d
Forbs	Epilobium angustifolium				-0.86				
	Lysichiton americanum						0.83		
	Montia spp				-0.76				
	Oenanthe sarmentosa					0.80			
	Ranunculus repens								0.79
	Stachys spp					0.74			
	Trifolium spp				-0.81				
Ferns	Athyrium felix-femina	0.64							
	Blechnum spicant	0.80							
	Equisetum spp								
	Polystichum munitum	0.77							
Grasses	Bromus spp		-0.86						
	Dactylis glomerata		-0.80						
	Poa spp		-0.76						
Sedges	Carex spp			-0.82					
Rushes	Juncus spp			-0.82					
Conifers	Tsuga heterophylla								
Shrubs	Gaultheria shallon								
	Rubus spectabilis	-0.59							
	Salix spp							0.88	
	Sambucus racemosa					0.66			

Appendix L. Multiple regression analyses of reproductive success and principal components of percent forage species in elk diets. Only principal components with coefficients significantly different from zero were included. Elk diet data was for nine herds in the Hoko GMU, Washington, March – December 2001. Significant dummy variables for sampling period were included.

Dependant Variable	Independent variable	Regression coefficient (Bi)	SE	P	F	n	R^2
Birthrate	Intercept	0.396	0.026	<0.001			
	Principal component 2d	-0.096	0.018	<0.001			
	Principal component 7d	-0.156	0.041	0.002			
	Model*			<0.001	14.6	18	0.66
Survival	Intercept	0.744	0.028	<0.001			
	Principal component 3d	-0.057	0.026	0.033			
	Model*			0.033	4.9	45	0.1
Mean calf:cow	Intercept	0.394	0.01	<0.001			
	Principal component 2d	-0.04	0.01	<0.001			
	Principal component 5d	0.031	0.009	0.002			
	Model*			<0.001	10.6	45	0.34
December calf:cow	Intercept	0.352	0.012	<0.001			
	Dummy 3 (Sept/Oct)	-0.067	0.029	0.027			
	Principal component 2d	-0.051	0.011	<0.001			
	Principal component 5d	0.045	0.011	<0.001			
	PC8d	0.033	0.011	0.006			
	Model			<0.001	10.3	45	0.51
Productivity index	Intercept	4.74	0.276	<0.001			
	Dummy 3 (Sept/Oct)	-1.737	0.693	0.016			
	Principal component 2d	-1.518	0.262	<0.001			
	Principal component 5d	1.11	0.244	<0.001			
	PC8d	1.231	0.269	<0.001			
	Model*			<0.001	18.2	45	0.65

* Weighted Regression using Huber's method

Appendix M. Multiple regression analyses of reproductive success and principal components of percent forage species in elk diets. Only principal components with coefficients significantly different from zero were included. Elk diet data was for nine herds in the Hoko GMU, Washington, March 2001 – February 2002. Significant dummy variables for sampling period were included.

Dependant Variable	Independent variable	Regression coefficient (Bi)	SE	P	F	n	R^2
Birthrate	Intercept	0.493	0.014	<0.001			
	Principal component 2d	-0.031	0.014	0.028			
	Principal component 3d	0.038	0.014	0.009			
	PC6d	-0.038	0.014	0.009			
	Model*			<0.001	6.6	54	0.28
Survival	Intercept	0.745	0.026	<0.001			
	Principal component 3d	-0.061	0.026	0.023			
	Model*			0.023	5.5	54	0.1
Mean calf:cow	Intercept	0.404	0.009	<0.001			
	Principal component 2d	-0.024	0.009	0.01			
	PC6d	-0.03	0.009	0.003			
	Model*			<0.001	8.4	54	0.25
December calf:cow	Intercept	0.368	0.012	<0.001			
	Dummy 3 (Sept/Oct)	-0.081	0.032	0.015			
	Principal component 2d	-0.036	0.011	0.001			
	Principal component 5d	0.031	0.011	0.006			
	PC8d	0.043	0.012	<0.001			
	Model*			<0.001	7.2	54	0.37
Productivity index	Intercept	5.12	0.278	<0.001			
	Dummy 3 (Sept/Oct)	-2.2	0.767	0.006			
	Principal component 2d	-1.186	0.253	<0.001			
	Principal component 5d	0.856	0.256	0.002			
	PC8d	1.411	0.286	<0.001			
	Model*			<0.001	13.3	54	0.52

* Weighted Regression using Huber's method