

**CHEMICAL COMPOSITION
OF DOUGLAS-FIR FOLIAGE
ON MULE DEER WINTER RANGE**

by
M.J. Waterhouse, R.J. Dawson,
and H.M. Armlieder

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M.J. Waterhouse, R.J. Dawson, and H.M. Armleder

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EXECUTIVE SUMMARY

In the interior of British Columbia, Douglas-fir litterfall is a major source of mule deer winter food. Dawson *et al.* (1990) found that preference for Douglas-fir foliage was correlated with tree diameter. This study set out to identify the underlying ultimate factors of selection so that wildlife managers might have a wider range of forage enhancement options on mule deer winter range. Such options might include, for example, planting, thinning, or fertilizing trees to improve palatability.

Samples of Douglas-fir foliage were collected from trees at Knife Creek and Big Lake, and analysed for minerals, tannins and *in vitro* digestible dry matter (IVDDM). Phosphorus was the only mineral correlated with preference in three of four study sites. It also correlated with dbh on two other sites where preference was not known. Douglas-fir samples were found to be phosphorus-deficient, so perhaps small differences in concentration are important to deer. Tannins, which are digestibility-reducing compounds, were not well correlated with preference. No preference data were collected on sites where IVDDM of Douglas-fir was measured. Digestibility did not seem to affect selection of Douglas-fir foliage, as suggested by the lack of correlation between IVDDM and dbh. Our results, however, must be interpreted with care because the study had design limitations. Future studies could be improved with an increased sample size, the testing of a wider variety of chemicals, and the use of foliage that has a wider range of chemical concentrations.

The nutrient content of Douglas-fir is important because it is a large part of deer winter diet in the Cariboo Forest Region. The Douglas-fir foliage sampled meets minimum ruminant requirements for nitrogen (crude protein), potassium, magnesium, iron, zinc, and calcium/phosphorus ratio. Sulphur, sodium and, in some cases, calcium and copper concentrations are lower than required. Manganese is 2–10 times greater than the suggested forage level. Deficiencies may be supplemented by other plants during winter or by plants eaten in other seasons.

TABLE OF CONTENTS

EXECUTIVE SUMMARY.....	iii
INTRODUCTION	1
STUDY AREAS	1
METHODS.....	1
RESULTS.....	2
DISCUSSION	4
RESEARCH LIMITATIONS AND RECOMMENDATIONS	6
REFERENCES	8

APPENDICES

1 Chemical content of Douglas-fir twigs from various sections of trees of different diameters collected at Big Lake in 1987 and Knife Creek in 1985.....	10
2 Chemical content of Douglas-fir twigs from various sections of trees of different diameters collected at Knife Creek in 1986.....	13

TABLES

1 Concentration of chemicals found in each size class of trees on the Big Lake and Knife Creek study areas.....	3
2 Correlation coefficients and probability levels for preference versus several minerals, tannins, and dbh using Big Lake (1987) and Knife Creek (1985) tree section samples for each site.....	3
3 Correlation coefficients and probability levels for dbh of sample trees versus several minerals, tannins, and IVDDM using Knife Creek (1986) tree sections (n = 7) from two sites.....	4
4 Recommended mineral levels for ruminant forage compared to those found in Douglas-fir samples from the Big Lake and Knife Creek study areas.....	5

INTRODUCTION

In British Columbia, where Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) reach the northern limit of their continuous distribution, Douglas-fir (*Pseudotsuga menziesii*) is a major source of winter food (Willms *et al.* 1976). On drier winter ranges in the Cariboo Forest Region, Douglas-fir comprises 50–90% of the winter diet.¹ It is available to deer as litterfall, tree blowdown, and live foliage from branches within reach of deer.

Deer are selective feeders and choose specific types of Douglas-fir foliage. Some studies have related preference to proximate factors such as tree size, tree position, site, and genotype (Dimock *et al.* 1976; Tucker *et al.* 1976). Others have associated preference with ultimate factors such as essential oils (Oh *et al.* 1970; Radwan 1972), chlorogenic acid (Radwan 1975; Radwan and Crouch 1978), and both moisture and crude protein (Tucker *et al.* 1976).

The study reported here was done in conjunction with an experiment which examined mule deer preference for Douglas-fir from different sized trees (Dawson *et al.* 1990). This study had two objectives. The first objective was to investigate whether mule deer preferences for foliage from different sized Douglas-fir trees correlated with levels of minerals, tannins, and *in vitro* digestible dry matter. Results to this question may provide an insight into areas of future research. The second objective was to provide baseline information on nutritional quality of Douglas-fir in the interior of the province.

Using proximate factors, Dawson *et al.* (1990) could only recommend that forest managers retain enough mature and older trees in a stand to provide adequate forage and shelter for deer. We believe that by identifying specific ultimate factors that influence deer forage preference, we may be able to find options for promoting trees with high forage value.

STUDY AREAS

Samples of Douglas-fir foliage from different sized trees were collected from two mule deer winter ranges in the Cariboo Forest Region of the central interior of British Columbia. The Knife Creek winter range lies 15 km southeast of Williams Lake, B.C.; the Big Lake winter range is situated 10 km west northwest of 100 Mile House, B.C.

Both areas are in the Interior Douglas-fir subzone (IDFb), which is characterized by uneven-aged climax stands of Douglas-fir growing on orthic grey luvisol soils.² Understory shrubs are sparse compared to the Douglas-fir regeneration which grows in thick patches on moister sites. The herb layer is usually dominated by pinegrass (*Calamagrostis rubescens*). The climate is typified by warm, dry summers and cold, dry winters. The mean January minimum temperatures range from -14.5°C to -18.5°C ; the mean July maximum temperature ranges from 19°C to 24°C . The average January month-end snowpack is 40 cm and the annual precipitation is 41 cm, as recorded at Williams Lake airport.

METHODS

In 1985, two sites on the Knife Creek winter range were located on south to southwest slopes along a forest edge where all trees received full sunlight. The slope was 25% at site 1 and 3% at site 2. At Big Lake, both sites were located on a gentle (3%) northeast slope within a multi-layered stand. On both study areas, sites were 300–400 m apart.

At each site, one tree was felled in each of the following diameter classes: small pole (14–25 cm), large pole (25–30 cm), and mature (40–48 cm). Three trees in the regeneration class (3–6 cm) were also felled.

¹ M.J. Waterhouse, H.M. Armleder, and R.J. Dawson. 1990. Winter food habits of mule deer in the central interior of British Columbia. B.C. Min. For., Victoria, B.C. In prep.

² Coupé, R. and A. Yee. (editors). 1982. Identification and interpretation of ecosystems of the Cariboo Forest Region, B.C. Min. For., Williams Lake, B.C. Unpubl. report.

Height, diameter at breast height (dbh), and age of all sample trees were recorded. The crowns of the mature, large pole and small pole trees were divided into quarters, thirds and halves respectively for ease of estimation. Every 1–3 days, the percent of browsing on each tree and on the regeneration class were assessed until browsing rate substantially declined or virtually 100% of any size class was browsed. The percent browsed was calculated by estimating the cumulative proportion of available green twig ends eaten for each tree section. The amount of browsing on the whole tree equalled the mean of the sections.

In 1986, Douglas-fir samples were collected from two other south aspect sites on the Knife Creek winter range. The terminal 4 cm of 100 green twigs were cut from the top and bottom sections of trees in four dbh classes: old growth (90 cm +), mature (47 cm), pole (18–27 cm), and regeneration (5–10 cm). Only south aspect foliage was clipped. Piles of twigs from the different diameters and sections of trees were weighed and counted, then placed on the ground for deer to forage on. Because the deer ignored these piles, no preference data were collected.

For chemical analyses, 500 g of green twig ends, 4 cm in length, were collected from throughout each tree section and from the regeneration immediately after felling in 1985 and 1987. In 1986, the twig ends were picked from the live trees. The samples were frozen directly after collection. They were later oven-dried for 24 hours at 58°C, then ground through a #20 mesh sieve. The ground samples were sent for mineral and tannin analyses at Griffen Laboratories Corporation, Kelowna, B.C.

At the laboratory, the concentration of potassium, phosphorus, calcium, magnesium, sulphur, boron, copper, iron, manganese, zinc, and sodium in each sample was determined using a ICP — AES (Inductively Coupled Plasma — Atomic Emission Spectrometer) (Hong Chuah, pers. comm., Agrologist, June 1988). The samples were wet-digested with a nitric perchloric acid and an aluminum block digester. Nitrogen concentration was assessed by the Technician Auto-analyses method which used hypochlorite — salicylate — nitroprusside solution. This method was modified from the Kjeldahl method, by using a digester block. The tannin content of each sample was determined by the protein precipitation method (Hagerman and Butler 1978).

The 1986 ground Douglas-fir samples from Knife Creek were also sent for *in vitro* digestible dry matter analyses (IVDDM) at Washington State University (Wildlife Habitat Laboratory). The two-stage digestibility method was used (Tilley and Terry 1963).

We used correlation analyses to examine the relationships between preference and chemical content of sections of trees of various sizes, at each site chosen in 1985 at Knife Creek and in 1987 at Big Lake. To determine whether similar results emerged, *r* values from the four sites were compared. Dawson *et al.* (1990) found preference and dbh to be strongly correlated ($r = .84$; $p = .001$), so we correlated the Knife Creek (1986) chemical data with dbh. To compare our mineral, IVDDM, and tannin levels with the values reported in the literature, we used the overall mean value.

RESULTS

The physiological characteristics of each tree, the final percent browsed on each tree section, and the chemical content of the green twigs collected from each tree at Knife Creek in 1985 and Big Lake in 1987 are summarized in Appendix 1. Chemical and digestibility data for the Douglas-fir samples collected at Knife Creek in 1986 are located in Appendix 2.

Within each tree, the level of calcium decreased and the level of potassium tended to increase with distance from the point of germination. The concentrations of nitrogen, phosphorus, magnesium, sulphur, copper, boron, iron, manganese, zinc, tannin, and IVDDM fluctuated inconsistently.

Table 1 summarizes the concentration of each chemical by study area, year and tree type. Concentrations of chemicals differed between study areas and years. The range of values for calcium, iron and zinc are higher at Big Lake than at Knife Creek; potassium, boron and tannins were lower at Big Lake than at Knife Creek. The 1986 Knife Creek samples were lower in calcium, copper, iron, manganese, zinc, and tannin than the 1985 samples.

Preference and dbh are highly correlated at the Knife Creek (1985) and Big Lake (1987) sites (Table 2). Despite significant correlations ($p = .1$) between some chemicals and preference, none were consistently correlated at all four sites. Only phosphorus was significantly correlated with preference at three out of four sites. Phosphorus was also positively correlated with dbh at the two 1986 Knife Creek sites (Table 3).

TABLE 1. Concentration of chemicals found in each size class of trees on the Big Lake and Knife Creek study areas

Study area	Year	Tree type	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (mg/kg)	Cu (mg/kg)	Na (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Tannin A(510/g)
BL	1987	MA	—	.168	.456	.756	.126	.08	15.8	4.0	—	153.0	—	39.9	4.2
BL	1987	LP	—	.174	.421	.824	.130	.08	18.7	4.0	—	138.7	—	32.9	4.6
BL	1987	SP	—	.167	.474	.905	.125	.08	17.2	4.1	—	166.6	—	39.1	3.1
BL	1987	RE	—	.149	.468	.720	.084	.08	16.3	4.1	—	147.1	—	32.9	5.6
KC	1985	MA	1.0	.21	.52	.66	.16	—	24.0	3	13	109	284	24	15.8
KC	1985	LP	1.0	.15	.56	.70	.15	—	38.8	5	8	96	279	30	8.5
KC	1985	SP	1.0	.18	.63	.45	.16	—	21.0	4	10	99	365	26	13.9
KC	1985	RE	0.9	.17	.62	.59	.14	—	21.5	5	16	93	445	28	15.8
KC	1986	OG	—	.170	.52	.429	.16	.085	—	1.7	—	73.9	71	17.0	4.1
KC	1986	MA	—	.149	.52	.382	.14	.078	—	1.6	—	64.5	106	22.6	5.3
KC	1986	PO	—	.139	.49	.332	.15	.081	—	1.0	—	62.5	119	18.2	3.1
KC	1986	RE	—	.121	.59	.278	.11	.061	—	0.8	—	44.2	106	16.5	8.6

^a MA = mature, LP = large pole, SP = small pole, PO = pole, RE = regeneration, OG = old growth.

TABLE 2. Correlation coefficients and probability levels for preference versus several minerals, tannins, and dbh using Big Lake (1987) and Knife Creek (1987) tree section samples for each site

Chemical	Big Lake ^a Site 1		Big Lake ^a Site 2		Knife Creek ^b Site 1		Knife Creek ^b Site 2	
	r	p	r	p	r	p	r	p
Nitrogen (N)	—	—	—	—	.11	.77	-.08	.83
Phosphorus (P)	-.45	.17	.75	.01	.75	.01	.62	.05
Potassium (K)	-.08	.82	.55	.08	-.72	.02	-.66	.04
Calcium (Ca)	.38	.25	-.75	.01	.33	.35	-.06	.86
Magnesium (Mg)	-.30	.37	.40	.22	.58	.08	.19	.59
Sulphur (S)	.55	.08	-.45	.16	—	—	—	—
Boron (B)	-.54	.08	-.02	.96	.06	.87	-.49	.15
Copper (Cu)	.29	.39	-.46	.15	-.21	.56	-.56	.10
Iron (Fe)	.40	.23	-.41	.20	.15	.69	.27	.44
Manganese (Mn)	—	—	—	—	-.40	.25	-.57	.08
Zinc (Zn)	.73	.01	-.40	.22	-.48	.16	-.48	.16
Sodium (Na)	—	—	—	—	.47	.17	.04	.91
Tannin	-.59	.06	.82	.01	.44	.20	.52	.13
Ca/P	.61	.05	-.76	.01	-.10	.77	-.36	.30
dbh	.71	.01	.85	.01	.96	.01	.91	.01

^a n = 11

^b n = 12

At the two 1985 Knife Creek sites, manganese was negatively correlated to preference and at the two 1986 Knife Creek sites it was negatively correlated to dbh, though the relationships were not significant at $p = .1$ in 2 of the 4 cases. The range of manganese concentrations was much lower at Knife Creek in 1986 than in 1985. The Big Lake samples were not analyzed for manganese.

TABLE 3. Correlation coefficients and probability levels for dbh of sample trees versus several minerals, tannins, and IVDDM using Knife Creek (1986) tree sections ($n = 7$) from two sites

Chemical	Knife Creek Site 1		Knife Creek Site 2	
	r	p	r	p
Phosphorus (P)	.93	.01	.80	.03
Potassium (K)	.28	.54	-.65	.11
Calcium (Ca)	.88	.01	.56	.19
Magnesium (Mg)	.29	.53	.65	.11
Sulphur (S)	.67	.10	.66	.11
Copper (Cu)	.51	.24	.80	.03
Iron (Fe)	.62	.13	.47	.29
Manganese (Mn)	-.46	.30	-.89	.01
Zinc (Zn)	-.51	.24	.50	.25
Ca/P	.26	.57	.15	.75
Tannin	-.28	.54	-.36	.42
IVDDM	-.06	.89	-.69	.09

DISCUSSION

Preference of forage is a function of availability and palatability (Silen and Dimock II 1978). Dawson *et al.* (1990) found that given choice of sizes of Douglas-fir, wild mule deer strongly preferred foliage from larger trees ($r^2 = .71$; $p = .0001$; $n = 16$). Captive mule deer also prefer foliage of old trees to that of young trees (Tucker *et al.* 1976). Other researchers found deer to select twig ends from mature tree cuttings rather than from regeneration (Dimock II 1974; Radwan 1975).

Forage selection based on proximate factors such as size and age begs questions about the ultimate factors involved. Identifying a specific compound responsible for palatability could stimulate genetic and silvicultural programs to produce the desirable foliage characteristics. For example, winter ranges could be fertilized with known deficient chemicals. Or, if there were plans to thin and fertilize certain areas, then the treatments could be modified to benefit mule deer. If more palatable trees were planted or produced through silvicultural techniques within the stand, perhaps more than the recommended percent of commercially valuable trees could be harvested according to the method outlined in Armleder *et al.* (1986). Requirements for snow interception, thermal and security cover would also have to be met.

Because of experimental design limitations, results presented in this study have to be interpreted with care. At three of the four sites, phosphorus was correlated with preference. This result was supported by positive correlations between phosphorus and dbh at the two 1986 sites. Deer may be selecting for minute differences in the phosphorus content of Douglas-fir, since most samples from both winter ranges are phosphorus-deficient (Table 4). Such phosphorus deficiency can cause lower organic blood phosphorus level, depletion of the mineral content of bones, decreased rate of weight gain, and possible reduction in fertility (Church 1971).

At the four Knife Creek sites, preference and dbh tended to be negatively correlated with manganese, another essential element. This result may not be meaningful because the range of concentrations is different between years and no preference data were available for 1986 (Table 4). Whether or not the high level of

manganese in our Douglas-fir samples between 71 and 445 mg/kg is toxic for deer is unknown. Maynard (1979) found manganese to be toxic for cattle at 2000 mg/kg.

TABLE 4. Recommended mineral levels for ruminant forage compared to those found in Douglas-fir samples from the Big Lake and Knife Creek study areas

Mineral	Interior Douglas-fir	Recommended maintenance requirements	Animal	Reference
Phosphorus (%) ^a	0.12 – 0.21	0.20 – 0.25	Deer	Wallmo (1981)
Potassium (%)	0.42 – 0.59	0.20 – 0.50	Ruminants	Natl. Res. Council (1975)
Calcium (%)	0.28 – 0.91	0.40 – 2.00	Deer	Ullrey <i>et al.</i> (1973)
Magnesium (%)	0.08 – 0.16	0.04 – 1.00	Cattle/horse	Maynard <i>et al.</i> (1979)
Sulphur (%)	0.06 – 0.09	0.14 – 0.18	Ruminants	Natl. Res. Council (1975)
Copper (mg/kg)	0.8 – 5.0	5.0 – 8.0	Cattle	Maynard <i>et al.</i> (1979)
Iron (mg/kg)	44.0 – 166.0	25.0 – 40.0	Ruminants	Maynard <i>et al.</i> (1979)
Manganese (mg/kg)	71.0 – 445.0	16.0 – 40.0	Cattle	Maynard <i>et al.</i> (1979)
Zinc (mg/kg)	16.5 – 39.9	20.0 – 30.0	Cattle	Maynard <i>et al.</i> (1979)
Sodium (mg/kg)	8.0 – 16.0	86.0 – 600.0	Ruminants	Weeks and Kirkpatrick (1976)
Calcium/phosphorus ratio	2.3 – 5.4	1 – 5	Deer	Wallmo (1981)

^a % of dry matter.

When other minerals were correlated with either preference or dbh, results were inconsistent between sites. Although these micronutrient levels can not be related to specific preferences for types of Douglas-fir, the essential element content of Douglas-fir provides useful information on winter forage quality. This is especially important on drier interior winter ranges where Douglas-fir makes up 50–90% of the diet. Essential minerals measured in our Douglas-fir samples are calcium, potassium, magnesium, iron, sulphur, copper, zinc, and sodium. Concentrations of phosphorus, calcium, potassium and magnesium are similar to those documented for Douglas-fir elsewhere (Beaton *et al.* 1965; Radwan and Crouch 1974; Kiilsgaard *et al.* 1987), but sulphur was lower (Beaton *et al.* 1965).

The calcium level in the Big Lake (1987) and Knife Creek (1985) samples equalled or exceeded the minimum 0.4% requirement, but most of the 1986 Knife Creek samples were slightly lower (Table 4). The calcium to phosphorus ratio is nutritionally important, because excess calcium reduces phosphorus assimilation and vice versa. In our samples, this ratio was within the recommended range (Table 4).

The range of concentrations we found for potassium, magnesium, iron, and zinc in Douglas-fir meet the minimum requirements for ruminants (Table 4). Copper in the 1985 and 1987 samples was slightly deficient; in the 1986 samples it was quite low. Copper is essential for hemoglobin, bone, collagen and elastin formation, as well as for the functioning of some enzymes (Maynard 1979). Sulphur concentrations found in our samples were less than the minimum ruminant requirement (Table 4). Such sulphur deficiency may cause reduction in diet intake and cellulose digestion (Maynard 1979). Sodium levels found in Douglas-fir were far less than those required by domestic ruminants. This may not be critical to the health of deer, however, since deer can maintain a positive sodium balance on a low sodium diet by various physiological processes (Weeks and Kirkpatrick 1976).

The nitrogen concentration of our samples indicates a crude protein content of 5–6.9%. A level of 6–7% in forage is considered to be essential to maintain body functions (Milchunas *et al.* 1978; Swift *et al.* 1980). In our study, nitrogen content was not significantly correlated with preference; however, there was not a wide range for deer to choose from. Tucker *et al.* (1976) also did not find a relationship between crude protein in various sizes, ages, and parts of Douglas-fir and preference. In contrast, Oh *et al.* (1970) found deer to prefer seedlings treated with nitrogen fertilizer over those that were unfertilized.

Mineral deficiencies may only be temporary because diet and range location change seasonally. Shrubs and lichens in the winter diet may also compensate for the low levels of nitrogen, phosphorus, copper, sulphur and sodium found in Douglas-fir.

In vitro digestible dry matter of different size trees was not highly correlated with preference. The IVDDM can be measured to assess the degree to which a forage can be altered chemically and physically by the digestive process, making nutrients available for absorption. The digestibility of conifers is important to deer when it makes up the bulk of the diet because it affects the rate of forage intake. Our Douglas-fir samples were less digestible (32–43% IVDDM) than those (47% IVDDM) reported by Rochelle (1980) on Vancouver Island. Shrubs, the other major winter food, have similar digestibilities (25–53% IVDDM) to Douglas-fir (Milchunas *et al.* 1978; Rochelle 1980). Lichens (*Alectoria* spp.), a minor diet species, on the other hand, are highly digestible (73–85% IVDDM) during winter (Rochelle 1980; Robbins 1987).

A large body of literature discusses the effects of tannins on ruminants. Tannins are anti-quality compounds which depress digestion (Walker 1975; Mattson 1980). They are able to bind with plant proteins and gastro-intestinal enzymes, reducing protein and cell wall digestion (Zucker 1983). A detailed review of the role of tannins in forage quality, however, concluded that although plant tannins can be toxic to micro-organisms and animals, there is no direct evidence that they have a detrimental effect on the grazing ruminant (McLeod 1974). Herbivores may actually have a variety of methods to deal with forage high in tannin and other phenolics. For example, recent work by Robbins *et al.* (1987) documents that deer saliva is rich in proline, a tannin-binding protein produced by the parotid gland. The authors hypothesized that the tannin-proline complex passes through the digestive tract intact, enabling deer to eat highly tanniferous forage. Our study found no consistent negative correlations between tannins and preference.

RESEARCH LIMITATIONS AND RECOMMENDATIONS

Firm conclusions can not be reached in this study because of the limitations in the experimental design. In this section, we discuss each limitation and suggest improvements in design.

1. Although phosphorus was positively correlated with preference, untested chemicals may have confounded results. For example, other researchers have explored the role of chlorogenic acid, essential oils, moisture and carbohydrates in forage selection.

Some clones of coastal Douglas-fir are more resistant to deer browsing than others. Some data suggest that resistance to browsing decreases with increasing levels of chlorogenic acid (Radwan 1975; Radwan and Crouch 1978). Tucker *et al.* (1976) reported chlorogenic acid to be positively related to relative preferences ($r = .41$); however, Silen *et al.* (1986) recently found only a weak correlation ($r = .106$).

Oh *et al.* (1968) found that essential oils (specifically oxygenated monoterpenes) inhibited rumen microbial activity in deer. Later work reported that oxygenated monoterpenes might be absent or nearly absent from new growth, but common in mature foliage (Oh *et al.* 1970). Mule deer tend to eat the tips of fir twigs. Radwan and Crouch (1978) showed no relationship between essential oils of various clones of Douglas-fir and preference. Connolly *et al.* (1980), working with Douglas-fir seedlings, found a tendency for browsed plants to have more terpenes that are digestion promoters than terpenes that are inhibitors.

Tucker *et al.* (1976), using trees of various sizes and ages and from various locations, found a negative relationship between preference and moisture content ($r = -.57$; $p = .01$). This result contrasts with those of other authors who have found a positive relationship when using a variety of species (Radwan and Crouch 1974). Other studies looking at deers' forage selection by plant species document that desirable forage is low in fiber and high in soluble carbohydrates (Nagy *et al.* 1969). Radwan and Crouch (1978) also suggest *in vitro* cellulose digestibility to be a good general indication of species preference.

The experimental design would be improved if a wider range of chemicals were analyzed, although, as the literature suggests, the search for one compound may be elusive since palatability probably results from a balance between nutrients, toxins and digestibility-reducing compounds (Oh *et al.* 1970).

2. The second limiting factor in this experiment is sample size. A larger sample would enable analyses of the interacting factors which affect preference. It would also indicate the variance of chemicals within diameter class and site. As well, more samples are needed to compare variation among sites, study areas and years.
3. The experiment was designed to examine the relationship between preference and diameter. Because trees were not picked according to chemical concentrations, the range of values found for some chemicals may have been too narrow to affect preference. Also, once a chemical reaches a threshold nutrient requirement, it may no longer be selected for or selected against. Although phosphorus and preference are correlated, the range of values tested was narrow. This result might be strengthened if a wider range of values were tested. Experimental trees could receive various levels and types of fertilization, and so provide the variation in nutrient levels required to test various hypotheses adequately.
4. The degree of deer preference for younger trees in the absence of mature trees should be tested.

The following experimental design is proposed to address the problems of sample size, range of chemical concentrations, and variety of chemicals tested: Large branches from trees within the same diameter class and site could be placed in piles at a feeding site. Branches could be selected for the widest possible variation in colour, solar exposure, vigour and tree position, and this could be replicated in each diameter class. Sample size and variation in chemical concentration would also be increased. This design could be analysed with both analysis of variance, and multiple or logistic regression.

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APPENDIX 1. Chemical content of Douglas-fir twigs from various sections of trees of different diameters collected at Big Lake in 1987 and Knife Creek in 1985

Study ^a area	Site	Tree ^b type	Age	Height (m)	Dbh ^c (cm)	Tree ^d part	N (%)	P (%)	K (%)
BL	1	MA	178	23.3	40.3	B	—	0.153	0.437
BL	1	MA	178	23.3	40.3	MB	—	0.179	0.487
BL	1	MA	178	23.3	40.3	MT	—	0.176	0.458
BL	1	MA	178	23.3	40.3	T	—	0.157	0.481
BL	1	LP	186	20.8	29.5	B	—	0.208	0.389
BL	1	LP	186	20.8	29.5	M	—	0.199	0.422
BL	1	LP	186	20.8	29.5	T	—	0.197	0.465
BL	1	SP	83	14.6	21.4	B	—	0.177	0.514
BL	1	SP	83	14.6	21.4	M	—	0.172	0.548
BL	1	SP	83	14.6	21.4	T	—	0.185	0.618
BL	1	RE	27	3.3	3.5	W	—	0.139	0.490
BL	2	MA	146	24.7	47.6	B	—	0.167	0.402
BL	2	MA	146	24.7	47.6	MB	—	0.170	0.456
BL	2	MA	146	24.7	47.6	MT	—	0.170	0.451
BL	2	MA	146	24.7	47.6	T	—	0.173	0.474
BL	2	LP	123	19.0	29.0	B	—	0.143	0.400
BL	2	LP	123	19.0	29.0	M	—	0.144	0.398
BL	2	LP	123	19.0	29.0	T	—	0.156	0.453
BL	2	SP	144	14.9	25.5	B	—	0.151	0.374
BL	2	SP	144	14.9	25.5	M	—	0.148	0.359
BL	2	SP	144	14.9	25.5	T	—	0.168	0.434
BL	2	RE	27	3.4	3.6	W	—	0.159	0.447
KC	1	MA	120	22.8	43.0	B	0.9	0.210	0.470
KC	1	MA	120	22.8	43.0	MB	1.0	0.220	0.570
KC	1	MA	120	22.8	43.0	MT	0.9	0.220	0.510
KC	1	MA	120	22.8	43.0	T	1.1	0.220	0.560
KC	1	LP	120	15.3	25.5	B	1.0	0.160	0.560
KC	1	LP	120	15.3	25.5	M	0.9	0.160	0.580
KC	1	LP	120	15.3	25.5	T	1.1	0.130	0.620
KC	1	SP	70	12.6	16.5	B	0.9	0.180	0.590
KC	1	SP	70	12.6	16.5	T	1.0	0.180	0.650
KC	1	RE	37	5.3	5.7	W	0.9	0.150	0.620
KC	2	MA	200	23.0	44.5	B	0.9	0.230	0.520
KC	2	MA	200	23.0	44.5	MB	0.9	0.190	0.490
KC	2	MA	200	23.0	44.5	MT	1.0	0.170	0.520
KC	2	MA	200	23.0	44.5	T	0.9	0.190	0.480
KC	2	LP	120	16.0	25.0	B	1.0	0.150	0.510
KC	2	LP	120	16.0	25.0	M	1.0	0.170	0.560
KC	2	LP	120	16.0	25.0	T	0.9	0.130	0.540
KC	2	SP	135	11.0	14.5	B	0.9	0.180	0.620
KC	2	SP	135	11.0	14.5	T	1.1	0.170	0.660
KC	2	RE	21	—	3.7	W	0.8	0.180	0.620

^a Study area: BL = Big Lake, KC = Knife Creek.

^b Tree type: MA = mature, LP = large pole, SP = small pole, RE = regeneration.

^c Dbh is the diameter of the tree 1.3 m above the point of germination.

^d Tree part: T = top, MT = mid top, MB = mid bottom, B = bottom, W = whole.

APPENDIX 1. — *Continued*

Study ^a area	Site	Tree ^b type	Tree ^d part	Ca (%)	Mg (%)	S (%)	B (mg/kg)	Cu (mg/kg)	Na (mg/kg)
BL	1	MA	B	1.029	0.121	0.08	16.3	3.7	—
BL	1	MA	MB	0.981	0.106	0.10	19.2	4.1	—
BL	1	MA	MT	0.941	0.108	0.09	13.6	4.2	—
BL	1	MA	T	0.697	0.093	0.09	18.1	4.0	—
BL	1	LP	B	0.955	0.132	0.07	21.3	3.9	—
BL	1	LP	M	0.809	0.132	0.08	18.9	3.8	—
BL	1	LP	T	0.615	0.129	0.09	18.7	3.8	—
BL	1	SP	B	1.042	0.118	0.07	21.6	3.4	—
BL	1	SP	M	0.909	0.105	0.08	17.6	4.3	—
BL	1	SP	T	0.684	0.106	0.08	21.5	3.4	—
BL	1	RE	W	0.569	0.090	0.07	23.1	3.9	—
BL	2	MA	B	0.805	0.164	0.07	17.3	3.8	—
BL	2	MA	MB	0.660	0.143	0.07	14.3	3.9	—
BL	2	MA	MT	0.543	0.144	0.07	16.0	4.0	—
BL	2	MA	T	0.395	0.131	0.07	11.6	4.0	—
BL	2	LP	B	0.929	0.128	0.07	18.0	3.9	—
BL	2	LP	M	0.932	0.139	0.07	17.9	4.5	—
BL	2	LP	T	0.702	0.122	0.07	17.6	4.1	—
BL	2	SP	B	1.084	0.139	0.08	11.2	4.8	—
BL	2	SP	M	0.989	0.138	0.08	14.6	4.8	—
BL	2	SP	T	0.724	0.144	0.10	16.8	3.7	—
BL	2	RE	W	0.871	0.078	0.08	9.4	4.2	—
KC	1	MA	B	1.070	0.190	—	27.0	3.0	15
KC	1	MA	MB	0.690	0.170	—	26.0	3.0	8
KC	1	MA	MT	0.770	0.160	—	24.0	4.0	11
KC	1	MA	T	0.420	0.160	—	25.0	3.0	8
KC	1	LP	B	0.820	0.150	—	48.0	9.0	5
KC	1	LP	M	0.680	0.150	—	38.0	3.0	7
KC	1	LP	T	0.480	0.130	—	28.0	4.0	6
KC	1	SP	B	0.600	0.170	—	24.0	3.0	10
KC	1	SP	T	0.360	0.150	—	16.0	3.0	6
KC	1	RE	W	0.670	0.120	—	19.0	3.0	8
KC	2	MA	B	0.850	0.200	—	24.0	3.0	8
KC	2	MA	MB	0.720	0.160	—	22.0	3.0	13
KC	2	MA	MT	0.370	0.140	—	26.0	3.0	14
KC	2	MA	T	0.400	0.130	—	21.0	3.0	26
KC	2	LP	B	0.890	0.150	—	46.0	3.0	6
KC	2	LP	M	0.720	0.170	—	40.0	8.0	15
KC	2	LP	T	0.600	0.120	—	33.0	3.0	10
KC	2	SP	B	0.510	0.150	—	24.0	7.0	23
KC	2	SP	T	0.340	0.160	—	20.0	3.0	12
KC	2	RE	W	0.510	0.150	—	24.0	7.0	23

^a Study area: BL = Big Lake, KC = Knife Creek.

^b Tree type: MA = mature, LP = large pole, SP = small pole, RE = regeneration.

^c Dbh is the diameter of the tree 1.3 m above the point of germination.

^d Tree part: T = top, MT = mid top, MB = mid bottom, B = bottom, W = whole.

APPENDIX 1. — *Continued*

Study ^a area	Site	Tree ^b type	Tree ^c part	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Tannin A(510/g)	Browse (%)
BL	1	MA	B	186.1	—	40.2	2.84	90.0
BL	1	MA	MB	175.2	—	45.7	2.95	70.0
BL	1	MA	MT	181.2	—	47.0	2.92	37.0
BL	1	MA	T	185.2	—	41.3	3.20	72.0
BL	1	LP	B	226.4	—	34.6	4.21	8.0
BL	1	LP	M	120.4	—	31.4	5.30	0.1
BL	1	LP	T	107.3	—	29.4	4.94	0.0
BL	1	SP	B	166.3	—	28.1	3.12	3.0
BL	1	SP	M	200.4	—	27.8	2.60	28.0
BL	1	SP	T	159.2	—	24.9	2.79	15.0
BL	1	RE	W	161.3	—	29.0	6.63	0.0
BL	2	MA	B	138.1	—	40.0	5.21	15.0
BL	2	MA	MB	118.8	—	36.5	5.77	25.0
BL	2	MA	MT	108.8	—	34.9	5.42	25.0
BL	2	MA	T	130.9	—	33.6	5.16	20.0
BL	2	LP	B	137.2	—	36.3	4.91	2.0
BL	2	LP	M	136.5	—	34.1	4.05	3.0
BL	2	LP	T	104.5	—	32.1	4.04	1.0
BL	2	SP	B	185.3	—	49.8	3.78	0.0
BL	2	SP	M	173.9	—	56.3	3.12	1.0
BL	2	SP	T	114.6	—	47.4	3.38	2.0
BL	2	RE	W	132.9	—	36.8	4.56	0.5
KC	1	MA	B	106.0	415	26.0	16.50	98.0
KC	1	MA	MB	77.0	275	23.0	16.50	100.0
KC	1	MA	MT	165.0	339	26.0	15.70	100.0
KC	1	MA	T	114.0	236	24.0	20.00	99.0
KC	1	LP	B	117.0	330	31.0	8.00	25.0
KC	1	LP	M	98.0	231	25.0	11.00	65.0
KC	1	LP	T	71.0	238	27.0	8.20	40.0
KC	1	SP	B	145.0	410	25.0	14.00	5.0
KC	1	SP	T	78.0	313	25.0	15.70	15.0
KC	1	RE	W	93.0	462	28.0	15.50	2.0
KC	2	MA	B	98.0	331	23.0	14.20	95.0
KC	2	MA	MB	91.0	258	23.0	15.00	95.0
KC	2	MA	MT	99.0	210	20.0	11.20	95.0
KC	2	MA	T	121.0	208	23.0	17.50	95.0
KC	2	LP	B	80.0	367	24.0	8.00	3.0
KC	2	LP	M	132.0	212	48.0	7.20	8.0
KC	2	LP	T	79.0	296	25.0	8.70	5.0
KC	2	SP	B	93.0	428	28.0	12.70	5.0
KC	2	SP	T	79.0	309	25.0	13.00	18.0
KC	2	RE	W	93.0	428	28.0	16.00	0.3

^a Study area: BL = Big Lake, KC = Knife Creek.

^b Tree type: MA = mature, LP = large pole, SP = small pole, RE = regeneration.

^c Dbh is the diameter of the tree 1.3 m above the point of germination.

^d Tree part: T = top, MT = mid top, MB = mid bottom, B = bottom, W = whole.

APPENDIX 2. Chemical content of Douglas-fir twigs from various sections of trees of different diameters collected at Knife Creek in 1986

Site	Tree ^a type	Age	Height (m)	Dbh ^b (cm)	Tree ^c section	P (%)	K (%)	Ca (%)	Mg (%)
1	OG	200	32.7	104	B	.180	.55	.503	.14
1	OG	200	32.7	104	T	.181	.57	.422	.13
1	MA	89	23.3	47	B	.136	.44	.375	.14
1	MA	89	23.3	47	T	.154	.54	.358	.13
1	P	54	9.8	18	B	.132	.47	.363	.15
1	P	54	9.8	18	T	.139	.51	.248	.13
1	RE	17	5.3	10	B	.107	.59	.264	.10
2	OG	200	29.4	91	B	.154	.45	.406	.19
2	OG	200	29.4	91	T	.167	.49	.385	.16
2	MA	136	28.8	47	B	.144	.54	.460	.15
2	MA	136	28.8	47	T	.162	.56	.335	.13
2	P	53	11.8	27	B	.139	.51	.342	.17
2	P	53	11.8	27	T	.145	.48	.374	.15
2	RE	53	3.3	5	B	.135	.59	.292	.12

^a Tree type: OG = old growth, MA = mature, P = pole, RE = regeneration.

^b Dbh is the diameter of the tree 1.3 m above the point of germination.

^c Tree section: T = top, B = bottom.

Site	Tree type	Tree part	S (%)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Tannin A(510/g)	IVDDM ^d (%)
1	OG	B	.090	2.0	79.6	56.5	16.4	3.05	40.32
1	OG	T	.082	1.1	64.3	104.4	15.3	3.70	35.65
1	MA	B	.077	1.3	58.8	96.8	21.7	5.20	35.44
1	MA	T	.076	1.9	71.7	133.4	27.0	5.70	40.63
1	P	B	.082	1.3	69.7	118.8	23.3	2.45	42.83
1	P	T	.079	1.0	54.5	101.5	20.2	2.40	41.15
1	RE	B	.063	.8	43.7	94.3	17.8	8.15	32.98
2	OG	B	.081	1.7	45.6	63.3	19.2	4.20	36.87
2	OG	T	.085	1.9	106.1	60.6	17.2	5.50	34.41
2	MA	B	.080	1.3	64.8	103.7	21.2	4.65	41.92
2	MA	T	.077	1.9	62.7	88.5	20.5	5.45	41.56
2	P	B	.082	1.0	57.7	112.5	15.0	4.05	39.45
2	P	T	.080	.5	68.0	142.6	14.2	3.50	41.79
2	RE	B	.058	.8	44.7	117.6	15.1	8.95	39.48

^d IVDDM — *in vitro* digestible dry matter.