FREP

REPORT #34

FOREST AND RANGE EVALUATION PROGRAM

December 2012

EFFECTS OF LIVESTOCK GRAZING ON FORAGE PRODUCTION, FORAGE QUALITY, AND SOIL PROPERTIES AT SIX SITES IN THE SOUTHERN INTERIOR

Prepared by:
Rick Tucker, Matt Fairbarns and Francis Njenga

December 2012

FREP
Forest & Range
Evaluation Program

BRITISH
COLUMBIA

Sustainability of Forest and Range Resources Through Science and Stewardship

MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS
FOREST AND RANGE EVALUATION PROGRAM

EFFECTS OF LIVESTOCK GRAZING ON FORAGE PRODUCTION, FORAGE QUALITY, AND SOIL PROPERTIES AT SIX SITES IN THE SOUTHERN INTERIOR

Prepared by:
Rick Tucker, Matt Fairbarns and Francis Njenga

December 2012

FREP monitoring identifies resource practices that have proven effective in sustainably managing forest and range resource values and highlights opportunities for continued improvement.

The FREP Mission:
To be a world leader in resource stewardship monitoring and effectiveness evaluations; communicating science-based information to enhance the knowledge of resource professionals and inform balanced decision-making and continuous improvement of British Columbia's forest and range practices, policies and legislation. *http://www.for.gov.bc.ca/hfp/frep/index.htm*

FREP
Forest & Range
Evaluation Program

BRITISH COLUMBIA

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the Government of British Columbia of any product or service to the exclusion of any others that may also be suitable. Contents of this report are presented for discussion purposes only. Funding assistance does not imply endorsement of any statements or information contained herein by the Government of British Columbia.

Management of forest and range resources is a complex process that often involves the balancing of ecological, social, and economic considerations. This evaluation report represents one facet of this process. Based on monitoring data and analysis, the authors offer the following recommendations to those who develop and implement forest and range management policy, plans, and practices.

Citation:
Tucker, R., Fairbarns, M. and Njenga, F. Effects Of Livestock Grazing On Forage Production, Forage Quality, And Soil Properties At Six Sites In The Southern Interior. Ministry of Forests, Lands and Natural Resource Operations, Range Branch, Kamloops, BC FREP Report 34.
http://www.for.gov.bc.ca/hfp/frep/publications/index.htm

Prepared by: Rick Tucker, Matt Fairbarns and Francis Njenga

Copies of this report may be obtained, depending on supply, from:
Government Publications
PO Box 9452, Stn Prov Govt
Victoria BC V8W 9V7

In Victoria (250) 387-6409
Outside Victoria 1-800-663-6105

http://www.publications.gov.bc.ca

For more information on Forest Practices Branch publications, visit our web site at:
http://www.for.gov.bc.ca/hfp/meta/publications.htm

© 2012 Province of British Columbia

ACKNOWLEDGEMENTS

This project was partially funded by the Forest and Range Evaluation Program of the B.C. Ministry of Forests, Lands and Natural Resource Operations. Barb Zimonick, Mona Doney, Nicole Brand, Shirley Bradley, Sadie Cox, Weston Pike, Brian Wikeem, Sandra Wikeem, Nick Hamilton, and Cynthia Fell conducted the field sampling. Percy Folkard assisted with the statistical analysis. Doug Fraser and Susan Bannerman provided edit and review of the project documents.

EXECUTIVE SUMMARY

The effects of livestock grazing and canopy closure on forage production, forage quality, and soil properties were assessed at several locations near Kamloops, B.C., for 3 years from 2004 to 2006. Each site represented a different ecosystem and each had a distinct grazing history over the past 50–100 years.

To estimate annual above-ground forage production, litter accumulation, and forage quality, grass and forb species were clipped in five 0.5 m^2 plots inside and outside livestock exclosures. The six locations where sampling took place included Hunter's Range, Smith Camp, Tunkwa Lake, Will Lake Lodgepole Pine, Will Lake Douglas-fir, and Yellow Pine Spacing Trial. Clipped material was separated to species, dried at 60°C for 24 hours, and weighed to the nearest .01 g. For the forage quality analysis, samples were pooled and analyzed for nitrogen and acid detergent fibre (ADF). An index of available digestible nitrogen for each species at each location each year was used as a surrogate for forage quality. Although sampling involved no interspersed replication, care was taken to select sites that were similar in the expression of abiotic factors (elevation, slope, aspect, and soil type, soil depth and parent material), leaving grazing or canopy closure effects as the most likely cause of any observed differences.

To estimate the effects of grazing on soil chemistry, soil samples were collected inside and outside of livestock exclosures at all locations except Smith Camp. Samples were analyzed for pH, cation exchange capacity and electro-conductivity, exchangeable Al, Na, Ca, Fe, K, Mg, and Mn, extractable Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, P, and Mn, available P, and total C and total N.

Depending on the number of the treatments tested at each site, a two- or three-factor analysis of variance was used to detect significant differences between the forage quantity and quality samples collected inside and outside exclosures. Significant differences within factors were determined by a Tukey's multiple range test. For the soil chemistry analyses, simple t-tests or a single-factor analysis of variance were used to detect significant differences between samples collected inside and outside exclosures.

The statistical analyses revealed that few differences were evident in soil chemistry inside and outside the exclosures, suggesting that grazing did not affect the soil properties at any of the sites. However, the statistical analyses for forage quantity and quality showed that biomass production and digestible nitrogen were lower outside the exclosures than inside at four of the sites (Hunter's Range, Tunkwa Lake, Yellow Pine Spacing Trial, and Will Lake Douglas-fir); at the two other sites (Smith Lake and Will Lake Lodgepole Pine), no statistically significant differences were observed.

Our results suggest an effect of grazing on forage production and digestible nitrogen at four locations and no effect at the other two. In particular, management favouring heavy use (> 60%) and lack of rest (annual grazing) at the Tunkwa Lake, Yellow Pine Spacing Trial, and Will Lake Douglas-fir sites led to reduced forage biomass, lower accumulations of litter, and reduced forage and litter digestible nitrogen. Lower litter digestible nitrogen has serious consequences because the inherent low soil nitrogen on these sites and few mechanisms for nitrogen inputs. The Smith Camp and Will Lake Lodgepole Pine sites both had lower levels of livestock grazing (< 25%), and showed no difference in forage productivity or digestible nitrogen between the grazed and ungrazed sites.

These results also suggest that the benefit of the heavily grazed sites to the livestock industry has diminished. Short-term gains from this management may be offset in the future by severe reductions in productivity, susceptibility to invasive plants, and an elevated risk of erosion. Care needs to be taken to select stocking rates and grazing regimes that will maintain appropriate levels of forage production.

It is also reasonable to conclude that as canopy cover increases, forage production and forage digestible nitrogen decreases. Opportunities are available to manage for both optimal tree canopies and forage production. Management for either maximum timber production or maximum forage production will lead to reduced net benefits.

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

Livestock grazing, range practices, and range developments on Crown range are governed by the *Forest and Range Practices Act* (FRPA). Because sustainable livestock operations depend on healthy plant communities, maintaining or enhancing forage quantity and quality for livestock and wildlife are key components of the Forage and Associated Plant Communities objective noted in the Range Planning and Practices Regulation under FRPA. The Forest and Range Evaluation Program (FREP) is assessing whether the legislation, regulations, management standards, and practices under the act are effective in managing the province's forest and range resources sustainably. Through its priority evaluation question for the Forage and Associated Plant Communities objective, FREP specifically seeks to determine: "what impacts are forest and range practices having on the quality and quantity of forage, and on species composition and structure of the forest understorey."

This report describes a research project that tested the magnitude of grazing impacts by comparing species biomass and forage quality, both inside and outside range exclosures, over a 3-year period in the Southern Interior of British Columbia. Six sites near Kamloops, B.C., were selected that represented a broad spectrum of range areas with different grazing histories. Two of the locations had different tree canopy covers, allowing an additional comparison of the effect of canopy closure on both forage production and forage quality. The report also identifies variations in soil chemistry in range exclosures at five of the sites.

2.0 BACKGROUND AND METHODOLOGY

Grazing is suspected of affecting species composition and biomass, forage quality, and soil properties. As part of a comprehensive system of more than 350 range reference areas across British Columbia, range exclosures have been established on rangelands to protect vegetation from grazing and browsing. Managed by the B.C. Ministry of Forests, Lands and Natural Resource Operations, these permanent vegetation sampling plots aid in determining the impact of livestock, wildlife, and other disturbances on British Columbia rangelands.

Range exclosures allow the study and monitoring of climax species composition on grassland and forested range types that exhibit similar site conditions. These sites are subject to the same year-to-year climatic fluctuations as adjacent managed grasslands and thus also allow for direct comparison of changes over time. As such, range exclosures provide evidence of recovery from the effects of grazing.

2.1 *Sampling Considerations in Range Reference Areas*

To test inferences about ecosystem responses to the reduction or removal of grazing, multiple range exclosures should ideally be established at each research site, allowing data to be collected from interspersed grazed and ungrazed areas. Nevertheless, replicated experiments are uncommon in studies of large-scale systems because of their expense and inherent complexity. Instead, "replicate" data are collected from several locations within an exclosure and an equal number of locations outside. However, if inferences about the effects of livestock exclusion are then drawn from this data, one is guilty of what Hurlbert (1986) referred to as simple "pseudoreplication." In this type of experimental design, chance events directly affecting one sample unit within a treatment group are more likely to affect other sample units within that group than sample units in other treatment groups. As a result, treatment effects cannot be rigorously estimated.

Many, including Oksanen (2001), widely share the belief that scientists have become too concerned about pseudoreplication, and Heffner et al. (1996) also criticized those who take an "unflinching view of unreplicated experiments." Although Hurlbert (1986) did not object to the use of unreplicated data, and noted that "... the quality of an investigation depends on more than good experimental design," he did object to situations in which authors imply a treatment effect through the use of graphs, showing treatment means with non-overlapping standard errors or confidence limits, for example. However, if the collected data is not used to estimate the degree of the treatment effects, then pseudoreplication is not an issue.

Some exclosures examined in this research project were established over the past 15 years and baseline information was collected on vegetation cover at the time of establishment; however, pre-treatment data was not collected on plant biomass, foliar chemical composition, or soil nutrient levels. Consequently, it is not possible to determine whether distinctions observed between plots reflect pre-existing conditions. Nevertheless, in unreplicated range exclosure studies, it is reasonable to test for significant differences between conditions inside and outside an exclosure and then discuss these differences in light of responses that are likely a result of grazing treatments, although grazing practices are only one possible explanation for the differences observed; follow-up studies are often needed to directly test such inferences.

2.2 *Study Sites*

Table 1 summarizes the characteristics of the six study sites near Kamloops, B.C.[1]

Table 1. ***Characteristics of six study sites near Kamloops, B.C.***

Site	Elevation (m) BEC	Community type	Management history	Primary treatment	Secondary treatment
Hunter's Range	1865 ESSFwc4	Subalpine Tall Forb	Light grazing (30%) for the last 5 years; heavy cattle grazing (> 60%) for the previous 20 years	Inside ungrazed exclosure (built 1994) *vs.* Outside grazed area	Not applicable
Smith Camp	1140 IDFxh2	Douglas-fir/ Pinegrass	Moderate cattle use (35%) for at least 20 years; some year-long horse grazing	Inside ungrazed exclosure (built 1997) *vs.* Outside grazed area	Not applicable
Will Lake Lodgepole Pine	1250 MSdm2	Lodgepole Pine/Pinegrass	Light to moderate cattle use (25%) for at least 40 years	Inside ungrazed exclosure (built 1997) *vs.* Outside grazed area	Not applicable
Tunkwa Lake	1200 IDFdk1	Rough Fescue grassland	Heavy livestock use (> 60%) for about 100 years; year-long horse use	Inside ungrazed old exclosure (built 1960) *vs.* Inside ungrazed new exclosure (built 1993) *vs.* Outside grazed area	Not applicable
Yellow Pine Spacing Trial	610 IDFxh2	Yellow Pine/ Rough Fescue–Pinegrass	Severely burned in 1959 and planted to yellow pine in 1960 at various spacings; heavy grazing (> 60%) since 1960	Inside ungrazed exclosure (built 1960) *vs.* Outside grazed area	2.4-m spacing ungrazed *vs.* 6.1-m spacing ungrazed
Will Lake Douglas-fir	1070 IDFdk2	Douglas-fir/ Pinegrass	Moderate cattle grazing (35%) for about 50 years; Heavy cattle grazing (> 60%) beginning in early 1990s	Inside ungrazed exclosure (built 1997) *vs.* Outside grazed area	Recently logged *vs.* Not logged for at least 60 years

---

[1] Note that the Smith Camp location was not used for the soil chemistry analyses.

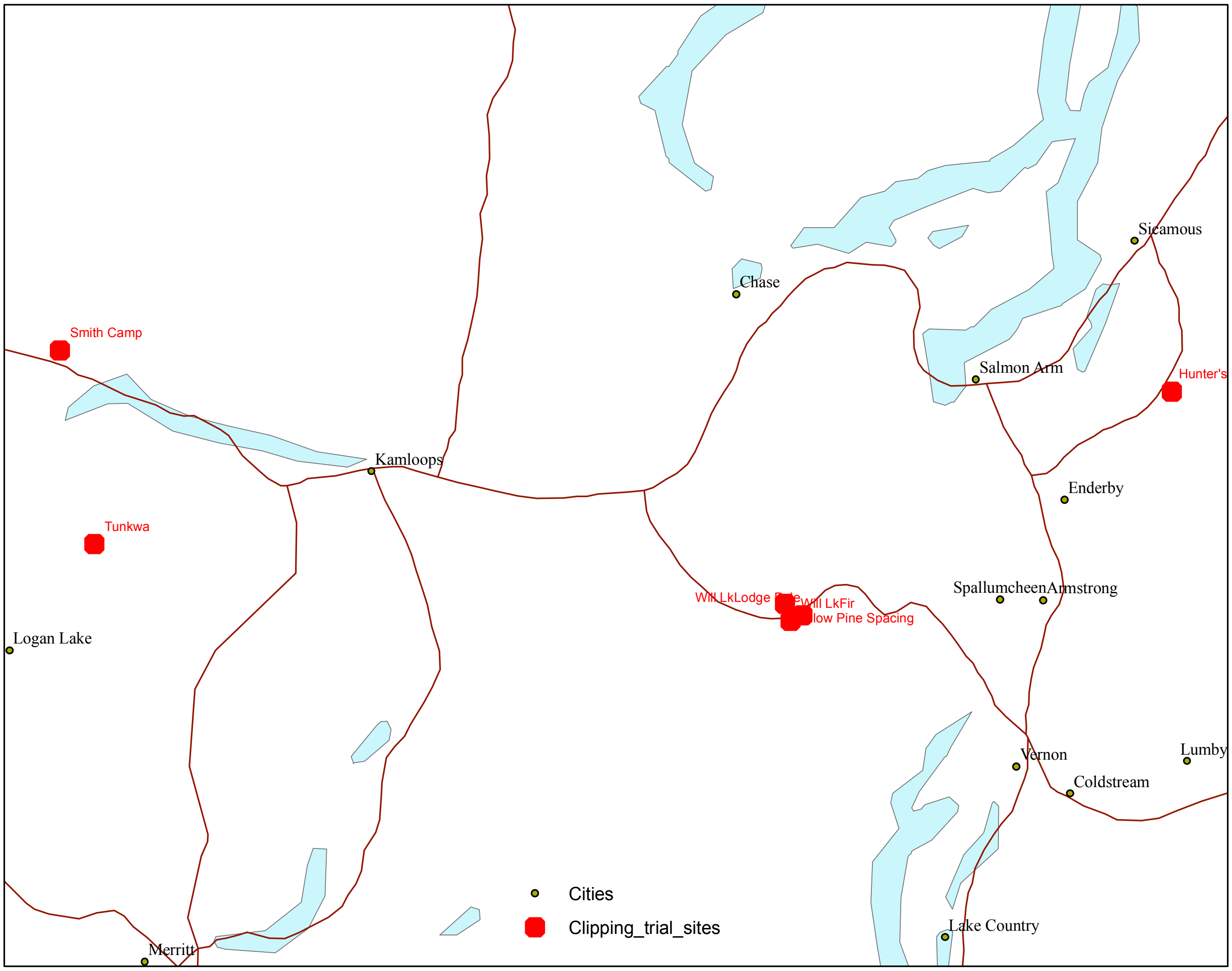


Figure 1. *Map of Sampling sites*

2.3 *Sample Plot Layouts*

Figures 1–4 illustrate the conceptual layout of sample plots at the six study sites.

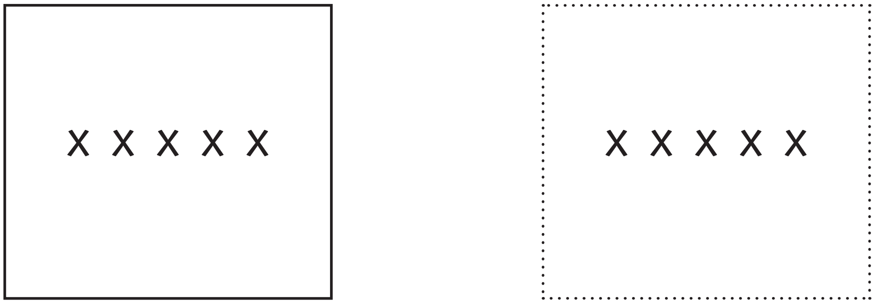


Figure 2. *Conceptual layout of sample plots (Version 1). Solid lines indicate the boundaries of the (ungrazed) exclosure. Dotted lines indicate boundaries of external (grazed) sample plot; "x" indicates the five subsample locations. The Hunter's Range, Smith Camp, and Will Lake Lodgepole Pine sites followed this layout.*

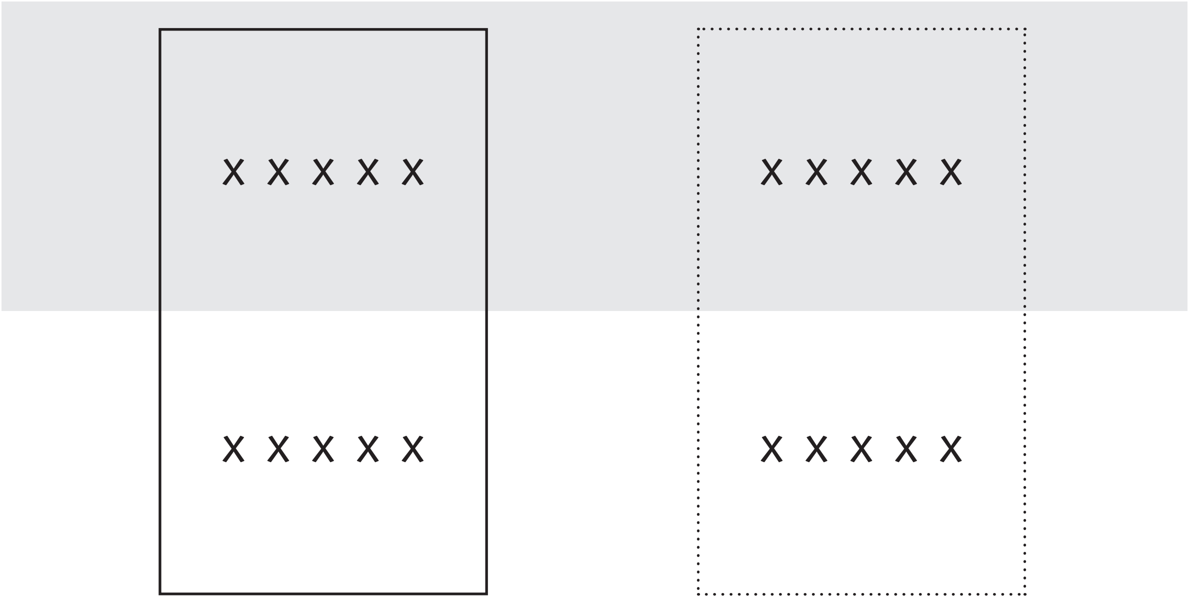


Figure 3. *Conceptual layout of sample plots (Version 2). As in Figure 1 but addition of grey block shows where the tree cover was reduced. The Will Lake Douglas-fir site followed this layout.*

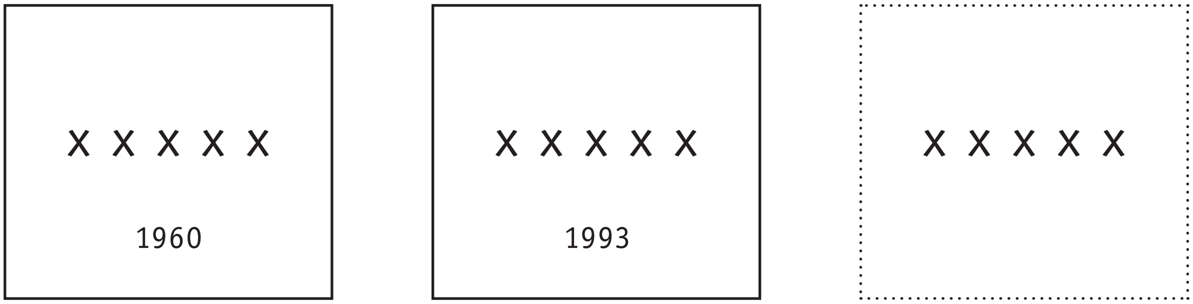


Figure 4. *Conceptual layout of sample plots (Version 3). As in Figure 1 but with two exclosure treatments of different ages. The Tunkwa Lake site followed this layout.*

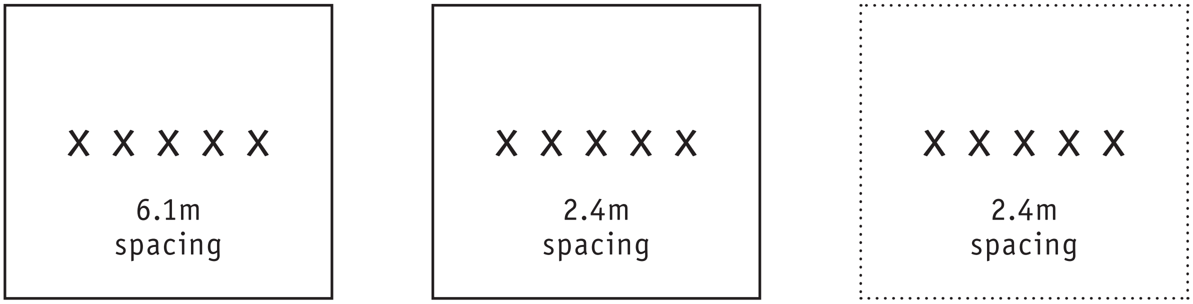


Figure 5. *Conceptual layout of sample plots (Version 4). As in Figure 1 but with two, differently spaced tree cover exclosure sites and one grazed area. The Yellow Pine Spacing Trial site followed this layout.*

2.4 Data Collection and Laboratory Techniques

Figures 1–4 illustrate the conceptual layout of sample plots at the six study sites.

At Hunter’s Range, Smith Camp, and Will Lake Lodgepole Pine sites, five 0.5 m^2 plots were placed inside a livestock exclosure (“inside treatment”) and five 0.5 m^2 plots were selected outside the exclosure (“outside treatment”) to represent the same habitat as that within the exclosed plots. The outside plots had cages placed over them in April before grazing commenced.

At the Yellow Pine site 5 plots were placed in the 2.4m spacing, 5 plots were located in the 6.1m spacing and 5 plots placed outside the exclosure.

At the Will lake Douglas-fir site 5 plots were placed in the recently logged areas inside and outside of the exclosure, 5 plots were placed in the unlogged area inside and outside of the exclosure.

For the forage quantity and quality sampling, all herbage (grass and forbs) in the plots was clipped to ground level in August. Litter was collected by gently raking the plot with fingers. Clipped material was separated to species (minor species were combined). Material was dried at 60°C for 24 hours and weighed to the nearest .01 g. New plots were selected for subsequent years sampling

To establish forage quality values, the samples for each species were pooled and analyzed for nitrogen and acid detergent fibre (ADF). Nitrogen values were ascertained with a Fisons (Carlo-Erba) NA-1500 Analyzer, and ADF values were determined using the Forage Fibre Analysis method (Goering and Van Soest 1970). Percent digestible nitrogen was calculated by: nitrogen concentration x (1 – ADF). This value provides an index of digestible protein. Total digestible nitrogen was calculated by: biomass x nitrogen concentration x (1 – ADF). This value, in kilograms per hectare, provides an index of the overall forage quality of the site. Appendix A lists the nitrogen and acid detergent fibre values by species.

To establish soil chemistry values, six soil samples were collected from inside and outside plots at five of the study sites.[2] Samples were collected from the top 15 cm, which included the A soil horizon where it existed and a portion of the B horizon when the A horizon did not extend to that depth. This depth captured the majority of the rooting zone, and also represents the depth at which management practices are most likely to affect soil chemistry.

Each soil sample was submitted to the B.C. Ministry of Forests, Land and Natural Resource Operations for chemical analysis where the following attributes were measured:

- pH, cation exchange capacity, and electro-conductivity
- exchangeable aluminum (Al), sodium (Na), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), and manganese (Mn)
- extractable (“Mehlich-3”) Al, boron (B), Ca, copper (Cu), Fe, K, Mg, Mn, Na, phosphorus (P), and zinc (Zn)
- available P
- total carbon (C) and total nitrogen (N)

2.5 Statistical Analysis: Forage Quantity and Quality

A two-factor analysis of variance was used to detect significant differences between samples collected inside and outside exclosures at the Smith Camp, Hunter’s Range, and Will Lake Lodgepole Pine sites over 3 years.

A three-factor analysis of variance was used to detect significant differences at Tunkwa Lake (old exclosure, new exclosure, and grazed area treatments), at the Yellow Pine Spacing Trial (2.4m spacing ungrazed, 6.4m spacing ungrazed, and 2.4m spacing grazed treatments), and at the Will Lake Douglas-fir site (logged and unlogged, and grazed and ungrazed treatments) over 3 years.

Significant differences within factors (as identified by the analysis of variance) were determined by a Tukey’s multiple range test.

2.6 Soil Chemistry

Simple t-tests were used to detect significant differences between samples collected inside and outside exclosures at the Hunter’s Range and Will Lake Lodgepole Pine sites as well as to examine soil chemistry data from the Will Lake Douglas-fir site.

A single-factor analysis of variance was used to detect significant differences between samples collected in the three different treatments at Tunkwa Lake and at the Yellow Pine Spacing Trial.

In general, data were not transformed because of the robust nature of these simple tests. The one exception was the C:N ratios, which were log-transformed before testing for significant differences among sample sets.

---

[2] Please note that soil chemistry was not tested at the Smith Camp location.

3.0 RESULTS AND DISCUSSION

3.1 *Hunter's Range*

Hunter's Range Inside

Hunter's Range Outside

3.1.1 Herbage production

Herbage biomass showed interaction among years and between treatments (Figure 5). For the ungrazed, inside area in 2004, herbage biomass (143 g/0.5 m^2) was higher than the rest of the treatment x year combinations except for the grazed, outside area in 2006 ($p < 0.1$). For the grazed area in 2006, herbage biomass (112 g/0.5 m^2) was greater than the grazed area in 2004 and both 2005 treatments ($p < 0.5$). Grazing does not appear to have a consistent effect on herbage biomass. Although a large difference was evident in 2004, this was not apparent in the other years.

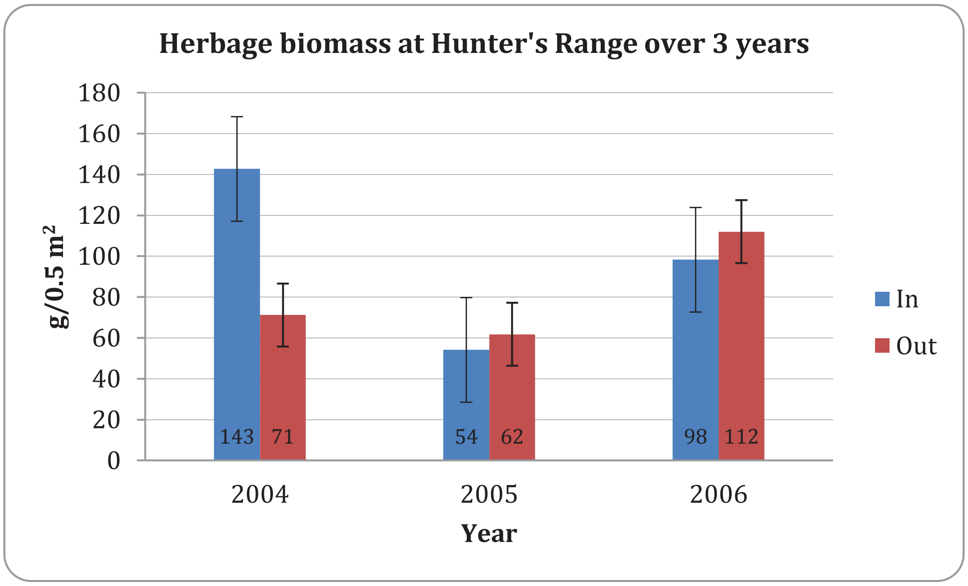


Figure 6. *Herbage biomass at the Hunter's Range site. Error bars indicate standard error.*

3.1.2 Herbage quality

An interaction was evident among years and treatments for digestible nitrogen (Figure 6), with the ungrazed treatment showing greater digestible nitrogen values in 2004 (32 kg/ha) than for 2005 and 2006 (average: 6.7 kg/ha; $p < 0.01$).

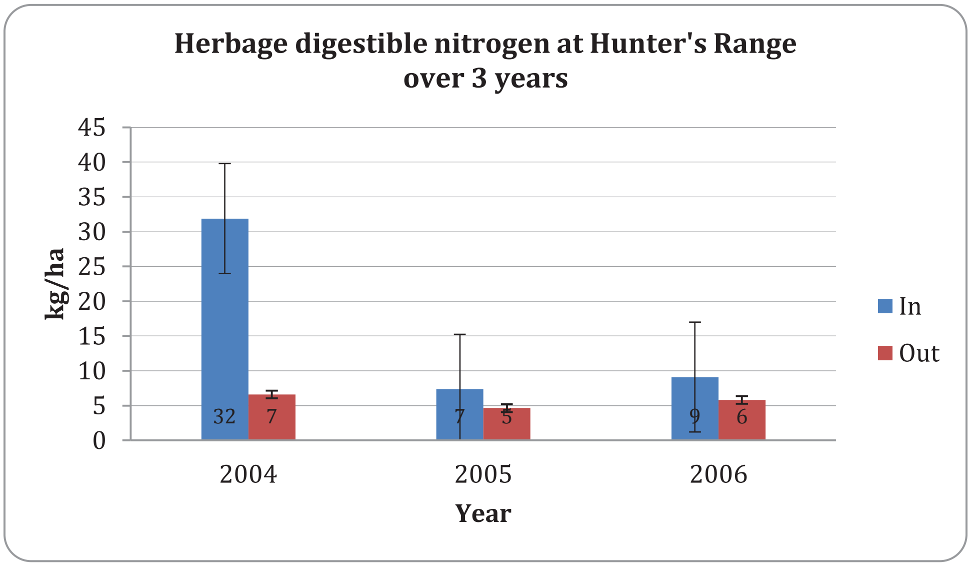


Figure 7. *Herbage digestible nitrogen at the Hunter's Range site. Error bars indicate standard error.*

A definite pulse of digestible nitrogen is evident in 2004 and, as can be seen below, hairy arnica and arctic lupine contributed to this pulse (see sections 3.1.6 and 3.1.8, respectively). For 2004, therefore, it could be inferred that grazing caused a substantial impact on available nitrogen, although it is impossible to determine why this effect did not happen in the subsequent years.

3.1.3 Litter production

Litter biomass was different among years but not different between treatments (Figure 7). In 2006, litter biomass (35 g/0.5m^2) was greater than other combinations of year and treatment ($p < 0.01$).

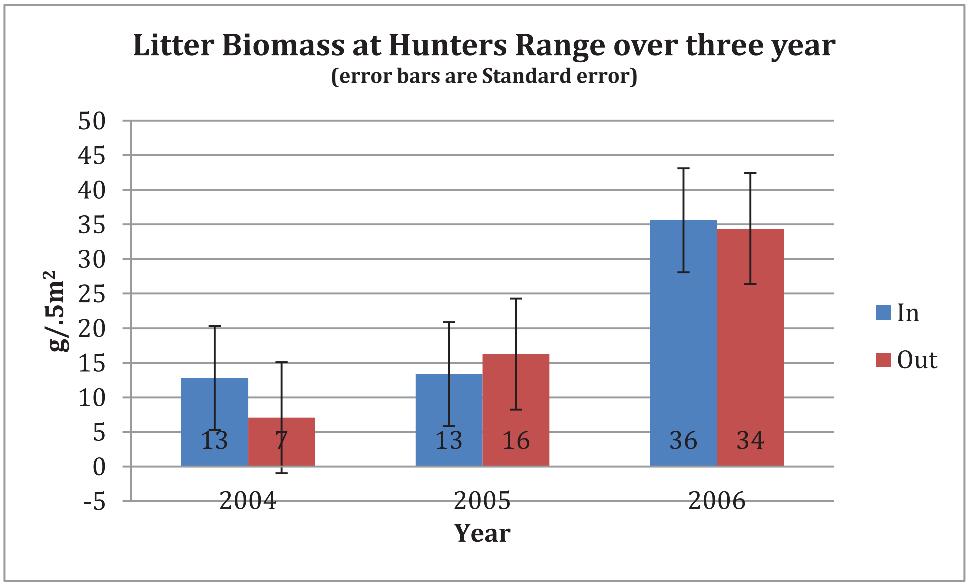


Figure 8. *Litter biomass at the Hunter's Range site. Error bars indicate standard error.*

3.1.4 Litter quality

Litter digestible nitrogen was different among years but not between treatments ($p < 0.01$) (Figure 8). The 2006 value (6.1 kg/ha) was greater than the other years 2.2 kg/ha, which was due to the differences among years in the litter biomass. The nitrogen and ADF values were very similar for all 3 years (Table 2). The litter differences are possibly due to the pulse of biomass noted for herbage in 2004.

Table 2. ***Nitrogen (N), acid detergent fibre (ADF), biomass (Wt), and digestible nitrogen (DigN) of litter at the Hunter's Range site over 3 years***

Year	N (%)	ADF (%)	Wt (G/0.5m^2)	DigN (kg/ha)
2004	1.9	60.2	9.9	1.6[a]
2005	2.0	52.8	14.8	2.8
2006	2.1	58.6	35.0	6.1

[a] This is the weighted average of N x (1–ADF) x Wt for each treatment x year combination and therefore is not equal to a calculation using the averages given in the table. [The average of the products is not equal to the product of the averages.]

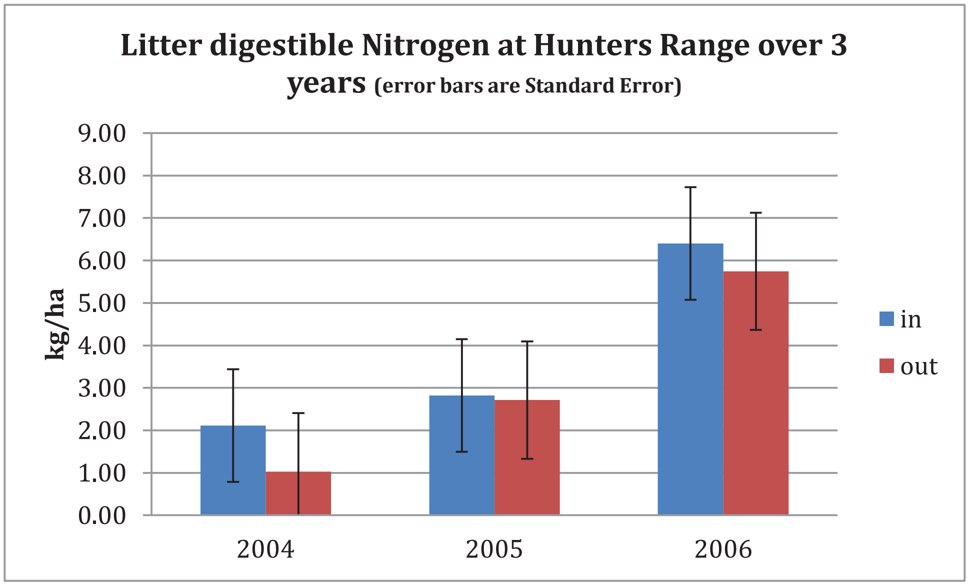


Figure 9. ***Litter digestible nitrogen at the Hunter's Range site. Error bars indicate standard error.***

3.1.5 Hairy arnica production

Hairy arnica biomass interacted with treatments and years (Figure 9). In 2004, the ungrazed treatment had greater arnica biomass (11 g/0.5 m^2) than the other combinations. The ungrazed plots in 2005 had greater biomass (6 g/0.5 m^2) than the grazed treatment that year and both treatments in 2006. Grazing appears to have reduced hairy arnica in two of the years, but in 2006 little biomass was evident either inside or outside the exclosure.

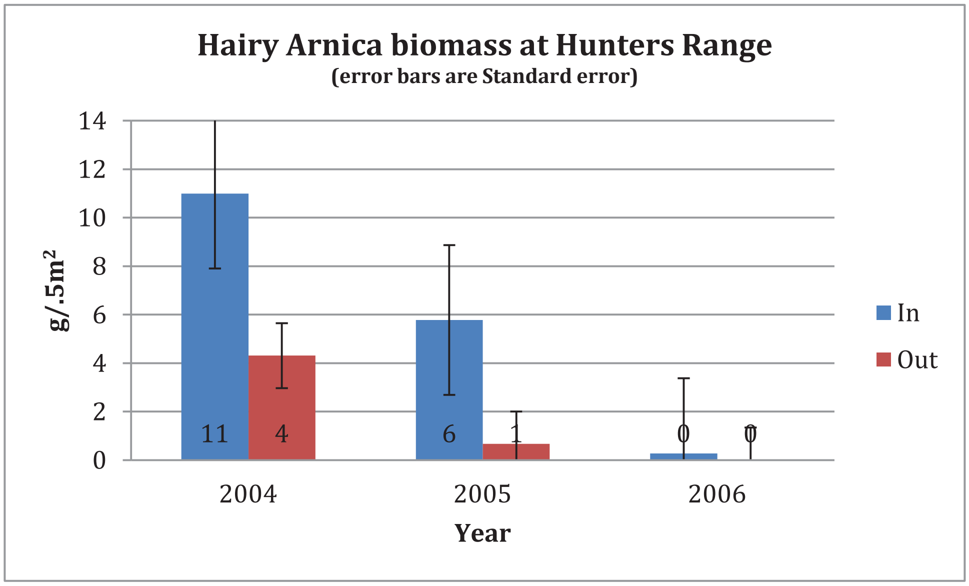


Figure 10. *Hairy arnica biomass at the Hunter's Range site. Error bars indicate standard error.*

3.1.6 Hairy arnica quality

An interaction was evident among years and treatments for digestible nitrogen in hairy arnica (Figure 10). In 2004, digestible nitrogen inside the exclosure (2.7 kg/ha) was greater than the rest of the combinations. In 2006, the plots outside the exclosure had the lowest value (0.0 kg/ha), whereas the other values were not different. The large difference between grazed and ungrazed treatments in 2004 could be interpreted as a substantial impact from grazing.

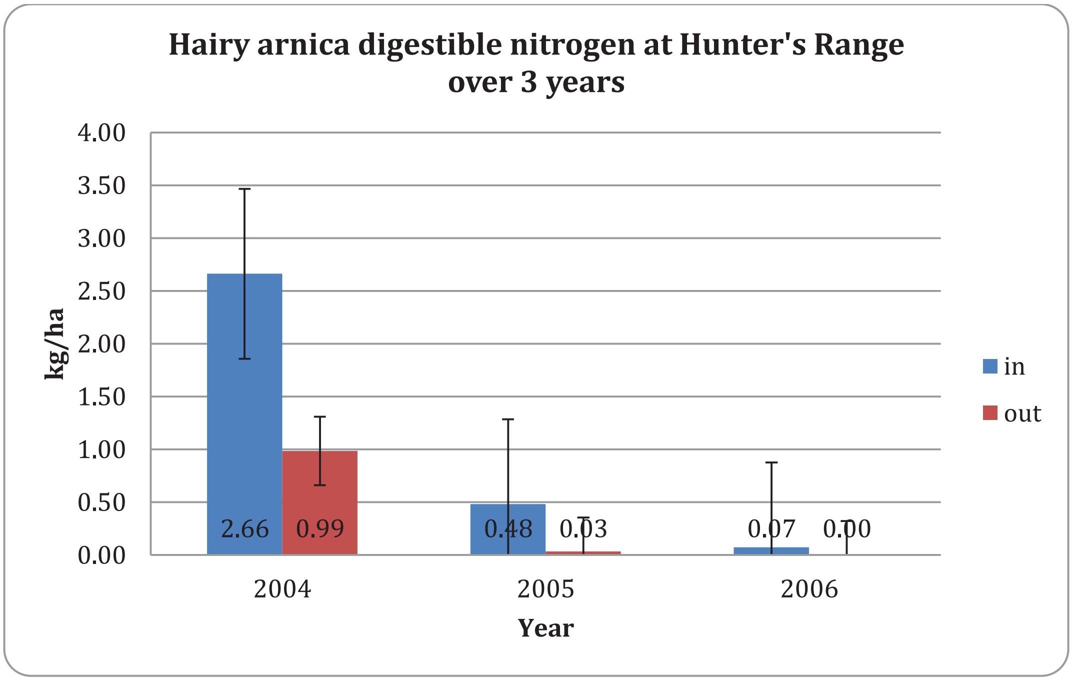


Figure 11. *Hairy arnica digestible nitrogen at the Hunter's Range site. Error bars indicate standard error.*

3.1.7 Arctic lupine production

Lupine biomass was different between treatments and among years (Figure 11). The ungrazed treatment biomass (34 g/0.5 m^2) was greater than the grazed treatment (5 g/0.5 m^2; $p < 0.001$) and 2004 (32 g/0.5 m^2) had greater biomass than the other 2 years (3 g/0.5 m^2; $p < 0.1$). Rest from grazing has allowed arctic lupine to increase. This increase may be short lived as lupine is replaced by late seral species.

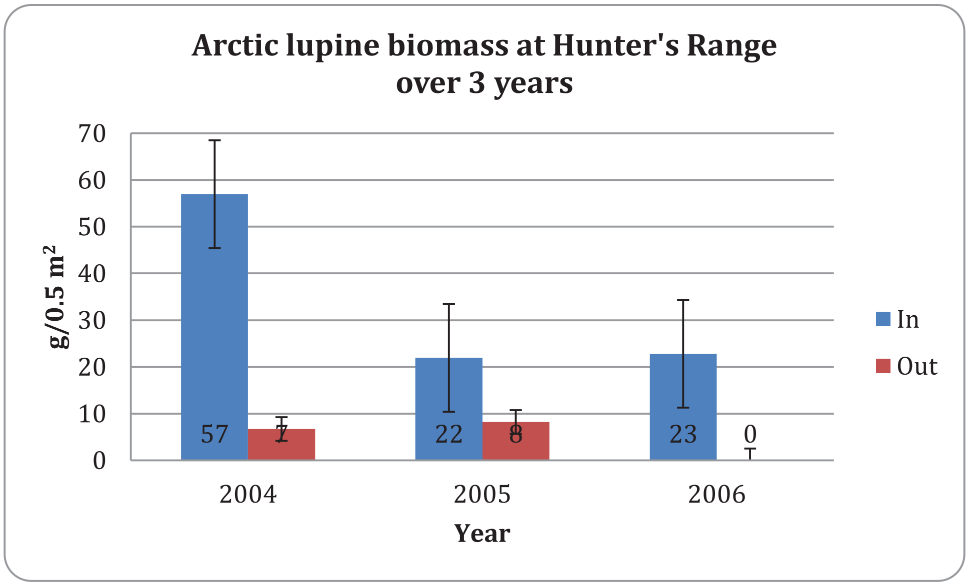


Figure 12. *Arctic lupine biomass at the Hunter's Range site. Error bars indicate standard error.*

3.1.8 Arctic lupine quality

An interaction was evident between treatments and among years for digestible nitrogen in arctic lupine (Figure 12). In 2004, the ungrazed exclosure treatment (19.6 kg/ha) was different ($p < 0.01$) from the other treatment x year combinations, which averaged 2.9 kg/ha.

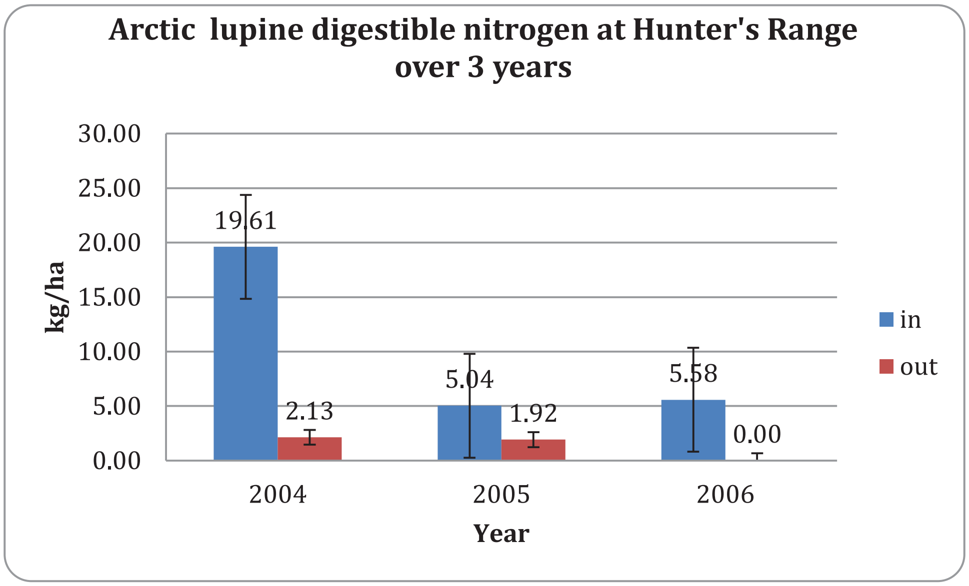


Figure 13. *Arctic lupine digestible nitrogen at the Hunter's Range site. Error bars indicate standard error.*

3.1.9 Soil chemistry

Table 3 presents the results of the soil chemistry analysis for the Hunter's Range plots. Differences in pH, although statistically significant, are of little or no biological importance. It is not unusual for soils to vary by as much as 0.2 units over relatively brief periods. The cation exchange capacity of soils was significantly higher inside than outside the exclosure, although both values are relatively low considering the soil's high carbon content. The electro-conductivity of the soil was also significantly higher inside than outside the enclosure, but this distinction has little biological importance because the values are all quite low and soil salinity is not a concern at this location.

Table 3. ***Soil chemistry at the Hunter's Range site***

	Inside treatment		**Outside treatment**		
Soil attribute	**Mean**	**Variance**	**Mean**	**Variance**	***t*-test[a]**
pH	4.7	0.0	4.9	0.0	–2.343*
Cation exchange capacity	2.85	2.59	1.30	0.44	2.433*
Electro-conductivity	0.14	0.00	0.08	0.00	3.485*
Na: Exchangeable	0.036	0.000	0.029	0.000	1.528
Na: Mehlich-3	6.40	1.54	5.32	1.73	1.634
Ca: Exchangeable	1.90	1.87	0.71	0.10	2.323*
Ca: Mehlich-3	228	26 866	88	1840	2.269*
K: Exchangeable	0.48	0.01	0.34	0.07	1.457
K: Mehlich-3	188	1669	153	10 130	0.885
Mg: Exchangeable	0.30	0.02	0.16	0.01	2.024
Mg: Extractable	15.5	43.8	9.5	20.8	2.015
Al: Exchangeable	0.038	0.001	0.029	0.000	0.719
Al: Mehlich-3	2336	34 246	2619	76 305	–2.330*
Fe: Exchangeable	0.017	0.000	0.014	0.000	0.457
Fe: Mehlich-3	168	2889	162	10 910	0.147
Mn: Exchangeable	0.084	0.004	0.025	0.001	2.357*
Mn: Mehlich-3	17.1	236.1	6.3	48.5	1.759
Cu: Mehlich-3	1.38	0.13	1.30	0.06	0.504
Zn: Mehlich-3	2.93	3.39	1.45	0.62	2.032
B: Mehlich-3	0.25	0.02	0.15	0.00	1.978
P: Available	9.8	4.3	15.6	172.1	–1.192
P: Mehlich-3	16.8	11.2	14.2	28.9	1.159
N: Total	0.74	0.01	0.65	0.02	1.522
C: Total	10.7	1.5	9.7	0.6	1.810
C:N	14.7	0.88	15.3	3.19	0.373

[a] *t*-values with asterisk are statistically significant.

Most of the macronutrients (N, P, K, and Mg) were not significantly different inside versus outside the exclosure. The exception is Ca—both exchangeable Ca and Mehlich-3 Ca were significantly higher within the exclosure than outside. This difference probably underlies the difference in cation exchange capacity as well. The fact that the pH inside the exclosure appears to have been lower than outside is surprising, since higher Ca levels tend to be associated with higher pH; however, why the exclusion of grazing may lead to a rise in soil Ca levels cannot be clearly explained.

Exchangeable Mn was significantly higher inside the exclosure, and the same trend held true (though not statistically significant) for Mehlich-3 Mn. Given the observed differences in pH, this may not be surprising; however, attributing higher Mn levels to differences in pH is suspect when one considers that Ca levels were higher inside the exclosure. No statistically significant differences were evident in the levels of other micronutrients (B, Cu, Fe, and Zn) inside or outside the exclosure.

No significant differences were apparent in the levels of Al and Na inside versus outside the exclosure; neither element was present at levels that might be expected to have biological consequences.

There was no significant difference ($t = 0.373$) in the C:N ratio inside *vs.* outside the exclosure. C:N ratios were consistently between 13-18, values which suggest that the organic materials can decompose rapidly releasing N in a form available to plants.

3.2 *Smith Camp*

Smith Camp Range Inside

Smith Camp Range Outside

3.2.1 Herbage, litter, and species production

No significant differences were evident in herbage, litter, or any species biomass between treatments or among years. Total herbage was 26 g/0.5 m^2 and litter was 7 g/0.5 m^2. The only major species, pinegrass, was 19 g/0.5 m^2. The light grazing at this site appears not to have had an impact on forage production.

3.2.2 Herbage quality

Digestible nitrogen from herbage was the same for all treatments and years, averaging 2.0 kg/ha. No apparent impact of grazing on digestible nitrogen was evident at this site.

3.2.3 Litter quality

Digestible nitrogen from litter average over the three years was greater in the ungrazed plots (0.5 kg/ha) than in the grazed plots (0.2 kg/ha; $p < 0.1$), despite no reported difference in litter biomass (Section 3.2.1) (Figure 13). This could indicate that the residual forage after grazing has less digestible nitrogen; this could also indicate a gradual loss of nitrogen from the system.

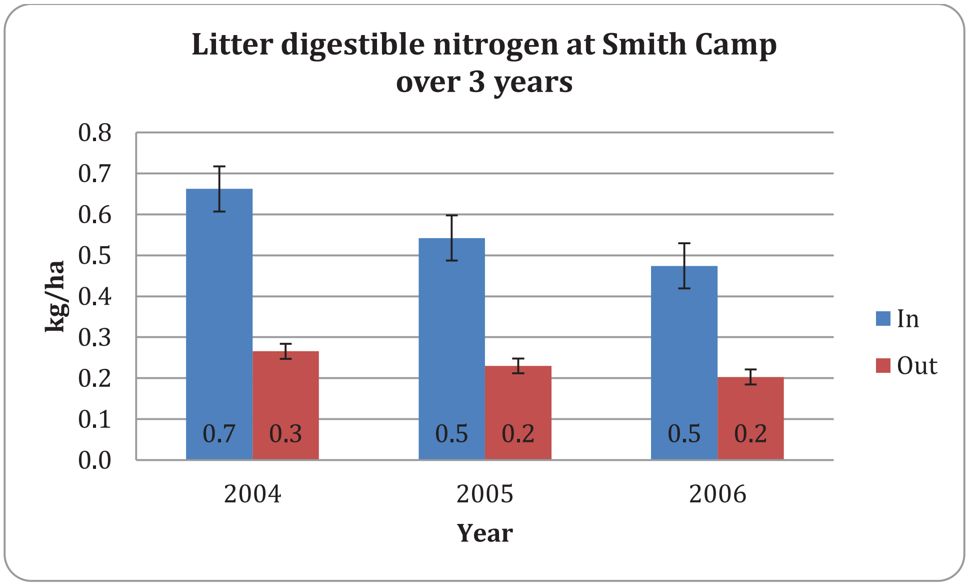


Figure 14. *Litter digestible nitrogen at the Smith Camp site. Error bars indicate standard error.*

3.2.4 Species quality

No significant differences were evident in plant digestible nitrogen for any species between treatments or among years. Grazing does not appear to have affected the digestible nitrogen of live plant material at this location.

3.3 *Will Lake Lodgepole Pine*

Will Lake Lodgepole Pine Inside

Will Lake Lodgepole Pine Outside

3.3.1 Herbage, litter, and species production

The Will Lake Lodgepole Pine site was logged in 2005, greatly changing forage production, so only data for 2004 and 2005 are reported. No significant difference was evident in herbage, litter, or any species biomass between treatments or years. Total herbage was 9 g/0.5 m^2 and litter was 3 g/0.5 m^2; the only major species, pinegrass, was 8 g/0.5 m^2. The light grazing at this location did not have an impact on forage production.

3.3.2 Herbage, litter, and species quality

As noted above, the 2005 logging at this location greatly changed forage production, so only data for 2004 and 2005 are reported.

No significant differences were evident between treatments or years in digestible nitrogen for herbage, litter, or any species. Herbage had 0.82 kg/ha of digestible nitrogen, most of which was from pinegrass (0.62 kg/ha) and litter was 0.13 kg/ha. Grazing did not appear to have an impact on the digestible nitrogen at this location.

3.3.3 Soil chemistry

Table 4 presents the results of the soil chemistry analysis for the Will Lake Lodgepole Pine plots. No statistically significant differences were observed in pH, cation exchange capacity, or electro-conductivity.

Levels of two macronutrients, Ca and K, inside the ungrazed exclosure were not significantly different from levels found outside. Two other macronutrients, N and P, were significantly higher outside the exclosure, but Mg was significantly lower. Higher levels of N outside the exclosure may have resulted from greater inputs through dung and urine. The difference in P levels, paralleled in most of the other sites, is not easily explained. Although the pH inside the exclosure was slightly greater than outside, the difference was not sufficient to explain the higher levels of base cations such as Mg (other base cations including K, and Ca, showed a similar response although only the Na Mehlich-3 difference was statistically significant). Acid cations (Zn, Al, Fe, and Mn but not Cu) tended to be more abundant outside the exclosure, although the difference was only statistically significant for Fe and Al measured using the Mehlich-3 procedure. The slightly lower pH measurements outside the exclosure are too small to explain the tendency to greater acid cation concentrations.

No significant difference was apparent in the C:N ratio inside versus outside the exclosure (t = −0.60). The C:N ratios were consistently between 21 and 30, which suggests that the organic materials can decompose rapidly, releasing N in a form available to plants.

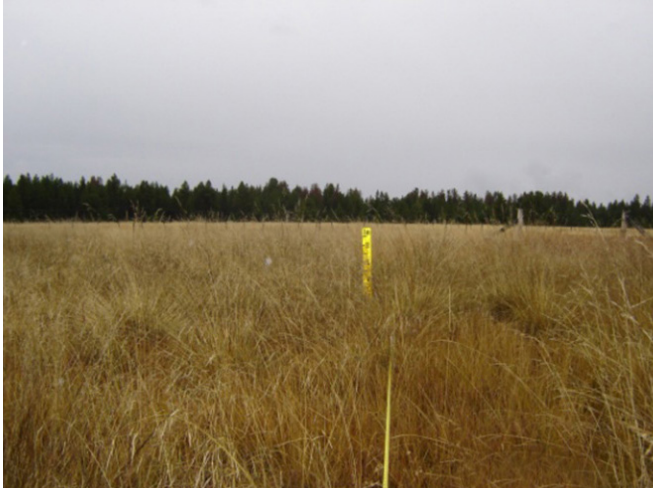
Table 4. ***Soil chemistry at the Will Lake Lodgepole Pine site***

Soil attribute	Inside treatment		Outside treatment		*t*-test[a]
	Mean	**Variance**	**Mean**	**Variance**	
pH	5.3	0.1	5.2	0.0	0.77
Cation exchange capacity	12.7	16.3	8.9	13.4	1.59
Electro-conductivity	0.15	0.00	0.15	0.00	−0.37
Na: Exchangeable	0.05	0.00	0.04	0.00	1.63
Na: Mehlich-3	10.8	31.9	5.8	9.5	3.24*
Ca: Exchangeable	7.4	5.1	5.7	7.6	1.04
Ca: Mehlich-3	1316	141 646	951	161 860	1.53
K: Exchangeable	0.41	0.03	0.49	0.04	−1.27
K: Mehlich-3	198	4501	238	8617	−1.40
Mg: Exchangeable	4.6	3.3	2.3	1.1	2.56*
Mg: Mehlich-3	306	22 884	140	1807	2.70*
Al: Exchangeable	0.027	0.003	0.158	0.132	−1.13
Al: Mehlich-3	1065	4142	1365	70785	−3.55*
Fe: Exchangeable	0.001	0.000	0.003	0.000	−1.29
Fe: Mehlich-3	344	2487	486	4530	−4.39*
Mn: exchangeable	0.12	0.00	0.17	0.01	−1.49

Soil attribute	Inside treatment		Outside treatment		*t*-test[a]
	Mean	Variance	Mean	Variance	
Mn: Mehlich-3	105	2375	117	1665	−0.54
Cu: Mehlich-3	0.59	0.14	0.45	0.17	1.84
Zn: Mehlich-3	2.7	1.0	4.3	8.6	−1.87
B: Mehlich-3	0.04	0.00	0.05	0.00	−1.01
P: Available	62	509	214	6506	−4.42*
P: Mehlich-3	83	937	259	10 388	−4.10*
N: Total	0.07	0.00	0.09	0.00	−2.25*
C: Total	1.63	0.22	2.21	0.30	−2.19
C:N ratio	23.4	1.1	24.4	14.2	−0.60

[a] *t*-values with asterisk are statistically significant.

3.4 *Tunkwa Lake*



Tunkwa Lake Old Exclosure

Tunkwa Lake New Exclosure

Tunkwa Lake Outside

3.4.1 Herbage production

Herbage production was different among treatments with some year x treatment interaction ($p < 0.01$) in 2004 (Figure 14). The old ungrazed exclosure had the greatest production followed by the new ungrazed exclosure although in 2004 the new ungrazed treatment had more herbage production than the old ungrazed treatment.; the least forage production occurred in the grazed area ($p < 0.001$).

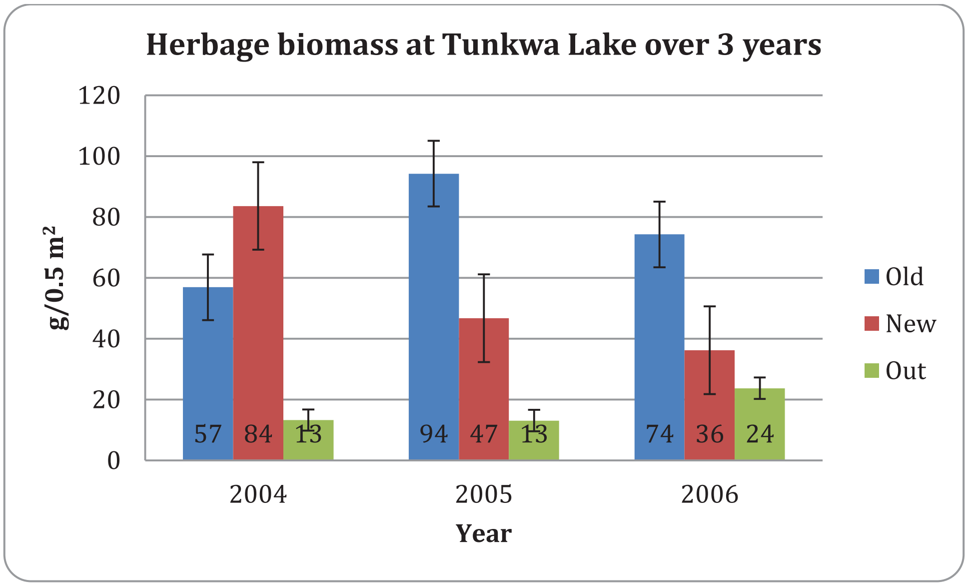


Figure 15. *Herbage biomass at the Tunkwa Lake site. Error bars indicate standard error.*

The old ungrazed treatment forage production average over the three years was 75g/.5m^2 while the grazed treatment produced 17 g/.5m^2. Grazing appears to have reduced herbage production by 59 g/.5m^2 compared to the long-term rest.

3.4.2 Herbage quality

An interaction was evident among treatments and years for herbage digestible nitrogen. In general, the ungrazed treatments had higher values (5.1 kg/ha) than the grazed treatment (1.8 kg/ha; $p < 0.001$) (Figure 15). In 2004, the new ungrazed treatment had higher digestible nitrogen than the old ungrazed treatment (8.9 kg/ha *vs.* 5.1 kg/ha), whereas in the other years the ungrazed treatments were the same (4.2 kg/ha). The very high value for the new ungrazed treatment in 2004 cannot be explained. The differences between the grazed and ungrazed treatments were likely due to grazing impacts.

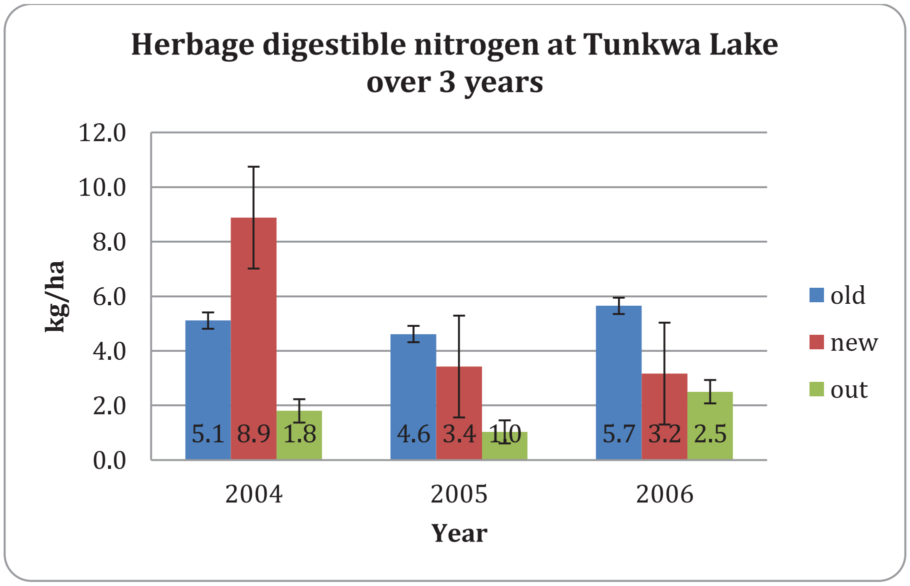


Figure 16. *Herbage digestible nitrogen at the Tunkwa Lake site. Error bars indicate standard error.*

3.4.3 Litter production

Litter production was different among treatments, with a treatment x year interaction (Figure 16). The old ungrazed treatment had the highest litter biomass in 2004 and 2005 ($p < 0.001$), whereas in 2006 it was not different from the new ungrazed treatment. In all years, the grazed treatment had the lowest litter biomass ($p < 0.001$).

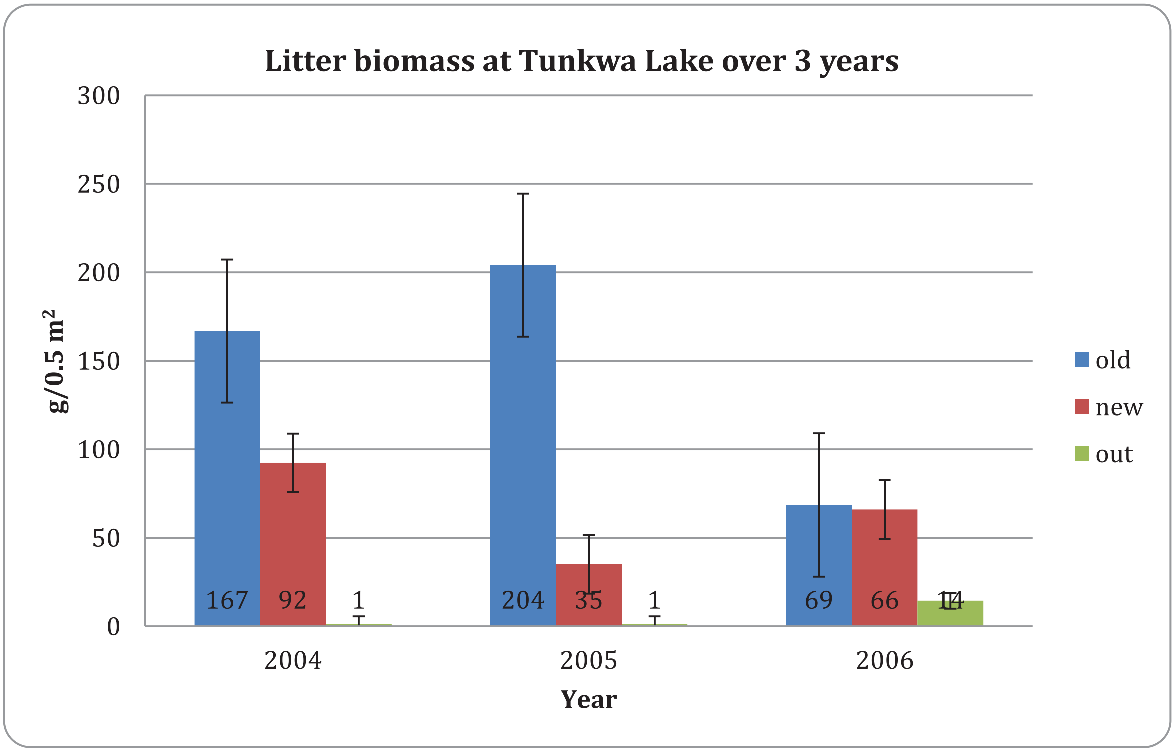


Figure 17. *Litter biomass at the Tunkwa Lake site. Error bars indicate standard error.*

Heavy grazing over many decades appears to have reduced litter biomass compared to the long-term and short-term ungrazed treatments.

3.4.4 Litter quality

An interaction was evident among treatments and years (Figure 17). In the old exclosure, the 2004 and 2005 digestible nitrogen values were the same, averaging 9 kg/ha, which was greater than the rest of the combinations (2.5 kg/ha; $p < 0.01$).

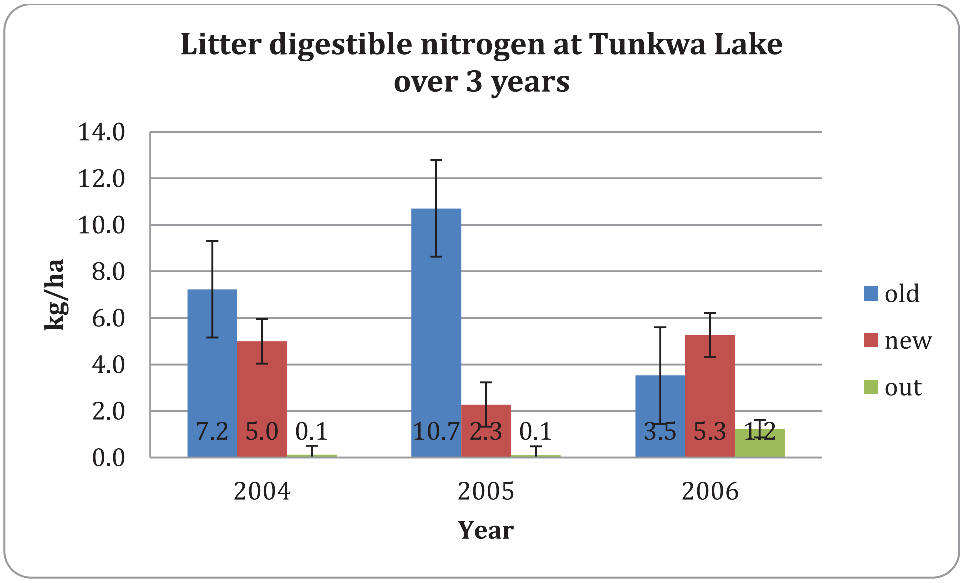


Figure 18. ***Litter digestible nitrogen at the Tunkwa Lake site. Error bars indicate standard error.***

A reasonable interpretation of this data is that exclusion from grazing increased the digestible nitrogen of litter in 2004 and 2005.

3.4.5 Rough fescue production

Rough fescue biomass was different among treatments with a treatment x year interaction (Figure 18). The highest biomass occurred in the old ungrazed treatment in 2005 and 2006, whereas rough fescue biomass was the same in the old and new ungrazed treatments in 2004. In the grazed treatment, rough fescue was lower than the old ungrazed treatment ($p < 0.001$), whereas the new ungrazed treatment had more rough fescue than the grazed treatment in 2004 ($p < 0.01$) but was not different in 2005 and 2006. Long-term exclusion from grazing appears to have increased rough fescue biomass, but over the short term any differences have not yet become evident.

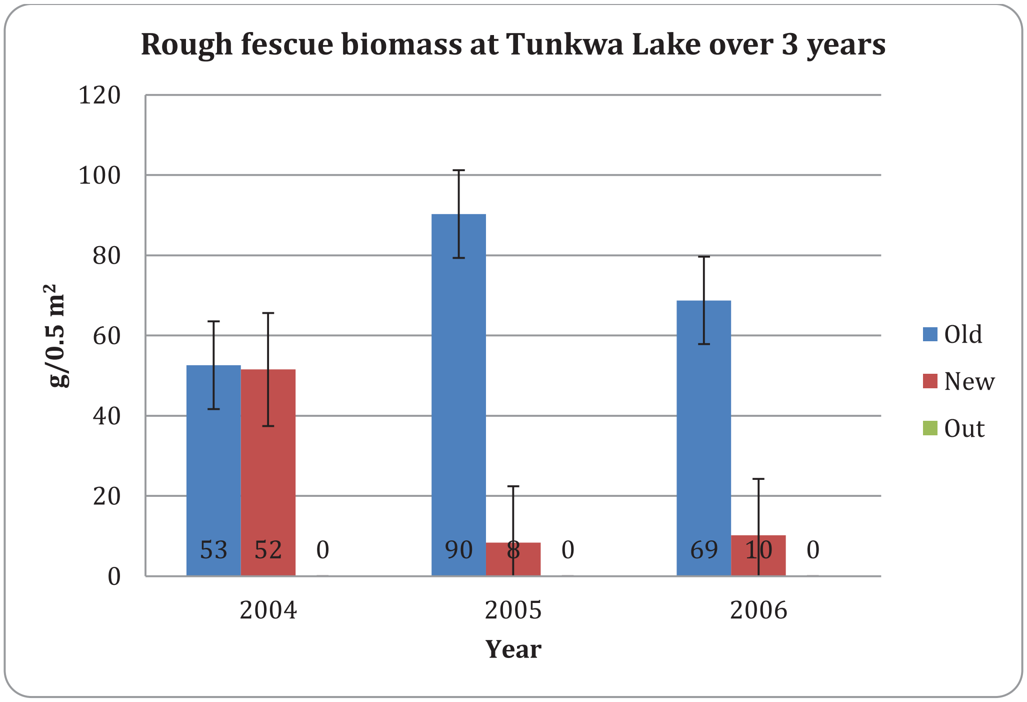


Figure 19. *Rough fescue biomass at the Tunkwa Lake site. Error bars indicate standard error.*

3.4.6 Rough fescue quality

Digestible nitrogen in rough fescue differed among treatments but not among years (Figure 19). The old exclosure had the highest values (4.6 kg/ha; $p < 0.01$) followed by the new exclosure (1.8 kg/ha), which was greater than the grazed treatment (0.0 kg/ha; $p < 0.1$).

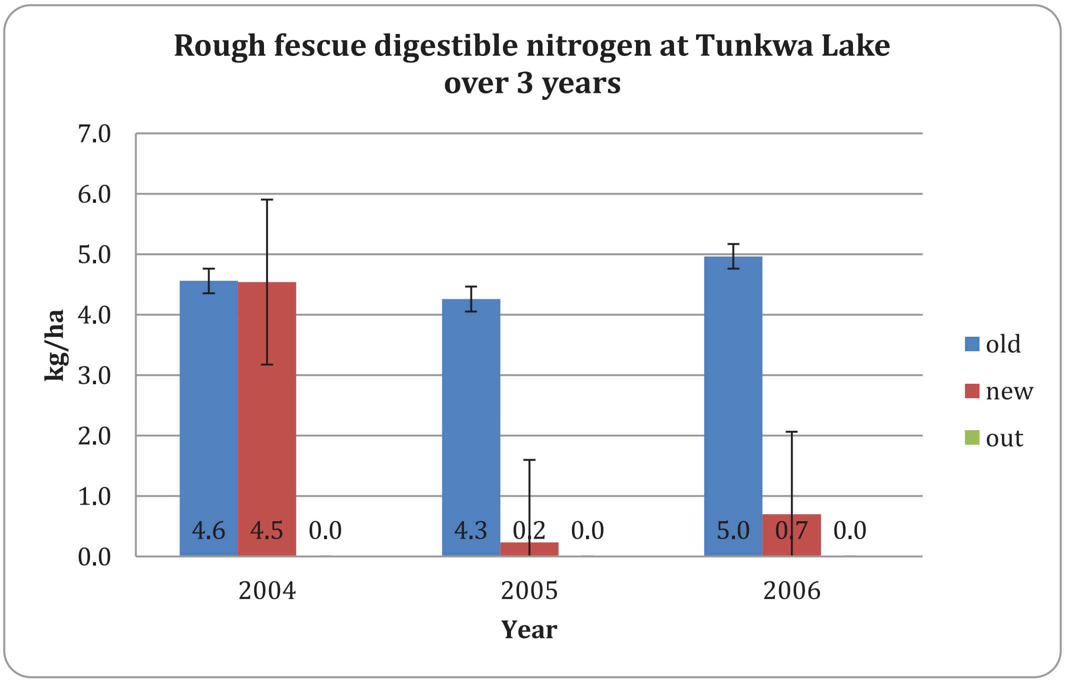


Figure 20. *Rough fescue digestible nitrogen at the Tunkwa Lake site. Error bars indicate standard error.*

3.4.7 Kentucky bluegrass production

Kentucky bluegrass biomass was greatest in the new ungrazed treatment ($p < 0.001$), with no difference between the old ungrazed exclosure and grazed treatment (Figure 20). Through time, grazing removes rough fescue, replacing it with Kentucky bluegrass, which with further grazing is removed and replaced by needle grasses and weedy forbs. The new ungrazed treatment is showing a reverse trend as Kentucky bluegrass recovers from grazing. Rough fescue is expected to replace the Kentucky bluegrass.

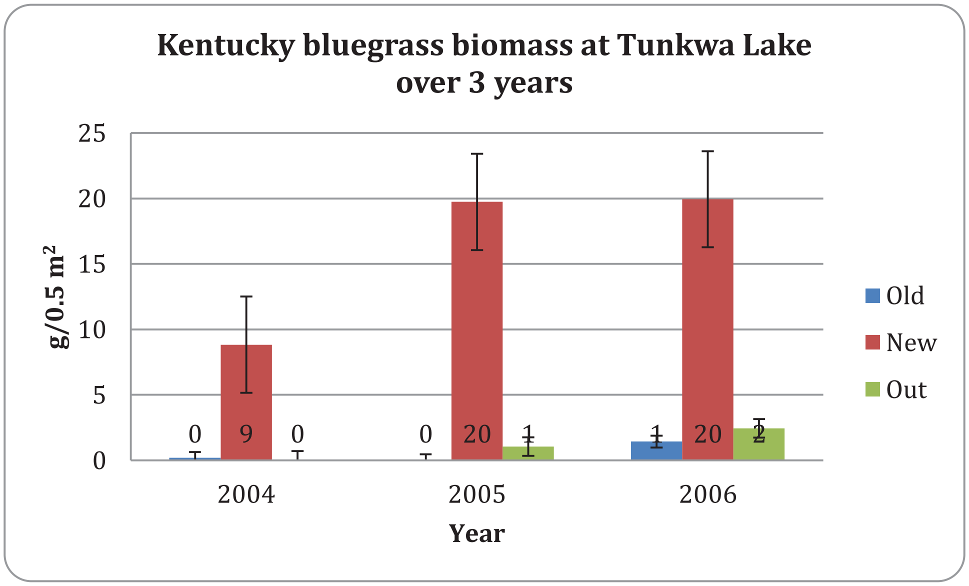


Figure 20. *Kentucky bluegrass biomass at the Tunkwa Lake site. Error bars indicate standard error.*

3.4.8 Kentucky bluegrass quality

Digestible nitrogen in Kentucky bluegrass was different among treatments (Figure 21). The new exclosure had greater values (1.4 kg/ha) than the old exclosure or grazed treatment (0.04 kg/ha; $p < 0.001$)

Over the short term, exclusion from grazing has allowed digestible nitrogen in Kentucky bluegrass to increase. Over the long term, exclusion from grazing in the old exclosure has allowed rough fescue to replace Kentucky bluegrass.

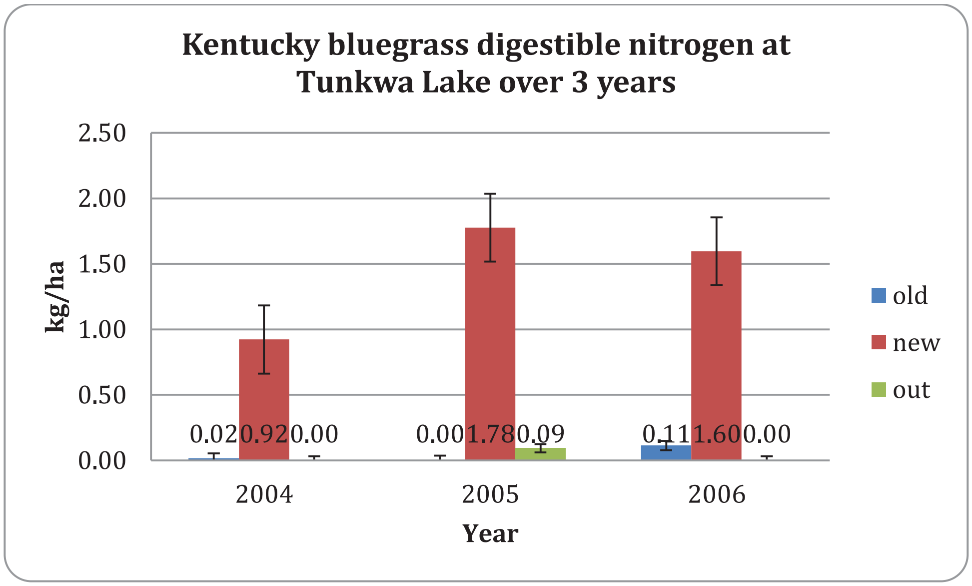


Figure 22. *Kentucky bluegrass digestible nitrogen at the Tunkwa Lake site. Error bars indicate standard error.*

3.4.9 Soil chemistry

Table 5 presents the results of the soil chemistry analysis for the Tunkwa Lake plots. Levels of K within the old exclosure were significantly lower than levels outside. Intermediate levels were found in the new exclosure. Potassium is the most labile of the base cations and is easily leached from plant material because it is not present in cell walls. It is thus easily removed from soil exchange sites. The differences are of limited biological significance, however, because K is present at levels that are unlikely to be biologically limiting.

No statistically significant differences were observed in the other soil chemistry attributes.

Table 5. ***Soil chemistry at the Tunkwa Lake site***

	Mean squares			Mean values			Tukey comparisons		
Soil attribute	**Groups**	**Error**	***F*[a]**	**Old**	**New**	**Out**	**Old**	**New**	**Out**
pH	0.090	0.026	3.437	6.02	6.16	6.26			
Cation exchange capacity	22.7	21.7	1.046	30.1	26.2	28.1			
Electro-conductivity	0.005	0.002	2.211	0.157	0.209	0.202			
Na: Exchangeable	0.040	0.040	0.990	0.027	0.175	0.041			
Na: Mehlich-3	1661	1840	0.903	4.75	34.87	7.56			
Ca: Exchangeable	31.5	16.0	1.974	22.4	18.2	18.8			
Ca: Mehlich-3	794 264	263 074	3.019	3339	2717	2702			
K: Exchangeable	0.220	0.055	3.975*	0.99	1.16	1.37	a	ab	b
K: Mehlich-3	51 773	9156	5.655*	477	628	646	a	b	b
Mg: Exchangeable	3.29	2.11	1.562	6.66	6.63	7.93			
Mg: Mehlich-3	5857	23 242	0.252	380	416	442			
Al: Exchangeable	0.000	0.000	0.332	0.004	0.002	0.004			
Al: Mehlich-3	14 393	9641	1.493	982	891	904			
Fe: Exchangeable	0.000	0.000	1.226	0.000	0.000	0.000			
Fe: Mehlich-3	651	1 357	0.480	202	198	182			
Mn: Exchangeable	0.001	0.000	1.602	0.015	0.029	0.010			
Mn: Mehlich-3	691	723	0.956	42.1	63.5	52.8			
Cu: Mehlich-3	0.71	0.30	2.357	3.97	3.59	3.28			
Zn: Mehlich-3	39.099	18.939	2.064	5.85	10.45	6.22			
B: Mehlich-3	0.012	0.058	0.215	0.719	0.794	0.800			
P: Available	176	75	2.337	11.5	21.7	19.7			
P: Mehlich-3	580	246	2.362	46.9	63.3	64.6			
N: Total	0.002	0.006	0.346	0.341	0.336	0.305			
C: Total	0.53	1.30	0.405	4.87	4.65	4.28			
C:N ratio	0.48	0.32	1.50	14.3	13.8	14.0			

[a] F-values with asterisk are statistically significant.

3.5 *Yellow Pine Spacing Trial*

Yellow Pine Inside: 2.4m spacing

Yellow Pine Inside: 6.1m spacing

Yellow Pine Outside: 2.4m spacing

3.5.1 Herbage production

Herbage biomass was the same in the 2.4m and 6.1m spacing treatments (20 g/0.5 m^2) with no significant difference among years. Herbage production was lower in the grazed treatment (11 g/0.5 m^2; $p < 0.001$) (Figure 22). Grazing appears to have reduced herbage biomass, but canopy cover did not produce a detectable difference.

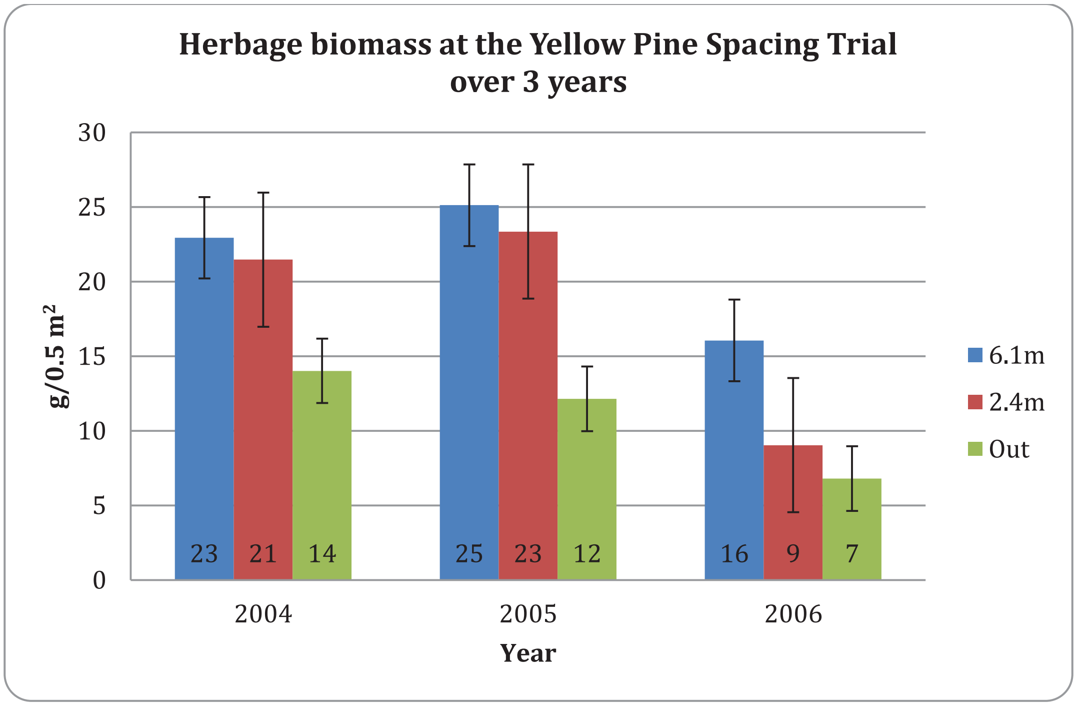


Figure 23. *Herbage biomass at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.2 Herbage quality

In 2004, the 6.1m spacing treatment, the grazed treatment and the 2006 6.1m spacing treatment had virtually the same herbage digestible nitrogen, averaging 1.8 kg/ha, which was greater than the rest of the combinations (Figure 23). The dynamics of the response digestible nitrogen at this site are not understood.

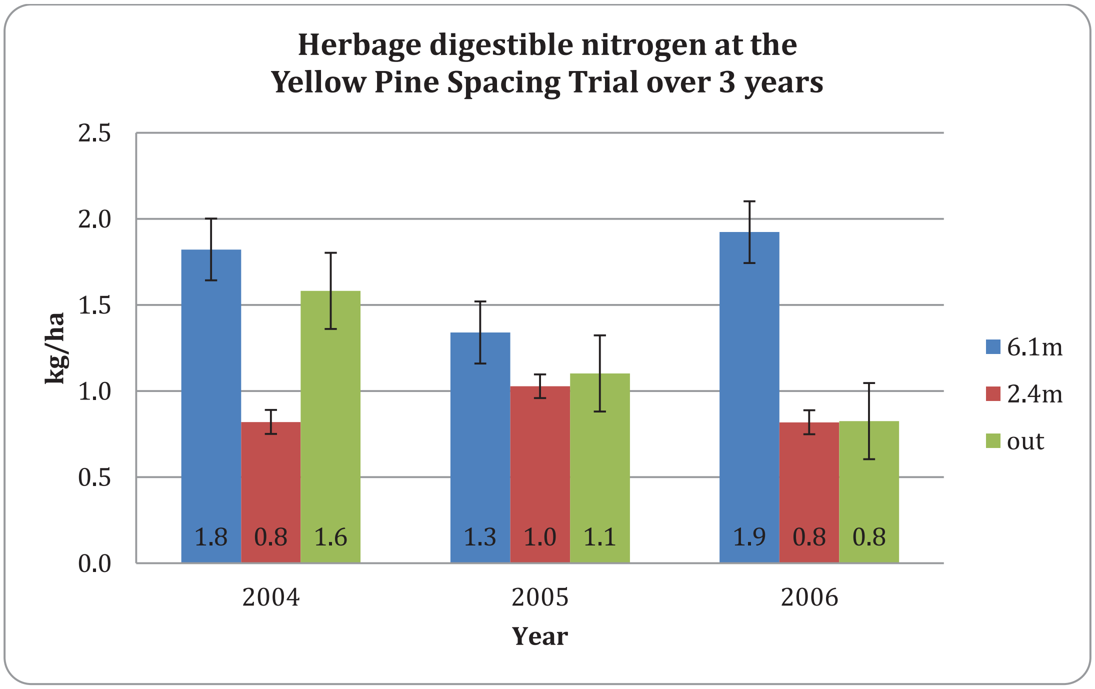


Figure 24. *Herbage digestible nitrogen at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.3 Litter production

Litter biomass differed among treatments (Figure 24). Averaged over the three years the 2.4m and 6.1m spacing treatments had the same litter biomass (9 g/0.5 m^2), whereas the grazed treatment (1 g/0.5 m^2) was less ($p < 0.001$). Grazing appears to have reduced litter biomass but level of canopy closure did not. This is consistent with herbage production response to these treatments.

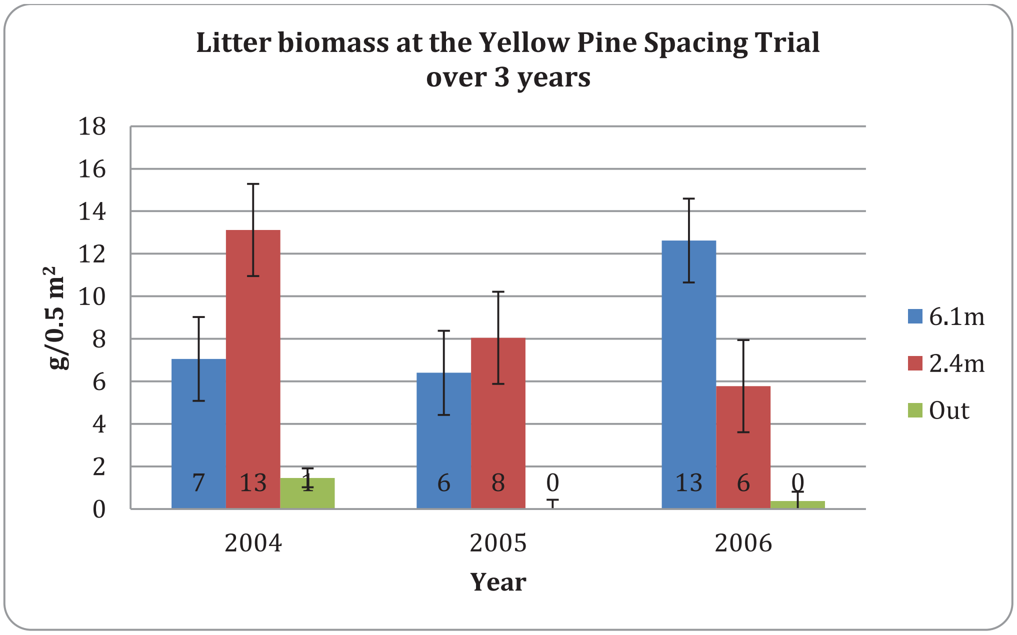


Figure 25. *Litter biomass at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.4 Litter quality

Digestible nitrogen in litter was different among treatments but not among years (Figure 25). The 2.4m and 6.1m spacing treatment results were the same averaged over the three years (0.36 kg/ha) and greater than those for the grazed treatment (0.04 kg/ha; $p < 0.001$). No consistent canopy influence was evident, but the difference between grazed and ungrazed treatments may indicate a large grazing impact.

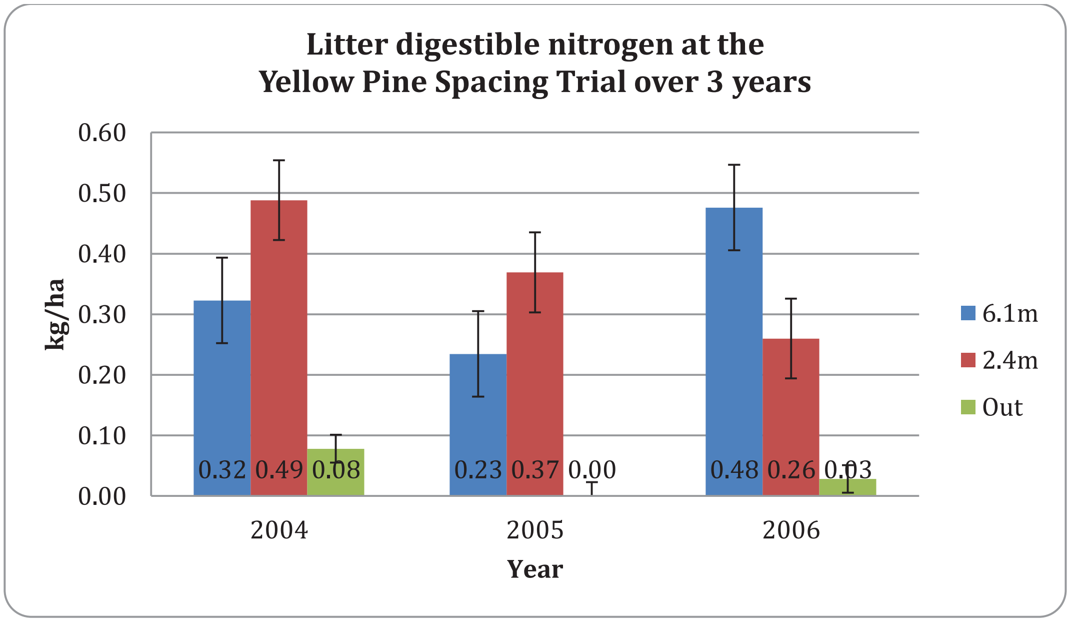


Figure 26. *Litter biomass at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.5 Rough fescue production

Rough fescue biomass was different among treatments (Figure 26). Biomass averaged over the three years in the 6.1m spacing treatment was greater (5 g/0.5 m^2) than the grazed plots (0.1 g/0.5 m^2; $p < 0.05$). The high variance of the rough fescue data was linked to the size of the tussocks in relation to the size of the plots and the sparse number of tussocks. If a tussock was hit during sampling, then plot biomass was high but was zero if a tussock was not sampled. This increased variance and thus reduced the ability to detect differences. The *p*-value for the difference between the 2.4m and 6.1m spacing treatments was 0.11, or just above the selected significance threshold. The canopy closure in the 2.4m spacing treatment was expected to reduce rough fescue biomass; however, with the high variance, this difference was not great enough to be significant.

Grazing appears to have reduced the rough fescue biomass but canopy closure did not.

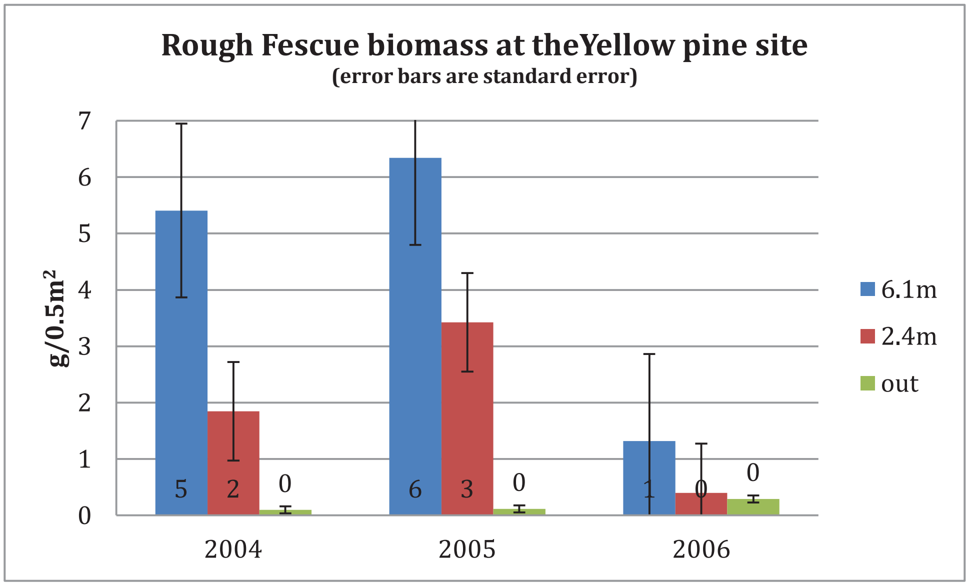


Figure 27. *Rough fescue biomass at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.6 Rough fescue quality

Rough fescue digestible nitrogen was different among treatments (Figure 27). Digestible nitrogen was the was the same in the 2.4m and 6.1m spacing treatments averaged over the three years (0.23 kg/ha) and greater than the grazed treatment (0.01 kg/ha; $p < 0.001$. No consistent canopy influence was evident. The difference between grazed and ungrazed treatments could indicate a large impact of grazing. As mentioned above, because of the high variance in the rough fescue, the ability to detect differences in rough fescue digestible nitrogen was reduced.

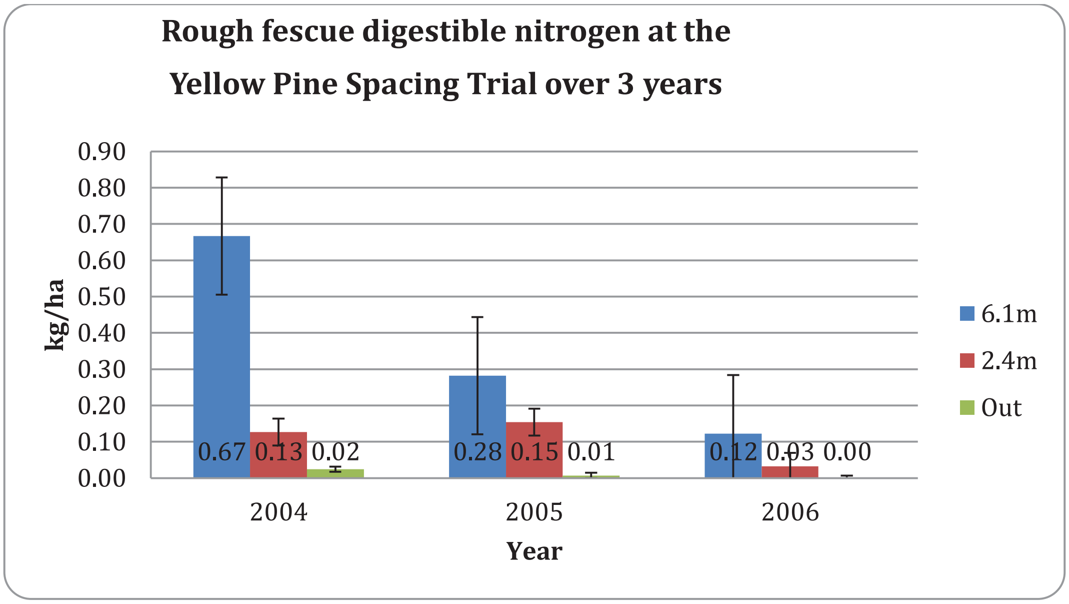


Figure 28. *Rough fescue digestible nitrogen at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.7 Pinegrass production

Pinegrass biomass was different among treatments and years (Figure 28). The 2.4m and 6.1m spacing treatments had virtually the same pinegrass biomass (12 g/0.5 m^2) and were both greater than the grazed area (3 g/0.5 m^2; $p < 0.001$). Grazing appears to have reduced pinegrass production but canopy closure had no detectable effect.

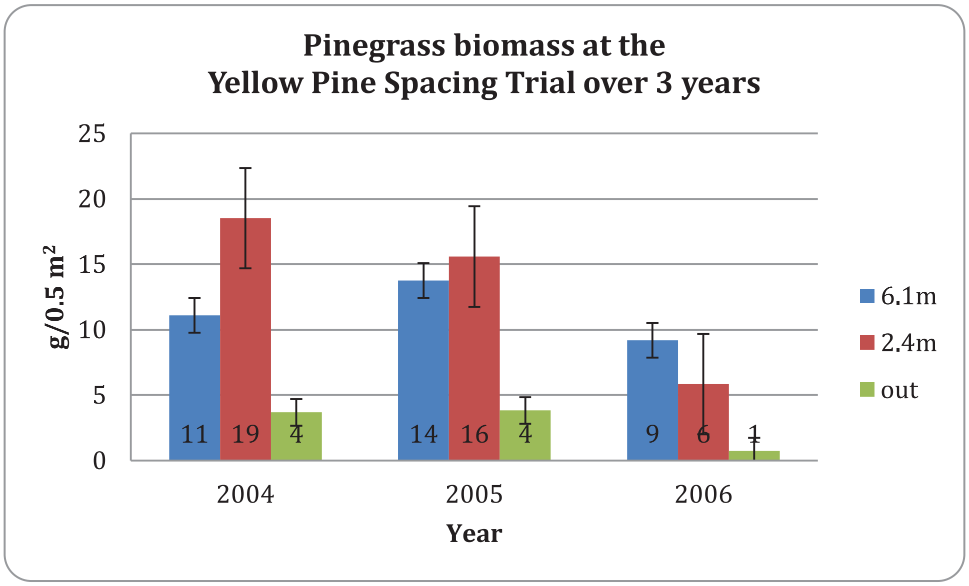


Figure 29. *Pinegrass biomass at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.8 Pinegrass quality

Pinegrass digestible nitrogen was different among treatments (Figure 29). Results from the 2.4m and 6.1m spacing treatments were virtually the same (0.63 kg/ha) and greater than the grazed treatment (0.29 kg/ha; $p < 0.1$). No consistent canopy influence was detected. The difference between grazed and ungrazed treatments may indicate a grazing impact.

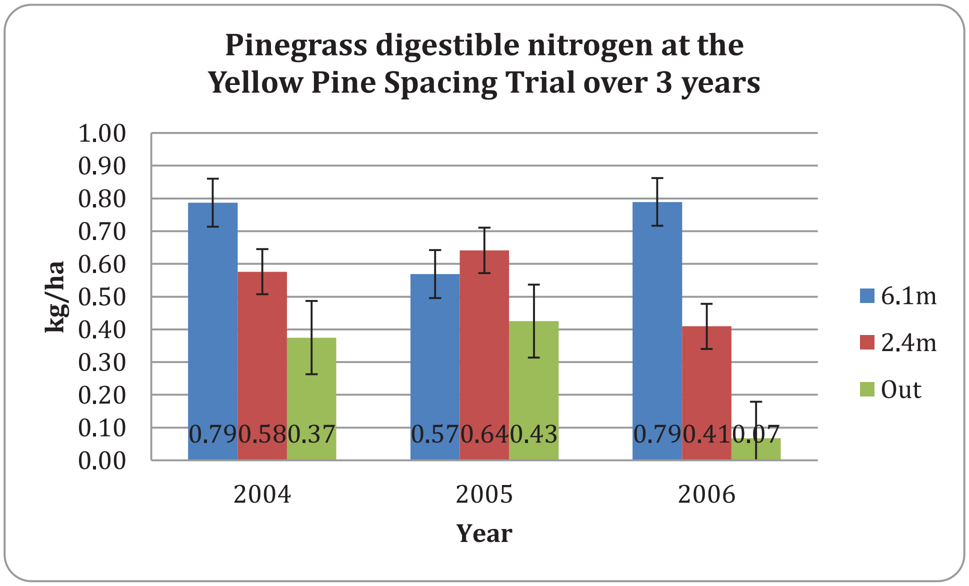


Figure 30. *Pinegrass digestible nitrogen at the Yellow Pine Spacing Trial site. Error bars indicate standard error.*

3.5.9 Soil chemistry

Table 6 presents the results of the soil chemistry analysis for the Yellow Pine Spacing Trial plots. No statistically significant differences were observed in pH, cation exchange capacity, or electro-conductivity.

Levels of three macronutrients (Ca, Mg, and N) were not significantly different among the three treatments (2.4m and 6.1m spacing and outside). The C:N ratio was between 17 and 21 for all three treatments, which suggests that the organic materials can decompose rapidly, releasing N in a form available to plants. The C:N ratio was significantly higher in the 2.4m spacing treatment than in the other two treatments, but these differences were slight.

Significant differences were evident in levels of two macronutrients, P and K. Levels of P (both available and Mehlich-3) were significantly higher outside the exclosure than in the 2.4m yellow pine spacing treatment. The higher levels outside the exclosure may reflect contributions from animal dung and urine. The higher levels of K found outside the exclosures are difficult to explain but parallel results found at most of the other sites.

Apart from K (see above), no significant differences were evident in levels of base cations between treatments. Acid cations (Zn, Al, Fe, Mn, and Cu) tended to be more abundant outside the exclosure, at least compared to the 2.4m spacing treatment. The difference was statistically significant for Al, Mn, and Cu using the Mehlich-3 procedure, although levels of exchangeable Mn were lowest outside the exclosure, a distinction that was also statistically significant. None of the elements were present at levels that might affect plant growth.

Table 6. *Soil chemistry at the Yellow Pine Spacing Trial site*

	Mean squares			Mean values			Tukey comparisons		
Soil attribute	**Groups**	**Error**	***F*[a]**	**6.1m**	**2.4m**	**Outside**	**6.1m**	**2.4m**	**Outside**
pH	0.186	0.079	2.354	6.6	6.4	6.7			
Cation exchange capacity	35.3	42.2	0.837	13.7	18.4	16.8			
Electro-conductivity	0.000	0.002	0.015	0.212	0.216	0.211			
Na: Exchangeable	0.000	0.000	0.880	0.026	0.041	0.034			
Na: Mehlich-3	2.88	9.71	0.297	5.25	5.39	6.51			
Ca: Exchangeable	22.8	29.8	0.765	10.6	14.5	12.7			
Ca: Mehlich-3	165 391	55 728	2.968	1823	1944	2151			
K: Exchangeable	0.081	0.073	1.103	0.766	0.691	0.919			
K: Mehlich-3	52,828	8967	5.891*	367	259	446	ab	b	a
Mg: Exchangeable	1.648	0.903	1.826	2.18	3.09	3.08			
Mg: Mehlich-3	2309	3961	0.583	151	161	189			
Al: Exchangeable	0.000	0.000	0.631	0.004	0.006	0.003			
Al: Mehlich-3	26 232	3775	6.949*	759	704	836	ab	b	a
Fe: Exchangeable	0.000	0.000	1.135	0.000	0.001	0.000			
Fe: Mehlich-3	1,075	1149	0.935	215	215	239			
Mn: Exchangeable	0.002	0.000	3.928*	0.041	0.066	0.032	ab	a	b
Mn: Mehlich-3	15 524	2893	5.365*	173	142	241	ab	b	a
Cu: Mehlich-3	0.485	0.109	4.430*	1.34	1.33	1.82	ab	b	a
Zn: Mehlich-3	6.27	5.65	1.109	4.31	2.99	5.00			
B: Mehlich-3	0.041	0.017	2.471	0.347	0.268	0.434			
P: Available	750	129	5.797*	30.7	18.9	41.2	ab	b	a
P: Mehlich-3	1226	224	5.464*	48.7	30.8	59.0	ab	b	a
N: Total	0.001	0.000	2.464	0.077	0.084	0.099			
C: Total	0.244	0.130	1.876	1.37	1.71	1.73			
C:N ratio	12.00	2.14	5.597	17.7	20.2	17.7	b	a	b

[a] *F*-values with asterisk are statistically significant.

3.6 *Will Lake Douglas-fir*

Will Lake Open Inside

Will Lake Open Outside

Will Lake Closed Inside

Will Lake Closed Outside

3.6.1 Herbage production

Herbage biomass was different among treatments with no difference among years (Figure 30). The grazed treatments (14 g/0.5 m^2) had less herbage than the ungrazed treatments (23 0.5g/m^2; $p < 0.001$) and the open canopy (23 0.5g/m^2) had more herbage than the closed canopy (13 g/m^2; $p < 0.001$). Grazing and tree canopy both reduced forage production.

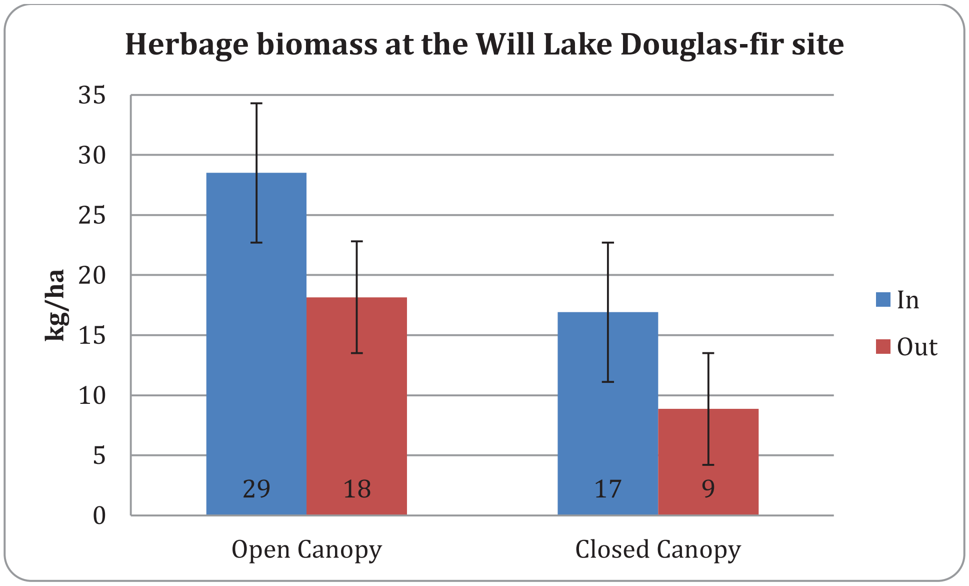


Figure 31. ***Herbage biomass at the Will Lake Douglas-fir site. Error bars indicate standard error.***

3.6.2 Herbage quality

Herbage digestible nitrogen was different among treatments and years with no interactions (Figure 31). Averaged of both treatments for 2004 and 2006 (2.3 kg/ha) were the same but different from 2005 (1.5 kg/ha; $p < 0.05$). The open-canopy treatment (2.5 kg/ha) was greater than that for the closed-canopy treatment (1.5 kg/ha) averaged over the three years.

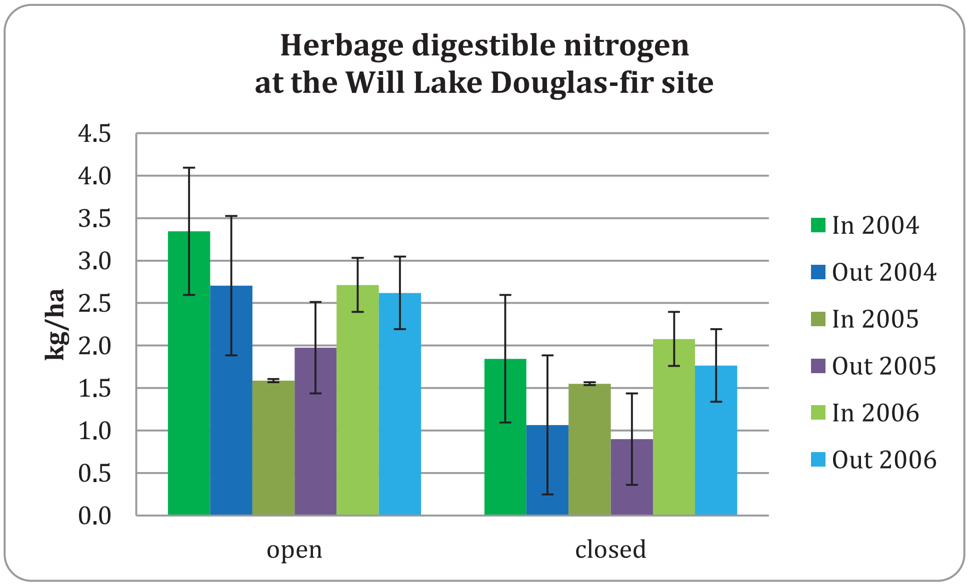


Figure 32. ***Herbage digestible nitrogen at the Will Lake Douglas-fir site. Error bars indicate standard error.***

Even though averaged values for digestible nitrogen in the grazed and ungrazed treatments are not different, the contribution from grass and forb is quite different between these two areas. In the ungrazed treatment, grasses contributed most of the digestible nitrogen (71%), whereas grasses contributed only 29% in the grazed treatment (Figure 32).

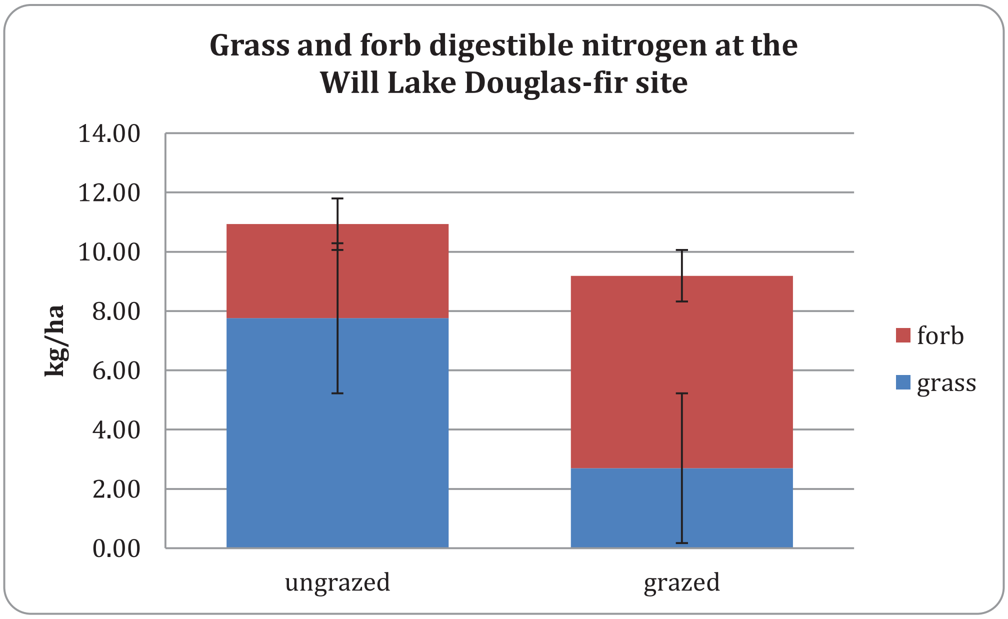


Figure 33. *Grass and forb digestible nitrogen at the Will Lake Douglas-fir site. Error bars indicate standard error.*

3.6.3 Litter production

An interaction was evident among grazing treatments, canopy closure, and year (Figure 33). In 2004 and 2006, the open ungrazed treatment had higher litter biomass (24 g/0.5 m^2) than the rest of the treatments and years (4 g/0.5 m^2; $p <$ 0.001). This site receives very heavy use through most of the grazing season, and the potential of the forest opening to have higher litter biomass is lost when it is grazed in this manner.

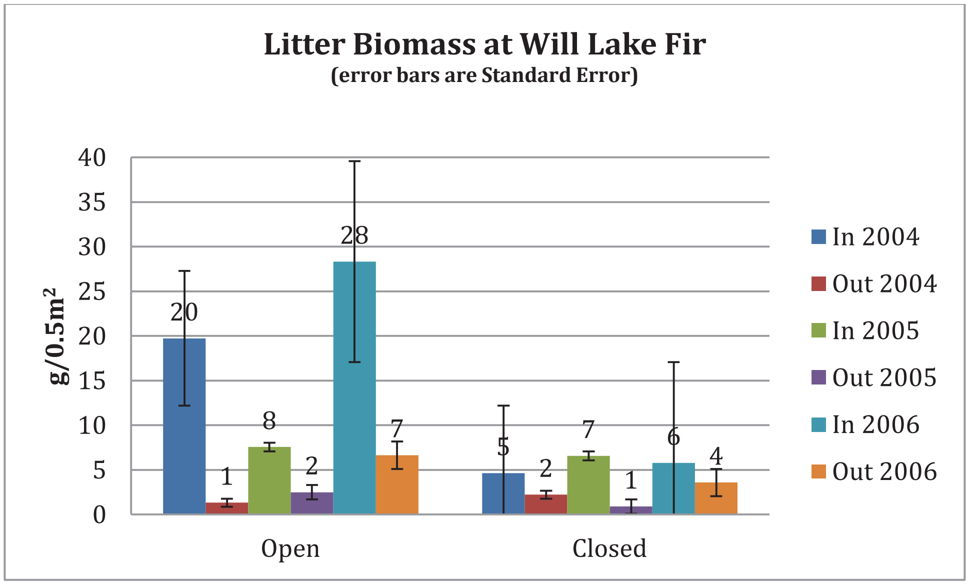


Figure 34. *Litter biomass at the Will Lake Douglas-fir site. Error bars indicate standard error.*

3.6.4 Litter quality

An interaction was evident among the grazing and canopy closure treatments and year (Figure 34). In 2004 and 2006, litter on the open, ungrazed plots had higher digestible nitrogen (0.98 kg/ha) levels than the rest of the plots and years (0.25 kg/ha; $p < 0.001$). This location receives very heavy use through most of the grazing season, and the potential of the forest opening to have higher digestible nitrogen in the litter is lost when it is grazed in this manner.

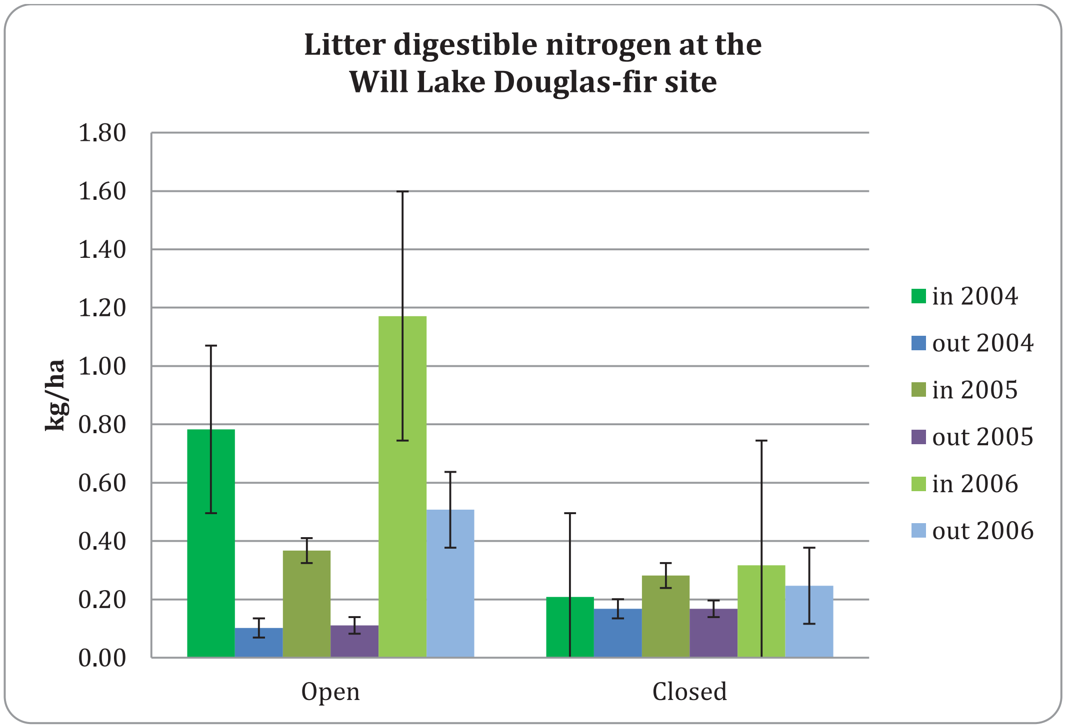


Figure 35. *Litter digestible nitrogen at the Will Lake Douglas-fir site. Error bars indicate standard error.*

3.6.5 Pinegrass production

An interaction was evident between the grazing and canopy cover treatments for pinegrass biomass (Figure 35). The open ungrazed plots had higher biomass (22 g/0.5 m^2; $p < 0.001$) than any other treatment. The ungrazed closed-canopy plots had more pinegrass biomass (8 g/0.5 m^2; $p < 0.001$) than the grazed treatments (3 g/0.5 m^2; $p < 0.001$) but less pinegrass biomass than the ungrazed open-canopy plots. Opening the canopy on this site had the potential to increase pinegrass biomass by 14 g/0.5 m^2, but such potential was lost when the area was heavily grazed. Grazing also reduced the pinegrass biomass in the closed-canopy plots.

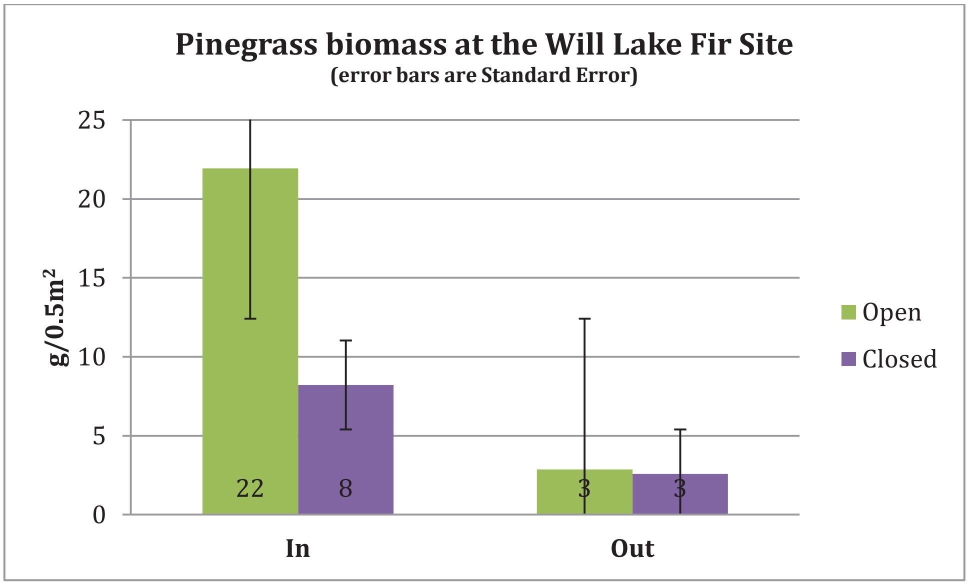


Figure 36. *Pinegrass biomass at the Will Lake Douglas-fir site. Error bars indicate standard error.*

3.6.6 Pinegrass quality

An interaction was evident among all factors for pinegrass digestible nitrogen (Figure 36). In the ungrazed open-canopy plots, levels of pinegrass digestible nitrogen were higher than in the closed canopy and ungrazed treatments, with 2004 and 2006 showing the highest values (2 kg/ha) compared to the rest of the combinations (0.5 kg/ha; $p < 0.001$). This indicates that the open canopy has the potential to produce greater digestible nitrogen but that such potential is lost when the area is heavily grazed.

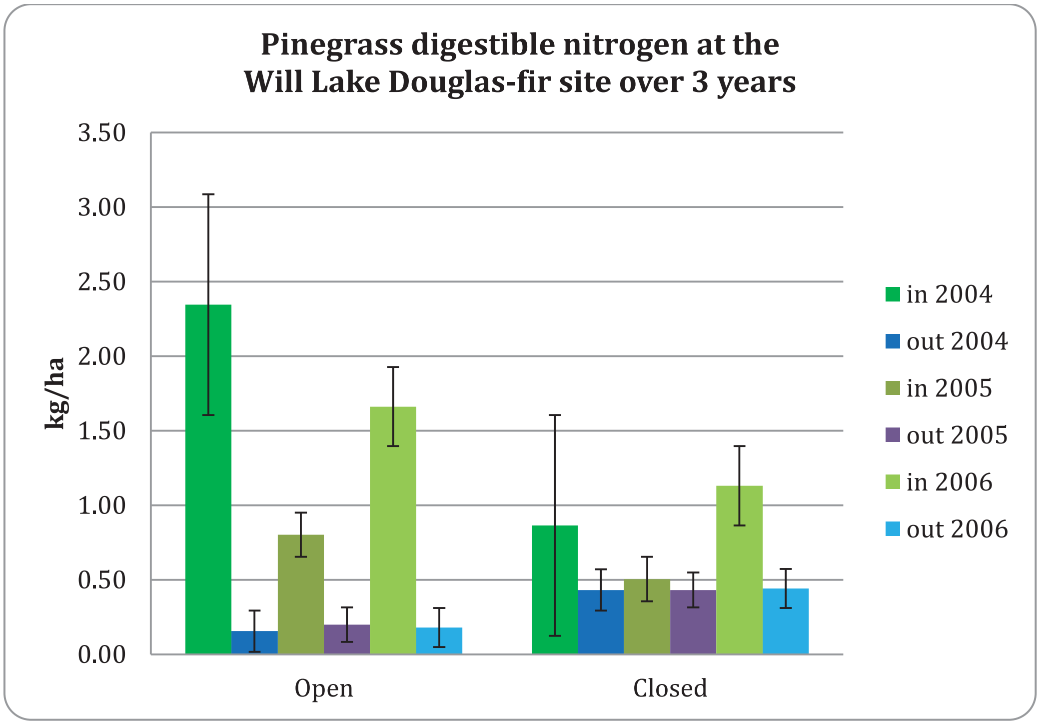


Figure 37. *Pinegrass digestible nitrogen at the Will Lake Douglas-fir site. Error bars indicate standard error.*

3.6.7 Soil chemistry

Only one soil sample was collected from the open unlogged area outside the exclosure. The lack of replication precluded statistical analysis of differences between the unlogged areas inside and outside the exclosure and the apparent interactions between logging and grazing. Table 7 presents the results of the chemical analysis of soils data from the logged plots inside and outside the exclosure at the Will Lake Douglas-fir site.

No statistically significant differences were observed in pH, cation exchange capacity, or electro-conductivity.

Levels of Cu within the logged exclosure were significantly lower than levels in the unlogged area outside. The soil Cu levels at both locations were well below thresholds at which Cu becomes toxic to plants, but given that no documented evidence links grazing with increased soil Cu levels, these results may simply reflect underlying site differences between plots in the two treatments.

Apart from the differences observed in Cu levels, no other soil chemistry attributes were found to differ significantly between the exclosure and the surrounding area within the logged forest.

Table 7. *Soil chemistry at the Will Lake Douglas-fir site (logged area)*[a]

	Inside exclosure		Outside exclosure		
Soil attribute	**Mean**	**Variance**	**Mean**	**Variance**	***t*-test**[b]
pH	6.03	0.10	6.18	0.11	–0.804
Cation exchange capacity	25.4	44.9	32.6	78.2	–1.592
Electro-conductivity	0.23	0.00	0.25	0.01	–0.418
Na: Exchangeable	0.046	0.000	0.062	0.000	–1.608
Na: Mehlich-3	7.21	16.79	10.88	39.33	–1.201
Ca: Exchangeable	19.8	30.0	24.1	34.2	–1.311
Ca: Mehlich-3	3262	750 622	3957	927 633	–1.313
K: Exchangeable	0.72	0.04	1.29	1.03	–1.349
K: Mehlich-3	353	8145	571	120 055	–1.494
Mg: Exchangeable	4.72	1.55	7.08	13.00	–1.514
Mg: Mehlich-3	290	24 196	410	35 276	–1.205
Al: Exchangeable	0.003	0.000	0.004	0.000	–0.379
Al: Mehlich-3	946	13 445	979	21,197	–0.445
Fe: Exchangeable	0.000	0.000	0.000	0.000	–1.000
Fe: Mehlich-3	296	2178	274	5144	0.635
Mn: Exchangeable	0.105	0.002	0.081	0.002	0.843
Mn: Mehlich-3	158	5236	148	2008	0.274
Cu: Mehlich-3	0.493	0.089	0.903	0.050	–2.698*
Zn: Mehlich-3	5.79	12.68	6.35	16.91	–0.252
B: Mehlich-3	0.294	0.008	0.423	0.018	–1.965
P: Available	46.4	111.9	44.9	122.4	0.232
P: Mehlich-3	67.9	264.9	67.6	240.6	0.031
N: Total	0.131	0.001	0.162	0.001	–1.747
C: Total	3.09	0.72	3.58	0.47	–1.098
C:N ratio	23.4	5.4	22.3	3.9	0.923

[a] Data for unlogged area outside the exclosure not presented because this analysis was incomplete.

[b] *t*-values with asterisk are statistically significant.

4.0 CONCLUSIONS

Although sampling involved no interspersed replication, the pairing of grazed and ungrazed sites at each location were similar in the expression of abiotic factors (elevation, slope, aspect, and soil type, soil depth and parent material), leaving grazing or canopy closure effects as the most likely cause of any observed differences.

The statistical analyses revealed that no biologically important differences were evident in soil chemistry inside and outside the exclosures, suggesting that grazing did not affect the soil properties at any of the sites.

Statistical analyses for forage quantity and forage quality showed that biomass production and digestible nitrogen were lower outside the exclosures than inside at four of the sites (Hunter's Range, Tunkwa Lake, Yellow Pine Spacing Trial, and Will Lake Douglas-fir); at the two other sites (Smith Lake and Will Lake Lodgepole Pine), no differences were infered.

Our results thus suggest an effect of grazing on forage production and digestible nitrogen at four locations and no effect at the other two. In particular, management favouring heavy use (> 60%) and lack of rest (annual grazing) at the Tunkwa Lake, Yellow Pine Spacing Trial, and Will Lake Douglas-fir sites led to reduced forage biomass, lower accumulations of litter, and reduced forage and litter digestible nitrogen. Lower litter digestible nitrogen has serious consequences because the inherent low soil nitrogen on these sites and few mechanisms for nitrogen inputs. The Smith Camp and Will Lake Lodgepole Pine sites both had lower levels of livestock grazing (< 25%), and showed no difference in forage productivity or digestible nitrogen between the grazed and ungrazed treatments.

These results also suggest that the benefit of the heavily grazed sites to the livestock industry has diminished. Short-term gains from this management may be offset in the future by severe reductions in productivity, susceptibility to invasive plants, and an elevated risk of erosion. Care needs to be taken to select stocking rates and grazing regimes that will maintain appropriate levels of forage production.

It is also reasonable to conclude that as canopy cover increases, forage production and forage digestible nitrogen decreases. Opportunities are available to manage for both optimal tree canopies and forage production. Management for either maximum timber production or maximum forage production will lead to reduced net benefits.

APPENDICES

APPENDIX A. NITROGEN CONCENTRATION AND ACID DETERGENT FIBRE BY SPECIES

Nitrogen Concentration and Acid Detergent Fibre

Nitrogen

Within-species, differences among nitrogen concentrations could not be tested because only one value was collected for each species at a given site. There is, however, merit in discussing some of the findings in general terms. This appendix lists the nitrogen and acid detergent fibre values by species, showing the plant collection locations and grazed or ungrazed treatments. An average is shown for all values of a species, and percent digestible nitrogen was calculated for each species.

Nitrogen values range from 0.27% for Stipa comata (needle-and-thread grass) at the Yellow Pine Spacing Trial site to 2.93% for Astragalus agrestis at the Tunkwa Lake site, with an average of 1.2% and median of 1.1%. Legumes (Trifolium repens, Astragalus agrestis, A. miser, Lupinus arcticus) were common in the higher values (> 2%), although high values were also observed for Mitella breweri, Pyrola asarifolia, Trisetum spicatum, Goodyera oblongifolia, Sibbaldia procumbens, and Valeriana sitchensis. Low values (i.e., < 0.6%) were seen for needle-and-thread grass, June grass, heart-leaved arnica, narrow-leaved cow-wheat, Idaho fescue, and northern bedstraw.

A few species comparisons are worthy of discussion. Calamagrostis rubescens (pinegrass) ranged from 0.44% to 1.69%, with an average of 0.95%. This wide range should indicate caution in forming generalizations about its forage quality. Festuca scabrella (rough fescue), which is generally considered better forage than pinegrass, had very similar range (0.42% to 1.37%, with an average of 0.83%). The mean acid detergent fibre values for these two species were the same (57%), indicating that digestibility should be similar as well. It appears that when these species were clipped in August, they were very similar in forage value.

Acid Detergent Fibre

Acid detergent fibre (ADF) is a negative indicator of digestibility. Low ADF indicates high digestibility. Differences among ADF values could not be tested because only one value was collected for a species at a given site. These values ranged from 10.2% for Achillea millefolium at the Yellow Pine 6.1m spacing site to 89.3% for Erigeron compositus at the Tunkwa Lake grazed site. The average was 47.4% and the median was 48.7%. The highest values (> 70%) were from Arnica mollis, Arabis holboellii, Erythronium grandiflorum, Veronica wormskjoldii, and Erigeron compositus. Low values (< 25% came from Achillea millefolium, Antennaria neglecta, Pyrola asarifolia, Agrostis humilis, Fragaria virginiana, Mitella breweri, Aster conspicuus, Arnica cordifolia, Erigeron peregrinus, and Astragalus agrestis.

Relationship between Nitrogen and Acid Detergent Fibre

A general negative correlation was evident between nitrogen and ADF, although in our data this relationship is weak (R2 = 0.29), with some species contributing considerably to the residuals. In the following table, the colour ramps can be used to find species that did not correspond to the general trend. Matching colours indicate compliance with the trend, whereas non-matching colours indicate a departure. For example, Erigeron compositus is coloured blue for nitrogen (indicating a high concentration) with a red ADF value indicating high fibre content. Little should be read into this distinction other than that both attributes contribute to an evaluation of the forage quality but neither tells the whole story.

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Smith Camp	*Achillea millefolium*		1.07	1.53		1.42	1.13	1.32		42	40		39	45	42	0.77
Tunkwa Lake New Exclosure		1.53	0.82	1.63								37	54	38		
Tunkwa Lake Outside					1.64	0.98	1.44		39	58	40					
Yellow Pine Spacing Trial 6.1m spacing			0.99	1.48								36	49	46		
Yellow Pine Spacing Trial 2.4m spacing		1.15	1.05	1.68						50	10					
Yellow Pine Spacing Trial Outside					1.79	1.05	1.31		43	45	40					
Smith Camp	*Achnatherum nelsonii*	0.98						0.98	49						49	0.50
Yellow Pine Spacing Trial Outside	*Agropyron cristatum*				1.04	0.63	0.64	0.77				51	56	54	54	0.36
Hunter's Range	*Agrostis humilis*				1.27	1.13		1.2					22		22	0.94
Tunkwa Lake New Exclosure	*Pseudoroegneria spicata*	0.81						0.69					57		58	0.29
Tunkwa Lake Old Exclosure			0.61							66						
Tunkwa Lake Outside						0.64			52							
Smith Camp	*Allium cernuum*	1.19	1.01		1.32	0.48	1.55	1.04	47	36		44	60	43	46	0.56
Yellow Pine Spacing Trial 2.4m spacing		0.71							48							
Hunter's Range	*Anemone occidentalis*				1.41	1.28		1.34				25	35		30	0.94
Smith Camp	*Antennaria umbrinella*					0.94	1.13	1.03					56	50	53	0.49
Yellow Pine Spacing Trial	*Antennaria*							1.42							52	0.68
2.4m spacing	*microphylla*															
Yellow Pine Spacing Trial Outside					1.52	1.32						50	55			

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**	**Mean**	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**	**Mean**	
Tunkwa Lake Outside	*Antennaria neglecta*						1.21	1.27						50	39	0.77
Yellow Pine Spacing Trial 6.1m spacing			0.93									37	44	18		
Yellow Pine Spacing Trial 2.4m spacing		1.61	1.18							37						
Yellow Pine Spacing Trial Outside					1.58	1.19	1.21		45	43						
Will Lake Douglas-fir Open Canopy	*Antennaria racemosa*	1.14	1.01	1.05	1.38	1.09	1.16	1.13	31	29	38	28	26	41	36	0.72
Will Lake Douglas-fir Closed Canopy		1.07	1.14	1.23	1.65	1.16	1.38		37	36	45	37	34	44		
Will Lake Lodgepole Pine		0.93	0.42						44	38						
Tunkwa Lake Outside	*Arabis holboellii*					0.61		0.61					71		71	0.18
Yellow Pine Spacing Trial 6.1m spacing	*Arctostaphylos uva-ursi*		0.7					0.7		53					53	0.33
Will Lake Douglas-fir Open Canopy	*Arnica cordifolia*	0.64			0.85		1.07	0.77	30			29		32	31	0.53
Will Lake Douglas-fir Closed Canopy		0.61		0.76					33		34					
Will Lake Lodgepole Pine		0.84		1	0.67				29			28				
Yellow Pine Spacing Trial 2.4m spacing		0.47							34							
Hunter's Range	*Arnica mollis*	1.97	1.16	1.96	1.83	0.85		1.55	39	64	34	37	70		49	0.79
Yellow Pine Spacing Trial 6.1m spacing	*Aster conspicuus*	1.18	0.86					1.02	23	37					30	0.71
Tunkwa Lake New Exclosure	*Aster ericoides*	1.44	1.12					1.21				34	45		40	0.73
Tunkwa Lake Old Exclosure		1.17	1.03						40	41						
Tunkwa Lake Outside					1.57	0.92			35	43						

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Tunkwa Lake Old Exclosure	*Astragalus agrestis*	2.64						2.79				25			26	2.08
Tunkwa Lake Outside					2.93											
Tunkwa Lake New Exclosure		2.79							26							
Tunkwa Lake New Exclosure	*Astragalus miser*	1.5						1.88	39						42	1.10
Tunkwa Lake Old Exclosure			2.34							33						
Tunkwa Lake Outside					1.78				34	55	40	35	52	43		
Will Lake Douglas-fir Open Canopy		1.74	1.64	2.23	2.65	1.4	2.16					39	58	28		
Yellow Pine Spacing Trial 6.1m spacing		1.53	1.41	1.92					43	49	43					
Yellow Pine Spacing Trial 2.4m spacing		1.76							48							
Yellow Pine Spacing Trial Outside					1.94	1.95	2.21		29							
Tunkwa Lake New Exclosure	*Bromus inermis*	0.64	0.64					0.73	48	53					55	0.33
Yellow Pine Spacing Trial 2.4m spacing		0.91	0.75	0.71					60	56	58					
Smith Camp	*Calamagrostis rubescens*	1.14	0.62	0.75	1.1	0.55	0.81	0.95	50	57	56	52	58	56	57	0.41
Will Lake Douglas-fir Open Canopy		1.04	0.58	0.97	1.26	0.6	0.92		55	62	55	53	58	54		
Will Lake Douglas-fir Closed Canopy		1.33	0.88	1.24	1.69	1.28	1.51		58	59	55	54	61	54		
Will Lake Lodgepole Pine		1.22	0.73	1.16	1.23	0.61	0.66		58	64	52	59	62	55		
Yellow Pine Spacing Trial 6.1m spacing		0.83	0.52	0.85								55	60	48		
Yellow Pine Spacing Trial 2.4m spacing		0.44	0.55	0.88					57	60	50					
Yellow Pine Spacing Trial Outside					1.12	1.4	0.89		64	63	60					

	Species	Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
		2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Smith Camp	*Carex concinnoides*		0.9	0.77	1.01	0.84	1	0.94		50	51	52	51	49	51	0.46
Will Lake Douglas-fir Open Canopy		0.8	0.91	0.83	1.02	0.97	0.87		58	50	51	50	51	54		
Will Lake Douglas-fir Closed Canopy		1.06	1.02	0.88	1.11	1.2	0.9		52	55	51	52	53	53		
Will Lake Lodgepole Pine		1.02	0.88	0.85	1.1		0.82		46	49	43	53		51		
Yellow Pine Spacing Trial 2.4m spacing																
Tunkwa Lake Outside	*Carex petasata*					0.69		0.69					57		57	0.30
Smith Camp	*Carex rossii*		0.92	1				0.96		51	49				50	0.48
Yellow Pine Spacing Trial 6.1m spacing	*Centaurea maculosa*	1.4	0.48	0.89				0.92	31	65	51				49	0.47
Tunkwa Lake Outside	*Cerastium arvense*					1.07	1.37	1.27					41	45	44	0.71
Tunkwa Lake New Exclosure		1.56	1.07						39	50						
Will Lake Lodgepole Pine	*Cirsium edule*						0.73	0.73						43	43	0.42
Hunter's Range	*Elymus glaucus*	2.05	0.42					1.24	31						31	0.86
Tunkwa Lake Outside	*Erigeron compositus*				2.31			2.31				84			84	0.37
Hunter's Range	*Erigeron peregrinus*	2.36	0.8	1.04	2.56	1.19	1.67	1.6	33	61	51	23	37	41	41	0.94
Smith Camp	*Erigeron speciosus*				1.6	1.2	2	1.6				37	36	40	38	1.00
Tunkwa Lake Outside	*Eriogonum heracleoides*				1.27	1.07	1.31	1.22				51	42	37	43	0.69
Hunter's Range	*Erythronium grandflorum*	0.98		1.1	0.72		0.9	0.93	65		72	73		64	69	0.29
Will Lake Douglas-fir Open Canopy	*Festuca occidentalis*					0.62	0.79	0.9					56	55	52	0.43
Will Lake Douglas-fir Closed Canopy						1.29							45			

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Smith Camp	*Festuca campestris*		0.42		1.37			0.83		66		49			57	0.35
Tunkwa Lake New Exclosure		0.94	0.43	0.78					53	67	56					
Tunkwa Lake Old Exclosure		0.92	0.66	0.85					53	64	57					
Yellow Pine Spacing Trial 6.1m spacing		0.86	0.56	1.03								49	60			
Yellow Pine Spacing Trial 2.4m spacing		0.87	0.58	0.9					55	60	55					
Yellow Pine Spacing Trial Outside					1.36	0.77			58	61	55					
Tunkwa Lake New Exclosure	*Festuca idahoensis*		0.57					0.57		57					57	0.25
Will Lake Douglas-fir Open Canopy	*Fragaria virginiana*	1.11	1.02	0.97	1.6	1.1	1.12	1.23	25	29	30	24	27	33	29	0.87
Will Lake Douglas-fir Closed Canopy			1.05	1.71	1.44		1.71		27	32	23	31		23		
Will Lake Lodgepole Pine		1.02	1.24	1.11			0.95		30	26	32			45		
Yellow Pine Spacing Trial Outside					1.24							30				
Smith Camp	*Gallium boreale*					0.59		1.11					42		45	0.61
Yellow Pine Spacing Trial 6.1m spacing		0.94	1.06	1.27					43	42	46					
Yellow Pine Spacing Trial 2.4m spacing		1.03	1.07	1.48					52	48	42					
Yellow Pine Spacing Trial Outside							1.4									
Will Lake Douglas-fir Open Canopy	*Gentianella amarella*					1.18		1.18					57		57	0.50
Smith Camp	*Goodyera oblongifolia*				2.1			1.91				26			33	1.28
Will Lake Douglas-fir Closed Canopy		1.88	1.54	1.99	2.12	1.84	2		33	36	25	26	32	27		
Will Lake Lodgepole Pine		2.19			1.91	1.51			28			64	32			

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Will Lake Douglas-fir Open Canopy	*Hieracium albiflorum*					1.18	1.27	1.21					57	40	44	0.68
Will Lake Douglas-fir Closed Canopy					1.28	1.37	1.33					38		39		
Will Lake Lodgepole Pine							0.84							43		
Hunter's Range	*Hieracium gracile*				1.35			1.35				36			36	0.86
Hunter's Range	*Juncus drummondii*	1.89	1.13	1.28	1.89	1.18		1.47	42	43	43	42	40		42	0.85
Tunkwa Lake New Exclosure	*Koeleria macrantha*		0.35	0.82				0.63					56	50	58	0.26
Tunkwa Lake Outside						0.62	0.96			61	49					
Yellow Pine Spacing Trial Outside						0.4							75			
Hunter's Range	*Litter*	2.03	2.46	2.33	1.87	1.62	1.89	2.03	59	57	61	61	49	56	57	0.87
Smith Camp	*Litter*	0.68	0.99	0.74	0.69	0.95	0.71	0.79	59	70	56	65	69	71	65	0.28
Tunkwa Lake New Exclosure	*Litter*	0.73	0.89	1.04				0.89				65	62	62	63	0.33
Tunkwa Lake Old Exclosure	*Litter*	0.58	0.86	0.78				0.74	63	64	62				63	0.28
Tunkwa Lake Outside	*Litter*				1.41	0.97	1.14	1.17	63	70	67				66	0.39
Will Lake Douglas-fir Open Canopy	*Litter*	0.59	0.81	0.76	0.82	0.91	0.92	0.8	67	70	67	49	75	58	64	0.29
Will Lake Douglas-fir Closed Canopy	*Litter*	0.65	0.72	0.7	1	0.83	0.86	0.79	69	70	60	62	70	60	65	0.28
Will Lake Lodgepole Pine	*Litter*	0.49	0.76	0.9	0.63	0.68	0.77	0.71	71	69	67	62	69	66	67	0.23
Yellow Pine Spacing Trial 6.1m spacing	*Litter*	0.66	0.63	0.6				0.63				65		44	55	0.29
Yellow Pine Spacing Trial 2.4m spacing	*Litter*	0.58	0.72	0.69				0.66	65	71	68				68	0.21
Yellow Pine Spacing Trial Outside	*Litter*				0.76		0.67	0.72	68	68	67				68	0.23
Hunter's Range	*Lupinus arcticus*	2.62	2.53	2.32	2.87	2.11		2.49	34	55	47	44	44		45	1.37
Hunter's Range	*Luzula sp.*	1.95			1.86	0.7		1.5	33			45	63		47	0.79

	Species	Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
		2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Will Lake Lodgepole Pine	*Melampyrum lineare*		0.52					0.52		40					40	0.31
Hunter's Range	*Minor forbs*	1.83	2.03		2.36	1.06	1.33	1.72	41	56		26	61	46	46	0.93
Smith Camp	*Minor forbs*	1.09		1.14	1.33	1.34	1.14	1.21	31		34	48	34	34	36	0.77
Tunkwa Lake New Exclosure	*Minor forbs*	1.43	1.28	1.48				1.4				37	44		41	0.83
Tunkwa Lake Old Exclosure	*Minor forbs*	1.26	1.46	1.24				1.32	36	44	46				42	0.77
Tunkwa Lake Outside	*Minor forbs*				1.48	1.2		1.34	43	49	39				44	0.76
Will Lake Douglas-fir Open Canopy	*Minor forbs*	1.11		1.15	1.47			1.25	33		50	26			36	0.80
Will Lake Douglas-fir Closed Canopy	*Minor forbs*				1.24			1.24				39			39	0.75
Will Lake Lodgepole Pine	*Minor forbs*	1.02		1.3	1.38	0.8		1.13	36		33	41	35		36	0.72
Yellow Pine Spacing Trial 6.1m spacing	*Minor forbs*	1.24	1.02					1.13				38			38	0.70
Yellow Pine Spacing Trial 2.4m spacing	*Minor forbs*	1.15	1.23	1.19				1.19	40	42					41	0.70
Yellow Pine Spacing Trial Outside	*Minor forbs*				1.85			1.85	58	45	40				48	0.97
Smith Camp	*Minor grasses*	1.04		0.63				0.84	48		60				54	0.38
Hunter's Range	*Mitella breweri*	2.11		2.39	2.11	1.39	2.03	2.01	27		31	27	23	31	28	1.45
Will Lake Lodgepole Pine	*Orthilia secunda*				1.27			1.27				44			44	0.71
Smith Camp	*Oryzopsis asperifolia*						0.89	0.89						45	45	0.49
Tunkwa Lake New Exclosure	*Oxytropis campestris*	1.26	0.98	3.17				1.53							48	0.79
Tunkwa Lake Outside						0.69										
Yellow Pine Spacing Trial Outside									50	67	27					
Tunkwa Lake Old Exclosure	*Penstemon procerus*	0.97						0.97	46						46	0.52
Hunter's Range	*Phleum alpinum*	1.77	0.88		1.49	0.71	0.94	1.16	25	56		40	56	45	45	0.64

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Tunkwa Lake New Exclosure	*Poa pratensis*	1.05		0.81				0.85					49	55	52	0.41
Tunkwa Lake Old Exclosure		0.97		0.79					52		50					
Tunkwa Lake Outside						0.87	0.86					51		48		
Will Lake Douglas-fir Open Canopy					1.15	0.45	0.75		50	50	51					
Tunkwa Lake New Exclosure		1.05		0.81									65			
Yellow Pine Spacing Trial Outside						0.66										
Tunkwa Lake Outside	*Poa sandbergii*				0.61	0.66		0.63				58	58		58	0.26
Smith Camp	*Poa species*	1.14	0.58	0.54	0.74			0.99	49	55	55	54			46	0.53
Hunter’s Range		1.31			1.62	1.02			37			32	35			
Yellow Pine Spacing Trial 6.1m spacing		0.95										50				
Yellow Pine Spacing Trial Outside					1.04				48							
Will Lake Douglas-fir Closed Canopy	*Pyrola asarifolia*		1.93					1.93		20					20	1.54
Hunter’s Range	*Senecio species*				1.13			1.13				58			58	0.48
Hunter’s Range	*Senecio triangularis*	1.7	0.87	1.32	1.57	0.61	1.04	1.19	43	60	59	34	46	41	47	0.63
Hunter’s Range	*Sibbaldia procumbens*				2.31	1.51		1.91				25	36		30	1.33
Tunkwa Lake New Exclosure	*Stipa columbiana*	1.03	0.7					0.87					58		53	0.41
Tunkwa Lake Old Exclosure		1.47	0.5						52	55	50					
Tunkwa Lake Outside						0.66			47	56						
Yellow Pine Spacing Trial Outside	*Stipa comata*					0.27		0.27					73		73	0.07
Will Lake Douglas-fir Open Canopy	*Stipa hymenoides*						1.11	1.11						58	58	0.47

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Tunkwa Lake Outside	*Stipa occidentalis*					0.66	0.92	0.75					58	50	54	0.35
Tunkwa Lake Old Exclosure			0.5	0.94						56	50					
Smith Camp	*Stipa richardsonii*					0.66	0.71	0.74					56	50	55	0.33
Tunkwa Lake New Exclosure		0.87	0.59	0.67					51	57	53					
Yellow Pine Spacing Trial 6.1m spacing		0.53		0.79					62		56					
Tunkwa Lake Old Exclosure			0.55	0.73								49	54	49		
Tunkwa Lake Outside					1.18	0.59	0.82			65	55					
Yellow Pine Spacing Trial Outside					0.87	0.8						57	61			
Smith Camp	*Taraxacum officinale*				0.99			1.15				25			29	0.82
Tunkwa Lake New Exclosure				1.06							43					
Will Lake Douglas-fir Open Canopy				0.77	1.64	1	1.44				26	22		28		
Will Lake Douglas-fir Closed Canopy	*Thalictrum occidentale*	1.11		1.56				1.34	34		29				31	0.92
Will Lake Douglas-fir Open Canopy	*Trifolium hybridum*					1.25		1.25					57		57	0.54
Smith Camp	*Trifolium repens*					1.84		1.87					40		34	1.24
Will Lake Douglas-fir Open Canopy						1.93				28						
Will Lake Lodgepole Pine			1.82													
Hunter's Range	*Trisetum spicatum*	2.09			1.88			1.98				39			39	1.20
Hunter's Range	*Vahlodea atropurpurea*	1.64	0.59	1.45	2.26	0.7		1.33	38	65	41	32	41		43	0.76
Hunter's Range	*Valeriana sitchensis*	1.89	1.47	1.74	2.43		2.09	1.93	35	54	40	26		26	36	1.23
Hunter's Range	*Veratrum viride*	1.88	1.35	1.54				1.59	29	63	30				41	0.94

		Nitrogen concentration (%)							Acid detergent fibre (%)							Nitrogen digestability (%)
					Outside exclosure				Inside exclosure			Outside exclosure				
	Species	2004	2005	2006	2004	2005	2006	Mean	2004	2005	2006	2004	2005	2006	Mean	
Will Lake Douglas-fir Open Canopy	*Verbascum thapsus*						0.82	0.82						48	48	0.43
Hunter's Range	*Veronica wormskjoldii*				1.55	1.05		1.3				39	77		58	0.55

REFERENCES

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures and some applications). U.S. Department of Agriculture, Washington, D.C. Handbook No. 379.

Heffner, R.A., M.J. Butler, and C.K. Reilly. 1996. Pseudoreplication revisited. Ecology 77(8):2558–2562.

Hurlbert. S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54(2):187–211.

Oksanen, L. 2001. Logic of experiments in ecology: is pseudoreplication a pseudoissue? Oikos 94:27–38.