Pacific Forest Research Centre

ISSN 0706-9413

Environment Canada / Environnement Canada
Forestry Service / Service des Forêts

Fertilization and Thinning Effects on a Douglas-fir Ecosystem at Shawnigan Lake on Vancouver Island

Some Observations on Salal and Bracken Fern Undergrowth

W. STANEK, D. BEDDOWS AND D. STATE

VICTORIA, B.C.
BC-R-1, APRIL, 1979

ABSTRACT

A thinning and N-fertilization experiment was established in an even-aged Douglas-fir forest at Shawnigan Lake, Vancouver Island in 1971, with replication in 1972. This study was concerned with the treatment effects on above-ground biomass, ground cover percent, and N content of salal, Gaultheria shallon Pursh., and bracken fern, Pteridium aquilinum (L.) Kuhn.

Forest thinning and fertilization as applied to forest stands in order to increase their productivity, also affect herbaceous and shrubby undergrowth. Thinning caused more light to penetrate through tree canopies and thus increased the undergrowth biomass. In contrast, fertilization caused an increase in density of tree canopies, thus decreased undergrowth ground cover and biomass. Combination of fertilization and thinning treatments benefited the undergrowth, heaviest thinning and moderate fertilization being the most beneficial.

The amounts of nitrogen tied up by undergrowth of fertilized plots were relatively small and are not likely to be critical for tree growth except in under very nitrogen-deficient soil conditions and in very young stands.

RÉSUMÉ

Une expérience d'éclaircie et de fertilisation à l'azote a été effectuée dans une forêt équienne de Douglas taxifolié au lac Shawnigan, sur l'île Vancouver en 1971, avec répétition en 1972. L'étude visait les effets d'un traitement sur la biomasse au-dessus du sol, le pourcentage couvrant le sol et la teneur en azote de la Gaulthérie, (Gaultheria shallon) Pursh., et de la Fougère aigle, Pteridium aquilinum (L.) Kuhn.

Les éclaircies et la fertilisation telles qu'appliquées aux peuplements forestiers pour augmenter leur productivité, affectent aussi les plantes herbacées et les arbustes du sous-étage. L'éclaircie a permis à une plus grande quantité de lumière de pénétrer le couvert forestier, augmentant ainsi la biomasse du sous-bois. Par contre, la fertilisation a augmenté la densité du couvert en diminuant la couverture vivante et sa biomasse. La fertilisation et l'éclaircie combinées ont profité au sous-bois, l'éclaircie maximale et une fertilisation modérée étant les plus bénéfiques.

Les quantités d'azote retenues par le sous-bois dans des placettes fertilisées ont été relativement faibles et ne seront pas critiques pour la croissance des arbres, sauf sur les sols très pauvres en azote et dans les peuplements très jeunes.

INTRODUCTION

Growing demand for fibre materials necessitates the intensification of forest utilization and application of silvicultural measures to improve forest productivity. In British Columbia, maintenance and enhancement of wood yields of Douglas-fir are of economical concern and effects of thinnings and fertilization on growth of forest stands are being studied.

Lesser vegetation (the herb and shrub layer, here called undergrowth) are a part of these studies. As a subordinate component of forest ecosystems, the undergrowth depends on the chemical and physical attributes of the environment (Daubenmire 1968). It utilizes nutrients, light and water, and thus could compete with trees, the dominant component of forest plant communities. The degree of competition by the undergrowth may vary with the type of silvicultural treatment applied to the forest stand. For instance, thinning and fertilization affect the tree canopy development and thus the amount of light available to the undergrowth. Since species composition, vigor, biomass, nutrient element contents and other attributes of the undergrowth will be affected by the surrounding environment, the question arises of how much the undergrowth competes with the trees, and to what degree it could affect their productivity.

The study reported here is part of the Pacific Forest Research Centre's Shawnigan Lake project (Crown and Brett 1975) investigating fertilization and thinning effects on a Douglas-fir ecosystem. The objective was to examine responses of two plant species, bracken fern, Pteridium aquilinum (L.) Kuhn, and salal, Gaultheria shallon Pursh., frequently growing under thinned and fertilized Douglas-fir stands in the Pacific Northwest and to elucidate any meaningful effects their growth might have on productivity of tree stands.

METHODS

The experiment was established in an even-aged Douglas-fir forest and utilized a completely randomized design of three nitrogen (N) fertilization levels administered in the form of urea with 46% N content (Crown and Brett 1975).

- F_0 - no fertilization (control)
- F_1 - moderate fertilization - 224 Kg N/ha
- F_2 - heavy fertilization - 448 Kg N/ha

and three thinning schedules,

- T_0 - no thinning (control)
- T_1 - moderate thinning (approx. 1/3 basal area removed)
- T_2 - heavy thinning (approx. 2/3 basal area removed)

These nine treatment combinations were replicated twice, in 1971 and in 1972, resulting in a total of 36 plots (Table 1). Each treated plot is 28.3 by 28.3 m (0.08 ha) in size and is surrounded by a 10-m-wide buffer zone.

The study reported here was concerned with the above-ground biomass, ground cover percent and nitrogen contents of salal and bracken fern. For each plot, the vegetal cover percent was estimated visually on 25 subplots of 1 m^2, laid out in a stratified design. Surveyed were: in 1973, 5 plots (6, 14, 29, 33 and 39), in total 125 subplots; in 1974, 4 plots (4, 18, 25 and 38), in total 100 subplots; and in 1975, 4 plots (6, 14, 29 and 39), in total 100 subplots. Distribution of plots by treatment and year of establishment is shown in Table 1.

In late summer of 1977, vegetal cover percent estimates were obtained for each of the 36 plots by averaging estimates made on five randomly distributed subplots by two independent observers.

The biomass per square metre (dry weight in g/m^2) of each species was determined per plot on five subplots whose individual cover percent came closest to the average of all subplots (in 1973, 25 subplots; in 1974, 20 subplots, and in 1975, 20 subplots), in total 65 subplots. The destructive sampling consisted of clipping all undergrowth to ground level within the vertical projection of subplot boundaries (including any overhanging vegetation), and separating the clippings by species to be oven-dried and weighed. Heights of salal and bracken fern were estimated to provide an indication of plant vigor.

Total N contents in percentage of oven-dry weight were determined by the micro-Kjeldahl method (McMullan 1971). For each plot and species analyzed, the average of two 10g composite samples, taken from the oven-dry biomass obtained 2 years after treatment, from plots 4, 6, 14, 25, 29, 38 and 39 was determined. The N contents in g/m^2 per plot were calculated, using the percent N and the average dry weights of biomass per plot.

Table 1. Distribution of 38 plots by fertilization and thinning treatments, and years of establishment. Plots are identified by number.

Thinning		Year	Fertilization, treatments, kg N/ha None F_0	224 F_1	448 F_2
No thinning; control	T_0	1971	6 21	19 40	29 45
		1972	2 38	13 34	16 18
Intermediate: removal of approx. 1/3 of basal area.	T_1	1971	10 37	9 24	15 43
		1972	17 30	12 44	5 35
Heavy: removal of approx. 2/3 of basal area.	T_2	1971	11 39	1 8	14 33
		1972	20 25	28 41	4 31

The number of trees per plot and their basal areas were determined in 1976. The percent stocking of the remaining plots was determined in proportion to plot 45 which contained the largest basal area of 1.97 m^2.

Light intensity was determined using a Lambda Instruments Corporation, LI-170 quantum/radiometer/photometer and LI-190s quantum sensor which measures in microeinsteins (m^2 sec^{-1}) the photosynthetically active radiation spectrum between 400 and 700 nm. Five readings were taken at equal distances, diagonally across each plot, avoiding direct sunlight and deep shade, and their values were averaged to give the average "diffuse" light intensity for each of the 36 plots. Readings were taken on a sunny day in late summer of 1977, from 1100 to 1400 hours.

Relationships between cover percent, light intensity, percent stand stocking and N content per square metre, and the degree of fertilizing and thinning were analyzed according to standard statistical methods (Li 1964). Data were processed by means of an IBM-360 computer, using the MINITAB II program (Ryan 1976), and a Digital PDP-11 computer, utilizing the ENB-2 program (Simmons 1975). Multiple range tests were not shown where results are non-significant.

RESULTS

The evaluation of thinning and fertilization effects on above-ground biomass of salal and bracken fern required an initial determination and testing of overall relationships of biomass on cover percent. Tested were 65 data pairs in salal and 50 data pairs in bracken fern (15 of the subplots for bracken fern contained unreliable information), collected from 1973 to 1975.

The best fit was given by curvilinear regressions (Fig. 1) for bracken fern:

$$y = 1.02x + .009x^2; R^2 = .91; SE_E = 15.7 \qquad 1)$$

for salal:

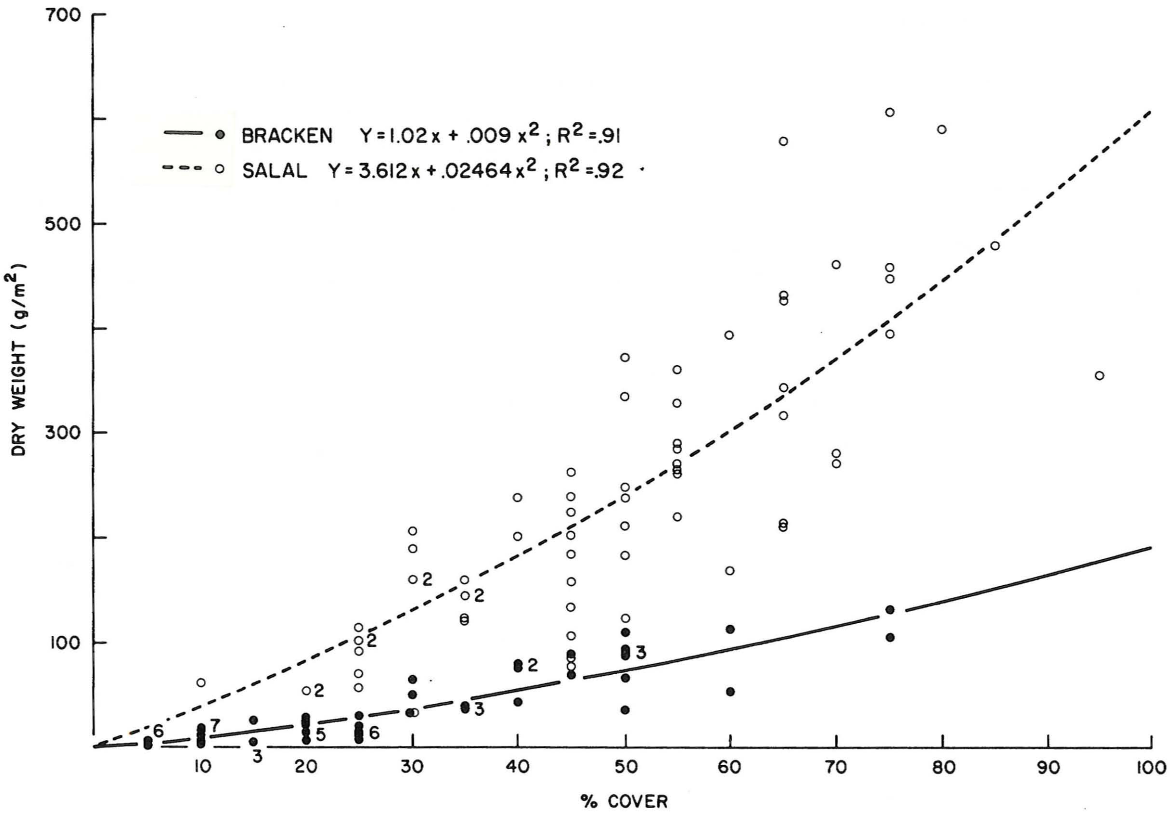

Fig. 1. Distribution and regression of salal (65 plots) and bracken fern (50 plots) biomass (g/m^2) on % cover.

$$y = 3.612x + .02464x^2;\ R^2 = .92;\ SE_E = 78.9 \qquad 2)$$

(y = biomass in dry weight g/m^2; x = vegetal cover in percent)

Application of the curvilinear regression equations showed that biomass of bracken fern collected from 1973 to 1975 increased by 1.1 g/m^2 per 1 percent cover increase for the 0-10 percent cover range; by 1.85 g/m^2 per 1 percent cover in the 40-50 percent range, and by 2.4 g/m^2 in the range of 70-80 percent cover. In salal, a 1 percent cover increase gave an increase in biomass of 3.8 g/m^2 for the 0-10 percent cover range; 5.7 g/m^2 for the 40-50 percent cover range, and 7.2 g/m^2 for the range of 70-80 percent cover. These relationships applied for the range of vegetal cover heights from 0.2-1.0 m in bracken, and from 0.1-1.5 m in salal, the upper heights of which were not exceeded during the 5 to 6 years after treatment. The data were not split according to treatments, because observations were few and infrequent.

In 1977, biomass of salal and bracken fern was not measured but was estimated by interpolation, using the 1977 cover percent and regressions 1 and 2. The resulting values were subjected to analyses of variance (Table 2 and 3) and multiple range tests (Tables 4-6) to elucidate the effects on biomass of thinning, fertilizing, year of establishment and interactions of thinning and fertilizing.

Table 2. Analysis of variance of bracken fern biomass (g/m^2) by treatments and their interactions.

Treatments	DF	SS	MS	F	PROB	
Thinning	2	9439.2	4719.6	32.3	0.000	***
Fertilizing	2	835.2	417.6	2.9	0.076	NS
Year of establishment	1	20.2	20.2	0.1	0.713	NS
Thinning & fertilizing	4	588.8	147.2	1.0	0.422	NS
Error	26	3800.0	146.2			
TOTAL	35	14683.4				

*** = 0.1% level of significance; NS = non-significant.

Table 3. Analysis of variance of salal biomass (g/m^2) by treatments and their interactions.

Treatments	DF	SS	MS	F	PROB	
Thinning	2	445323.0	222661.5	89.2	0.000	***
Fertilizing	2	55983.6	27991.8	11.2	0.000	***
Year of establishment	1	5311.2	5311.2	2.1	0.157	NS
Thinning & fertilizing	4	50636.5	12659.1	5.1	0.004	**
Error	26	64869.4	2495.0			
TOTAL	35	622123.7				

*** = 0.1% level of significance; ** 1% level of significance; NS = non-significant.

Table 4. Multiple range test of bracken fern and salal biomass (g/m^2) means (12 observations per mean) by the three thinning levels. Means in order of magnitude (underlined means not statistically different).

	T_0	T_1	T_2
Bracken fern	5.2	20.1	44.6
Salal	153.1	271.5	424.8

Table 5. Multiple range test of bracken fern and salal biomass (g/m^2) means (12 observations per mean) by three fertilization levels. Means in order of magnitude (underlined means not statistically different at the 5% level).

	F_0	F_1	F_2
Bracken fern	29.0	23.8	17.2
Salal	312.5	309.5	227.4

Table 6. Multiple range test of (bracken fern and salal) biomass (g/m^2) means (12 observations per mean) by nine fertilization and thinning interactions. Means in order of magnitude (underlined means not statistically different at the 5% level).

	T_2F_1	T_2F_0	T_2F_2	T_1F_0	T_1F_1	T_1F_2	T_0F_0	T_0F_2	T_0F_1
Bracken fern	48.8	46.8	38.2	32.7	18.9	8.9	7.6	4.6	3.8

	T_2F_1	T_2F_0	T_2F_2	T_1F_1	T_1F_0	T_0F_0	T_1F_2	T_0F_1	T_0F_2
Salal	486.9	395.0	392.5	319.4	311.1	231.5	184.1	122.1	105.6

Thinning, in comparison with control, significantly increased above-ground biomass of bracken fern, 3.8 times by moderate thinning and 8.4 times by heavy thinning; and of salal, 1.8 times by moderate thinning and 2.8 times by heavy thinning (Table 4). Fertilization, in contrast to thinning, appeared to cause an overall decrease of above-ground biomass, although the only significant value occurred in salal after heavy fertilization (Table 5). Similar effects of fertilization on salal biomass were reported by Heilman (1961). The interaction of thinning and fertilization had no significant effect on biomass of bracken fern (Table 2), whereas in salal (Table 3), it was significant. The multiple range tests (Table 6) appear to indicate that both species benefited from thinning and from fertilization with thinning, and that undergrowth biomass generally was the smallest in untreated plots and largest with heavy thinning and moderate fertilizer application. Year of establishment had no significant effect on biomass of either species (multiple range test not shown).

Further effects of thinning were shown in the direct relationship of diffuse light intensity to percentage of Douglas-fir stand stocking. The highly significant linear regression

$$y = 881 - 8.3x;\ R^2 = .639;\ SE_E = 117; \qquad 3)$$

(y = average diffuse light intensity in microeinsteins; x = percent stocking) showed that every 1 percent increase in stocking caused an 8.3 microeinstein decrease in average diffuse light intensity.

Regressions were also developed for vegetal cover percent on light intensity, using 1977 data: in bracken fern:

$$y = 0.05275x;\ R^2 = .843,\ SE_E = 0.04; \qquad 4)$$

in salal:

$$y = 0.14325x;\ R^2 = .903;\ SE_E = 0.09; \qquad 5)$$

(in both cases y = percent cover; x = average diffuse light intensity in microeinsteins). They indicated that an increase in diffuse light intensity by one microeinstein effected a corresponding cover increase in bracken fern of 0.05 percent, and in salal of 0.14 percent. A similar cause and effect relationship was reported by Long and Turner (1975) and Paddock (1962), between salal above-ground biomass and the amount of overstory foliage.

The amounts of N in biomass of bracken fern and salal as affected by thinning and fertilizing were subjected to analyses of variance (Tables 7 and 8). Thinning in bracken fern, and both thinning and fertilizing in salal significantly affected the amounts of N per unit area, whereas treatment interactions were insignificant. Heavy thinning significantly increased the amounts of N per unit area of undergrowth (Table 9). In contrast to control, in bracken fern, this increase was more than seven-fold and in salal, more than 1.7 times.

Fertilization significantly increased the amount of N per unit area of salal by a factor of 1.72 (Table 10). In bracken fern, the trends were similar, though statistically non-significant. In both species, the N contents in kg/ha were the lowest in untreated plots (Table 11). On a dry weight basis, in comparison to unfertilized plots, fertilization in both unthinned and heavily thinned plots appears to have led to increases, and heavy thinning to decreases of N.

Table 7. Analysis of variance of nitrogen content (g/m^2) of bracken fern as affected by thinning, fertilizing and their interactions.

Treatment	DF	SS	MS=SS/DF	F	Significance
Thinning	1	1.7	1.7	37.1	***
Fertilizing	1	0.1	0.1	2.3	NS
Fertilizing & thinning	1	0.0	0.0	.8	NS
Error	4	.1	0.0		
TOTAL	7	1.9			

*** = 0.1% level of significance; NS = non-significant.

Table 8. Analysis of variance of nitrogen content of salal (g/m^2) as affected by thinning, fertilizing and their interactions.

Treatment	DF	SS	MS=SS/DF	F	Significance
Thinning	1	1.6	1.6	9.9	*
Fertilizing	1	1.4	1.4	9.0	*
Fertilizing & thinning	1	.0	.0	.3	NS
Error	4	.6	.2		
TOTAL	7	3.6			

* = 1% level of significance; NS = non-significant.

Table 9. Means of table of nitrogen (g/m^2) tied up in bracken fern and salal of untreated (control-T_0) and heavy thinned plots (T_2).

	T_0	T_2	Difference	
Bracken fern	.14	1.06	.92	***
Salal	1.23	2.12	.89	*

*** = 0.1% level of significance; * = 5% level of significance

Table 10. Means table for nitrogen (g/m^2) tied up in bracken fern and salal of untreated (control=F_0) and heavy fertilized plots (F_2).

	F_0	F_2	Difference	
Bracken fern	.49	.71	.22	NS
Salal	1.25	2.10	.85	*

* = 5% level of significance; NS = non-significant.

Table 11. Nitrogen content (% dry weight), biomass (kg/ha) and Nitrogen content in biomass (kg/ha) of bracken fern and salal by treatments.

Species	Treatment	N in % of dry wt. [1]	Biomass dry wt. (kg/ha)	N content of biomass (kg/ha)
Bracken	T_0F_0	1.675	55	0.9
	T_0F_2	1.777	130	2.3
	T_2F_0	1.120	714	8.0
	T_2F_2	1.564	798	12.5
Salal	T_0F_0	.5860	1495	8.8
	T_0F_2	.6226	2483	15.5
	T_2F_0	.5442	2958	16.1
	T_2F_2	.7667	3421	26.2

1) Average of two separate samples from plots 4, 14, 6, 38, 29, 25 and 39.

DISCUSSION

Undergrowth biomass was directly related to its cover percent (equations 1 and 2) and this was related to the average diffuse light intensity available beneath the tree canopy (equations 4 and 5). Light intensity was inversely related to percent stocking of the stand (i.e., with increased stocking the diffuse light intensity decreases). Thinning, therefore, increased the available light, while fertilization, in promoting the growth of tree crowns, tended to decrease the light available to the understory vegetation. Therefore, thinning might be expected to lead to an increase in undergrowth biomass, while fertilization would tend to decrease it.

Increases in biomass utilize nutrients otherwise available to the trees. For example, in contrast to control, heavy thinning increased biomass and the amounts of N (g/m^2) tied up in bracken fern rose from .14 to 1.06 and in salal from 1.23 to 2.12 (Table 9). The increase in biomass of 8.4 times in bracken fern and of 2.8 times in salal (Table 4) produced by heavy thinning, utilized 14.4 kg/ha of N (7.1 kg in bracken fern and 7.3 kg in salal (Table 11)). Where fertilization takes place during the same period as the thinning, some of the fertilizer N will be tied up by the undergrowth (Björkman _et al._ 1971). The biomass and the amounts of N contained in it (Table 11) indicate that in contrast to control (T_0F_0), fertilization without thinning (T_0F_2) increased slightly both the above-ground concentration of nitrogen and the biomass; heavy thinning without fertilization (T_2F_0) increased the biomass but decreased considerably the nitrogen concentration, and the heavily thinned and fertilized plots (treatment T_2F_2) experienced an upsurge in vigor of the undergrowth with slightly higher nitrogen concentration and considerably higher biomass production than heavily thinned but unfertilized plots. Comparisons, especially between heavily thinned, fertilized or unfertilized plots, would indicate that increased availability of light stimulated undergrowth which, in turn, caused increased demands on the available nitrogen. The above-ground parts of bracken fern and salal of untreated plots contained approximately 9.7 kg/ha of N, whereas those of heavily thinned and heavily fertilized plots contained approximately 38.7 kg/ha. Compared with 277 kg/ha of N contained in above-ground parts of a 15- to 20-year-old Douglas-fir stand (Webber 1973), the proportions were 3.5 percent and 13.9 percent, respectively. Though the increased undergrowth found in this study in thinned stands will temporarily tie up nitrogen until the tree canopy closes again, this small amount is not likely to be critical for tree growth except under very nitrogen-deficient soil conditions and in very young stands.

The above-ground parts of bracken fern contained approximately double the amount of N per unit dry weight as salal (Table 11) and, in contrast to salal, die in the fall and become litter (how soon and how much of N becomes available would merit further studies). In bracken fern, the biomass of the subterranean parts exceeds that of the above-ground parts, the rhizome of bracken fern commonly penetrating deeper and more intensively into the soil than the roots of salal. These differences would indicate a different ecological role for the two species within the forest community.

Gessel et al. (1973) found that the nitrogen content in the sub-vegetation of a Douglas-fir ecosystem amounted to 0.2 percent of the total and that most of the nitrogen is contained in the forest floor and in the soil (approximately 90 percent). Similar results were reported by Björkman et al. (1967) and Mead and Pritchett (1975). According to Ulrich (1971), 73 to 93 percent of bioelements taken up in spruce stands were returned to the forest floor in the same year. Therefore, one could assume that in most productive stands any negative effect of competition by undergrowth will be only temporary (Miller et al. 1976). The beneficial effects that undergrowth has on the aeration of soil, retention of ground water and nutrient elements, increase of soil fauna, and prevention of erosion and leaching will probably more than make up for the N consumption. Turner and Long (1975) found that the understory of a stand, in terms of productivity and organic matter return, is more important than the distribution of biomass indicates.

This study showed that the undergrowth competed with trees for nitrogen and other elements, including water, and Black et al. (1976) indicated that the advantages of increased water supply per tree in thinning Douglas-fir stands was partly offset by the water consumption of the undergrowth.

Other experiments with complete removal of above-ground parts of the undergrowth, in contrast to stands with undisturbed undergrowth, apparently showed favorable tree growth improvement and decreased water stress (per. comm. Dr. H. Brix, PFRC).

The results of this study are interesting in that they indicate the important role undergrowth could play in the ecology of a forest community. It would be desirable to undertake further, more intensive studies, to predict the effects of certain undergrowth species on tree growth in managed stands growing on commonly occurring forest sites in British Columbia.

REFERENCES

Björkman, E. and G. Lundeberg. 1971. Studies of root competition in a poor pine forest by supply of labelled nitrogen and phosphorus. Stud. For. Suecica, 94: 16pp.

Björkman, E., G. Lundeberg and H. Nommik. 1967. Distribution and balance of N^{15} labelled fertilizer nitrogen applied to young pinetrees (Pinus silvestris L.). Stud. For. Suecica, 48: 23p.

Black, T.A., C.S. Tan and J.U. Nnyamah. 1976. Effect of thinning on evapotranspiration from a Douglas-fir forest. Environment Canada, Pac. For. Res. Centre, Victoria. Info. Rept. PC-23-170X, 72pp.

Crown, M. and C. Brett. 1975. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake: An establishment report. Environment Canada, Pac. For. Res. Centre, Victoria. Info. Rept. BC-X-110, 45pp.

Crown, M., R.V. Quenet and C. Layton. 1977. Fertilization and thinning effects on a Douglas-fir ecosystem at Shawnigan Lake: 3 Year growth response. Environment Canada. Pac. For. Res. Centre, Victoria. Info. Rept. BC-X-152, 36pp.

Daubenmire, R. 1968. Plant communities: A textbook of plant synecology. Harper and Row, New York, Evanston, London. 300pp.

Freese, F. 1967. Elementary statistical methods for foresters. Agriculture Handbook 317, U.S. Department of Agriculture, Forest Service, 87 pp.

Gessel, S.P., D.W. Cole and E.C. Steinbrenner. 1973. Nitrogen balances in forest ecosystems of the Pacific Northwest. In Soil Biology and Biochemistry, Ed. Dr. J.S. Wald, Pergamon Press, Oxford, New York, Brauschweig, 5: 19-34.

Heilman, P.E. 1961. Effects of nitrogen fertilization on the growth and nitrogen distribution of low-site Douglas-fir stands. Ph.D. Thesis, Univ. of Washington, Seattle. (referred to in Turner and Long 1975).

Li, C.R. 1964. Statistical inference I and II. Edwards Brothers Inc., Ann. Arbor, Michigan. 658 & 575 pp.

Long, J.N. and J. Turner. 1975. Above-ground biomass of understory in an age sequence of four Douglas-fir stands. J. Appl. Ecol. 12: 179-188.

McMullan, E.E. 1971. Methods of analysis: soils-biochemistry laboratory service I. Environment Canada. Pac. For. Res. Centre, Victoria. Info. Rept. BC-X-50, 49pp.

Mead, D.J. and W.L. Pritchett. 1975. Fertilizer movement in slash pine ecosystems. II. N. distribution after two growing seasons. Plant and Soil 43: 467-478.

Miller, R.E., D.P. Lavender and C.C. Grier. 1976. Nutrient cycling in the Douglas-fir type - silvicultural implications. Proc. Soc. Amer. For. 1975: 359-390.

Paddock, R.W. 1962. Certain quantitative nutrient descriptions for different stages of plant succession of the Fern Lake watershed. M.F. Thesis. Univ. of Washington, Seattle (referred to in Turner and Long 1975).

Ryan, T. 1976. Minitab Student Handbook. Duxbury Press, Scituhee, Mass. 341 pp.

Simmons, C. 1975. User's guide to ENB-2: General purpose analysis of variance. PFRC Computing and Applied Statistics. Unpublished report. Environment Canada. Pac. For. Res. Centre, Victoria. 32pp.

Turner, J. and J.N. Long. 1975. Accumulation of organic matter in a series of Douglas-fir stands. Can. J. For. Res. 5: 681-690.

Webber, B.D. 1973. Plant biomass and nutrient distribution in a young Pseudotsuga menziesii forest ecosystem. Oregon State Univ. PhD Thesis. Environment Canada, Pac. For. Res. Centre, Victoria. Int. Rept. BC-41. 163pp.

Ulrich, D. 1971. Investigations on cycling of bioelements in forests of Central Europe (preliminary results of the Solling project). Productivity of Forest Ecosystems. Proc. Brussels Symp. UNESCO and IBP October 27-3, 1969. Ed. P. Duvigneaud, UNESCO Place de Fontenoy, 75 Paris-7e, Ecology and Conservation No. 4: 707 pp.

Environment Canada
Canadian Forestry Service
Pacific Forest Research Centre
Victoria, B.C. V8Z 1M5
BC-R-1, April 1979