UREA DOSAGE TRIAL IN SEMIMATURE JACK PINE FOREST, CHAPLEAU, ONTARIO: FIFTH-YEAR RESULTS

I. K. MORRISON, D. A. WINSTON AND N. W. FOSTER

GREAT LAKES FOREST RESEARCH CENTRE

SAULT STE. MARIE, ONTARIO

REPORT O-X-251

CANADIAN FORESTRY SERVICE

DEPARTMENT OF THE ENVIRONMENT

OCTOBER 1976

Copies of this report may be obtained from

Information Office,
Great Lakes Forest Research Centre,
Canadian Forestry Service,
Department of the Environment,
Box 490, Sault Ste. Marie, Ontario.
P6A 5M7

ABSTRACT

In 1970, an experiment was established to determine the optimum amount of urea required to stimulate increment (diameter, basal area, volume) in a 45-year-old, even-aged jack pine (*Pinus banksiana* Lamb.) stand. The stand, of fire origin, was on a Site Class I sandy site near Chapleau, in north-central Ontario. Periodic annual increment on controls was estimated at 6.0 m^3/ha. Five levels of urea application, from 0 to 448 kg N/ha, were tested. After 5 years the response variables, mean DBH increment, BA increment, percent BA growth, total volume increment and merchantable volume increment, were estimated. The three higher levels of application differed significantly (5%) from controls for all response variables. The best response was to urea applied at 224 kg N/ha. This resulted in an increase in merchantable volume of approximately 6 m^3/ha over controls over 5 years, or 1.2 m^3/ha/yr. Responses are compared with published results of other studies concerning jack pine in eastern Canada, and pines elsewhere, including Scots pine (*Pinus sylvestris* L.) in Scandinavia.

RÉSUMÉ

En 1970, une expérience fut mise sur pied dans le but de déterminer la quantité optimale d'urée nécessaire pour stimuler l'accroissement (en diamètre, en surface terrière (ST) et en volume), dans un peuplement équienne de Pins gris (*Pinus banksiana* Lamb.) de 45 ans. Le peuplement, originant après un incendie, était une station sableuse de classe I, située près de Chapleau, dans le Centre-Nord ontarien. Sur des arbres témoins, l'accroissement annuel périodique fut de 6.0 m^3/ha. Cinq niveaux d'application d'urée, de 0 à 448 kg N/ha furent testés. Au bout de 5 ans, les variables de réponse, l'accroissement moyen du d.h.p., l'accroissement de ST, le pourcentage d'augmentation de ST, l'accroissement du volume total et du volume marchand furent évalués. Les trois niveaux d'application plus élevée ont différé significativement (5%) des témoins pour toutes les variables de réponse. La meilleure réponse fut celle à l'urée appliquée à raison de 224 kg N/ha. Elle produisit une hausse du volume marchand d'approximativement 6 m^3/ha comparativement aux témoins sur une période de 5 ans, ou 1.2 m^3/ha/an. Les réponses sont comparées aux résultats publiés d'autres études concernant le Pin gris dans l'Est du Canada, et les Pins d'autres pays, 6 compris le Pin sylvestre (*Pinus sylvestris* L.) en Scandinavie.

ACKNOWLEDGMENTS

The following employees, past and present, of the Canadian Forestry Service, Great Lakes Forest Research Centre, contributed to the research reported here: Messrs. W. Hall, F. Hegyi, D. Kurylo, D. Ropke, and B. Smith. Data analysis was by D. Ropke.

TABLE OF CONTENTS

INTRODUCTION

In northern Ontario, climate and geography have combined to create forests dominated by relatively few species and trees of relatively small dimensions. Two species, black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine (*Pinus banksiana* Lamb.), account for 42% of the standing volume (Dixon 1963). A high proportion of the northern Ontario forest industry is geared to manufacturing these species into pulp and paper for domestic and export markets. Slow growth rates here, relative to those elsewhere in the world, necessitate wide deployment of effort, with concomitant high costs of tending, harvesting and transporting. At the same time, as allowable cuts in some areas are approached, the traditional avenue of expansion, i.e., increasing the area of exploitation, is curtailed.

Following development of forest fertilization technology in various parts of the world, particularly in Scandinavia where conditions of climate and geography are similar to those in Canada, there was increasing interest, especially during the latter half of the last decade, in the use of mineral fertilizers to increase growth of eastern Canadian pulpwood forests.

Jack pine occupies second place among Ontario conifers in standing volume and volume cut. It occurs on a variety of sites, in pure stands and in mixture with black spruce and other species. It occurs most commonly in pure, even-aged stands of fire origin on deep, acid, glacio-fluvial sands. As a pioneer species it occupies much the same ecological niche as does Scots pine (*Pinus sylvestris* L.) in northern Europe. Its selection for forest fertilization research was made on several grounds. It is a major source of raw material for the northern Ontario pulp and paper industry and occurs on sites amenable to mechanized silviculture. It is somewhat easier to regenerate than other species in the region, is relatively free of insects and diseases, and grows rapidly; in consequence, it has a high potential for intensive management. Furthermore, it is commonly associated with sites of low fertility, yet makes its most rapid growth on sites of high fertility. The selection of the semimature age class, i.e., stands approximately a decade from harvestable age, for fertilizer application was made on economic grounds, to reduce interest charges on money invested in fertilization to the lowest practical level.

Literature suggests that nitrogen (N) is the element whose lack most limits tree growth in the boreal forest. Responses to N-containing fertilizers by various species of conifers on both mineral and organic sites have been widely reported. Hoyt (1973) found that jack pine in New Brunswick responded only to N, despite applications of phosphorus (P) and potassium (K) fertilizers. Morrison et al. (1976), reviewing a series of fertilization trials in semimature jack pine forest in northwestern Ontario, observed that N was the only element which, when applied singly, readily elicited a significant growth response. However, evidence also suggested (ibid.) that when N demand was met, a second element (P in that particular case) could become limiting. Urea has been a favored source of N because its high N content (45%) results in low application cost per unit weight of N. Also, it is nitrate-free, and this lessens the chance of loss by percolation and subsequent contamination of groundwater.

The objective of the present experiment was to ascertain, for this stand of jack pine, the dosage of urea fertilizer required to produce the greatest increase in volume. A range of urea application levels was chosen to bracket the expected value.

STUDY AREA

The study area (lat. 47°38'N; long. 83°15'W) is located in Dupuis Township (formerly Township 12E) of Sudbury District, Ontario, some 25 km SSE of the town of Chapleau. It is within the Missinaibi—Cabonga Section (B.7) of the Boreal Forest Region (Rowe 1972). The average length of growing season based on a 5.5°C index is 161 days, i.e., roughly May through September, inclusive (Chapman and Thomas 1968). Mean total precipitation measured at the nearest weather station (Chapleau) is 810 mm annually (Anon. 1973). Approximately 53% of the precipitation falls during the growing season (ibid.). Potential evapotranspiration has been estimated at 480 mm annually (Chapman and Thomas 1968). The study area is located on the common boundary of the Foleyet Site District of Site Region 3E, the Mississagi Site District of Site Region 4E (Hills 1955), and the Arctic—Great Lakes watershed. The soil, unmapped, is in profile a Mini Humo-Ferric Podzol (Anon. 1974b) developed in silt loam over loamy sand, the latter commencing at a depth of approximately 30 cm below the mineral surface.

The stand at the beginning of the experiment was a 45-year-old (stump age), relatively thrifty, uniform jack pine forest of fire origin. Mean dominant height was approximately 16.5 m; mean diameter at breast height (DBH), 10.7 cm (range 3.8-26.9 cm); basal area (BA), 31.2 m^2/ha; total standing volume 178.6 m^3/ha; merchantable standing volume 131.8 m^3/ha; and number of trees, 3184/ha. The Site Class was I (Plonski 1974). The forest floor (Appendix I) was occupied by a continuous moss layer with *Pleurozium schreberi* (BSG.) Mitt. predominating and *Dicranum polysetum* SW and *Hypnum crista-castrensis* Hedw. in lesser abundance. The herb and shrub layer was light, with frequently occurring species including *Maianthemum canadense* Desf., *Anemone quinquefolia* L., *Cornus canadensis* L., *Vaccinium angustifolium* Ait., *Diervilla lonicera* Mill. and *Linnaea borealis* L.

METHODS

The experiment consisted of five N treatments: 0, 56, 112, 224 and 448 kg N/ha, with N applied as commercial-grade prilled urea. There were five replications of each treatment, for a total of 25 treatment plots arranged in a Latin square design. Plots were square, 0.04 ha in area with shared boundaries, treatment and measurement plots being one and the same. Trees were numbered with metal tags. In late May, 1970, predetermined amounts of urea were hand broadcast to the soil surface, in two or more systematic passes to ensure uniform coverage. The DBH of all trees, and height of one randomly selected tree in each 2.5-cm diameter class in each plot, were recorded when the experiment was initiated, and diameters were remeasured 5 years later, in late May, 1975. Trees which died during the period 1970-1975 were removed from the record. All measurements were in English units and were subsequently converted to S.I. units.

The following 5-year response variables were calculated: mean DBH increment, BA increment, percent BA growth, total volume increment, and merchantable volume increment. Mean DBH and BA increment and percent BA growth were calculated in the usual manner. The two volume increments were estimated as follows: a regression of height-on-diameter, derived from pooled measurements on the sample trees (augmented by data from similarly selected trees in nearby experiments) was used to approximate the height of each tree. Total and merchantable volumes, for both 1970 and 1975, were computed on a tree-by-tree basis for each plot, using estimated heights, measured DBHs, and Honer's (1967) volume equations. Total and merchantable volume increments were calculated for each plot by subtracting 1970 from 1975 figures. Data were subjected to analysis of variance and Duncan's New Multiple Range Test for the detection of significant differences among means.

RESULTS

Results of analysis of variance (F-ratios) are summarized in Table 1. No significant difference for any response variable occurred for either rows or columns. Significant (5%) differences among treatments occurred for mean DBH increment, BA increment and total and merchantable volume increments. A highly significant (1%) difference among treatments occurred for percent BA growth.

Table 1. Analysis of variance: summary of F-ratios

	Mean DBH increment	Basal area increment	Basal area growth (%)	Total volume increment	Merchantable volume increment
Row	.43	2.68	3.08	2.73	2.49
Column	.86	.63	1.21	.59	.54
Treatment	2.14	4.57*	7.05**	4.51*	4.54*

* Statistically significant, P = 5%
** Statistically significant, P = 1%

Lowest and highest mean DBH increments (Table 2) were associated with the 56 kg N/ha and the 224 kg N/ha treatments, respectively. The difference between these treatments was significant (5%). In Table 2, corresponding superscript letters in vertical columns denote no significant (5%) difference between means. No N treatment produced a statistically significant increase in mean DBH increment over controls.

Table 2. Five-year growth response of 45-year-old jack pine to increasing levels of nitrogen supplied as urea

Treatment (kg N/ha)	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Basal area growth (%)	Total volume increment (m^3/ha)	Merchantable volume increment (m^3/ha)
Control	0.81^{ab}	4.03^{a}	14.04^{a}	30.48^{a}	30.52^{a}
N 56	0.71^{a}	4.35^{ab}	14.88^{ab}	32.86^{ab}	32.90^{ab}
N 112	0.76^{ab}	4.59^{b}	16.20^{bc}	34.46^{b}	34.56^{b}
N 224	0.91^{b}	4.80^{b}	17.34^{c}	36.15^{b}	36.47^{b}
N 448	0.86^{ab}	4.76^{b}	17.98^{c}	35.84^{b}	35.80^{b}

NOTE: Corresponding superscript letters in vertical columns indicate no significant (5%) differences between means.

Basal area, total volume and merchantable volume increments were least with no N, and greatest with 224 kg N/ha (Table 2). Beyond this, there was a small but nonsignificant decrease in all three response variables. From the control, periodic annual increment (PAI) in terms of either total or merchantable volume is estimated at 6.1 m^3/ha/yr. The most favorable N treatment in terms of merchantable volume gave an additional 1.2 m^3/ha yearly or approximately 6 m^3/ha over 5 years (Fig. 1). Percent basal area growth was greatest following application of 448 kg N/ha (Table 1).

DISCUSSION

The absence of buffer strips surrounding measurement plots might be cited as a design failing of the present experiment, although this deficiency does not appear to have decreased the sensitivity of the analysis, as statistical separation of results was readily achieved. It might be noted in this regard that any edge-effect errors, i.e., errors relating to scavening by the roots from one plot into the next, would be necessarily conservative. The tendency is presumably for increased N uptake by trees in low N plots, and decreased uptake by trees in high N plots.

Total and merchantable volume increments on the control plots of the present experiment, however, were essentially of the same order of magnitude as corresponding increments (authors' unpublished data) on nearby buffer-equipped unfertilized plots, suggesting that the problem is not one of major concern. The present result is further supported by the following facts: first, each treatment was replicated for a total of five plots per application rate, as against the more usual two to four; second, individual measurement plot area was almost twice as great and the average number of trees per plot was over twice as great as that estimated by Hegyi (1973), as being necessary for experimental work in 40- to 50-year-old even-aged jack pine forest. These estimates were based on studies of stand variability.

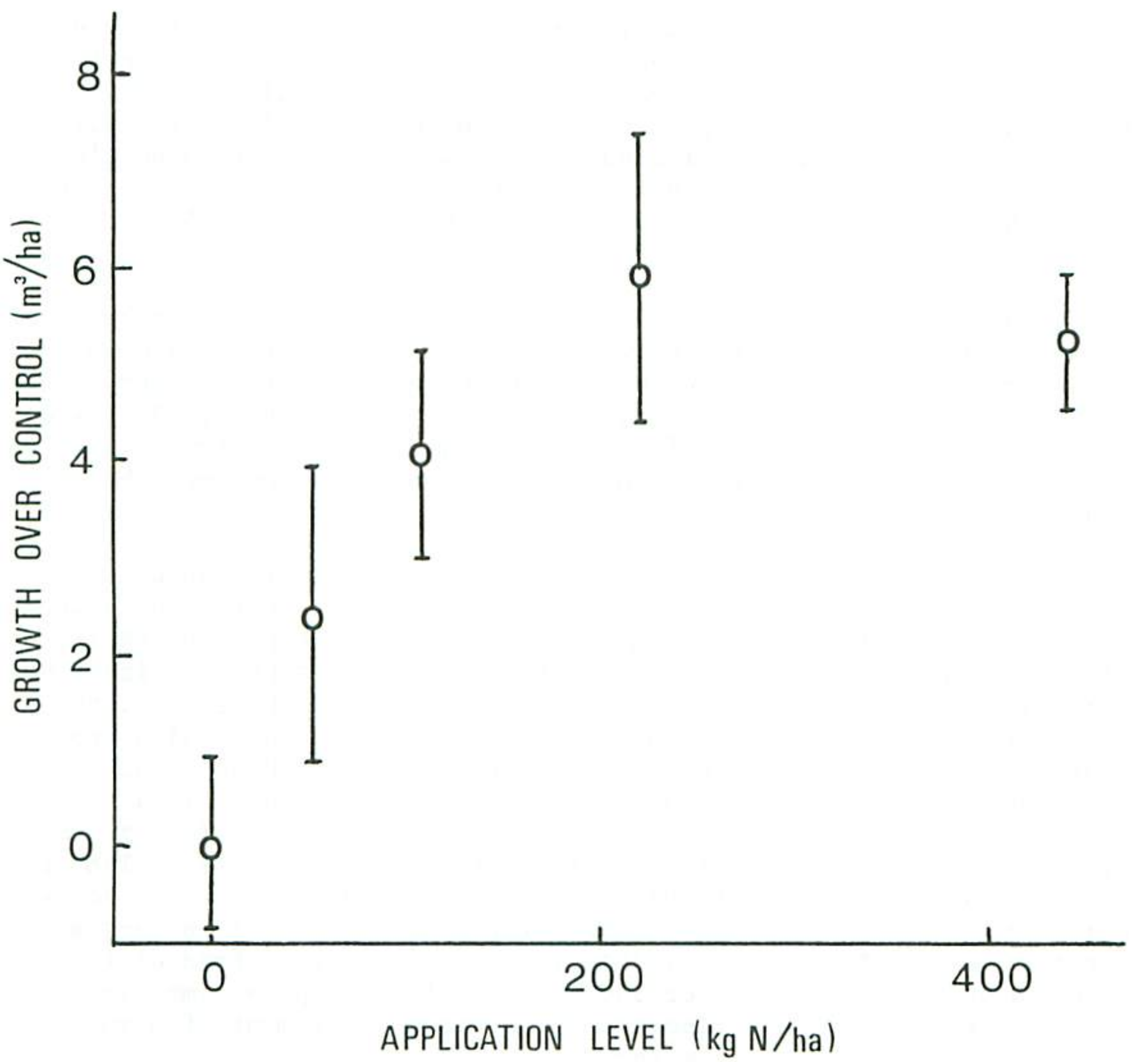

Fig. 1. Five-year merchantable volume growth over control (m^3/ha) of 45-year-old jack pine forest in relation to urea application level (means ± standard errors).

On the basis of the results of the present study, the optimum dosage of urea for this 45-year-old jack pine stand would be about 500 kg/ha of prilled fertilizer, supplying 224 kg N/ha. This could be expected to produce a gain over controls of approximately 6 m^3/ha of merchantable wood over 5 years, or 1.2 m^3/ha of extra merchantable wood annually. This is somewhat lower than that reported for a similar application of urea in an experiment of similar design (differing only in one level of application) in 55-year-old, somewhat less thrifty (PAI = 5 m^3/ha/yr) jack pine forest in northwestern Ontario (Anon. 1974a, Morrison et al. 1976) where 224 kg N/ha produced approximately 6.8 m^3/ha of extra wood over 4 years, or approximately 1.7 m^3/ha/yr. In this same northwestern Ontario series of experiments, responses to urea applied at rates of 200-250 kg N/ha were, in some cases, in excess of 2.5 m^3/ha/yr. In one instance, a response in excess of 3.2 m^3/ha/yr was observed for a combination of urea and triple superphosphate supplying 151 kg N and 67 kg P/ha. On the basis of experience in northwestern Ontario (Anon. 1974a, Morrison et al. 1976), there appeared to be a general inverse relationship between fertilizer response and site quality, suggesting that the low response in the present experiment may have been related partly to high site index. The order of magnitude of these results and their implications concerning the influence of site quality seem to substantiate Hoyt's (1973) finding that fertilizing jack pine on Site Class I sites with urea at 168 kg N/ha increased PAI by 1.4 and 1.5 m^3/ha for 39- and 55-year-old stands, respectively.

The use of increase in PAI for comparative purposes, as has just been done, is probably justified when response periods are reasonably similar in length. Evidence with Scots pine in Europe (Höhne and Fiedler 1970, Möller and Rytterstedt 1975, Ipatiev and Paavilainen 1975) suggests that current annual increment (CAI) increases during the first 3 to 5 years after treatment, thereafter decreasing and finally disappearing by the sixth to tenth year.

For similar assessment periods (4 to 5 years), response to comparable dosages (200 to 250 kg N/ha) of urea by adult Scots pine stands in Scandinavia generally ranges from 2 to 4 m^3/ha/yr (Erkén 1970, Möller 1971, 1974, Viro 1972), somewhat more than in the present experiment but in the same range as the northwestern Ontario series. Generally, the biologically optimum amount of urea, or that amount beyond which growth is not significantly increased by more fertilizer, has been found to be in the range 200 to 300 kg N/ha. In a different geographic locality, Wells et al. (1976), working with pole-sized loblolly pine (*Pinus taeda* L.) in Virginia, on a Piedmont site low in N, reported that urea at 168 kg N/ha increased the increment over that on controls by 13.8 m^3/ha in 5 years; the increase using 338 kg/ha was only slightly greater. In a 35-year-old plantation of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in southwestern Washington, Miller and Pienaar (1973) applied ammonium nitrate at 314 kg N/ha and reported an increased increment of almost 60 m^3/ha over 7 years or 8.5 m^3/ha/yr.

In general, it seems that while the responses observed in the present study were low, volume response to urea by jack pine in northern Ontario is not entirely out of line with reported response by pines in Scandinavia and the eastern United States. The optimum dosage appears to be somewhat in excess of 224 but less than 448 kg/ha. Because aerial application of fertilizer causes overlap, resulting in areas of over- and under-application (Armson 1972), amounts lower than the optimum should be applied. Additional increment would not be realized on the overlap strips (these presumably having been fully satisfied on the first pass); the extra fertilizer would be wasted. The generally poorer response in this experiment on a Site Class I site (Plonski 1974), compared with the northwestern Ontario experiments, mainly on Site Class II and Site Class III sites, suggests that urea fertilization usually would be more successful on less productive sites, although the evidence is by no means conclusive. This is consistent with the general theory of N-deficiency on such sites.

LITERATURE CITED

Anon. 1973. Canadian normals. 2. Precipitation 1941-1971. Can. Dep. Environ., Atmos. Environ. Serv. 330 p.

Anon. 1974a. Proceedings of a workshop on forest fertilization in Canada. Can. For. Serv., Sault Ste. Marie, Ont. For. Tech. Rep. 5. 131 p.

Anon. 1974b. The system of soil classification for Canada. Can. Dep. Agric., Publ. 1455. 255 p.

Armson, K. A. 1972. Fertilizer distribution and sampling techniques in the aerial fertilization of forests. Univ. Toronto, Fac. For., Tech. Rep. 11. 27 p.

Chapman, L. J. and M. K. Thomas. 1968. The climate of northern Ontario. Can. Dep. Transp., Meteorol. Br., Climatol. Stud. 6. 58 p.

Dixon, R. M. 1963. The forest resources of Ontario. Ont. Dep. Lands For., Timber Br. 107 p.

Erkén, T. 1970. [Fertilizing with large dosages of N.] Arsb. Fören. Skogstradsforadl. 1969. p. 144-152.

Hegyi, F. 1973. Optimum plot dimensions for experimental designs in jack pine stands. Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-180. 13 p.

Hills, G. A. 1955. Field methods for investigating site. Ont. Dep. Lands For., Site Res. Man. 4. 120 p.

Höhne, H. and H. J. Fiedler. 1970. [Nitrogen fertilizing in Scots pine stands of medium age. I. Yield studies up to the disappearance of the effect of a 3-year N fertilizing experiment.] Arch. Forstw. 19: 899-919.

Honer, T. G. 1967. Standard volume tables and merchantable conversion factors for the commercial tree species of central and eastern Canada. Can. Dep. For. Rur. Dev., Ottawa, Ont. Inf. Rep. FMR-X-5.

Hoyt, J. S. 1973. Growth increases after fertilization in mature jack pine and balsam fir stands. N. B. Dep. Nat. Resour., For. Br., TR3-73. 81 p.

Ipatiev, V. and E. Paavilainen. 1975. Lannoituksen vaikutuksen kestoaika vanhassa tupasvillarämeen männikössä. Folia For. 241. 13 p.

Miller, R. E. and L. V. Pienaar. 1973. Seven year response of 35-year-old Douglas fir to nitrogen fertilizer. USDA For. Serv. Res. Pap. PNW-165. 24 p.

Möller, G. 1971. Skogsgödsling: hittills vunna erfarenheter. Skogen 58: 360-367, 374.

Möller, G. 1974. Val av gödselmedel och godslingstidpunkt. Skogen 61: 80-89.

Möller, G. and P. Rytterstedt. 1975. [Duration and course of response to nitrogen fertilizer in pine and spruce stands.] Arsb. Fören. Skogstradsforadl. 1974: 75-97.

Morrison, I. K., F. Hegyi, N. W. Foster, D. A. Winston and T. L. Tucker. 1976. Fertilizing semimature jack pine (*Pinus banksiana* Lamb.) in northwestern Ontario: Fourth-year results. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-240. 42 p.

Plonski, W. L. 1974. Normal yield tables (metric) for major forest species of Ontario. Ont. Min. Nat. Resour., Div. For. 40 p.

Rowe, J. S. 1972. Forest regions of Canada. Can. For. Serv., Ottawa, Ont. Publ. 1300. 172 p.

Viro, P. J. 1972. Die Walddüngung auf Finnischen Mineralböden. Folia For. 138. 19 p.

Wells, C. G., D. M. Crutchfield, and I. F. Trew. 1976. Five-year volume increment from nitrogen fertilization in thinned plantations of pole-size loblolly pine. For. Sci. 22: 85-90.

APPENDIX

APPENDIX I

Occurrence of lesser plant species prior to treatment, 1969, expressed as percentage of plots on which species occurred; based on sample of 2 mil-acre subplots per plot.

Species	Occurrence (%)
LICHENS	
Cladonia mitis Sanst.	4
MOSSES	
Dicranum polysetum SW.	36
Hypnum crista-castrensis Hedw.	24
Pleurozium schreberi (BSG.) Mitt.	100
FLOWERING PLANTS	
Picea mariana (Mill.) B.S.P.	24
Calamagrostis canadensis (Michx.) Nutt.	4
Oryzopsis asperifolia Michx.	72
Carex spp.	36
Clintonia borealis (Ait.) Raf.	4
Maianthemum canadense Desf.	100
Goodyera repens (L.) R. Br.	4
Salix spp.	60
Comptonia peregrina (L.) Coult.	8
Corylus cornuta Marsh.	4
Anemone quinquefolia L.	96
Clematis verticillaris DC	4
Coptis groenlandica (Oeder) Fern.	28
Sorbus decora (Sarg.) Schneid.	4
Amelanchier spp.	28
Fragaria virginiana Duchesne	4
Rubus pubescens Raf.	4
Rosa acicularis Lindl.	72
Prunus pensylvanica L.	4
Polygala paucifolia Willd.	72
Cornus canadensis L.	100
Viola spp.	52
Epilobium angustifolium L.	8
Aralia nudicaulis L.	8
Pyrola secunda L.	4
Pyrola virens Schweigger	4
Monotropa uniflora L.	4
Ledum groenlandicum Oeder	28
Epigaea repens L.	44
Vaccinium myrtilloides Michx.	60
Vaccinium angustifolium Ait.	100
Trientalis borealis Raf.	36
Diervilla lonicera Mill.	92
Linnaea borealis L.	92
Solidago bicolor L.	60
Aster macrophyllus L.	8