Effect of Fire Intensity and Depth of Burn on Lowbush Blueberry, *Vaccinium angustifolium*, and Velvet Leaf Blueberry, *Vaccinium myrtilloides*, Production in Eastern Ontario

LUC C. DUCHESNE[1] and SUZANNE WETZEL[2,3]

[1]Forest BioProducts Inc., 945 Queen Street East, Sault Ste Marie, Ontario P6A 2E5 Canada
[2]Natural Resources Canada, Canadian Forestry Service, 1219 Queen Street East, Sault Ste Marie, Ontario P6A 3A5 Canada
[3]Corresponding author at swetzel@NRCan.gc.ca

Duchesne, Luc C., and Suzanne Wetzel. 2004. Effect of fire intensity and depth of burn on Lowbush Blueberry, *Vaccinium angustifolium,* and Velvet Leaf Blueberry, *Vaccinium myrtilloides,* production in eastern Ontario. Canadian Field-Naturalist 118(2): 195-200.

The effects of prescribed fire intensity and depth of burn were investigated on Lowbush Blueberry (*Vaccinium angustifolium*) and Velvet Leaf Blueberry (*Vaccinium myrtilloides*) stem density, blueberry production and the number of blueberries/stem in a clear-cut Jack Pine, *Pinus banksiana,* ecosystem of eastern Ontario. Blueberry production and stem density were significantly ($P < 0.001$) increased by low intensity prescribed fires of 597 and 1268 kW/m. In contrast, prescribed fires of medium and high intensities did not affect blueberry production and stem density. The number of blueberries/stem was not affected ($P = 0.056$) by prescribed burning, two years after treatment. Pearson's multiple correlation analysis showed that blueberry production (R: -0.683, $P < 0.01$), stem density (R: 0.733, $P < 0.01$) and the number of blueberries/stem (R: 0.803, $P < 0.01$) correlated with depth of burn. As well, blueberry production (R: 0.507, $P < 0.05$) and stem density (R: -0.504, $P < 0.05$) correlated with fire intensity. Depth of burn was a better predictor of berry production and stem density than fire intensity. These results suggest that only low intensity fires with little penetrating effect in the ground should be used to manage blueberry crops.

Key Words: Lowbush blueberry, *Vaccinium augustifolium, Vaccinium myrtilloides,* wildfire, nontimber forest products (NTFP).

Nontimber forest products (NTFP) are all botanical commodities harvested from the forest excluding industrial timber use (Duchesne et al. 2000). NTFP are critical to the economy of forest and rural communities by providing food as well as supplemental income, which often improves the standard of living of rural and First Nation communities (Brubaker 1997; Duchesne et al. 2001; Mohammed 1999). Despite the socio-economic importance of this industry there has been little scientific research conducted for its support, presumably because of its novelty. However, the long-term success of the NTFP industry depends on acquiring precise knowledge regarding the availability, and sustainability of wild harvests as well as strategies to domesticate and manage many of the most sought after NTFP species. Species such as Lowbush Blueberry (*Vaccinium angustifolium*) and Velvet Leaf Blueberry *(Vaccinium myrtilloides*) need to be further domesticated and/or managed in natural ecosystems to meet the growing demand from the food and nutraceutical industries (Duchesne et al. 2001). This paper describes research conducted to improve blueberry management.

Canada is the world's largest producer of wild blueberries (Lowbush and Velvet Leaf blueberries) with an annual output of $42 425 million in farm gate value resulting in production of 43 511 tonnes of frozen blueberries (Agriculture and Agri-Food Canada 2002). The demand for Lowbush and Velvet Leaf blueberries is such that management of natural or established sites is conducted to promote optimal yields ranging from 3360 to 8967 kg/ha (Mohammed 1999). Given that blueberries are worth approximately $1.00/kg to farmers, the annual output of managed fields ranges from $3360 to $8967/ha, which is far superior to the average timber growth of Canada's forests of 1.59 m^3/ha/year (Lowe et al. 1996) with an approximate value of $100/ha/year.

Pruning of blueberry fields, either by mowing or burning, is used routinely to maximize blueberry production (Badcock 1958; Eaton 1958; Eaton and White 1960) as it stimulates the development of new shoots from shallow rhizomes (Van Hoefs and Shay 1981). In turn, new shoots are preferred over old shoots as the ratio of flower buds to leaf buds is greater on new shoots than on older shoots (Hall et al. 1972). Fire pruning of blueberry fields is generally accomplished by using straw as a fire carrier or tractor mounted oil or propane gas burners that emit a constant flame (Blatt et al. 1989). Burning also has the added advantage of reducing problems with insects and disease (Blatt et al. 1989; Smith and Hilton 1971). Although fire is frequently used for the management of Lowbush and Velvet Leaf blueberries (Blatt et al. 1989), which form one commercial crop, there is a lack of information about the relationship between fire behaviour and its impact on berry production. Indeed, current prescriptions aim at using fires that kill all stems (Blatt et al. 1989). However, fire behaviour varies a great deal even during prescribed burns, which in turn affects the ecological outcome of post-fire ecosystems (McRae et al. 2001).

Frontal fire intensity (or Byram's fireline intensity) is a measurement of the quantity of energy liberated as a fireline moves through an ecosystem, and is the most encompassing physical measurement of fire behavior related to ecological impacts (reviewed by Alexander 1982 and McRae et al. 2001). Fire intensity is sometimes used together with depth of burn (Miller 1977), which is a measurement of heat penetration into the soil. However, both frontal fire intensity and depth of burn are relatively new concepts in fire ecology and have never been applied to blueberry management. Hence, the objective of this study was to investigate the effect of fires of different intensities and depth of burn on Lowbush and Velvet Leaf blueberry production and vegetative growth.

Materials and Methods

Study site

The study area is located at Frontier Lake (46°00'N, 77°33'W) in a Jack Pine, *Pinus banksiana,* stand in eastern Ontario within the middle Ottawa section (L.4c) of the Great Lakes – St. Lawrence Forest region (Rowe 1972). As reported by Herr et al. (1994), the site is near the Petawawa Research Forest, and is relatively flat, with a difference in elevation of approximately 4 m over 1.0 km. The surface deposit is a fine-grained and deep sand (10-30 m deep) (Gadd 1962) and the soil is a humo-ferric podzol. The study site was selected because of its uniformity in tree composition and topography. It was harvested in 1942 and 1943 leaving residual standing timber with a stump diameter of 17.5 cm or less. Dendrochronological analysis of dominant trees and snags with multiple fire scars suggests that the study site sustained several fires, with the most recent in 1943, presumably from broadcast slash burning following harvesting (E. Stechishen, personal communication).

Presently, the stand comprises a mix of Jack Pine (*Pinus banksiana)*, Red Pine (*Pinus resinosa*) and White Pine (*Pinus strobus*) with the Red and White pine forming an emergent layer (Herr et al. 1994). Although the Jack and Red pine are of similar ages, the Jack Pine has higher relative density and is the dominant tree species on the site. Other plant species found at the site include serviceberry (*Amelanchier* sp.), Sweet Fern (*Comptonia peregrina)*, Wintergreen (*Gaultheria procumbens*), Sheep Laurel (*Kalmia angustifolia)*, Ground Pine (*Lycopodium complanatum)*, Cow Parsnip (*Maianthemum canadense*), Hairy Solomon's Seal (*Polygonatum pubescens*), Bracken Fern (*Pteridium aquilinum*) and Sand Cherry (*Prunus pumila)*.

Treatments

In the summer of 1990, an area of 150 m × 1000 m was clear-cut with the slash left in place. The site was divided into 40 plots of 35 m × 70 m with 8 m fireguards established around each plot. In 1991, ten plots were burned under different indices of the Canadian Forest Fire Weather Index (FWI) system (Table 1) resulting in frontal fire intensities that varied from 597 to 21 305 kW/m and depth of burn that varied from 0.37 to 2.78 cm (McAlpine 1995). This range of fire intensity and depth of burn far exceeds the range of fire behaviour currently used in blueberry management (unpublished observations).

Pre- and post-burn fuel loads were measured for both slash and duff fuels (McRae et al. 1979). Fire rate of spread was measured with a pin grid network on each plot; fire arrival times at each pin were recorded to provide distance and time information. Fuel consumption was determined as the difference between these two values. Fire intensity was calculated using Byram's (Byram 1959: *cited in* McAlpine 1995)

TABLE 1. Fire weather[1], fire behaviour parameters[1] and blueberry production from thirteen 35 m × 75 m plots in a clear cut Jack Pine after prescribed burning of different fire intensities at Frontier Lake Experimental site in Eastern Ontario.

Plot Number	Date of burn[1]	FWI [1]	Depth[1] of Burn (cm)	Intensity[1] (kW/m)	Blueberries[2] (g/m^2)	Stem density[2] ($stems/m^2$)	Blueberries/stem[2] (N/plant)
2	08/08/91	3.1	0.37	597	492.86 a (167.4)	73.2 a (8.5)	7.53 a (3.4)
7	08/08/91	3.6	0.38	1 268	242.18 a (79.44)	44.2 b (9.8)	5.52 a (1.6)
44	06/24/91	15.8	1.79	2 305	10.81 b (7.6)	5.9 c (0.7)	2.26 a (1.8)
40	07/10/91	4.3	2.78	4 844	11.14 b (5.9)	9.4 c (2.9)	0.90 a (0.69)
32	07/12/91	9.6	1.85	7 600	8.78 b (8.7)	6.7 c (5.6)	0.53 a (0.46)
26	06/14/91	11.0	3.50	10 941	4.96 b (4.8)	9.9 c (7.1)	3.40 a (2.9)
46	06/24/91	17.4	1.95	12 065	2.01 b (1.1)	4.0 c (1.9)	3.10 a (2.7)
36	07/12/91	3.9	2.71	13 202	27.20 b (8.9)	12.1 c (4.6)	2.59 a (1.13)
43	07/10/91	8.8	2.64	20 334	0.53 b (0.24)	5.7 c (4.1)	0.50 a (0.42)
24	06/14/91	21.0	1.79	21 305	5.33 b (0.48)	13.8 c (2.4)	0.04 a (0.06)
	Controls[3]	—	—	—	9.01 b (2.6)	5.9 c (1.48)	0.78 a (0.25)

[1] from McAlpine (1995).

[2] within column means followed by a different letter are significantly different at $P < 0.05$ determined by ANOVA. Observed significance level was adjusted with the Bonferroni procedure.

[3] controls consisted of three unburned plots adjacent to the burned over plots.

intensity equation I=HwR, where I is the intensity of the fire (kW/m), H is the fuel low heat of combustion (assumed to be 18 000 kJ/kg), w is the weight of fuel consumed in the active front (kg/m^2) (all fuel consumed was assumed to have been burned by the active fire front), and R is the rate of spread (m/sec).

To determine depth of burn, ten 50 cm steel pins mounted with horizontal markers were used in each plot to mark the top of the soil litter layer prior to each burn. Immediately after the burn, the distance between the horizontal marker and the top of the litter layer was measured with a ruler and called depth of burn.

Two years following prescribed burning, there were 45 plant species in our research plots. The most important species in terms the biomass and frequency (in decreasing order of importance) were *P. aquilinum*, *V. angustifolium*, *V. myrtilloides*, *Amelanchier* sp., *P. pumila*, *Comptonia peregrina*, *Kalmia angustifolia*, Yellow Panic-grass (*Panicum xanthophysum*), and Houton's Sedge (*Carex houghtonii)* (Tellier et al. 1995, 1996).

Blueberry collection

To compare the effect of fire intensity and depth of burn, blueberries were collected two years after prescribed fire from the ten burned over plots and from three control plots. Controls consisted of three clearcut 35 m × 70 m plots adjacent to the burned-over plots. Blueberries were not collected in subsequent years because of logistical reasons limiting access to the research plots.

For this study, three 3 m × 3 m quadrats were randomly established in each of the 35 m × 70 m plots. The perimeter of each of the 3 m × 3 m quadrats was delineated with a string tied 40 cm above ground and all berries within the 3 m × 3 m quadrats were picked, advancing from the edge of the plot inwards. Ripe, over-ripe, green, and deformed blueberries were included in the harvest. All plots were harvested on 13 July and 14 July 1993. The harvested berries were kept in plastic coolers in the shade until the end of the collection day and their fresh weight determined in the laboratory the same evening. The bags were then placed in drying ovens at 50ºC for 5 days before weighing. Because the moisture content of blueberries (83.1 $\pm$ 0.8 %) was comparable among all plots ($P = 0.22$) and consistent with published data (Usui et al. 1994), the results were expressed in terms of fresh weight only. As well, no attempt was made to distinguish between *V. myrtilloides* and *V. angustifolium* as the frequency of these species (1:15- 1:30, *myrtilloides*: *angustifolium*) was not significantly different among treatments ($P = 0.57$).

To compare the effect of fire intensity and depth of burn on the vegetative abundance of *V. myrtilloides* and *V. angustifolium,* the number of stems of both species was determined two years after prescribed fire from the ten burned over plots and three control plots. Once the berries had been removed from the 3 m × 3 m quadrats, the number of stems was recorded for the entire quadrat and expressed as stems/m^2.

As well, the number of blueberries/stem was compared among the prescribed burns and the control. For this, 100 stems were selected randomly outside the 3 m × 3 m quadrats and the number of blueberries determined for each stem. This protocol was repeated in each of the ten prescribed burn plots as well as each of the three control plots.

Statistical analyses

Analysis of variance (ANOVA) was conducted to compare blueberry production, stem density and blueberry abundance/stem among the prescribed burns and the controls (Systat 1997). For statistical analyses the three control plots were pooled as one treatment whereas each of the ten burned over plots was treated as a separate treatment (McAlpine 1995). Means were compared using the Bonferroni procedure (Systat 1997). Pearson's multiple correlation analysis was conducted to determine the relationship between frontal fire intensity, depth of burn, berry production and the number of blueberries/stem (Systat 1997).

Results

Blueberry production (g/m^2) differed significantly ($P < 0.001$) among treatments. The greatest blueberry production was observed in prescribed fires of 597 and 1268 kW/m whereas there were no significant differences among blueberry production of the other treatments, including controls (Table 1). Likewise stem density/ha differed among treatments ($P < 0.001$) and was greatest in the fires of 597 and 1268 kW/m. There was no difference in the number of blueberries/plant among the other treatments including the controls ($P = 0.056$).

Pearson's multiple correlation analysis showed that fire intensity correlated ($P < 0.05$) with blueberry production, and stem density (Table 2). Depth of burn correlated ($P < 0.01$) with blueberry production, stem density and blueberries/plant. Depth of burn showed better correlations with blueberry production, number of blueberries/plant and stem density than fire intensity (Table 2).

Discussion

Several studies have demonstrated that the response of ecosystems varies greatly with frontal fire intensity and depth of burn. Fire intensity has been shown to correlate with *P. banksiana* regeneration (Weber et al. 1987) and post-fire abundance of *P. aquilinum* (Tellier et al. 1995). Low fire intensities stimulated *Corylus cornuta* sprouting and height growth of *Rubus ideaus* (Johnston and Woodard 1985). Biomass nutrient retention (Duchesne and Tellier 1997) and soil seed bank and competing vegetation dynamics along with *P. resinosa* and *P. strobus* seedling performance are also affected by prescribed burning intensity (Tellier et al. 1995, 1996; Whittle et al. 1997). Soil microbial activity and

TABLE 2. Pearson's multiple correlation analysis among fire intensity, depth of burn, blueberry biomass, number of blueberries/ stem, and stem density.

	Intensity	Blueberries/ha	Depth of burn	Blueberries/stem	Stem density
Intensity	1.000				
Blueberries/ha	-0.507*	1.000			
Depth of burn	0.517*	-0.683**	1.000		
Blueberries/stem	-0.461	0.803**	-0.577**	1.000	
Stem density	-0.504*	0.766**	-0.724**	0.471	1.000

* significant at P < 0.05
** significant at P < 0.01

diversity were also affected by fire intensity (Duchesne and Wetzel 2000; Staddon et al. 1998a, 1998b).

Fire has been used for hundreds of years in blueberry management by Indigenous people (Chapeskie 2001) and by farmers (Badcock 1958; Blatt et al. 1989), mostly using spring fires. This investigation presents the first comprehensive data on the effect of fire intensity and depth of burn on natural blueberry production, which are indicated as critical factors to consider in blueberry management. Indeed, the current findings show that fire intensity must be kept low in order to increase blueberry productivity using prescribed fire. As well, care must also be given to reduce depth of burn, which has a greater impact on blueberry production than fire intensity (Table 2). Whereas fire intensity is a measure of the caloric energy liberated by the fire front (Alexander 1982), depth of burn integrates the interaction between soil moisture conditions and fire intensity (Miller 1977) and is more closely linked to the response of blueberries to fire than fire intensity.

Since blueberry shoots arise from shallow rhizomes and portions of the above ground stem not killed by the fire (Flinn and Wein 1977; Martin 1955; Minore 1975), deep heat penetration in the humus layers is likely to reduce stem production. Similar conclusions have been reached in Ponderosa Pine (*Pinus ponderosa*) forests where depth of burn influenced greatly understory species regeneration (Armour et al. 1984) which is consistent with the concept that depth of buried propagules, together with heat penetration, is critical in post-fire survival (reviewed by Whittle et al. 1997). In turn, the differences observed in this investigation in post-fire blueberry stem densities, and the negative correlation between stem density and depth of burn may be ascribed to the deleterious effect of fire on the underground rhizomes as was demonstrated on Blue Huckleberry (*Vaccinium globulare*) (Miller 1977).

In practice, blueberry production can be maximized by burning in the spring of every second year, presumably to maintain a high ratio of flower buds to leaf buds (Hall et al. 1972). In this investigation, the number of blueberries/plant, which was hypothesized to be an estimate of the flower bud to leaf bud ratio, was not significantly different among treatments but inversely correlated with fire intensity. These results cannot be explained by conventional thinking regarding flower bud formation (Hall et al. 1972), as the number of blueberries/plant correlated with depth of burn. However, Smith and Hilton (1971) speculated that Lowbush Blueberry performance after fire pruning might result from the stimulative effects of the nutrients in ash deposited on the surface soil during burning. Further investigation is needed to assert the relevance of this hypothesis in blueberry flower biology.

Although this investigation shows that low intensity fires have a positive influence on blueberry production, natural blueberry ecosystems support a variety of wildfire characteristics (Moola et al. 1998; Usui et al. 1995). Hence the continuous effect of repeated fires should be investigated on the long term productivity and biological conservation of such ecosystems. In particular, it will be important to assess the impact of burning every second year, which is the recommended practice, on soil nutrients (Smith and Hilton 1971). Future work should also be conducted to investigate co-management of blueberries with timber values (Duchesne et al. 2001).

Documents Cited (marked * in text)

Agriculture and Agri-Food Canada. 2002. Canadian fruit situation and trends. http://www.agr.gc.ca/misb/hort.

Literature Cited

Alexander, M. E. 1982. Calculating and interpreting forest fire intensities. Canadian Journal of Botany 60: 349-357.

Armour, C. D., Sc. C. Bunting, and **L. F. Neuenschwander.** 1984. Fire intensity effects on the understory in ponderosa pine forests. Journal of Range Management 37: 44-49.

Badcock, A. C. 1958. Prescribed burning and the growing of blueberries. Pages 53-56 *in* Symposium on Prescribed Burning in Forestry, Agriculture and Wildlife Management. Published by the Newfoundland Research Committee, St. John's. Sponsored by The Newfoundland Department of Mines and Resources and Memorial University.

Blatt, C. R., I. V. Hall, K. I. N. Jensen, W. T. A. Neilson, P. D. Hildebrand, N. L. Nickerson, R. K. Prange, P. D. Lidster, L. Crozier, and **J. D. Silbey.** 1989. Lowbush blueberry production. Agriculture Canada Publication 1477/E. 56 pages.

Brubaker, D. 1997. Value-added forestry and aboriginal communities: the perfect fit. National Aboriginal Forestry Association, Ottawa, Ontario. 114 pages.

Chapeskie, A. J. 2001. Northern homelands, northern frontier: linking culture and economic security in contemporary livelihoods in boreal and cold temperate forest communities in northern Canada. Pages 31-44 *in* Forest communities in the third millennium: linking research, business, and policy toward a sustainable non-timber forest product sector. *Edited by* I. Davidson-Hunt, L. C. Duchesne and J. C. Zasada. USDA Forest Service, North Central Research Station. General Technical Report NC-217.

Duchesne, L. C., J. C. Zasada, and **I. Davidson-Hunt.** 2000. Nontimber forest products in Canada: Scope and research needs. Forestry Chronical 76: 743-746.

Duchesne, L. C., I. Davidson-Hunt, and **J. Zasada.** 2001. The future of the non timber forest products industry. Pages 149-152 *in* Forest Communities in the Third Millennium: First international conference on non-timber forest products in cold temperate and boreal forests. Kenora Ont. Oct 1-4, 1999. *Edited by* I. Davidson-Hunt, L. C. Duchesne, and J. C. Zasada . USDA Forest Service, North Central Research Station, General Technical Report NC-217.

Duchesne, L. C., and **R. Tellier.** 1997. Effect of prescribed burning intensity and disk trenching scarification on the nutrient status of aboveground non-crop vegetation in a Jack Pine (*Pinus banksiana* Lamb.) clear-cut. Forestry Chronical 73: 711-714.

Duchesne, L. C., and **S. Wetzel.** 2000. Effect of clear-cutting, prescribed burning and scarification on litter decomposition in an Eastern Ontario jack pine (*Pinus banksiana*) ecosystem. International Journal of Wildland Fire 9: 195-201.

Eaton, E. L. 1958. Blueberry burning and botanical relationship. Pages 57-58 *in* Symposium on Prescribed Burning in Forestry, Agricalature and Wildlife Management. Published by the Newfoundland Research Committee, St. John's. Sponsored by the Department of Mines and Resources and Memorial University.

Eaton, L., and **R. G. White.** 1960. The relation between burning dates and the development of sprouts and flower buds in the lowbush blueberry. American Society of Horticultural Science 76: 338-342.

Flinn, M. A., and **R. W. Wein.** 1977. Depth of underground plant organs and theoretical survival during fire. Canadian Journal of Botany 55: 2550-2554.

Gadd, N. R. 1962. Surficial geology – Chalk river, descriptive notes. Marginal notes to map 1131A, Canadian Geological Survey Committee, Ottawa, Ontario.

Hall, I. V., L. E. Aalders, L. P. Jackson, G. W. Wood, and **C. L. Lockhart.** 1972. Lowbush blueberry production in Canada. Canadian Department of Agriculture Publication 1477.

Herr, D. G., L. C. Duchesne, R. Tellier, R. S. McAlpine, and **R. L. Peterson.** 1994. Effect of prescribed burning on the ectomycorrhizal infectivity of a forest soil. International Journal of Wildland Fire 4: 95-102.

Johnston, M., and **P. Woodard.** 1985. The effect of fire severity level on postfire recovery of hazel and raspberry in east-Central Alberta. Canadian Journal of Botany 63: 672-677.

Lowe, J. J., K. Power, and **S. L. Gray.** 1996. Canada's forest inventory 1991: the 1994 version. An addendum to Canada's forest inventory, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. Information Report. BC-X-362E.

Martin J. L. 1955. Observations on the origin and early development of a plant community following a forest fire. Forestry Chronicle 31: 154-160.

McAlpine, R. S . 1995. Testing the effect of fuel consumption on fire spread rate. International Journal of Wildland Fire 5: 143-152.

McRae, D. J., M. E. Alexander, and **B. J. Stocks.** 1979. Measurement and description of fuels and fire behavior on prescribed burns: A handbook. Department Environment, Canadian Forest Service, Sault Ste Marie, Ontario. Information Report O-X-287.

McRae, D. J., L. C. Duchesne, B. Freedman, T. J. Lyndham, and **S. Woodley.** 2001. Comparisons between wildfire and forest harvesting and their implications in forest management. Environmental Review, 9: 223-260.

Miller, M. 1977. Response of blue huckleberry to prescribed fires in a western Montana Larch-Fir forest. USDA Forest Service Research Paper, INT-188, Intermontane Forest and Range Experimental Station, Ogden, Utah. 33 pages.

Minore D. 1975. Observations on the rhizomes and roots of *Vaccinium membranaceum*. Pacific Northwest Forest and Range Experimental Station. Research Note PNW-261, USDA. 5 pages.

Mohammed, G. H. 1999. Nontimber forest products in Ontario: an overview. Ontario Forest Research Institute, Ontario Ministry of Natural Resources. Forest Research Information Paper Number 145.

Moola, F. M., A. U. Mallik, and **R. A. Lautenschlager.** 1998. Effects of conifer release treatments on the growth and fruit production of *Vaccinium* spp. in northwestern Ontario. Canadian Journal of Forest Research 28: 841-856.

Rowe, J. S. 1972. Forest regions of Canada. Canadian Forestry Service Publication Number 1300.

Smith, D. W., and **R. J. Hilton.** 1971. The comparative effects of pruning by burning or clipping lowbush blueberries in northeastern Ontario. Journal of Applied Ecology 8: 781-789

Staddon, W. J., L. C. Duchesne, and **J. T. Trevors.** 1998a. Impact of clear-cutting and prescribed burning on microbial diversity and community structure in a Jack Pine (*Pinus banksiana* Lamb.) clear-cut. World Journal of Microbiology and Biotechnology 14: 119-123.

Staddon, W. J., L. C. Duchesne, and **J. T. Trevors.** 1998b. Acid phosphatase, alkaline phosphatase and arylsulphatase activities in a jack pine ecosystem after clear-cutting, prescribed burning, and scarification. Biology and Fertility of Soils 27: 1-4.

Systat. 1997. Systat 7.0. Evanston, Ilinois.

Tellier, R., L. C. Duchesne, J. C. Ruel, and **R. S. McAlpine.** 1995. Effets de l'intensité du brûlage dirigé et de la scarification sur la diversité des espèces végétales dans un peuplement de pin gris (*Pinus banksiana* Lamb.). Écoscience 2: 160-167.

Tellier, R., L. C. Duchesne, J. C. Ruel, and **R. S. McAlpine.** 1996. Effets du brûlage dirigé et du scarifiage sur l'établissment des semis et sur leur interaction avec la végétation concurrente. Forestry Chronicle 71: 621-626.

Usui, M., Y. Kakuda, and **P. Kevan.** 1995. Composition of energy values of wild fruits from the boreal forest of northern Ontario. Canadian Journal of Plant Science 74: 581-587.

Van Hoefs, M. E. G., and **J. M. Shay.** 1981. The effects of shade on shoot growth of *Vaccinium angustifolium* Ait after fire pruning in southwestern Manitoba. Canadian Journal of Botany 59: 166-174.

Weber, M. G., M. Hummel, and **C. E. Van Wagner.** 1987. Selected parameters of fire behavior and *Pinus banksiana* Lamb. regeneration in eastern Ontario. Forestry Chronicle 63: 340-346.

Whittle, C. A., L. C. Duchesne, and **T. Needham.** 1997. The impact of broadcast burning and fire severity on species composition and abundance of surface vegetation in a jack pine (*Pinus banksiana*) clear-cut. Forest Ecology and Management 94: 141-148.

Received 12 June 2002
Accepted 24 September 2004