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

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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 angustifolium*, *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 m³/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 measure 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 km. The surfaced 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 fire-guards 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)
intensity equation \( I = HwR \), where \( I \) is the intensity of the fire (\( \text{kJ/m}^2 \)), \( H \) is the fuel low heat of combustion (assumed to be 18 000 \( \text{kJ/kg} \)), \( w \) is the weight of fuel consumed in the active front (\( \text{kg/m}^2 \)) (all fuel consumed was assumed to have been burned by the active fire front), and \( R \) is the rate of spread (\( \text{m/sec} \)).

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 of the biomass and frequency (in decreasing order of importance) were \( P. \text{aquilinium} \), \( V. \text{angustifolium} \), \( V. \text{myrtilloides} \), Amelanchier sp., \( P. \text{pumila} \), Comptonia peregrina, Kalmia angustifolia, Yellow Panic-grass (\( P. \text{xanthophysum} \)), and Houton’s Sedge (\( C. \text{houghtonii} \)) (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 50°C for 5 days before weighing. Because the moisture content of blueberries (83.1 ± 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 \( V. \text{myrtilloides} \) and \( V. \text{angustifolium} \) as the frequency of these species (1:15-1:30, \( \text{myrtilloides:angustifoli} \)um) 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 \( V. \text{myrtilloides} \) and \( V. \text{angustifolium} \), 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/m².

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/m²) 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 \( P. \text{banksiana} \) regeneration (Weber et al. 1987) and post-fire abundance of \( P. \text{aquilinium} \) (Tellier et al. 1995). Low fire intensities stimulated \( C. \text{cornuta} \) sprouting and height growth of \( R. \text{ideaus} \) (Johnston and Woodard 1985). Biomass nutrient retention (Duchesne and Tellier 1997) and soil seed bank and competing vegetation dynamics along with \( P. \text{ressinosa} \) and \( P. \text{strobus} \) seedling performance are also affected by prescribed burning intensity (Tellier et al. 1995, 1996; Whittle et al. 1997). Soil microbial activity and
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).

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

<table>
<thead>
<tr>
<th></th>
<th>Intensity</th>
<th>Blueberries/ha</th>
<th>Depth of burn</th>
<th>Blueberries/stem</th>
<th>Stem density</th>
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<td>Intensity</td>
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<td></td>
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<tr>
<td>Blueberries/ha</td>
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<td>1.000</td>
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<td>Depth of burn</td>
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<td>-0.683**</td>
<td>1.000</td>
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<td>0.803**</td>
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<tr>
<td>Stem density</td>
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<td>0.766**</td>
<td>-0.724**</td>
<td>0.471</td>
<td>1.000</td>
</tr>
</tbody>
</table>

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

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