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Potential Role of Lowbush Blueberry (*Vaccinium angustifolium*) in Colonizing Metal-Contaminated Ecosystems

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The industrially damaged lands around the smelters of Sudbury are inhabited by several species of plants that can tolerate high levels of toxic metals (Hogan and Rauser 1978; Cox and Hutchinson 1980). One of these plants, the sweet lowbush blueberry (*Vaccinium angustifolium*), has colonized large areas of the smelter-affected area. It is particularly abundant within the birch transition forest described in the previous chapter (Chapter 18). This chapter reviews the attributes of *V. angustifolium* that made it successful in the Sudbury industrially damaged lands. There are actually two species of blueberry near Sudbury, *V. angustifolium* and *V. myrtilloides,* of which *V. angustifolium* is the more common of the two. Although they are similar (see descriptions of each in Vander Kloet [1988]) and grow in the same habitats, care was taken to restrict our studies to *V. angustifolium.*

Accumulation of Metals and Mechanisms of Tolerance

Extremely high levels of metals occur naturally in some parts of the world, and a surprising array of plants are able to thrive at these sites. For example, about 220 taxa are found on copper-rich soils in Upper Shaba in Zaïre, and one tree in nickel-rich sites in New Caledonia thrives while accumulating up to 25% nickel in its sap on a dry weight basis (Baker 1987). However, many studies of metal accumulation and adaptation have been conducted, not at naturally contaminated sites but in areas damaged by industrial activities, particularly areas in which smelting and refining of metals occur. From these studies, it has been determined that tolerance to metals can be achieved by mechanisms that allow plants to accumulate metals in their tissues without causing damage or, alternatively, by mechanisms that confer tolerance by excluding metal uptake. Tissue accumulation is often mediated by cellular processes that sequester metals and render them biologically inactive. Metal-sequestering proteins and molecules such as metallothioneins and phytochelatins have been implicated in this process (Rauser and Winterhalder 1984; Tomsett and Thurman 1988). Alternatively, metal exclusion by plants is often mediated by specific energy-dependent transport processes operating at the root–soil interface or in association with mycorrhizal symbionts, which aid in preventing movement of metals into the root (Jones and Hutchinson 1986; Baker 1987).

Ecosystems influenced by mining and smelting are useful for studying metal tolerance because they provide a natural laboratory where selection for metal tolerance and accumulation in plants can be examined in detail. Elevated levels of metals in soils at such sites

FIGURE 19.1. Lowbush blueberry growing on a barren site in Sudbury's industrially damaged ecosystem. (Photo by J.D. Shorthouse.)

may act as powerful agents for rapidly selecting genetically adapted, metal-tolerant ecotypes of various species of plants (Freedman and Hutchinson 1981; Baker 1987). Research in this area has consequently been driven by a need to understand the impact of metal pollution on plants and has a potential application in development of metal-tolerant ecotypes for habitat restoration.

Biology of Sweet Lowbush Blueberry

Vaccinium angustifolium is a broad-leaved, deciduous, low shrub endemic to North America, whose range in Canada extends from the east coast of Newfoundland to central Manitoba (Vander Kloet 1988). It tolerates a wide range of climatic conditions, is particularly adapted to a temperate climate, and grows best in acidic soils with pH 4.0–5.5 (Hall et al. 1964) and moderate-to-low fertility. It has woody stems and averages 20 cm in height. It is an effective colonizer of disturbed sites, including those modified by fire, smelters, and mine tailings (Sheppard 1991). Because of the concern about metal contamination in the berries, there have been several studies dealing with contaminant accumulation in this plant (see Sheppard [1991] for references).

The ability of lowbush blueberry to both colonize and survive (i.e., relict species) smelter-damaged lands near Sudbury has proved beneficial to both revegetation programs within the region and to the residents of the area who enjoy picking and consuming the berries. It is commonly one of the first plants to become established on sites devoid of almost all other plant species (Fig. 19.1).

Lowbush blueberry is one of many plants involved in natural succession from cleared land to forest. Most of the new shoots of mature plants develop from dormant buds on underground rhizomes. The tips of growing shoots die in the early part or middle of the summer, and the buds develop into either vegetative or flowering types. The extensive rhizome system of mature blueberry can play an important role in preventing slope erosion.

In Sudbury, lowbush blueberries have colonized part of the smelter damaged area and are commonly associated with white birch (*Betula papyrifera*) (Fig. 19.2). This association may benefit both species. Leaves of young birch growing in blueberry patches become entangled in the stems of blueberries, which helps retain moisture the following season. Thick mats of blueberry also accumulate snow, which similarly benefits both species. However, as birch increase in size, their shade becomes harmful to blueberry shrubs, and they disappear (Hall et al. 1979); but as described in

Figure 19.2. Mat of lowbush blueberry growing in association with white birch in Sudbury's birch transition zone. (Photo by J.D. Shorthouse.)

the previous chapter (Chapter 18), much of the coppiced birch forest in Sudbury is maintained as an open canopy, and as a result, shading by birch here is less of a problem for blueberries.

Lowbush blueberry reproduces by both seeds and rhizomes. Each berry contains an average of 13 seeds (Hall et al. 1979), and the seeds are spread in the droppings of birds such as the American robin (*Turdus migratorius*) and mammals such as black bears (*Ursus americanus*) and red fox (*Vulpes vulpes*). Plants usually flower and produce rhizomes 4 years after germination. The berries ripen in early July in Sudbury. Blueberry plants proliferate most rapidly once an organic layer is formed (Trevett 1956), and this presumably explains why mats near Sudbury are thickest near birch trees, where leaves and other organic debris collect. Asexual reproduction occurs when the rhizomes are cut or killed by fire, shading, burrowing, or frost action. The high incidence of frost-heaving within Sudbury's denuded areas (see Chapter 18) therefore likely contributes to asexual reproduction in this plant (Fig. 19.3). Rhizomes are the key to a continuing high level of productivity because it is primarily from rhizomes that new fruiting wood is initiated. This extensive rhizome sys-

Figure 19.3. Blueberry plantlets separated by frost-heaving. (Photo by J.D. Shorthouse.)

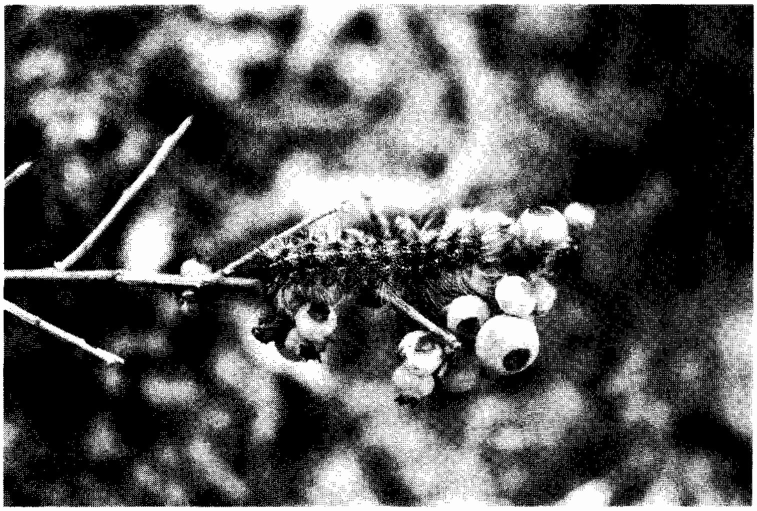

FIGURE 19.4. Larva of gypsy moth defoliating lowbush blueberry on one of Sudbury's barren sites. (Photo by J.D. Shorthouse.)

tem can also play an important role in preventing soil erosion.

Few insect herbivores attack lowbush blueberry in the Sudbury region; however, forest tent caterpillars (*Malacosoma disstria*) and caterpillars of gypsy moths (*Lymantria dispar*) defoliate plants during their peak years (Fig. 19.4). Important defoliators in the maritimes are the black army cutworm (*Actebia fennica*), the chain-spotted geometer (*Cingilia catenaria*), and a pest of the fruit, the blueberry maggot (*Rhagoletis mandax*). A stem gall found on vegetative shoots and induced by the chalcid wasp *Hemadas nubilipennis* is especially common on Sudbury plants (West and Shorthouse 1989). Shorthouse et al. (1986) also suggested that this insect may benefit the blueberry plant because the pruning effect produces a bushier plant.

Accumulation of Metals within Lowbush Blueberry near Sudbury, Ontario

Lowbush blueberry appears tolerant of elevated concentrations of certain metals. This species is therefore useful for studying the effects of metal pollution (Sheppard 1991). We examined the pattern of copper and nickel accumulation in tissues of lowbush blueberry collected in mid-July, when the plants were fruiting, at six sampling sites ranging from 7 to 74 km northwest from the Copper Cliff smelter (Bagatto and Shorthouse 1991). Data from this study and comparable information on a variety of other plants in the area are provided in Table 19.1.

The patterns of tissue accumulation of the metals (Fig. 19.5) is likely related to the physiological fates of the metals. High levels of copper (69 μg/g) and nickel (40 μg/g) in the roots confirm the observation that roots are sites of preferential copper and nickel accumulation when external supplies of these metals are excessive (Marschner 1986). These levels of copper and nickel are considerably elevated compared with root concentrations at 74 km (6 μg/g dry wt. [Cu] and 6 μg/g dry wt. [Ni]) and copper concentrations of 2–11 μg/g dry wt. reported in the literature (Ingestad 1973; Peterson et al. 1988). The considerably lower concentration of copper in leaves from the site closest to the smelter (22 μg/g) is below the 30 μg/g concentration considered toxic for most crop species (Robson and Reuter 1981).

It is interesting that the concentration of copper did not differ significantly between tissue types 23 km from the smelter and beyond. This is the expected pattern in habitats with typical background levels of copper where it functions as a plant nutrient participating in enzymatically bound copper redox reactions (Marschner 1986). Furthermore, organic mat-

TABLE 19.1. Copper and Nickel Concentrations (ppm-dry wt. or µg/g dry wt.) in Plants Collected within 15 km of the Sudbury Smelters

Species	Tissue	Nickel	Copper	Reference
Vaccinium angustifolium	Leaf	92	75	Hutchinson and Whitby 1974
Vaccinium angustifolium	Leaf	70	50	Freedman and Hutchinson 1980a
Vaccinium angustifolium	Leaf	33	21	Bagatto and Shorthouse 1991
Vaccinium angustifolium	Stem	49	54	Bagatto and Shorthouse 1991
Vaccinium angustifolium	Root	40	69	Bagatto and Shorthouse 1991
Vaccinium angustifolium	Berries	7	4	Bagatto and Shorthouse 1991
Acer rubrum	Leaf	98	37	Hutchinson and Whitby 1974
Acer rubrum	Leaf	60	15	Lozano and Morrison 1981
Acer rubrum	Leaf	100	140	Freedman and Hutchinson 1980a
Deschampsia flexuosa	Leaf	902	726	Hutchinson and Whitby 1974
Comptonia peregrina	Leaf	113	57	Hutchinson and Whitby 1977
Betula papyrifera	Leaf	95	148	Hutchinson and Whitby 1977
Betula papyrifera	Leaf	100	25	Lozano and Morrison 1981
Betula papyrifera	Leaf	170	100	Freedman and Hutchinson 1980a
Quercus rubra	Leaf	100	16	Lozano and Morrison 1981
Populus tremuloides	Leaf	150	15	Lozano and Morrison 1981
Populus tremuloides	Leaf	370	90	Freedman and Hutchinson 1980a
Osmunda claytoniana	Fronds	11	61	Burns and Parker 1988
Matteuccia struthiopteris	Fronds	111	47	Burns and Parker 1988
Typha latifolia	Shoot	60	13	Taylor and Crowder 1983
Typha latifolia	Fruit	19	17	Taylor and Crowder 1983
Typha latifolia	Rhizome	40	30	Taylor and Crowder 1983
Typha latifolia	Root	52	38	Taylor and Crowder 1983
Quercus borealis	Leaf	70	20	Freedman and Hutchinson 1980a
Pinus resinosa	Leaf	40	40	Freedman and Hutchinson 1980a
Salix humilis	Leaf	220	260	Freedman and Hutchinson 1980a
Myrica asplenifolia	Leaf	110	90	Freedman and Hutchinson 1980a
Diervilla lonicera	Leaf	60	90	Freedman and Hutchinson 1980a
Polygonum cilinode	Leaf	90	110	Freedman and Hutchinson 1980a
Solidago canadensis	Leaf	200	180	Freedman and Hutchinson 1980a
Epilobium angustifolium	Leaf	110	160	Freedman and Hutchinson 1980a
Deschampsia caespitosa	Leaf	240	370	Freedman and Hutchinson 1980a
Agrostis stolonifera	Leaf	130	70	Freedman and Hutchinson 1980a
Equisetum sylvaticum	Leaf	450	250	Freedman and Hutchinson 1980a
Polytrichum commune	Leaf	620	910	Freedman and Hutchinson 1980a

ter and pH increase with distance from the smelter (Freedman and Hutchinson 1980a,b), thereby decreasing the availability of copper ions in the soil. Of interest, Sheppard (1991) found that copper was at significantly higher concentrations in berries than in leaves and stems at many of the sites he examined across central Canada; however, Sheppard did not examine the levels of copper and nickel in the fruits of lowbush blueberry from near the Sudbury smelters. Concentrations of copper and nickel in the berries of *V. angustifolium* far from the North American sources of pollution are similar to those of berries growing near the Sudbury smelters (Bagatto and Shorthouse 1991).

The high concentration of nickel in blueberry roots likely represents cell wall adhesion in this tissue. The behavior of nickel in plants may be the result of it being a nonfunctional analog of copper and zinc as shown in studies of root transport (Cataldo et al. 1978). Although root concentrations of nickel were lower than that of copper, leaves and stems from all sites had proportionally higher nickel concentrations than copper. Also, the pattern

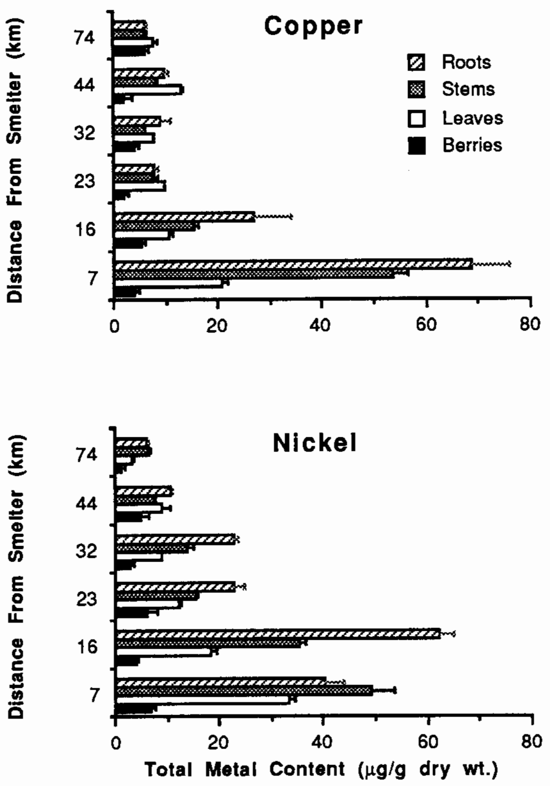

FIGURE 19.5. Concentrations of copper and nickel in tissues of lowbush blueberry at various distances from the Inco smelter.

of nickel accumulation at all sites was the same (roots>stems>leaves>berries), whereas with copper, this pattern changed at sites beyond 23 km from the smelter. The general nonessentiality of nickel as a plant nutrient and its greater availability within acidic soils of the Sudbury area would account for this finding.

Nickel is presumably taken up as a nonfunctioning analog of some other plant nutrient (copper or zinc), and its concentration in the plant would depend on the concentration of nickel in the environment. The levels of nickel in lowbush blueberry closest to the smelter far exceed requirements for nickel; however, they fall within the range of 3–300 µg/g considered non-toxic, depending on the species of plant, organ, developmental stage, and nutritional supply (Hutchinson and Whitby 1974).

We conclude that lowbush blueberry accumulate substantial amounts of copper and nickel in structural and vegetative tissues when growing in contaminated soils. However, the high levels of these metals, particularly in the roots and stems, appear non-toxic to the plants. It was particularly reassuring that the levels of copper and nickel were low in berries collected near the smelters, compared with plants from other parts of Canada, as plants in this area produce heavy crops of berries that are popular with local residents.

The only other site known to us where copper and nickel in the tissues of berries growing near smelters have been examined is that of the "Severonikel" complex in the Kola Peninsula of Russia (Barkan et al. 1993). Here, extremely high levels of copper and nickel were found in the berries of *Vaccinium vitis-idaea*, *V. myrtillus*, *Rubus chamaemorus*, and *Empetrum hermaphroditum*. Levels of copper and nickel were highest in the upper organic soils closest to the smelters, and the levels in berries were dependent on metal contents of the soil. Levels of copper as high as 53 µg/g dry wt. and nickel 96 µg/g dry wt. were found in berries of *V. vitis-idaea* within 6 km of the smelter, with copper at levels of 115 µg/g dry wt. and nickel at 83 μg/g dry wt. in the berries of *E. hermaphroditum* at the same site, all of which are about 10 times above the safe levels recommended by the Russian Health Protection Ministry and are unsuitable for food.

Summary

The historical atmospheric deposition of metal particulates from smelters has created a serious environmental stress on plant communities, and most species of plants in the Sudbury area appear to suffer accordingly. Unlike other forms of abiotic stress such as drought or anomalous weather, which are usually short-term, metal pollution represents a continuous source of stress for plants and animals. The lasting character of metal-induced stress implies that its effects on plants and animals may differ from those of other stresses and may result in certain adaptations by exposed organisms. Consequently, studies of the effects of metals on different components of ecosystems are not only of scientific interest but also are economically important and represent an important area of research. There is a shortage of knowledge about the ways in which plants such as lowbush blueberry cope biochemically, physiologically, ecologically, and genetically with elevated levels of pollutants.

Sulfur dioxide and heavy metals have potentially different effects on plants and insects. Moderate doses of sulfur dioxide can lead to enhanced performance of phytophagous insects feeding on plants fumigated by sulfur dioxide, whereas the effects of heavy metals on phytophagous insects are assumed to be mainly negative (Alstad et al. 1982). Little attention has been paid to possible interactions between sulfur dioxide and metals and the consequences for plants and insects (Riemer and Whittaker 1989). It has been suggested that sulfur dioxide emissions cause soil acidification, which, in turn, increases solubility of metals in the soil and enhances uptake by plants (Lobersli and Steinnes 1988). At certain levels, soil acidification can benefit some species such as blueberry, but the added metal load in stressed lands such as Sudbury can undoubtably create a complex set of effects, many of which may be detrimental to the plant.

Although there is little information about the adaptation to metal stress, it is known that populations of plants will evolve through natural selection in response to specific ecological conditions of its local environment and that adaptive genetic differentiation may occur (Bradshaw 1972). We suspect that populations of Sudbury blueberries have developed tolerance to copper and nickel and represent distinct metal-tolerant ecotypes, as has been shown for some grass species in the Sudbury area (Cox and Hutchinson 1980; Rauser and Winterhalder 1984; Archambault 1991). More important, the absence of elevated levels of metals in the berries of Sudbury plants may mean that the same will occur at other smelter sites. If so, the introduction of Sudbury lowbush blueberry to polluted sites in other parts of the world with similar climates should be considered. Not only would the Sudbury plants help colonize denuded sites, but local residents would be provided with edible berries as well.

In conclusion, we suggest that lowbush blueberry plays an important role in areas such as the industrially damaged lands near Sudbury because

- **they are adapted to high levels of copper and nickel and perhaps other metals**
- **they thrive on acidic soils**
- **high levels of metals accumulated within plant tissues are not passed to the fruit**
- **they have few herbivores**
- **once established, they produce a thick humus, which retains soil moisture and reduces soil erosion**
- **they can improve growing conditions for trees such as birch**
- **they exhibit good dispersal of seeds**
- **they can reproduce asexually as a result of heavy frost-heaving**

We also suggest that future research aimed at enhancing the colonizing ability of lowbush blueberry be undertaken in the following areas:

testing for metal- and acid-tolerant ecotypes
examining interactive relationships that affect the establishment and succession of other plants
identification of mechanisms for metal tolerance (e.g., role of mycorrhizae)

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