7

Natural Recovery of Vascular Plant Communities on the Industrial Barrens of the Sudbury Area

Keith Winterhalder

In 1972, the Coniston smelter and the Falconbridge iron ore sintering plant were closed, Inco Limited commissioned its 381-m Superstack, and other emission cutbacks came into effect. This led to expectations of rapid reestablishment of vegetation on the barrens, because it was widely believed that sulfur dioxide fumigation was the main factor directly impeding vegetation recovery. It was observed, however, that immediate recovery in the barren zone was at first confined to moist, sheltered, nutrient-enriched sites, such as stream channels (Fig. 7.1). In more exposed barren areas, recolonization did not begin until at least 10 years after the initiation of atmospheric improvement. The foreground of Figure 7.2 shows a site close to the Coniston smelter, photographed at 19-year intervals, in which the only change has been minimal colonization by tickle grass (*Agrostis scabra*), tufted hairgrass (*Deschampsia caespitosa*), and sorrel (*Rumex acetosella*).

In the case of the relict woody plants on the barrens, described in Chapter 2, all species except red maple either maintained or increased their size and vigor in the 20 years after 1970, whereas the red maple continued to undergo "regressive dieback."

The first hint that certain native vascular plant species might be capable of establishing themselves on acid, metal-contaminated soils became evident in 1972, when tickle grass began to colonize plots that had been treated with an N-P-K fertilizer, a treatment that was ineffective in detoxifying the soil for the nonnative experimental grass species (Winterhalder 1974). Tickle grass had formerly been noted in the Sudbury area along roadsides and creeks and in wet depressions. During the next 20 years, this weak perennial became increasingly common in the barren zone, at first appearing mostly on the flood plains of creeks, where it formed a cover so dense that potential new growth in the second year was smothered by the dead remains of the previous year's growth. It was also found under relict birches, poplars, and blueberries, where the soil had been enriched with organic matter, as well as in rock crevices on patches of the metal-tolerant moss *Pohlia nutans* (Beckett 1986). In 1991, Archambault demonstrated that the Sudbury population of tickle grass possessed enhanced metal tolerance.

The next native grass to colonize the barrens was tufted hairgrass (Fig. 7.3). The appearance of this grass in the Sudbury area was first noticed in 1972 and was documented by Cox and Hutchinson in 1980. Even as early as 1974, dense, partly senescent stands of this grass occurred in moist depressions in the barren zone, and it is likely that it began to colonize certain sites several years before its formal documentation. Hutchinson (*personal communication*) has hypothesized that the origin of

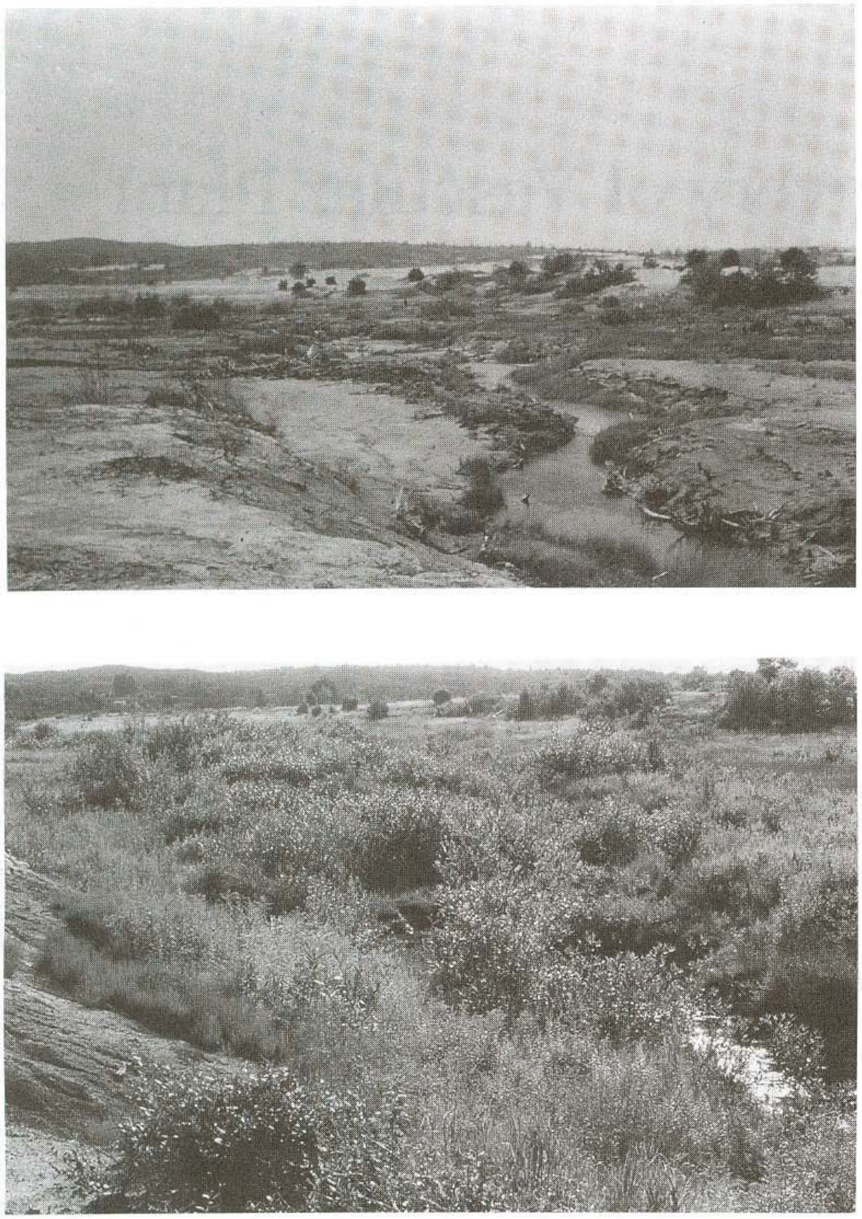

FIGURE 7.1. (*Upper photo*) Valley of Coniston Creek, 4 km north of the Coniston smelter in 1972, showing a narrow zone of unidentified sedges bordering the creek, with scattered relict shrubs in the background. (*Lower photo*) The same site 12 years later (August 1984), the edge of the stream colonized by *Carex aquatilis, C. retrorsa,* tufted hairgrass, field horsetail, *Solidago graminifolia,* prairie willow, and meadow willow.

the Sudbury population of *Deschampsia caespitosa* might be 80 km to the southwest, on Goat Island, near Little Current on Manitoulin Island. He suggested that seeds may have been transported to Sudbury with coal shipments on their way from the Lake Huron port of Little Current to the Sudbury smelters. An isozyme variation study by Bush and Barrett (1993) has cast some doubt on the likelihood of such an origin but has not disproved the hypothesis. Another metal-tolerant population of tufted hairgrass, at the mining center of Cobalt 150 km northeast of Sudbury, has been shown by Bush and Barrett (1993) to be genetically distinct from the Sudbury and Goat Island populations.

Two introduced grass species that have colonized barren sites to a more modest degree are redtop (*Agrostis gigantea*) and Canada bluegrass (*Poa compressa*). Although commercially available seed of both of these species is currently used in the revegetation operations described in Chapters 8 and 10, the populations seen colonizing barren land are often distant from revegetation sites, and it is likely that they have arisen from populations that predate revegetation activities. Both species favor heavier soils, and Canada bluegrass is a major colonist of the sides of the deeply gully-eroded "badlands" landscapes that characterize soils dominated by

FIGURE 7.2. (*Upper photo*) Barren site 2 km north of the Coniston smelter in July 1967. (*Lower photo*) The same site in July 1986, showing colonization by tickle grass, tufted hairgrass, and sorrel.

silty clays, whereas redtop is often found in the bottom of erosion gullies.

Enhanced metal tolerance has been demonstrated in both of these grasses. Hogan et al. (1977) found copper-tolerant strains of redtop on the copper- and nickel-rich surface of a roast bed west of Sudbury, some of which were later found (Hogan and Rauser 1979) to be nickel-tolerant, whereas Rauser and Winterhalder (1985) found enhanced zinc tolerance in some Canada bluegrass individuals near the old Coniston roast bed. Rauser and Winterhalder also found the alien grass foxtail barley (*Hordeum jubatum*) invading the Coniston roast bed surface itself, but this species proved not to be metal-tolerant; its presence had presumably been facilitated by the high pH and calcium content of this particular roast bed surface.

A *Carex* from the species group *Ovales* sometimes invades the drier lowland barren soils with the metal-tolerant grasses and, on occasion, can even colonize rocky slopes. It is not always easy to distinguish the species in the field, but in most cases, it appears to be *C. aenea*.

The sedges commonly colonizing the creek flood plains are wool sedge (*Scirpus cyperinus*),

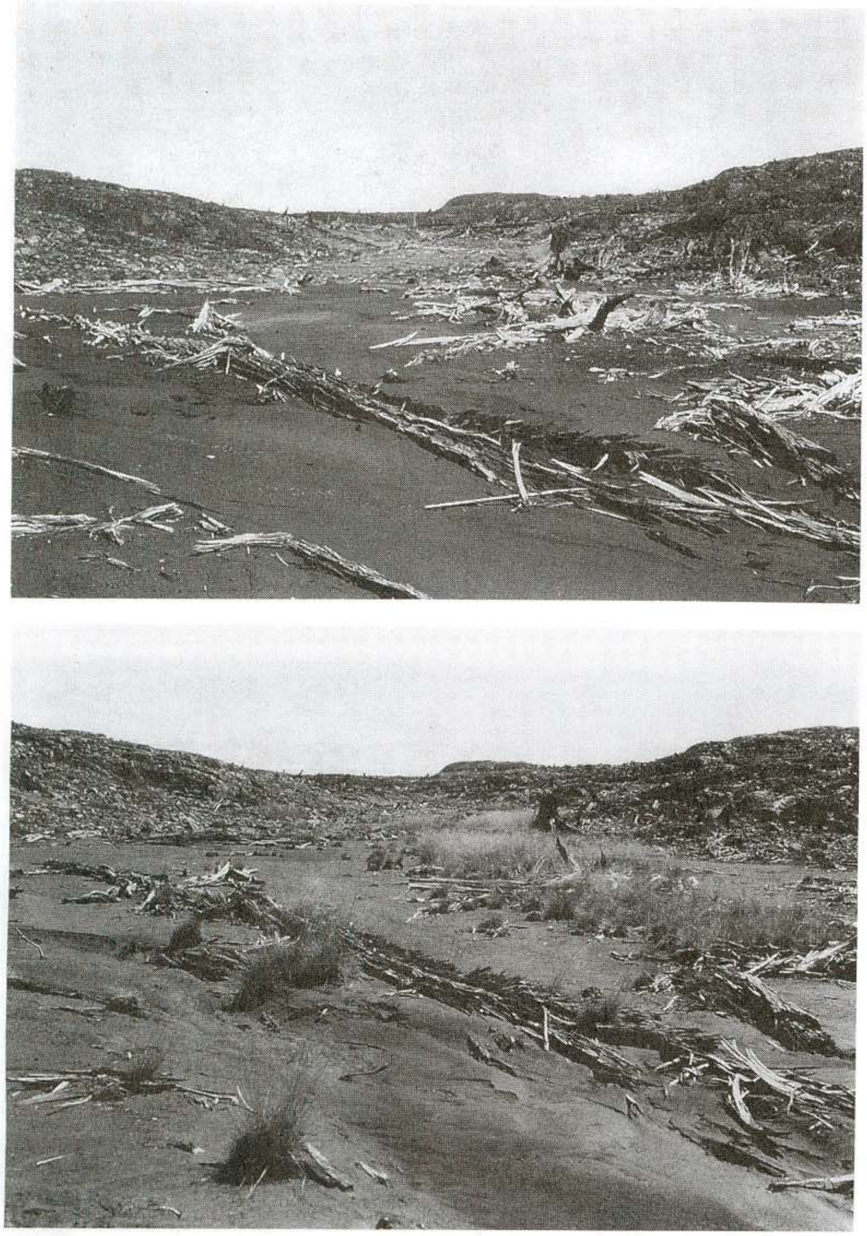

FIGURE 7.3. (*Upper photo*) Barren area 2.5 km northeast of the Copper Cliff smelter in July 1979. (*Lower photo*) The same site in August 1990, showing colonization by tufted hairgrass.

Carex retrorsa, and a *Carex* from the species group *Ovales,* probably *C. scoparia.* These sedges are often accompanied by willows, especially balsam willow (*Salix pyrifolia*), prairie willow (*S. humilis*), meadow willow (*S. gracilis*), and shining willow (*S. lucida*).

On metal-contaminated organic barren sites, the principal invaders since the 1970s have included a rush (*Juncus brevicaudatus*), wool sedge, and tickle grass. Figure 7.4 shows the changes that have taken place on a large barren peatland since 1974.

Although grasses and grasslike plants are the most common colonists of barren sites, a few broadleafed plants also play a role. Sorrel, a highly acid-tolerant plant, occasionally colonizes barren ground along with tickle grass. This species is a common colonizer of industrially disturbed sites in other parts of the world, invading very acidic (pH 3.4) coal measure spoils in the United Kingdom (Rees 1953–1954), and sulfur dioxide-fumigated land near Trail, British Columbia (Archibold 1978). It also occurs on metal-rich soils of the Hartz region of Germany (Schubert 1953–1954) and has been used as a geobotanical tool in northern Greece in exploration for metal sulfide deposits (Kelepertsis and Andrulakis 1983).

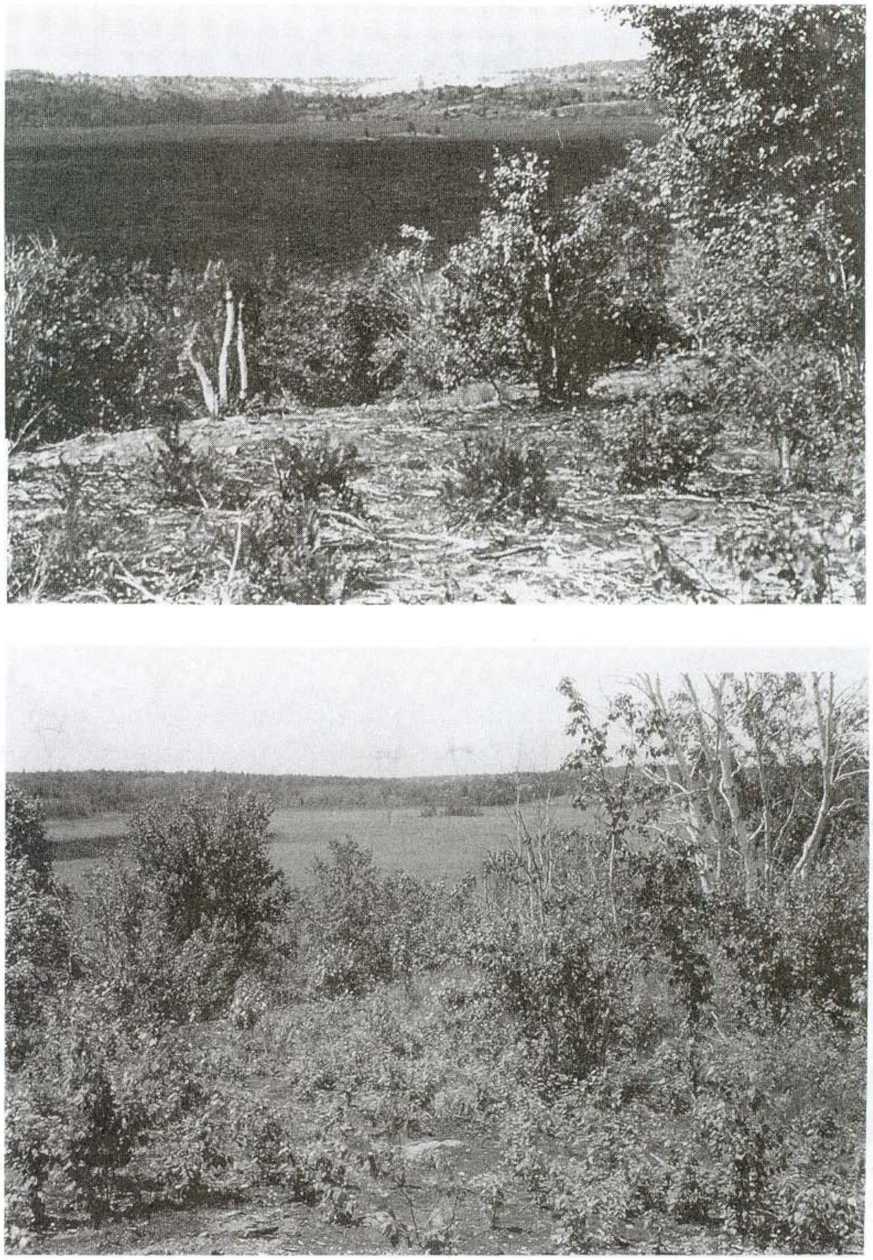

FIGURE 7.4. (*Upper photo*) A large barren peatland 4.5 km northwest of the Coniston smelter, July 1974, with cattail (*Typha latifolia*) in the moat, concentric rings of rattlesnake grass (*Glyceria canadensis*) and wool sedge around the margin, and a predominantly barren center. (*Lower photo*) The same peatland in July 1993, showing almost complete colonization of the center by *Juncus brevicaudatus* and tickle grass. Note the increased size and vigor of the white birches in the foreground. By 1993, the largest of these birches was dead, presumably as the result of bronze birch borer infestation of a drought-weakened tree.

Bladder campion (*Silene cucubalus*), known in Europe to be capable of selection for metal tolerance (Ernst 1974; Lolkema et al. 1986), sometimes becomes established on silty subsoils exposed by erosion. Among the non-flowering vascular plants, both field horsetail (*Equisetum arvense*) and wood horsetail (*E. sylvaticum*) are occasional colonizers of barren soils of a silty texture. It is clear that research is needed on the above species with respect to the possibility of genetic-based metal tolerance.

The shrub species dwarf or bog birch (*Betula pumila*) has shown a spectacular ability to colonize barren land. It began to move onto barren stony slopes from a small fen in the early 1980s (Fig. 7.5). Somewhat later, the same species began to spread onto barren soil and also into an open tufted hairgrass meadow from a single relict individual in a different locality. Roshon (1988) has shown that there has been some genetic selection for metal tolerance in the Sudbury population of dwarf birch, but it is suspected that its success is at least partly due to lack of competition and the enhanced moisture supply provided by run-off from the many rock outcrops.

The colonization phenomenon that is closest to normal boreal zone vegetation succes-

FIGURE 7.5. Dwarf birch colonizing a barren slope 4 km northeast of the Copper Cliff smelter, August 1988.

sion is that which is taking place in the vicinity of the Coniston smelter, which has been closed since 1972. Here, white birch (see Plate 7, following page 182), a typical boreal forest pioneer, began to colonize vigorously in the mid-1980s. Figure 7.6 shows colonization by white birch in a grove of dead maples near Coniston, where scattered relict birches were the seed source. Presumably, the cessation of emissions not only improved the quality of the atmospheric environment to which the aboveground component of vegetation was exposed but also reduced the level of dry deposition of sulfur dioxide and copper, nickel, and iron particulates into the barren and partially barren soils around the smelting operations. Soil pH changes of up to one unit have been observed in the vicinity of the Coniston smelter (K. Winterhalder, *unpublished data*). Although the predominant cause was probably the leaching of free acids, it is possible that weathering of residual glacial till material released bases such as calcium and potassium, which displaced some of the adsorbed hydrogen ions, which were, in turn, lost through leaching. The role of microorganisms in regulating pH in well-drained upland soils is likely to be insignificant when compared with that in lake sediments and wetland soils, which act as sulfur sinks and experience alkalinity generation through the activities of sulfur-reducing microorganisms.

While attempting to explain the greater tendency of tufted hairgrass to spread near the Coniston smelter than near the operating smelters, Cox and Hutchinson (1981) found that the soluble copper and nickel content of Coniston area soils were just as high 5 years after closure as those near active smelters, but that the soluble aluminum content was lower—an observation that would correlate well with the reduced acidity of the Coniston soils observed by the author. Presumably, the differential would be even greater 10–15 years after closure, facilitating white birch colonization. Cox and Hutchinson (1981) also suggested that the atmospheric deposition of copper and nickel particles onto the leaves of plants in an acid environment might have a direct toxic effect through the foliage.

It is interesting to contrast the behavior of white birch and red maple seedlings on barren sites under current improved soil conditions. The birch seedlings develop in a normal fashion, except for the development of the marginal chlorosis syndrome described in Chapter 2, whereas the maple seedlings produce a single pair of foliage leaves that turn red within a month and rarely survive past the first summer dry period. Healthy red oak seedlings are found within oak stands but not on the barrens, probably as a result of their large seed size and specialized mode of dispersal by ro-

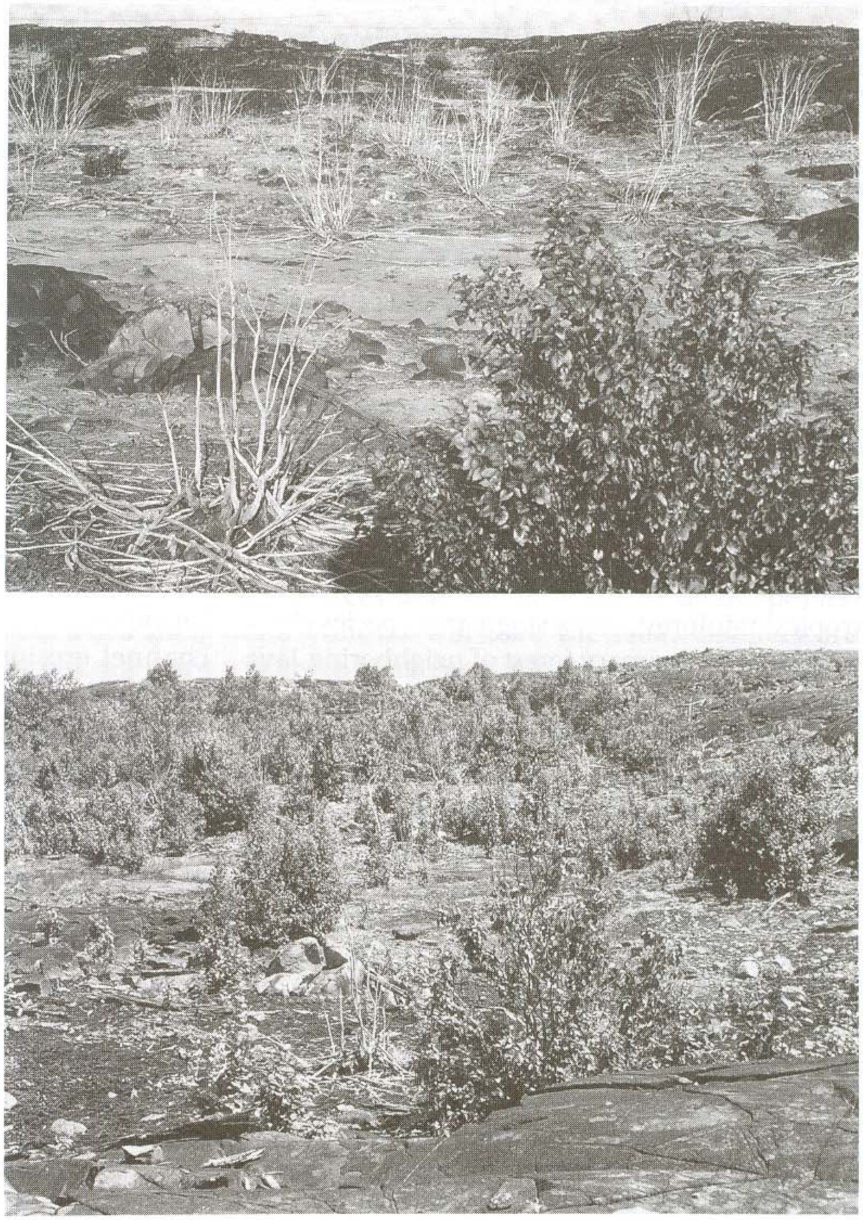

FIGURE 7.6. (*Upper photo*) Site 3.5 km northwest of the Coniston smelter in July 1980, showing scattered relict white birches with marginal chlorosis syndrome and many dead red maples. (*Lower photo*) Same site in June 1989, showing colonization by white birch seedlings.

dents such as squirrels. Single healthy pine seedlings are occasionally seen on barren sites, sometimes a great distance from the seed source, despite their large small-winged seeds. The rarity of such occurrences may have as much to do with seed predation and soil toxicity as with lack of dispersal. Bare mineral soil is normally considered to provide an ideal seed bed for pines, but in the case of the Sudbury barrens, a relatively non toxic site would also be necessary. As the result of differential erosion, surface soils on the barrens show great variability in their chemistry and phytotoxicity, which may explain why some sites suitable for pine seed germination exist.

It is clear that one of the factors determining the order in which plant species colonize the soil is the composition of the "rain" of seeds that land on the soil surface. Species that have the lighter wind-dispersed seeds and those that are present as relicts each have an initial advantage. However, after seed deposition, a second limiting factor comes into play—that of the plant's ability to grow on the metal-toxic soil. The differentiating effect of the second factor is illustrated well by white birch and red maple. The former has light wind-dispersed

Box 7.1. Colonization of Barren Sites Created by Volcanic Eruption: Krakatau and Mount St. Helens

The most famous historical account of colonization of a newly created patch of barren land is that which followed the eruption of the Indonesian island of Krakatau in 1883. Most of the original island disappeared, leaving only the smaller, barren, pumice-covered island of Rakata. Nine months after the explosion, the only living organism seen by a French expedition was a small spider, presumably carried to the island as part of the "plankton of the wind." By 1886, there were 15 plant species, by 1897 49, and by 1928 nearly 300. Yet even today, although the island is covered by what seems to be typical tropical rainforest, not a single tree species characterizing the primary forest of neighboring Java and Sumatra is to be found (Wilson 1992).

On May 18, 1980, Mount St. Helens in Washington State, U.S.A., erupted for the first time since 1921. The north side of the mountain collapsed into the north fork of the Toutle River Valley, and 550 km^2 of forest was destroyed by the force of the explosion. Additional areas scorched by the heat of the blast or buried by mud flows (lahars) resulting from the melting of glaciers brought the total extent of the damage to 600 km^2. In August 1982, the U.S. Congress set aside 44,000 ha of the affected area for education and scientific study, to be known as the Mount St. Helens National Volcanic Monument (Franklin et al. 1988).

In the extensive area of forest blow-down, recovery from surviving root systems began almost immediately. In the 96-km^2 area of scorched trees, many of the deciduous trees were able to leaf out fairly normally, whereas the conifers suffered relatively high mortality. Of particular interest to the restoration ecologist, however, is the 20-km^2 barren area to the north of the volcano, known as the Pumice Plains, which was first buried by a debris slide, then by pumice, leading to a complete destruction of plant life. In a small spring-fed oasis on the Pumice Plains, willow (*Salix commutata*), with its light wind-dispersed seeds, was a rapid colonizer. The only species that has established itself abundantly on the drier pumice is the sub-alpine lupine (*Lupinus lepidus*), a rather surprising occurrence because its seeds are relatively large and not wind-dispersed. It is a symbiotic nitrogen-fixer and, as such, plays an important role in nitrogen buildup in the ecosystem that develops on new growth material.

Against the advice of scientists, the Soil Conservation Service (SCS) has dispersed seeds of introduced revegetation species such as birdsfoot trefoil (*Lotus corniculatus*) by helicopter over 32,000 ha, including 2400 ha of the barren land, in an attempt to stabilize the surface and reduce soil erosion. Not only were the introduced plants ineffective in mitigating channel erosion, but they attracted small rodents, which, during the winter, killed established conifers by chewing the bark. Also, the Army Corps of Engineers, the Weyerhaeuser Corporation, and the Washington State Department of Natural Resources dispersed seeds of exotic species to the west of Mount St. Helens, and seeds were carried onto the slopes by wind and elk. The presence of these non-native plants, especially birdsfoot trefoil, proved to have a negative effect on conifer establishment and survival. As a consequence of these results, the SCS has established a native plant seed collection and nursery program.

The inhibitory effect of vigorous nitrogen-fixers in the early stages of succession may not be confined to exotics. Morris and Wood (1989) found that *Lupinus lepidus* had an effect that could either facilitate or inhibit survival and growth of two other herbaceous colonizers—fireweed (*Epilobium angustifolium*) and pearly everlasting (*Anaphalis margaritacea*), and del Moral and Bliss (1993) suggested that the lupine only facilitates colonization after its demise. Overall, primary succession on the pumice was slow, and there was a surprising paucity of algal, lichen, or moss pioneers (Dale 1992).

An interesting observation has been that "late successionals" (i.e., plants that would not normally be expected to attain dominance in the forests of the Pacific Northwest for centu-

Box 7.1. (continued).

ries after disturbance) such as hemlock and true fir are able to colonize the debris slide within the first decade after the eruption. This phenomenon is in keeping with Egler's theory of initial floristic composition, which suggests that plant succession is not always the orderly sequence from pioneer to climax that Clements hypothesized. To quote del Moral and Bliss (1993): "Stochastic elements and low-probability events play a greater role than has been realized in determining the early development of devastated landscapes."

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seeds and sufficient tolerance to become established on Coniston area soils, whereas red maple, with its heavier seeds but more frequent relict individuals, is relatively metal-intolerant.

The richer of the wooded sites discussed later, whether dominated by birch or by oak, are currently characterized by the presence of wavy hairgrass in the understory, and this species is just beginning to appear in previously barren sites that have been colonized by white birch. Wavy hairgrass was not mentioned by Gorham and Gordon (1960) as an understory component northeast of the Falconbridge smelter, although they commented on the presence of less conspicuous grasses such as poverty grass (*Danthonia spicata*) and rice grass (*Oryzopsis asperifolia*). It seems likely, therefore, that the wavy hairgrass is a relatively recent arrival in Sudbury's partially barren woodlands. In contrast, Gordon and Gorham (1963) recorded wavy hairgrass as present in the "fume-kill" area near the iron smelter at Wawa, Ontario, but only beyond 6.4 km from the smelter, whereas today it is a widespread dominant at that site. In comparing Sudbury and Wawa seed sources of wavy hairgrass, Archambault (1989) found no difference in copper or nickel tolerance between the two populations. It is likely that it is the species' well-known tolerance of low pH (Larcher 1975) rather than of metals that allowed its spread on both of these sites after the reduction of atmospheric pollutant inputs to the soil.

Conclusions and Prognosis

Natural recovery of plant communities on acid, metal-contaminated soils is likely to continue at a very slow rate compared with the rapid colonization that occurs after soil amelioration (see Chapters 8 and 14). Based on the present state of knowledge, grasses and deciduous trees and shrubs such as birch, poplar, and willows will take the lead. Conifers are likely to be later colonists, especially those that require a mineral soil seed bed, because much of the mineral soil is still heavily contaminated with toxic metals. However, there is already tangible evidence of conifers such as white pine becoming established from seed at distances far removed from a seed source. The vector is not known, but it is unlikely to be birds because most birds digest the seeds that they eat. It is equally unlikely that pine seeds would remain attached to animal fur, but a distinct possibility is transport by wind drift over the surface of hard-packed snow in winter.

It should not be forgotten that colonization (Box 7.1) and possibly ecological succession are not the only dynamic processes occurring during the natural recovery of a damaged ecosystem. Genetic selection in one or more of the colonizing species may also be taking place, the implications of which are thoroughly discussed by McNeilly (1987). The impoverished plant communities that are currently found in the Sudbury area are not only structurally and floristically different from the normal plant communities in the region, but they are likely to have a different genetic make-up.

As the unweathered glacial till components still present in these contaminated soils break down and release their bases and contribute to the soil's sand, silt, and clay fractions, the soils will become less toxic and there will be the opportunity for colonization by less metal-tolerant species and less tolerant ecotypes. It is difficult to estimate the amount of time that a naturally recovering contaminated site might take to reach a stable quasi-natural community structure and floristic composition, especially in view of the possibility of global climate change. It would seem likely, however, that the time frame might be in the order of at least a century.

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