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CHAPTER 24

ECOSYSTEM DEGRADATION AND RESTORATION OF BIRCH WOODLANDS IN ICELAND

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INTRODUCTION

Land degradation and soil erosion have changed Icelandic ecosystems during the 11 centuries since the arrival of man. Vegetation cover has decreased and the remaining vegetation is severely degraded. Degradation processes in Iceland are intense and the result is often totally barren land, a desert. At the time of settlement birch (*Betula pubescens*) woodlands are believed to have been extensive in the lowlands, but only a fraction are left (Sigurdsson, 1977; Blöndal and Gunnarsson, 1999; Aradottir *et al.*, Chapter 6). It is important to preserve the remaining native woodlands and to restore the original and productive birch ecosystems.

The native birch can be an early colonizer in succession in Iceland (Persson, 1964), and its role for ecosystem restoration has often been underestimated. Increased emphasis has recently been placed on finding suitable means to exploit the colonizing traits of the birch to restore Icelandic woodland ecosystems.

This Chapter will examine some of the degradation processes that have resulted in destruction of the Icelandic birch woodlands and the potential and methods for their restoration.

ECOSYSTEM DEGRADATION

Iceland is about 103,000 km^2 in area. The climate is maritime cold-temperate to sub-arctic, with annual rainfall ranging from about 500 mm north of Vatnajökull Glacier to > 2000 mm along the south coast. Principal soils are Andosols (FAO, 1998), soils that form in volcanic deposits. All Icelandic soils are influenced by a steady flux of aeolian materials originating from desert wind erosion areas. Icelandic wetland soils are also influenced by this flux, giving rise to high mineral contents and andic soil properties. Most of the desert soils are also Andosols due to the high content of volcanic glass (Arnalds, 1999a). Birch woodlands were the principal ecosystems associated with much of the classical undisturbed Andosols of Iceland that once covered most of the country (Brown Andosols, see Arnalds, 1999a).

The cover of birch-dominated Andosol ecosystems in Iceland has decreased considerably since the country was settled. Classified satellite images show that more than 37,000 km^2 are now barren deserts with an additional 10–15,000 km^2 of disturbed areas with limited plant production (LMI, 1993). The current extent of birch woodlands is 1165 km^2 (Gudjonsson and Gislason, 1998). It has been estimated that the birch woodlands covered as much as 28,000 km^2 (Sigurdsson, 1977) or even 40,000 km^2 (Bjarnason, 1974) at the time of settlement, and the deserts covered only 5000–15,000 km^2 (Arnalds, 2000).

Productivity of the vegetated ecosystems has also decreased considerably since the settlement (Thorsteinsson, 1986). Evidence for past ecosystems in Iceland include historical records, sagas, annals, old farm surveys, old place names, relict areas, current vegetation remnants, pollen analyses, and soils buried under sand (e.g. Thorarinsson, 1961; Einarsson, 1963; Arnalds, 1987; 1988; Hallsdottir, 1995; Kristinsson, 1995; Gisladottir, 1998). These sources indicate that widespread ecosystem degradation and soil erosion started soon after the settlement, with increased wind erosion and aeolian redistribution of materials (Thorarinsson, 1961; Gudbergsson, 1975; Sigbjarnason, 1969). No evidence for such massive land degradation and soil erosion before the settlement has been documented. The reasons for the rapid degradation and soil erosion are complex but can be summarized as the use by man of extremely fragile ecosystems. The ecosystems utilized by the Viking settlers were fertile in the beginning, with lush vegetation and abundant birch woodlands. There was a rapid human population increase soon after the settlement and the resources were heavily utilised (e.g. Gudbergsson, 1975). The settlers cleared large areas for farmsteads, building materials, hayfields and fuel. Fire was used for extensive clearing and sometimes burned out of control (Arnalds, 1987). Great quantities of birch wood were used to make charcoal, which was important for making iron and whetting scythes used for hay cutting until the nineteenth century (Thorarinsson, 1974; Arnalds, 1988).

Grazing by domestic herbivores, especially sheep, also had a very strong influence on the birch woodlands. A grazing experiment with sheep in a birch woodland, that had previously been protected from grazing for 70 years, clearly demonstrated the detrimental effect of sheep on rejuvenation of the woodlands (Thorsteinsson, 1986). After five years all birch seedlings and more than three-quarters of the young trees under 1 m in size had been killed (Thorsteinsson, 1986). Sheep grazing can open up dense sward and provide conditions for germination and emergence of birch seedlings, but it has a negative effect on the subsequent survival of seedlings (Emberlin and Baillie, 1980; Pigott, 1983). Sheep can also prevent rejuvenation by browsing on the basal sprouts of the birch, but basal sprouting is the primary mode of regeneration in many woodlands (Aradóttir *et al.*, Chapter 6). When the availability of other forage was low, as in winter and early spring, the grazing pressure on birch would be relatively greater than during other parts of the year. Winter grazing by sheep was a common practice in Iceland until the twentieth century and this had a negative effect on the condition of many woodlands.

Individual stems of birch are relatively short-lived. If grazing hampers rejuvenation by seed or basal sprouting, the birch can eventually disappear from the plant community. Continued grazing can lead to further deterioration in vegetation composition and vegetation, rich in herbs and grasses, which is preferred by sheep due to the relatively high protein content, can be replaced by less palatable vegetation dominated by dwarf shrubs, mosses, and hummocky terrain. Such plant communities are presently the most common vegetation types in Iceland (e.g., Thorsteinsson, 1986). These changes are described in more detail by Thorsteinsson (1986) and Arnalds (1987; 1988). After vegetation degradation reaches a critical point, massive soil erosion occurs, that removes most of the fertile Andosol cover, which is replaced by infertile desert soils. The deterioration of Icelandic birch woodlands and further vegetation degradation is likely to have followed stepwise degradation and desertification pathways, as described by Archer and Stokes (2000).

There are many reasons for the fragility of the Icelandic ecosystems, as reviewed by Arnalds (1999b; 2000). The Andosols lack cohesion and are extremely vulnerable to erosion when they are exposed to wind and water. A cooling climatic trend started about 2500 years ago (Bergthorsson, 1969), which made the ecosystems that had evolved under milder climatic conditions more sensitive to disturbance. The most unstable highland and mountain vegetation would have been the most susceptible to disturbance for this reason and there is evidence for massive soil erosion in the highlands soon after the settlement (e.g., Thorarinsson, 1961). The rate of the erosion involves several peaks, often associated with natural stress events such as extremely cold years that cause intense overuse of the vegetation due to lower production. Other such stress events include volcanic eruptions causing widespread deposition of volcanic ash. The systems lost their resilience against such events after intense use of the vegetation began after the settlement. As the climate grew colder, the glaciers advanced, creating larger areas of unstable sandy ground at their margins and along floodplains of glacial rivers. This has resulted in increased aeolian activity, with thicker and less stable soil mantles (see Arnalds, 2000). Cryogenic processes in Iceland are quite active due to frequent freeze–thaw cycles and conditions that allow for water transfer to a stationary freezing front. Hummocks, solifluction and other cryogenic features are quite common. There is evidence that hummocks grew much larger as the vegetation deteriorated and the climate became cooler during the Middle Ages, but the top of the hummocks are extremely vulnerable to disturbance and erosion. It can be said that all these factors created a snowball effect that has caused devastation of Icelandic ecosystems (Arnalds, 2000).

Erosion processes in Iceland are varied, depending on site conditions. The erosion has been mapped by a national soil erosion survey (Arnalds *et al.*, 1997). The survey is based on estimation of erosion severity on a scale from 0 (no erosion) to 5 (very severe erosion). The survey shows that considerable (3), severe (4) and very severe (5) soil erosion occurs on over half of Iceland. Such severe erosion and extensive deserts are found nowhere in the world outside of the driest desert regions, making Iceland a unique place in relation to ecosystem condition, i.e. the combination of severe erosion and a moist and cold climate. One of the most distinctive features of soil erosion in Iceland is the total removal of the unstable soil mantle which supports vegetation growth. This mantle is often 0.8–1.5 m thick and rests upon a 10,000-year-old glacial till surface or younger lava surface. It has been deposited by aeolian flux from unstable desert surfaces, volcanic ash deposition and redistribution of soil materials. Fertile Andosols (Brown Andosols) have formed in this mantle, rich in organic and clay materials with ample waterholding capacity (Arnalds *et al.*, 1995; Arnalds, 1999b). The erosion tends to completely remove this mantle, exposing the old surface which has low organic and clay content, and very limited waterholding capacity (Arnalds *et al.*, 1995). These surfaces support only limited vegetation cover and the low nutrient status, water availability and cryogenic processes impede regeneration and vegetation establishment. The desert surfaces are often sandy and very unstable which also has limiting effect on plant growth.

THE ROLE OF WOODLANDS IN PREVENTING EROSION

Vegetation cover is one of the most important factors in preventing soil erosion. While the birch woodlands were extensive, they probably played a major role in preventing soil erosion. The woodlands accumulate snow which has an insulating effect and reduces the intensity of cryogenic processes. Hardly any soil erosion takes place within birch woodlands. Further, they recover quickly where landslides have fallen through them which indicates relatively strong resilience towards disturbance when the woodlands are not grazed.

The birch woodlands can withstand events of large volcanic ash deposition, as clearly demonstrated by woodland remnants near Mount Hekla, the most active volcano in south Iceland. The woodland environment restricts movement of wind at the surface and the ash is therefore stable, enabling natural recovery. Willow (*Salix* spp.) shrubs have most likely been important in reducing erosion risks in the highlands.

Iceland is a mountainous island with deep glaciated valleys characterizing large portions of the country. The National Erosion Survey (Arnalds *et al.*, 1997) shows very poor conditions of hill slopes in Iceland, and there are about 6000 km^2 of vegetated slopes with considerable erosion. Many other slopes are now devoid of vegetation, often forming stony scree slopes (about 5000 km^2). The woodlands have played a major role in stabilizing soils on hill slopes. The trees have extensive root systems, accumulate snow and reduce cryogenic processes such as solifluction and the risk of running water on hill slopes. It is likely that hill slopes in southeast Iceland, which receive the highest amount of precipitation and high intensity rain storms, have been among the first areas to become desertified after grazing and wood cutting reduced the birch cover.

Destruction of the woodlands was one of the most detrimental factors leading to the massive degradation of Icelandic ecosystems. Reduced productivity of the land, due to land degradation and soil erosion, also means that less biomass energy is transferred to river systems, and this greatly affects their biota (Gislason *et al.*, 1998).

RESTORATION OF BIRCH WOODLANDS

Restoration in Iceland

Large-scale efforts to prevent erosion and reclaim severely degraded land began early in the twentieth century. The Icelandic Soil Conservation Service was established in 1907 to battle against soil erosion. The history of reclamation in Iceland has been reviewed by Runolfsson (1987) and Magnusson (1997).

Magnusson (1997) divided restoration efforts in Iceland into three main periods: I. Erosion control period (1907–1945); II. Cultivation period (1946–1985); and III. Ecological revegetation period (1986 to the present). During the first period, the emphasis was on halting catastrophic sand encroachment that is a particularly rapid and destructive form of land degradation. The second period was characterized by fertilization and sowing of grasses. In most cases, grazing was excluded or limited on areas being reclaimed. Vegetation cover of large areas has been reclaimed; the vegetation ranging from moss and lichen cover to well developed woodlands. The same methods are still the backbone of land reclamation work in Iceland, but ecological methods are becoming increasingly important. These include the use of native and introduced legumes, shrubs and trees, including birch. At the same time, there is a growing concern and debate about the introduction and use of exotic species for land reclamation and increased emphasis on the protection and restoration of the native birch woodlands (Eysteinsson, 1999).

The role of birch for vegetation establishment and restoration is currently increasing. Birch can be an early colonizer in succession in Iceland (e.g. Persson, 1964; Aradottir, 1991) and pollen records show the spread of the birch woodlands soon after the glaciation (Einarsson, 1963; Hallsdottir, 1995). Birch is also a dominant species of the mature woodlands (Steindorsson, 1964). The use of birch can have several different objectives, including restoration of original ecosystems, soil protection, carbon sequestration to balance greenhouse gas emissions and to improve options for future land use, such as for recreation, grazing and forestry (e.g. Aradottir, 1991, 1998; Arnalds *et al.*, 1999).

Restoration of the birch woodlands may take a very long time and may depend on cultural inputs, even at sites that were previously covered with birch. Restoration of woodlands may require reintroduction of birch in areas where the species is now extinct or has very low abundance. This can be accomplished by either direct seeding or planting of birch seedlings. The colonization of birch and other plants on severely degraded sites may be impeded by such factors as frost heave, low nutrient status, low waterholding capacity of the soil, and active

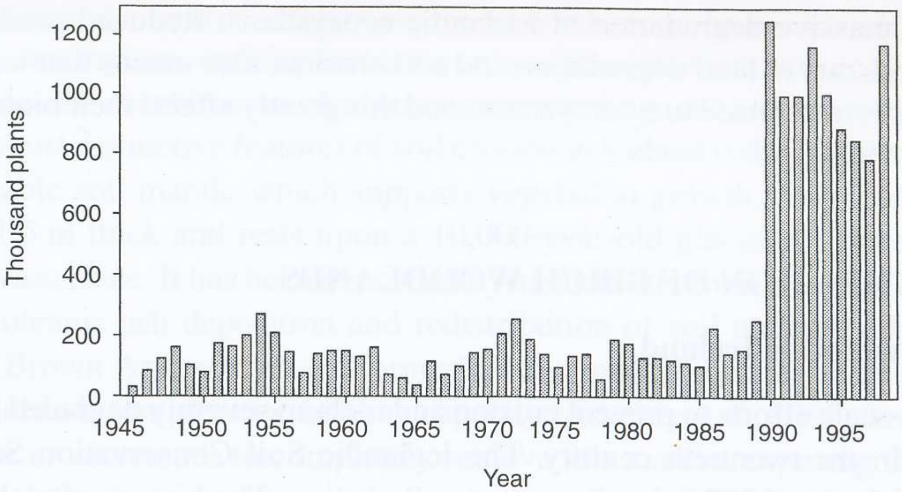

Figure 24.1 Number of birch seedlings delivered annually from nurseries in Iceland 1945–1998 (based on Petursson, 1999)

soil erosion (Arnalds *et al.*, 1987; Magnusson, 1997; Arnalds, 2000). There are three principal means of establishing birch woodlands: planting, seeding, and natural regeneration.

Planting

Over 15 million seedlings of birch were planted in Iceland from 1945 to 1998 and birch was the second most common species used in afforestation during that period (Petursson, 1999). The planting of birch increased markedly in 1990 (Figure 24.1), when a national effort of tree planting was initiated in order to reclaim degraded and barren areas. Since then, an average of one million tree seedlings has been planted annually as a part of this programme, at a total of 110 sites (Blöndal and Gunnarsson, 1999). Birch has been the most important species but larch (*Larix sukaczewii* and *L. sibirica)* and pine (*Pinus contorta*) are also important (Aradottir and Gretarsdottir, 1995).

Planting of tree seedlings for reclamation on a comparable scale had not been attempted earlier in Iceland and it was, therefore, important to learn from the mistakes and successes of the project. The survival and condition of the plantations has been surveyed on several occasions (Aradottir and Magnusson, 1992; Aradottir and Gretarsdottir, 1995). In 1992 and 1993, permanent transects were established at nine of about 80 sites planted in 1992 and 1993, with the objective of surveying the condition of seedlings planted in 1991–1993 (Aradottir and Gretarsdottir, 1995). These transects were surveyed again in 1996, when the seedlings were 4–6 years old (Gretarsdottir and Aradottir, unpubl.). Average survival in 1996 of seedlings planted in 1991 and 1992 was 70% for birch, 63% for pine and 44% for larch (Figure 24.2). The survival of birch at individual sites ranged from 32% to 94% for seedlings planted in 1991 and 55–89% for seedlings planted in 1992. This large variation reflects differences in

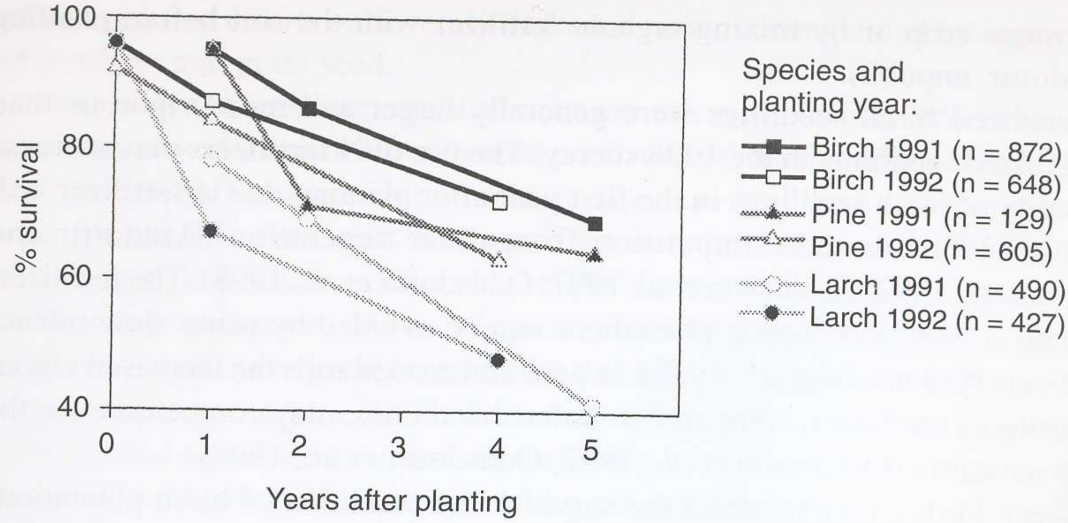

Figure 24.2 Survival of tree seedlings planted for reclamation of degraded and barren areas in Iceland in 1991 and 1992. Shown are results from surveys of permanent transects at nine sites in 1992, 1993 and 1996

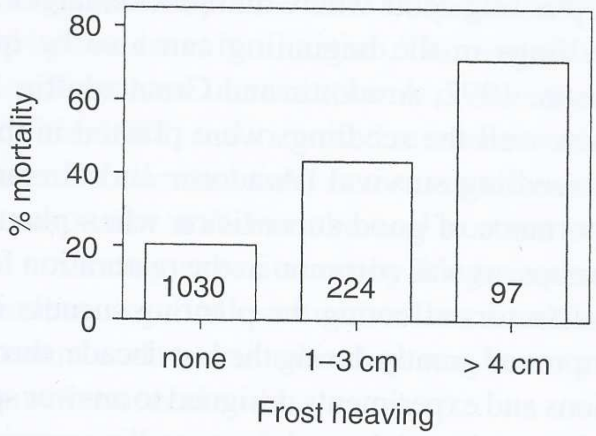

Figure 24.3 The effect of frost heave on mortality of birch seedlings planted for reclamation of degraded and barren areas in Iceland in 1991 and 1992. Numbers inside columns indicate number of seedlings in each category

environmental conditions, vegetation cover and surface characteristics of the planted areas, and different fertilization treatments, among other factors.

About 24% of the planted birch seedlings from 1991 and 1992 were reported as frost heaved. Mortality of the frost heaved seedlings was relatively high (Figure 24.3), indicating that frost heave was an important cause of mortality. Frost heave is much more serious where the seedlings are planted in spots with little or no vegetation cover, such as on barren land, than in spots with continuous vegetation cover (Aradottir and Magnusson, 1992; Aradottir and Gretarsdottir, 1995). Other studies have shown that frost-heaving at sites with little or no vegetation cover can be reduced by applying annual grass seeds and fertilizer at the planting spot (Oddsdottir *et al.*, 1998), by using lupin (*Lupinus nootkaatensis*) as a nurse crop or by mixing organic fertilizer with the soil before planting (Aradottir, unpubl.).

Fertilized birch seedlings were generally larger and more vigorous than unfertilized seedlings in the 1996 survey. The use of N fertilizers may increase mortality of birch seedlings in the first year after planting due to fertilizer–salt effects and increased competition from other vegetation (Aradottir and Magnusson, 1992; Oskarsson *et al.* 1997; Oddsdottir *et al.*, 1998). The fertilizer-induced mortality of young plantations can be avoided by using slow-release fertilizers (Oskarsson *et al.*, 1997). In poor and eroded soils the increased vigour of fertilized seedlings, compared to unfertilized ones, may compensate for the early mortality (Oskarsson *et al.*, 1997; Oddsdottir *et al.*, 1998).

Several other factors affect the survival and condition of birch plantations during the first years. *Otiorhyncus* larvae debark the roots and collars of the planted seedlings and can cause a considerable mortality in plantations (Halldorsson *et al.*, 2000). In the 1992–1996 surveys, over 10% of the dead birch seedlings had been damaged by *Otiorhyncus* larvae. The damage was probably more extensive, but it was not studied systematically from the beginning. Selection of planting spots where hummocks, larger stones or other objects shelter the seedlings in the beginning can also be quite important (Aradottir and Magnusson, 1992; Aradottir and Gretarsdottir, 1995). Finally, the workmanship, or how well the seedlings were planted in the mineral soil, had a strong effect on seedling survival (Aradottir and Gretarsdottir, 1995). This illustrates the importance of good supervision when planting is done by volunteers and youth groups, as was common in the restoration forestry project.

The understanding of factors affecting the planting success in eroded areas and exposed sites has improved greatly during the last decade, through systematic observations of plantations and experiments designed to answer specific research questions. This knowledge can be used to enhance seedling survival and growth, improve planting results, and allow direct planting at poor sites. Planting can be a useful method to establish birch stands, especially in parts of the country where birch is not now found. However, planting is costly and labour intensive and is, therefore, not well suited for restoration of woodland cover on extensive areas. Other means, which can be more effective for this purpose, are direct seeding and natural regeneration.

Direct seeding

Direct seeding of birch was tested on a small scale in the first half of the twentieth century, resulting in the establishment of a few small forest stands (reviewed by Magnusson and Magnusson, 1990). During the last 10–15 years, there has been a renewed interest in direct seeding of birch. Simple instructions on seed collection and seeding have been published and volunteer groups have collected seed that they have either sown on their own or donated to the Soil Conservation Service or the Forest Service. The seeding of birch is sometimes used as a part of revegetation efforts on severely degraded areas, accompanied by application of fertilizer and grass seed.

Safe sites for seedling establishment are microsites where probabilities of germination and survival are enhanced relative to other microsites (Harper, 1977; Fowler, 1988). Characterization of safe sites can be useful in targeting areas that are suitable for direct seeding. This may be accomplished by seeding experiments and studies of natural establishment.

Seedling emergence of birch is generally much higher in open microsites where the seeds have good contact with the mineral soil than in microsites with vegetation cover (Miles, 1973; Kinnaird, 1974; Magnusson and Magnusson, 1990). Field experiments to test the suitability of common microsites for birch establishment showed greatest seedling emergence in microsites on mineral soil, followed by fine gravel, microsites next to small rocks, dwarf shrubs (*Calluna vulgaris* and *Empetrum nigrum* ssp. *hermaphroditum*), grass sward and *Racomitrium* moss cushions, in that order (Aradottir, 1991). Winter survival was highest in the dwarf shrub microsites but lower in the open microsites, especially in mineral soil where there were many signs of frost heave, including up-rooted seedlings and displaced soil. Winter survival in the open microsites was augmented by low-level fertilization. This may be related to larger seedling size, as larger seedlings have increased levels of stored energy of nutrient reserves (Chapin, 1980; Skre, 1988) and increased resistance to frost heave (Perez, 1987). Fertilization can also alleviate frost heave via stimulation of the formation of cryptogamic crusts that stabilize the soil surface (Gunnlaugsdottir, 1985; Aradottir, 1991). Seeding experiments by Magnusson and Magnusson (1990) showed that seedling survival over winter was directly related to seedling size in the first autumn, and winter mortality was mainly caused by frost heave activity at sites with mineral soils.

Studying the environment of natural birch seedlings can also be used to characterize safe sites for seedling establishment. This method will give best information for young seedlings, because the surrounding vegetation and other features may change with time. Studies of birch colonization on barren and revegetated sites in Iceland indicate that cryptogamic crusts and thin moss layers are very important microsites for birch recruitment (Figure 24.4). Magnusson and Magnusson (1990) found no seedling emergence in sward thicker than 1 cm, except in a mire that had a moist moss layer.

Seeding near established plants can also affect the colonization potential, as shown by experiments of Magnusson and Magnusson (Chapter 26) where birch seedlings close to established *Salix* plants grew much better than seedlings farther away.

Natural regeneration

Natural regeneration of birch from seed is commonly observed near existing stands, especially where sheep grazing has been alleviated. Two factors govern

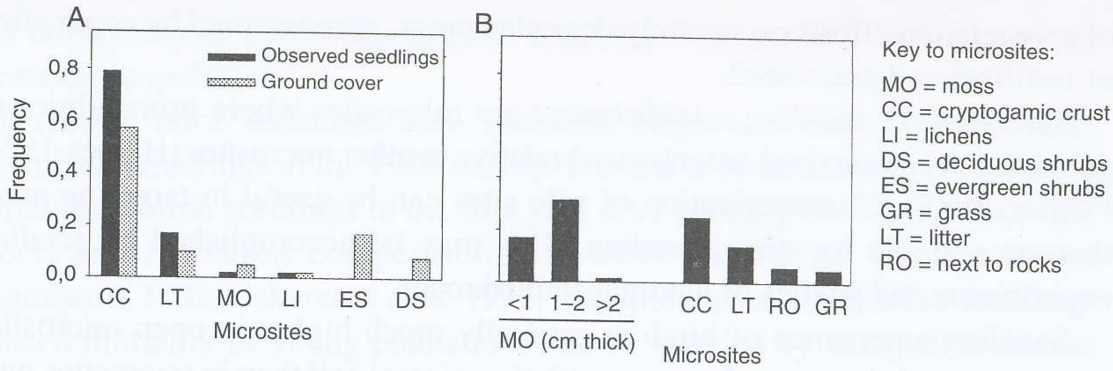

Figure 24.4 Colonization in different microsites on revegetated areas (based on Aradóttir, 1991). A. Observed frequency of birch seedlings in different microsites and cover of microsite types on transects radiating from mature birch plants in north Iceland. Seedlings were not randomly distributed among the microsite types ($\chi^2 = 117$; $p < 0.001$, n = 296). B. Frequency of birch seedlings in different microsites on transects radiating out from established birch clusters in south Iceland

the natural regeneration from seed: availability of safe sites and the density of the seed rain. The density of seed rain tends to decrease in a log-linear manner with increased distance from the seed source (Hughes and Fahey, 1988; Matlack, 1989; Aradottir, 1991). Hence, the seed rain becomes increasingly limiting for seedling establishment with increased distance from the seed source, which is reflected in a rapid decrease of seedling density (Aradottir, 1991; Green, 1983). There is abundance of seed closer to the seed source and recruitment is primarily limited by the availability of safe sites. Directionality in dispersal of birch seed is associated with strong prevailing winds (Ford *et al.*, 1983) and affected by humidity as the seeds are released from the catkins when humidity is low (Matlack, 1989). A strong directional distribution of seedlings around isolated birch stands with mean direction between 251° and 327° (west and northwest) was observed in south Iceland, as a response to seed dispersal by strong, dry easterly and northeasterly winds (Aradottir *et al.*, 1997).

Long-term changes in birch cover on a disturbed site in Gunnlaugsskógur, south Iceland have been quantified from aerial photographs (Figure 24.5). The birch were established by seeding of birch on small plots in 1939 and 1945. The cover of birch was 9000 m^2 in 1960, but had increased by 340% to 30,000 m^2 in 1984 (Aradottir, 1991). Some of the increase in birch cover was by early transplants from established birch clusters to new sites, but most was by natural regeneration (Aradottir, 1991). This example illustrates the potential of natural regeneration for re-establishment of birch woodlands on disturbed sites.

The extent of degraded land in Iceland where birch woodlands can potentially be restored is in the order of thousands of km^2. It is not feasible to use labour-intensive and costly methods, such as planting, in very large areas. Woodland remnants represent important seed sources for natural regeneration, but they have a very limited distribution (Sigurdsson, 1977; Aradottir *et al.*, Chapter 6)

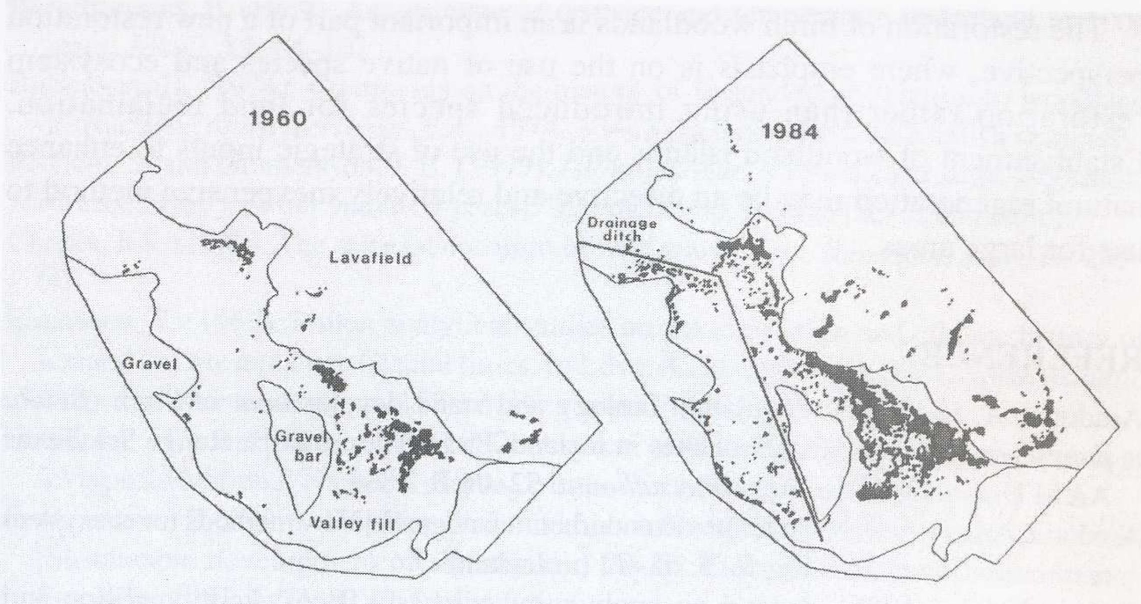

Figure 24.5 Distribution of birch (dark areas) on three landscape units at Gunnlaugsskógur, south Iceland in 1960 and 1984 (adapted from Aradóttir, 1991)

and the availability of safe sites for seedling establishment near them may be limited. The same applies to planted birch stands that can have an important role for further colonization. Natural regeneration can be encouraged by establishing small 'islands' of birch through planting or seeding at strategic locations across landscapes, from which the birch would gradually colonize the whole area (Aradottir, 1991; 1994). Such a strategy would concentrate resources (plants, seeds, fertilizer, etc.) at selected locations to enhance the probability of local establishment as opposed to spreading them over a larger area. This can accelerate further improvement of microenvironmental conditions and speed plant succession (cf. Ludwig and Tongway, 1996; Thurow, 2000). As the bulk of the seed rain falls close to the parent plants, a colonization front can be expected near the seed source. Stands serving as seed sources should, therefore, be established close to areas that have a high density of potentially safe sites for seedling establishment or where the availability of safe sites can be increased, e.g. by strategic fertilizer applications after good seed years.

CONCLUSIONS

Birch woodlands played a major role in conserving the fragile Icelandic soils in the past. Land degradation and desertification have removed much of Iceland's rich Brown Andosol cover and limited woodland cover remains. The woodland remnants are considered valuable, as they are sought after for recreation, summer dwelling, and for aesthetic values. Restoration of the Icelandic birch woodlands is, therefore, important for land conservation and socio-economic reasons.

The restoration of birch woodlands is an important part of a new restoration perspective, where emphasis is on the use of native species and ecosystem restoration rather than using introduced species for land reclamation. Establishment of woodland islands and the use of strategic inputs to enhance natural regeneration may be an effective and relatively inexpensive method to use for large areas.

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