EFFECT OF BIRCH ON MOORLANDS

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Dr. J. Miles
Institute of Terrestrial Ecology
Banchory

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Cover photographs by J. Miles.
Top: Birch (*Betula pendula*) invading heather on the Muir of Dinnet; Bottom left: Podzol profile under heather; Bottom right: Brown podzolic soil in profile, under 38-year old birch (*Betula pendula*); Centre: Primrose, part of new birch wood ground flora.

All other photographs by J. Miles.

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Dr. J. Miles
Institute of Terrestrial Ecology
Hill of Brathens
Glassel
Banchory
Kincardineshire AB3 4BY
033 02 (Banchory) 3434

This booklet firstly states why it is worth while studying moorlands and birch (*Betula pendula* and *B. pubescens*), secondly outlines research on the effects of birch on moorland soils and vegetation, and thirdly discusses certain implications of these findings.

WHY STUDY MOORLANDS AND BIRCH?

Both moorlands and birch are important natural resources. The former make up about 30% of the land area of Britain, including about 65% of Scotland (Plate 1). They are used in many ways, in particular for sheep and cattle farming, human recreation and wildlife conservation, and, in the north, cropping of red grouse and red deer stocks.

Birch is one of the most abundant trees in Britain; in 1970 it was estimated to comprise 13% of all stocked woodlands. It is particularly important in the Scottish Highlands, where scattered trees reduce the visual monotony of many conifer plantations, and where birch woods and scrub form a characteristic and attractive part of the landscape. These woods provide valuable browse and shelter for domestic live-stock and deer, firewood for man, and support a rich fauna and flora compared with surrounding moorlands. They are also a potential source of pulpwood and timber, a use which has been surprisingly neglected compared with many other countries, although the wood of birch formerly had an essential role in the rural economy.

However, it is possible that the main value of birch may hitherto have been largely overlooked. Before we began our work, birch had a reputation, based on very scanty evidence, as a soil "improver", of promoting depodzolization and the formation of mull humus and brown soils. Because of the potential implications of this reputation if true, research was begun in late 1973 to examine the effects of birch growing on poor moorland soils. The next section will show that this reputation increasingly seem justified. The main value of birch may indeed be an ability to maintain or increase the productive capacity of intrinsically poor upland soils, in contrast to the apparent effects of heather and certain conifers, and in opposition to the natural trend towards podzol development in Britain's oceanic climate. Further, the research has also proved to be a scientifically stimulating study of the processes by which plants influence the soil, and has indicated several fields of which we are profoundly ignorant.

THE EFFECTS OF BIRCH

The research approach

Any effects of a plant on the soil can only be demonstrated conclusively

Plate 1 Heather moorland, Central Highlands, Scotland.

Plate 2 Young birch *(B. pendula)* saplings establishing in burnt heather.

by experimentation, but with long-lived plants like trees the time span necessary for such experiments is daunting. Therefore, to obtain some evidence rapidly and to formulate hypotheses which could be tested by long-term experiments, we have been examining the soils under first generation birch stands of different ages and comparing them with soils of adjacent ground not colonized by birch. Thirteen sites situated from Sutherland to north Yorkshire were selected (Figure 1). Two of the sites were old quarry floors in

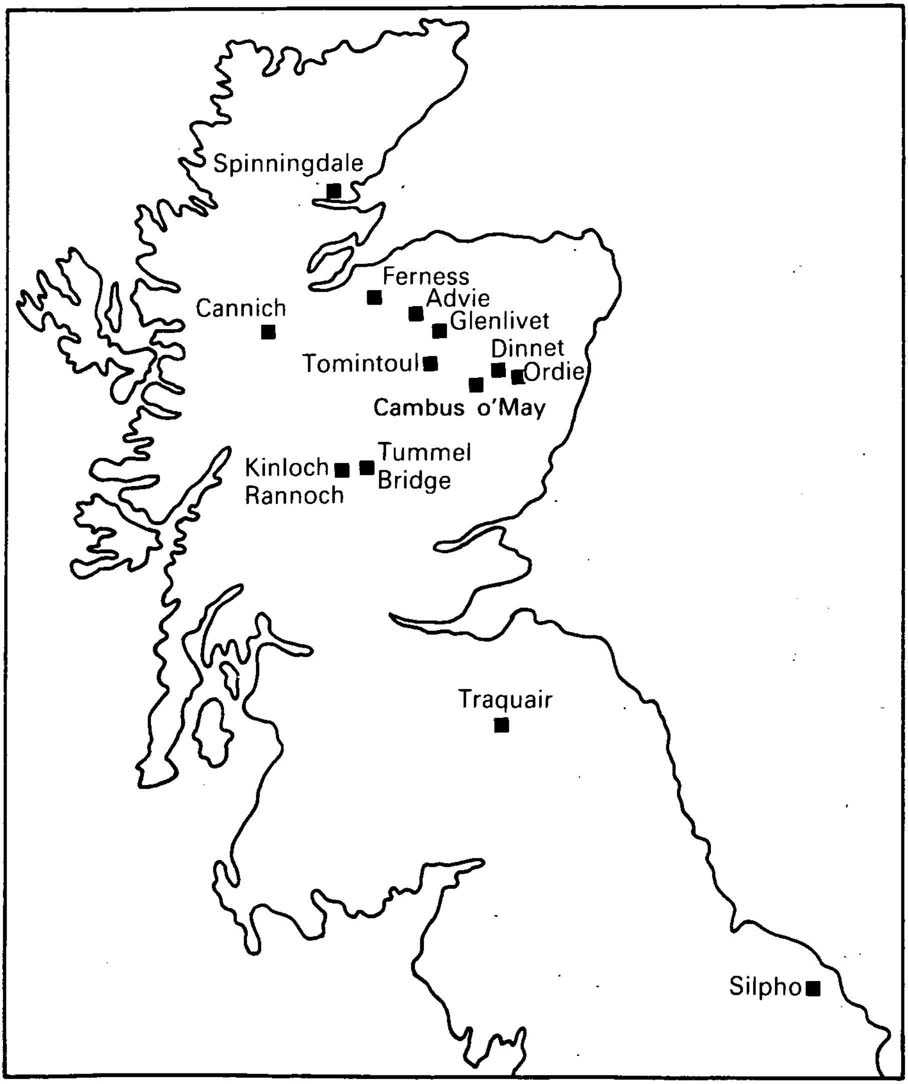

Figure 1. Location of sites

Plate 3 Young birch *(B. pendula)* colonising hillside after clear-felling of Scots pine plantation.

Plate 4 *Betula pendula* tree showing characteristic form.

heather moorland, three were felled Scots pine stands planted on former moorland, and the other eight were on heather (*Calluna vulgaris*) moorland (Plates 2 & 3). All the birch stands studied were effectively even aged, each having established after fire, felling or quarry abandonment in the few years before the vegetatively regenerating heather, or, in the case of the two quarry sites, the young birch stands themselves, achieved sufficient cover to prevent further birch establishment. Nine of the sites bore only single aged birch stands, but three of the moorland sites each bore three or more adjacent stands of different ages, thus allowing time sequences to be constructed.

To interpret differences in labile soil properties under moorland and adjacent birch stands as though they represented changes in time at a single point, it is necessary to determine:

1. that topography and relatively stable soil properties do not differ significantly between colonized and uncolonized moorland;
2. that the vegetation prior to birch colonization was the same as on the adjacent uncolonized ground;
3. that the birch stands are first generation.

If points 1 and 2 can be demonstrated, the assumption can be made that the labile soil properties did not differ significantly across the site before birch colonization began, while determining point 3 permits a time scale to be attributed to any inferred soil changes. The weak link in this argument is the premiss of antecedent similarity of labile soil properties. This assumption cannot be tested. However, it was thought that if a fairly large number of sites showed the same apparent soil trends, then the premiss was likely to be valid.

The variation across the sites of stable soil properties was determined by analysis of soil profiles and of soil mineralogy and particle size distribution. These have confirmed the effective uniformity of the sites in terms of relatively stable, plant-independent properties. For example, Figure 2 plots the relationships of the sand, silt and clay content of the soil from three random samples under each different aged stand at one site. It clearly shows that points from under heather and different ages of birch are completely intermingled, showing that variability within age classes is greater than that between age classes.

Information about the vegetation present before birch colonization was obtained by examining pollen, viable seed and stem fragments buried in the soil profiles. These gave unequivocal evidence that most of the birch stands examined were definitely first generation, having colonized ground without birch.

Labile soil properties at all sites have been examined by a wide range of analyses, while changes in the ground vegetation under birch canopies have

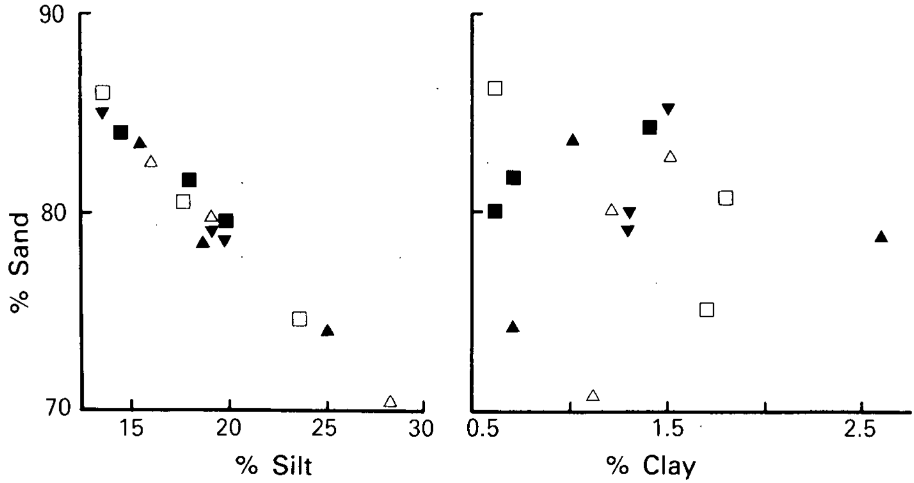

Figure 2. Relationships between the proportions of sand, silt and clay in soil under heather □, and *Betula pendula* aged 18 ■, 26 △, 38 ▲ and 90 years ▼, near Advie, Morayshire

also been investigated. Current measurements are concentrating on examining the processes of soil change under birch at a few sites only.

Findings

Substantially the same trends of change in vegetation and soil seem to be occurring at all sites, whether under *Betula pendula* or *B. pubescens*, though the extent and rate of change varies considerably (Plates 4 & 5). The changes are illustrated by results from the Advie site, given in Figure 3 and Tables 1 and 2.

Table 1. Changing numbers of vascular plant species found in heather moorland and adjacent *Betula pendula* stands of different ages near Advie, Morayshire.

	Heather	*Betula pendula* aged:			
		18 years	26 years	38 years	90 years
Number of species present as growing plants	12	20	19	24	30
*Total number of species present	16	24	23	28	33
*Total number of heather moorland species absent from the woodland	—	2	3	4	7
*Total number of species present in the woodland not occurring in the heather moorland	—	11	11	15	25

*Includes species present only as buried viable seed—an important part of any flora.

Plate 5 *Betula pubescens* stand showing bushy form common in the Highlands at higher altitudes.

Plate 6 Dying heather under birch surrounded by wavy hair-grass and bilberry.

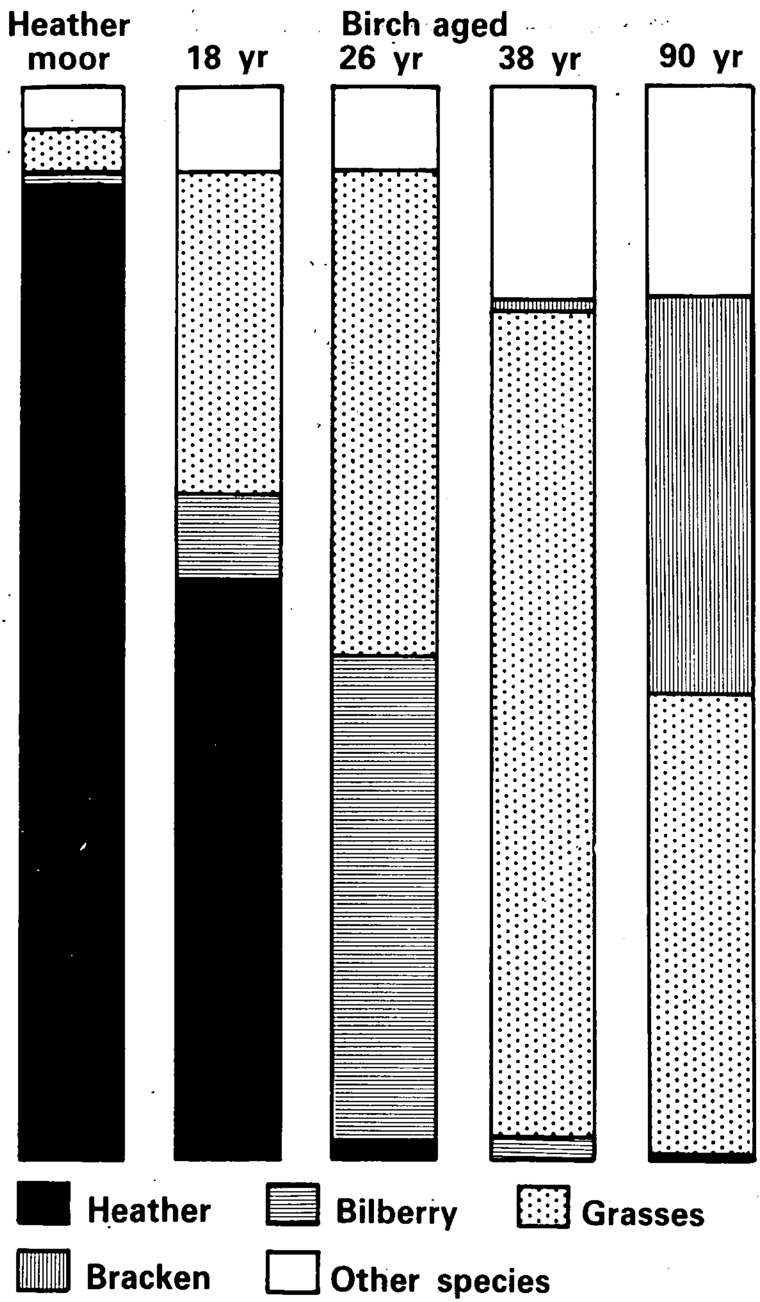

Figure 3. Mean percentage cover of different species in heather moorland and under adjacent birch stands of different ages, near Advie, Morayshire.

As birch canopies develop over heather swards, the heather gradually dies (Figure 3 & Plate 6), with natural senescence probably accelerated by the effects of shading. It is replaced initially by wavy hair-grass (*Deschampsia flexuosa*) and bilberry (*Vaccinium myrtillus*) in particular, apparently just by vegetative spread, the former especially on more mineral soils, the latter when more surface organic matter is present (Plate 7). Other species characteristic of moorland also disappear with time, but as soil conditions change their loss is more than compensated by the appearance of species characteristic of woodlands and grassland (Figure 3 & Table 1). The latter include bent grasses (*Agrostis* spp.), sweet vernal-grass (*Anthoxanthum odoratum*), Yorkshire fog (*Holcus lanatus*), slender St. John's wort (*Hypericum pulchrum*), wood-sorrel (*Oxalis acetosella*) and common violet (*Viola riviniana*). Bracken (*Pteridium aquilinum*) also tends to spread in when it is present nearby. These changes in the vegetation with time are also reflected in the viable seed and pollen content of the surface soil.

Concurrent with the changes in vegetation, several main trends of change occur in the soil (Table 2).

Table 2. Analysis of soil (0-15 cm, except for pH and organic matter, 0-5 cm) from heather moorland and adjacent *Betula pendula* stands of different ages near Advie, Morayshire.

	Heather	*Betula pendula* aged:				LSD at 5% level
		18 years	26 years	38 years	90 years	
Mean number of earthworms per 1 m² (by formalin extraction)	1	5	27	127	78	26
Organic matter (g dm^{-3})	194	153	143	120	97	31
Cellulose decomposition estimated by tensile strength loss in kg of cotton strips buried for 10 weeks						
(i) At 0-4 cm	4·5	16	22	23	22	3·6
(ii) at 16-20 cm	3·2	6·0	9·0	8·9	17	4·2
N mineralization after 14 days incubation (mg dm^{-3} week^{-1})	—1·3	25	41	45	40	10
pH	3·8	3·9	4·0	4·7	4·9	0·1
Exchangeable Ca (mg dm^{-3})	117	108	109	101	89	25
Total P (mg dm^{-3})	151	210	196	240	232	82
C/N ratio	30	26	19	22	15	11
C/P ratio	500	320	280	270	170	200
C/K ratio	440	430	410	460	310	210
Bioassay: mean dry weight (mg) of 8 week old radish;						
shoots	87	18	43	59	66	18
roots	3·3	16	39	74	77	30

Plate 7 Birch-heather boundary showing sharp transition between heather and changed vegetation under birch.

Plate 8 Moribund birch *(B. pubescens)* showing lack of regeneration.

1. A considerable increase in the numbers of surface living earthworms especially *Lumbricus rubellus*, and with *Lumbricus terrestris* and *Allolobophora* spp. appearing later as soil conditions change.
2. Following the death of the heather, a gradual breakdown of the old surface mor humus layer and its conversion to a mull-like form, probably due largely to earthworm feeding. This is reflected by a progressive decrease in the organic matter content of the top 5 cm of soil.
3. Increased rates of cellulose decomposition, very soon after birch establishment in the surface soil, but more slowly at greater depth, and also of nitrogen mineralization.
4. Increases in pH, exchangeable calcium and total phosphorus.
5. A decrease in the ratios carbon/nitrogen, carbon/phosphorus, and to a lesser extent carbon/potassium, from the critical levels present on the moorlands at which nutrient immobilization and deficiencies would be expected.
6. Points 2 to 5 suggest that soil under birch should support better growth of most plants than the moorland soils, i.e. it should be more 'fertile'. This expectation is fulfilled. In glasshouse trials, test plants, including radish, showed an increasing growth response.

These changes were profound under mature birch at all sites except at Silpho, in the North York Moors, where there was a negligible nutrient reserve in the soil minerals.

The sharp increases in nitrogen mineralization rate and in cellulose decomposition in the surface soil probably reflect changes in microbial populations with the change in litter fall from mainly heather to mainly birch and grass, with intrinsically higher decay rates because of higher nutrient contents. The particularly marked increases in pH and exchangeable calcium under 38 year old birch probably reflect in part a temporarily enhanced rate of calcium input from lower branches shed after canopy closure. The downward trend in exchangeable calcium and earthworm abundance under 90 year old birch suggests a cyclic trend, in the opposite direction to that apparently found under certain conifers. This pattern might be expected from the birch life cycle, where a stand develops a closed canopy and matures, with litter fall reaching a peak, and then opens up with tree senescence and death. Most Highland birch woods do not regenerate themselves directly (Plate 8). In the absence of incoming seeds of trees which would naturally succeed, the grassy ground vegetation tends to be replaced by invading heather, unless prevented by high grazing pressures.

The generalised sequence of vegetation changes occurring during the life cycle of a Highland birch wood, and the associated soil changes, are shown in Figure 3. It is clear that changes in the dominance of birch cause the other vegetation changes, while the vegetation changes cause the changes in soil.

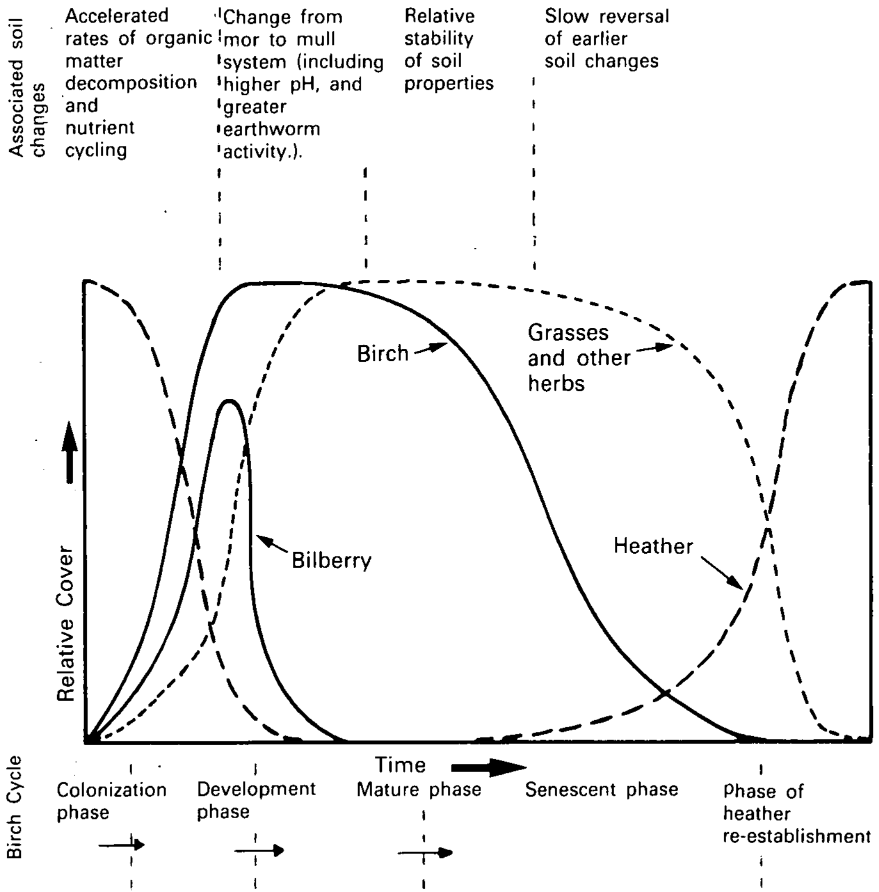

Figure 4. Generalized sequence of vegetation changes occurring during the life cycle of a Highland birch wood, together with associated trends in labile soil properties.

Studies to elucidate the processes involved in these soil changes are proceeding. Two questions in particular are being investigated. First, what is the origin of the increased exchangeable calcium in the topsoil, which through its effects on pH, and thus on the soil microflora and fauna, seems to 'drive' many of the other observed changes? While radiotracer studies are examining whether birch can absorb calcium from greater depths than heather, recent evidence suggests that birch accelerates the weathering of soil minerals compared with heather, especially in the topsoil (Plate 9). Second, there is a suggestion that the bleached Ea horizon of podzols is being gradually obliterated by incorporation of organic matter and ferric iron. If so, it seems that direct soil mixing must be largely responsible, with surface organic matter being mixed downwards and B horizon soil upwards. Many agents mix

Plate 9 One of the birch trees surrounded by the tubes used for injecting ^{32}P into soil in a study of root activity at different depths.

Plate 10 Scientists working at a moorland site with experimentally planted *Betula pubescens*.

soil, in particular earthworms, ants, the growth of roots and the tensioning of tree root systems when trees are rocked by strong winds. Which are most important here though, is as yet unknown.

A series of long term experiments is currently being established to verify the soil changes inferred from this survey. Birch is being planted on heather moorland sites on shallow podzols (Plate 10), and, because all the soil changes are thought to be reversible, heather dominant swards are being established after felling birch wood at sites with brown podzolic soils.

IMPLICATIONS OF THE WORK

Most moorlands developed during the last 200 to 2500 years following the destruction of the natural tree cover. Subsequent persistent burning and grazing by domestic live-stock inhibited woodland re-establishment and produced the present largely treeless landscape where the most extensive vegetation types usually contain few vascular species, and where heather often predominates over large areas. There have been two other important effects apart from loss of trees. First, although the prevalence of naturally acid soils would anyway have caused a relative proverty of plant species and herbivorous invertebrates, this has been greatly intensified by the effects of losing woodland cover and of the grazing and burning that followed. Second, there has been a trend towards podzol development in place of the acid brown soils and brown podzolic soils that predominated over most of the uplands under the natural woodlands. This has reduced the diversity of the soil fauna and flora, and has probably further contributed towards reducing above ground species diversity. Woodland loss, soil acidification under heather, and nutrient losses through burning probably contributed to podzolization. Britain's moorlands must therefore be regarded as degraded ecosystems. That they are now often regarded as desirable aesthetically or for recreation, or that parts may now be deemed to be of sufficient value to be designated for example as National Nature Reserves or Sites of Special Scientific Interest, does not change the fact that they are biologically improverished systems, with at least qualitatively if not quantitatively reduced productive capacities.

Clearly therefore, the changes taking place after birch has colonized heather moorland are a reversal of this historic process of ecosystem degradation, causing a more diverse flora and fauna above ground and in the soil, and increasing rates of nutrient cycling. The soil changes that have occurred within 30-60 years after birch colonization at most of the sites studied are broadly equivalent to the results of agricultural reclamation, but with no direct costs. Also, while the time span is long, areas too steep or rocky for conventional improvement can be changed under birch.

However, the rate and degree of soil 'regeneration' under birch seems broadly to vary with the size of the nutrient reserves in the soil, being fastest and most radical at sites with nutrient-rich soil minerals, and slowest and least profound at nutrient-poor sites. Indeed, at Silpho, in the North York Moors, where the soil is strongly podzolized and possesses very small nutrient reserves, soil changes under even 70 year old birch are minimal. Yet it is known from the evidence of soil profiles preserved under Bronze Age barrows that brown soils existed there under the former broad-leaved woodlands c.500 B.C. Is it possible that there is a threshold in the degeneration process beyond which irreversible change occurs (excluding the obvious irreversibility of most weathering of soil minerals) ? Or is it just that at very nutrient-poor sites like Silpho profound change may take centuries rather than decades ? We do not as yet know the answer, although the question of whether the basic resource, the soil, can be damaged irreversibly by particular land use practices, or at least damaged beyond remedy by the natural regenerative processes, is obviously important.

Earlier studies by the author indicated that the marked stability of heather moorland, shown by the tendency for it simply to regenerate itself after fire, was substantially due to soil infertility and a lack of seed of potential invaders. This study bears out those conclusions. As the soil changed under developing birch, species characteristic of woodland began to colonize. But while this addition of species was marked at sites like Advie where there was old woodland nearby with a woodland flora, at other sites more distant from seed sources far fewer species colonized over the same time spans. The rate of arrival of new species is not predictable however with current knowledge, even if the size and proximity of a seed source is known. Little information exists on effective dispersal ranges for most plant species or for most invertebrates for that matter.

Apart from the ecological implications, the results give a new force to questions that have often been posed about the long term consequences of growing conifer monocultures. It is known that spruce and pines acidify the soil, and can accelerate podzolization. Because podzols are normally associated with poorer volume growth of trees, even of species adapted to such conditions, than are brown soils, it might be expected that the lower acidity and faster rates of decomposition and nutrient release resulting from an admixture of birch, or other broadleaved trees having similar effects on the soil, would benefit the growth of conifers. However, the evidence from studies to date is equivocal or unconvincing, so it is still an open question whether these soil changes have any effects, positive or negative, on timber yields. Because there is doubt, and because of the increasing investment in, and importance of, monocultures of spruce and pine, the value of pure versus mixed stands clearly needs critical evaluation.

Part of any such study should be a comparison of forestry management techniques for maintaining soil fertility, especially ploughing and the increasing use of fertilizers, with natural processes. Under natural conditions, soils are usually subject to a succession of tree species, while indeed over much of the Scottish Highlands, Scots pine and birch may have tended to alternate. Should we therefore be considering rotations of species in our conifer plantations? Also, soils are naturally 'ploughed' through the effects of soil-living animals, of growing root systems, and when trees are shaken or uprooted by wind. These processes cause the downward movement and fragmentation of surface lying organic matter, and the upward movement of deeper lying, relatively unweathered, nutrient-rich mineral particles. The result is a gradual acceleration of the mobilization of nutrients, with the increased mobilization probably being more or less balanced by extra uptake by plants. In contrast to natural soil mixing, ploughing causes abrupt and gross disruption to the soil over large areas. It is likely to cause a surge in nutrient mobilization greatly exceeding the absorbtive capacity of the surviving vegetation, resulting in perhaps substantial losses of nutrients from the system. While ploughing is done for reasons other than the maintenance of soil fertility, its effects on nutrient cycling, and how these compare with natural processes, should be known. The need to spend increasing sums on fertilizers whose manufacture is energy-demanding surely justifies a thorough investigation of the subject.

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