

The Problems of Peatland Forestry

An Introduction

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I do not need to begin by persuading you that peatland forestry still has its problems. That so many of you have seen fit to attend this symposium is acknowledgment enough that there is a good deal about the growing and harvesting of trees on peat soils that we still have to learn. Forestry is a practical subject and its problems, in the first instance, are practical problems. They arise because of difficulties or failures in particular sets of circumstances and the form in which they are defined depends in part on the details of those circumstances and in part on the role and outlook of the persons recognizing them. For our present purpose we might consider separately the several practical problems which have arisen in the practice of peatland forestry but I am sure that satisfactory solutions to these problems will be arrived at all the sooner if we give priority at this stage to advancing our knowledge of the fundamental ecological relationships which lie at the roots not only of our failures but also of our successes. I propose therefore in this opening paper to consider the eco-systems with which we are dealing in the practice of peatland forestry in order to see if it is possible, on the basis of our present knowledge, to appreciate more fully the relationship between the practical problems already recognized and to anticipate some of the problems with which peatland forestry is likely to be faced in the future. In attempting the construction of a conceptual framework within which the practical problems might usefully be fitted I shall need to make some rather sweeping generalizations and to indulge in a certain amount of speculation. Since the more critical points which I shall make will be taken up and treated in greater detail in subsequent papers I shall not attempt here to indicate the source of all the information considered.

We have set ourselves during the next two days to deal specifically with peatland forestry so perhaps we should have at the outset some working definition of peatland itself. 'Peatland' is a term of convenience only with no generally accepted precise meaning. For survey purposes it has been found convenient to regard as peat soils those with a surface organic layer of more than twelve inches deep but I feel that we cannot expect the natural problems of peat soils to be bounded by such arbitrary limits. I would prefer to begin at any rate by defining peatland as land on which there is a superficial layer of organic matter within which the roots of the vegetation that it carries are entirely or almost entirely confined.

The problems which are encountered in attempts to grow tree crops on peat soils stem from the imperfections of the peatland environment

which for the sake of convenience we might consider under two headings; firstly, the imperfections of the peat itself as a substrate for tree growth; and secondly, the imperfections of the climatic component of the environment. Let us first consider the edaphic limitations, those of the peat itself. The peculiarities of bog peat as a rooting medium for trees will be dealt with in some detail in several of the subsequent papers; what I would like to do here is simply to attempt a broad comparison between bog-peat soils and mineral soils to see if some hint emerges as to the main defect or defects of bog peats as forest soils. Perhaps the most striking point of contrast lies in the high organic matter content of the peats. This however would not appear to confer any serious disadvantage in itself if we may judge from the generally high fertility of drained fen peats. The quantitative comparison of peat soils and mineral soils is complicated by this great difference in organic matter content. The active constituents of mineral soils are diluted by large amounts of relatively inert mineral material and those of peat soils by large amounts of carbon-rich organic matter and water. In the face of these major differences comparisons of absolute amounts of the active constituents, e.g. available plant nutrients, are likely to be of less value than comparisons of ratios between them. Of the many ratios which might give a clue to the imperfections of acid peat soils perhaps the one most worthy of consideration is the carbon/nitrogen ratio of its organic matter. The C/N ratio for the organic matter of base-rich mineral soils in moist temperate regions is usually about 10. The humus of acid mineral soils such as podsoles often has a value of about 20 but on sites showing unsatisfactory tree growth the ratio may be 30 and more. The ratio for bog peats varies a good deal from one peat type to another but it is usually more than 30 and values well above 40 have been reported. Under conditions of high C/N ratio, N and P are present mainly as complex organic compounds and are not readily available to the planted trees. The N and the P of the peat become available only through the activity of micro-organisms which bring about the decomposition of the organic matter and liberate these nutrient elements in much simpler molecular or ionic forms. Despite the physiological limitations which have been demonstrated for a number of known mycorrhizal fungi some of them at least may play a part in this process as well as the free-living micro-organisms. High values for the C/N ratio are associated with low concentrations of total N and total P. The primary reason for these low concentrations in peat is the low rate of organic matter decomposition. A higher rate of decomposition would increase the N and P percentage by bringing about a disproportionate loss of C as carbon dioxide. The low N percentage probably also results in part from the very low rate of nitrogen fixation. The total base content and the amounts of the individual bases present vary a good deal from one type of peat to another, particularly according to the extent to which the peat, during its growth, was influenced by mineral-rich drainage water. The ratios between the amounts of the individual bases present also vary a good

deal, but comparisons between base-rich soils and bog peats show that for bog peats the following ratios are considerably higher :

monovalent bases, $\frac{\text{Mg}}{\text{Ca}}$, and $\frac{\text{Na}}{\text{K}}$.

divalent bases $\frac{\text{Ca}}{\text{K}}$ If we include in our comparisons the corresponding ratios for leached, acid, mineral soils we find that these like the C/N ratios, are generally intermediate, resembling those for the bog peats but rather less extreme. From these considerations we might expect acid bog peats to present similar problems for tree growth as do poor mineral soils but in a more acute form. In as much as peat soils are characterized by the marked accumulation of organic matter we might suspect the most acute problems to arise in connection with the availability of N and P.

We know that our planted trees will make considerable demands on the site for the several macro-nutrient elements N, P, K, Ca, and Mg. Although the initial requirements for Ca are low the long-term demands for this element are considerable because Ca to a greater extent than the others is immobilized in the wood. This tendency becomes particularly important where forest produce is removed from the site. The trees also require S, Fe, Mn, Zn, Cu, B, Mo and perhaps other elements in small quantities. How are these demands to be met? The peatlands most likely to present problems of nutrient supply would appear to be those least influenced by mineral-rich drainage water. It is these which have the very high C/N ratios, the lowest base contents, and the most extreme base ratios; so I think that an understanding of the nutrient economy of these sites both in their undrained state and when ploughed and planted with coniferous trees would be particularly valuable.

It now seems clear that the nutrient supply of the living vegetation of an ombrogenous bog is drawn from two different sources. One source is the atmosphere from which measurable amounts of nutrients arrive dissolved in the precipitation, as both organic and inorganic dust, and possibly also as gaseous ammonia. The other source is the peat and less thoroughly decomposed plant residues within the root range of the bog plants. Over a particular period the nutrients incorporated within the living plants will be in part nutrients freshly arrived from the atmosphere and in part nutrients which have already been incorporated within the living plants on the bog in a previous season or seasons. Not very much is yet known about the nutrient relationships of the individual bog species but it is clear that most of them can absorb nutrients from substrata in which they are present at high dilutions and concentrate them within their various organs. In our seasonal climate most bog species show a marked alternation between periods of growth and periods in which there is a reduction in the amount of living material above the surface. Some of the nutrients absorbed in a particular growing season are shed with the leaves and other parts lost in the following winter and are available for re-absorption by the roots of the same or of different plants during the next season. Some are retained within the perennating parts of the plants and re-cycled within

the same plant during the next growing season. The combined effect of the reception of atmospheric nutrients at the bog surface, the recycling of nutrients between the plants and the peat surface, and the re-cycling of nutrients within the bog plants themselves is to concentrate the nutrients at the peat surface; in the living plants, in the litter, and in the surface peat. Profile analysis have repeatedly confirmed this generalization and shown that it applies particularly to K and P. Nutrients are lost from the system in two main ways. Some nutrient material is lost to the site altogether by being leached from the plants or from the peat and removed in drainage water. Still more is lost, to the living vegetation of the bog surface, by being built into the peat layer which because of further peat accumulation is passing out of root range.

What happens when the equilibrium of this system is disturbed by ploughing and tree planting? The draining and provision of an inverted peat ribbon enriched with a little mineral phosphate and a double layer of freshly dead vegetation give the planted trees an opportunity while they are still small and have poorly-developed root systems of competing on something like equal terms with the established bog species. After a few years of active growth the young trees, by shading and perhaps also by root competition, reduce the vigour of the bog plants around them and then kill them out. As the bog plants die and pass on to become 'organic matter' further supplies of nutrients become available to the trees, especially K and P. Peat accumulation ceases and the combined effects of drainage, transpiration of the stand, and tree root growth stimulate microbial activity and increase the rate of peat decomposition with further liberation of nutrients, particularly N and P. Practical experience is as yet too short for us to know and the relevant quantitative data is as yet too scanty for us to forecast with much confidence the long-term prospects of such a stand, but an optimistic account of their future might run as follows.

The continuing demands for nutrients made by the developing stand are met by further peat decomposition supplemented by the excess of the supply of atmospheric nutrients over the leaching losses. Additional N may become available through the fixation of atmospheric N. As the trees get older increasing quantities of nutrients are returned annually in needle and branch fall, branch rootlet renewal, and by crown leaching, to the peat surface where they are available for re-cycling. N, P, K and Ca are all involved in this process. Re-cycling of nutrients also takes place within the trees and with the gradual rise in proportion of wood to foliage, and with the initiation of heartwood formation, the importance of this internal re-cycling increases. In this process N, P, and K are again involved but the Ca which increases in concentration in the ageing timber is locked away until the tree itself in due course falls to decay on the forest floor. In this way, probably at about the stage of full crown development the overall annual nutrient requirement of the stand falls to a low level, low enough to be met by the annual supply of atmospheric nutrients together with any N fixation.

It would appear possible then that such a stand might be established on poor peatland and that it should maintain itself much as the native bog vegetation maintains itself by the concentration of the site nutrients at the surface and the continuous re-cycling of nutrients both within the plants themselves and between the plants and the peat surface. This is the most optimistic view and it requires some qualification before we leave it. Whether such a system as this could be established and maintained for a full rotation in the humid climate to which most of our peatland is subjected is very doubtful but if it could then it seems clear that it would be necessary to plant the most oligotrophic tree species available to us, namely lodgepole pine, a species which persists on undrained muskegs in Western North America. The quantitative data which we have already indicates that in such a system as we have envisaged tree growth rate would probably be severely limited by the supply of one or more nutrient elements, so it is possible that even though the trees might remain alive and continue to grow their growth rate would be very low. Our concept of the peatland forest self-maintaining in respect of nutrients takes no account of the removal of produce. Any nutrients removed in produce would have to be made good through the decomposition of more peat or through the addition of the appropriate minerals from outside. It is true that the deeper peats represent a considerable capital of plant nutrients but this capital is not easily realized. The N and P are only released on the decomposition of the peat itself. The basic nutrients are generally at very low concentrations as so for supplies to be maintained a very large volume of peat must be progressively exploited. It should be remembered here that these nutrients are not evenly distributed in depth. We have noted already how K and P in particular are markedly concentrated near the surface. Thus, continued exploitation of the peat in depth will not yield proportionate returns.

Peatland forests consist of more than peat and trees. There are clearly two other components of the ecosystem which are of major importance. One is the living vegetation of the bog surface which while alive provides both shelter and competition for the planted trees and when dead constitutes an important source of nutrients. The other is the microbial population of the peat itself through the agency of which all decomposition and nutrient release take place. Later contributions will illustrate the role of these in some detail; for the moment I should like simply to mention two particular kinds of interaction.

On many sites Sitka spruce passes into a state of 'check' a few years after planting. This condition has been attributed to N starvation, the result of unsuccessful competition with *Calluna*. It is true that *Calluna* where present in the original bog vegetation rapidly exploits the new rooting zone produced by ploughing, but whatever the role of *Calluna* here the trees are certainly N deficient. Although we know this, the problem of early 'check' of Sitka spruce is still with us. Top-dressing

with nitrogenous materials alone has been disappointing, responses have been slight and short-lived. Our young peatland forest does not react as a simple two-phase system. It has been standard practice in some parts to apply repeated dressings of phosphate to checked spruce and this treatment has clearly not been without some effect. Recent work both here and in Scotland has shown that heavy dressings of phosphate to checked spruce not only produce a marked growth response but also an increase in the N content of the foliage. In short, nitrogenous materials alone do not effectively correct the trees' deficiency of N but heavy dressings of P do, giving the same response as combined dressings of N and P. Phosphatic materials then in some way increase the trees' uptake of N from the peat. We do not yet know whether the phosphate acts by stimulating the trees in some way or by promoting the activity of the peat micro-organisms, in either N fixation or peat decomposition. Culture work with spruce seedlings* recently carried out in Sweden has produced no evidence for an internal relationship between P and N levels which would explain the behaviour of the trees growing on peat. A worker in Germany has more recently found that the addition of phosphate to raw humus samples from poor pine and spruce stands results in an increase in microbial activity as indicated by increased carbon dioxide evolution. These observations give at least a little support to the suggestion put forward some years ago by Mr. McEvoy, and now generally subscribed to, that the P acts by promoting peat decomposition and N release. If this suggestion is correct we probably have peat soils in which the P level although not limiting the growth of the planted trees directly is doing so by limiting the activity of the soil micro-flora and thus keeping the trees' N supply at a deficiency level.

The disappointing results from top-dressing with nitrogenous materials and the prohibitive cost of heavy applications of either mineral phosphates or organic manures containing both N and P, has directed attention to the possibility of using the much cheaper ground limestone to accelerate peat decomposition with the more rapid release of N and perhaps also of P in available forms. At first sight this might appear to be just a simple extension of the practice, currently employed in Europe, of using lime to 'activate' the raw humus of acid mineral soils. Two liming experiments here in Northern Ireland have served to remind us that the results of liming on peat are far from simple. In one experiment Sitka spruce trees were limed (at $2\frac{1}{2}$ tons of ground limestone per acre) at the time of planting in the Spring of 1957, the liming being in addition to a number of different N and P treatments. After three growing seasons a colour difference was apparent; the trees on the limed ground were a healthier green than those on the unlimed ground. This suggested a higher N level in their foliage and in turn more rapid mineralisation of the peat N. At the end of the fourth season measurements of current leader lengths revealed highly

* Norway spruce.

significant positive responses to liming, but only on the plots which had received no phosphate, i.e. 'Control' and 'Nitrogen only'. Lime had markedly reduced the 1960 growth when combined with several of the phosphate dressings. There is evidence here of increased N release but the response took several years to appear and was accompanied by an undesirable side effect.

Another trial involved a plantation which was growing on peat only about one foot deep and which at 18 years old had been brashed but not thinned. Ground limestone (at 2 tons per acre) was applied broadcast in the Spring of 1958. Diameter growth was followed by means of vernier bands and no growth response to liming has been detected even after four growing seasons. Needle samples were taken from branches of the topmost whorl in December 1960, three seasons after treatment. Analyses showed that the effect of liming had been to increase the Ca content of the foliage and to reduce the levels of the other cations, i.e. K, Mg, Na, and Mn. The mean N level in the foliage of the limed trees was also slightly lower but the difference was not significant at the 5% level. It is clear however that the lime did have some effect on the activity of the microbial population of the peat. In Spring the peat surface of the limed area becomes soft and appears highly humified but in Autumn it becomes densely felted with abundant basidiomycete mycelium. It is very conspicuous also that within the limed area the *Lactarius* sp. which is the apparent mycorrhizal associate of the spruce in the plantation very rarely forms sporophores. Several workers in the last few years have confirmed by the experimental incubation of peats and raw humus materials with lime that lime does stimulate microbial activity and bring about a narrowing of the C/N ratio but these changes are not always accompanied by an increase in the mineralisation of N. There may be losses of ammonia gas, or of gaseous N resulting from denitrification, but one thing seems clear, that the addition of lime to organic materials of high C/N ratio is likely to be followed by a protracted period during which the N remains unavailable to the rooted plants because it has been incorporated within the protoplasm of the expanded microbial population.

We have so far been concerned mainly with the ability of poor peat soils to provide the nutrients necessary for continued tree growth and have seen that a great deal depends on the establishment and maintenance of conditions which favour the decomposition of organic matter. Another approach to the problem of nutrient supply is at least theoretically possible. The absolute amounts of nutrients required by forest crops are relatively small and it might be considered worthwhile to supply these in fertilizer applications, regarding the peat, more or less, as an inert rooting medium. Unfortunately although generally poor in available plant nutrients the peat soil and the native vegetation which it carries, as some of our examples have shown, are far from inert and one cannot ensure that the addition of an element in available form to the peat-forest system will result in the passage of that element into the growing trees when and where it is required.

We have seen how the most important chemical inadequacy of bog peat lies in its poverty of available plant nutrients and you will be aware that in looking for tree species for planting on poor peatland sites consideration is given to the tolerance of different species for low nutrient levels. Perhaps the most important physical defects of peats are related to their very high water content. We might expect therefore to see trees planted which are tolerant of water-logged soils. In practice we don't, another approach is adopted, that of lowering the water content of the peat by drainage operations and thereby increasing its oxygen content. Peats vary a great deal in their response to these operations. It seems that at one extreme we have the coarsely fibrous, very slightly humified *Sphagnum* peats, from which a good deal of water actually runs when drainage channels are first cut. At the other extreme we have the several kinds of more highly humified peat which are highly colloidal and jelly-like in nature. In these drainage operations would seem to act mainly by facilitating the shedding of subsequent precipitation, the actual lowering of the water content of the peat being due directly to surface evaporation and transpiration of the rooted vegetation. The physical condition of the peat is of direct importance to growing trees in two ways. The degree to which drainage operations succeed in converting the peat into a porous aerated mass determines the extent of root penetration, and this in turn determines both the volume of peat which the tree roots can exploit for nutrients and it also determines, to a considerable extent, the stability of the growing trees. Perhaps these points are best illustrated by means of two examples.

During the last few years in Northern Ireland we have had the opportunity of studying the results of draining and planting a number of very wet ombrogenous bogs. These sites have included areas which before draining carried a mosaic of moss hummocks and pools of open water or were wet flats with *Trichophorum*, *Narthecium*, and *Eriophorum vaginatum* rooted in an almost continuous *Sphagnum* carpet. The earliest plantings on such sites were of lodgepole pine alone but in areas more recently drained Sitka spruce has also been tried. Great changes have taken place; the peat has drained readily and growth even of the spruce has been remarkably good. The root systems of the trees are exceptionally well developed and there are obvious signs of nutrient release. The *E. vaginatum* and *Narthecium* have responded with a great increase in vigour and the *Narthecium* has flowered profusely; here and there thriving plants of *Holcus lanatus* (Yorkshire Fog) and of *Chamaenerion angustifolium* (Fireweed) have appeared. What will be the fate of these plantations? At the moment they are flourishing and perhaps with some attention to the main drains as the surface peat consolidates they will continue to thrive. There are several reasons however why we should not take this outcome for granted. Incubation work with *Sphagnum* peats has demonstrated an early flush of N mineralization out of proportion to their low N percentage. Evidently it is to this and to the physical conditions which

allow them to exploit rapidly an unusually large volume of peat that the planted trees are responding. It is difficult to see how these relatively favourable conditions can be maintained. Precocious root growth must surely advance the onset of inter-tree competition and early N release leave the substrate in the long run all the more N deficient.

At the other end of the peatland spectrum we have the more highly humified flush peats, often rather shallow, and usually considerably enriched with bases and with P by the passage of water which has had access to the sub-soil or rock below. These sites too show a marked response to draining; the vegetation exhibits a great flush of growth which is no doubt associated with a release of nutrients. If the trees escape being swamped by rank grass in their first few years they grow well and continue to do so for several decades. Although the short-term effects of drainage and tree planting on the physical properties of peat are rather variable the long-term effect seems always to be much the same. The rapid growth of the trees is associated with continued decomposition of the peat and the formation of an amorphous black residue. After about twenty-five years or so the main tree roots lie exposed on the peat surface and the maximum rooting depth is reduced to a few inches. The amorphous peat residue erodes very easily, on flat sites it tends to accumulate in the drains and cause general water-logging and on slopes to be washed away altogether. The trees naturally become very susceptible to windthrow, and it is not surprising that the gales of the last few years have taken a heavy toll of such plantations. In plantations which do remain standing it is often possible to detect a marked falling off in height growth rate. The deterioration in the physical condition of their rooting medium may be thought enough to account for this but we now know for one such site that in addition the levels of N, P, and K in the peat residue are very low indeed. It would seem then that except for a period of a few years we cannot have the best of both worlds; we can either have a rooting medium which is physically favourable but which cannot continue to provide an adequate nutrient supply or we can have a medium in which continuous decomposition provides the nutrients but at the same time destroys the peat itself as a suitable rooting medium.

The climatic limitations of the peatland environment are naturally less specific than the edaphic ones; after all, peat soils and mineral soils occur side by side in the same climate. Peatland forests however are particularly susceptible to adverse climatic conditions because of their peculiar soils. The blanket peat areas, whether they are on the hills or along our western sea-board are subject to frequent gale-force winds. One could scarcely argue 'a priori' that peatland forests must be more susceptible to wind damage than those established on mineral soils in the same climate. In fact the reverse has been argued for Western North America. But it does seem that the methods of site preparation, establishment, and thinning used to date have not been particularly

successful in establishing wind-firm plantations. Present practice is directed mainly towards the creation of a crop in which the trees are individually wind-firm. Perhaps some fresh thinking is required here. It may be better to accept very shallow rooting as inevitable and plan for collective stability of the crop based on the strength and resilience of the intact tree root mat. We might be wiser to plan for a short rotation, to plant at wide spacing, not to thin, and to put up with rough produce.

We have seen that for the afforestation of peatland to succeed conditions which favour decomposition of the peat must be established and maintained. In this connection it is as well to remember that the very existence of peat on a site indicates that in the past over a very long period of time the rate of organic matter production exceeded that of its decomposition. Afforestation then must succeed in reversing this tendency. In dry climates peat formation is closely related to drainage impedance but in the 'blanket-bog climate' of our hills and Western seaboard it is largely independent of it. We can expect therefore that under these wetter conditions drainage operations alone might fail to halt peat formation and that greater efforts might be required to tip the scales in favour of decomposition. There is a good deal of evidence that this is indeed so. We have considered how a slow-growing plantation of an oligotrophic free species might be established on poor peatland and maintain itself on the supply of atmospheric nutrients. The indications are however that this would not be possible in the extremely humid climate of our blanket bogs. In many of our peatland plantations, planted without ploughing between 20 and 30 years ago there are many patches ranging from a few hundred square yards to several acres in extent on which the growth of the trees has been greatly retarded. The most extreme condition is represented by trees a few feet high growing only an inch or so a year. These trees typically stand among tall *Calluna* which being ungrazed and unburned for several decades is 'leggy' and forms an incomplete canopy. In the partial shade cast by the *Calluna* and the stunted trees there are accumulating large hummocks of several *Sphagnum* species. Quite clearly hand draining and turf planting have failed here to tip the scales in favour of organic matter decomposition. Surrounding each of these acutely retarded patches there is usually a zone in which the trees have become established and have grown well enough to have been brashed and even thinned. Here there has been a period of complete elimination of the bog vegetation followed by some peat decomposition, but with increasing light intensity resulting from the forestry operations, or as on many sites simply by precocious needle fall, fresh vegetation is developing on the forest floor. Unlike the cover of grasses, ferns, and brambles which develops under vigorous stands planted on base-rich flush peats and moist mineral soils the new vegetation of this marginal zone consists of rapidly growing mounds of *Sphagnum* often set in a thick spongy carpet formed by several pleurocarpous mosses. Apart from any active role which the *Sphagnum* may have in suffocating the tree

roots or interrupting the vital nutrient cycle of the stand its presence is certainly symptomatic of a return to conditions of organic matter accumulation.

We have seen how the acid peat of our bogs is poor raw material for a forest soil and we have seen how the windiness and wetness of our climate only serve to make more difficult the satisfactory establishment and maintenance of forest growth on our peatlands. Most of us however would probably agree that the barren peatlands present to us a challenge which must be answered. On exactly how it should be answered in terms of both practical forestry and of research there is still room for much difference of opinion, and I expect we shall be made well aware of this before the close of this symposium.
