RECONCILING CONSERVATION AND AMENITY WITH PRODUCTION FORESTRY

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CONTENTS

	Page
SUMMARY	(i)
RESEARCH RECOMMENDATIONS	(iv)
Main priorities	
1. Mixtures	(iv)
2. Invertebrates	(iv)
3. Deer	(v)
Other priority projects	(v)
Ground vegetation	(v)
Invertebrates	(v)
Birds	(vi)
Mammals	(vi)
Microclimate	(vii)
Sylvicultural systems	(vii)
Recreation and amenity aspects	(vii)
1. INTRODUCTION	1
2. PAST AND PRESENT RESEARCH REVIEWED	5
2.1. Soils and water	5
2.1.1. Soil types and forestry possibilities	6
2.1.2. Effects of trees on soils and water	6
2.1.2.a. Effects of trees on soils	7
2.1.2.b. Effects of trees on soil water	13
Interrelationships	15
2.2. Ground vegetation	15
2.2.1. Vegetation changes in planted blocks	16

2.2.1.a. Establishment to canopy closure.................. 16
2.2.1.b. Canopy closure to clearfelling.................. 17
2.2.1.c. Clearfelling and replanting.................. 17

2.2.2. Vegetation changes in unplanted areas.............................. 19

2.2.3. The effects of sylvicultural management on vegetation............. 20

2.3. Epiphytic flora......................... 21

2.4. Forest invertebrates..................... 22

2.4.1. Effects of afforestation on invertebrates..................... 22

2.4.1.a. The moorland invertebrate fauna............ 22
2.4.1.b. The invertebrate fauna of particular tree species.... 24
2.4.1.c. The invertebrate fauna of mixtures................. 24
2.4.1.d. Dynamic forest structure and invertebrates... 26

2.4.2. Control of harmful insects in forests.............................. 29

2.5. Birds in plantation forests............. 31

2.5.1. Effects of tree species on bird diversity and numbers............ 32
2.5.2. Effects of forest area on bird diversity and numbers............ 33
2.5.3. Effects of dynamic forest structure on bird diversity and numbers.............................. 33

2.5.3.a. Fencing to canopy closure...................... 33
2.5.3.b. Canopy closure to clearfelling................. 34
2.5.3.c. Clearfelling and replanting.................. 35

2.6. Mammals in plantation forests........... 36

2.6.1. Effects of tree species on mammal diversity and numbers.......... 37
2.6.2. Effects of dynamic forest structure on mammal diversity and numbers.............................. 38

2.6.2.a. Fencing to canopy closure........................ 38
2.6.2.b. Canopy closure to clearfelling................... 39
2.6.2.c. Clearfelling and replanting...................... 39

2.6.3. Mammals as forest pests and their control........................ 40

2.7. Dynamic forest structure and forest microclimate................................. 42

2.7.1. Fundamental processes which determine microclimate............... 43

2.7.1.a. Heat balance......... 43
2.7.1.b. Water balance........ 44

2.7.2. Plantation development and forest microclimate.................. 44

2.7.2.a. Windspeed........... 44
2.7.2.b. Air temperature...... 45
2.7.2.c. Radiation........... 46
2.7.2.d. Water balance........ 46

2.8. Tree species and sylvicultural systems.................................... 48

2.8.1. Tree species choice and mixtures............................. 48
2.8.2. Sylvicultural systems.......... 50

2.8.2.a. Even-aged sylvicultural systems......... 50

Oceanic forestry...... 51
No-thinning regimes... 51
Re-spacing systems.... 52
Chemical thinning..... 52
Self-thinning......... 52

2.8.2.b. Uneven-aged sylvicultural systems......... 53

Group selection....... 53
Individual tree selection............ 54

2.8.2.c. Coppice............. 54

2.8.2.d. Agroforestry......... 55

2.9. Recreation and amenity.................. 56

2.9.1. Forests and the broader landscape.......................... 56
2.9.2. Recreation and amenity within the forest......................... 58

3. ACKNOWLEDGMENTS................................. 60

4. BIBLIOGRAPHY.................................... 61

5. APPENDIX...................................... 85

Ranking of relevent ITE projects in their previous core groups on the basis of their present or potential importance in an overall programme of work on conservation and amenity aspects of production forestry: 1 - HIGH PRIORITY, 2 - INTERMEDIATE PRIORITY, 3 - LOW PRIORITY......................... 85

LIST OF FIGURES

1. The interrelationships between forest structure and wood yield, wildlife conservation value, recreation and amenity value of clearfell plantation forests

2. Flow diagram of deer in conifer plantations

SUMMARY

Progressive clearance of the original natural forest cover of Britain over many centuries led to our sharing with Holland and Ireland the distinction of being least forested among European countries. With our loss of large-scale forest cover went the tradition we as a people had for everyday multiple-use forestry, in which sport and recreation as well as the gathering of food, fuel and timber played a part. In this we differ very markedly from our continental cousins. They retain, through the committment and involvement of their peoples, a real concern for the forest as a valuable multi-use resource. No clearer indication of that concern could be required than the present widespread and politically significant alarm and outrage throughout continental western Europe over mass tree deaths ascribed to "acid rain".

Our productive plantation forests, which are mostly less than fifty years old, were established hurriedly in response to wartime alarm over national dependency on imported wood and wood products (still >90% imported). Initially, high-yield timber production, using the species known to thrive on the poor quality sites available for afforestation, and the simplest possible sylvicultural system, was the aim. Hence the dominance of even-aged, clearfell Sitka spruce plantations.

In the early days of the Forestry Commission, other functions of the forest including conservation and amenity were considered, if at all, as being very much of secondary importance to timber production. With the increasing population of people, blessed with mobility and more leisure time, seeking places to visit and things to do, and with increasing concern over nationwide loss of wildlife habitat and the need for careful conservation of that which remains, things have changed. The 1986 amendment to the Wildlife and Countryside Act makes it encumbent on the Forestry Commission, "to achieve a reasonable balance between (a) the development of afforestation, the management of forests and the production and supply of timber, and (b) the conservation and enhancement of natural beauty and the conservation of flora, fauna and geological or physiographical features of special interest": a significant change from their former responsibility under the Countryside Acts of 1967 and 1968 "to have regard to the desirability of conserving the natural beauty and amenity of the countryside". The new broadleaves policy, with its generous supplementary grants, indicates more directly the determination of government to drag commercial forestry out of the age of untrammelled timber production into a more multi-use orientated future.

Changes in practices and attitudes are essential if conservation and amenity are to be appreciably better served by forestry in the future than they have been in the past. Even-aged, single species clearfell plantations of the type that currently dominate British production forestry have been shown by research in many countries to be the worst silvicultural systems for wildlife conservation and amenity. Little improvement can probably be achieved in the planted blocks of such forests as they stand but it is essential that we gain as full an understanding as possible of their ecology so that the most can be made of the increasing willingness among foresters to consider opportunities for habitat and amenity improvement, particularly in the second rotation of existing forests. It is in the unplanted areas, however, that most can be done and in many cases the requirements of wildlife conservation and amenity happily coincide, so that prescriptions can be devised which will satisfy both. This is not always the case, however, some animals, for example, require peace and seclusion and will therefore need areas remote from regular human visitation. In many instances we do not know what constitutes optimum habitat in unplanted areas, if indeed such a concept is useful. More research is needed to determine the full potential of unplanted forest areas for nature conservation and amenity.

So far we have a reasonably good knowledge about the occurrence of some groups (flowering plants, birds), including changes in species diversity and abundance associated with dynamic forest structure. We also have a relatively good understanding of the effects of trees on soils and soil water, although much remains to be done. In other subject areas (cryptogamic plants, invertebrates, reptiles and amphibians, mammals with the exclusion of a few well-researched species) we know very little. The lack of information about invertebrates is of particular concern, because some of them are actual or potential pests while many are main food items for birds and carnivorous mammals and thus have a key effect in influencing their numbers. Studies of the effects of dynamic forest structure on insect diversity and abundance, of the type done for birds, should be initiated. Factors leading to insects becoming pests and the possible role of tree mixtures in limiting pest outbreaks also demand urgent attention.

One recurring theme throughout this review is the value of tree species mixtures, especially those containing a broadleaved element, for both wildlife conservation and amenity. There is also an accumulating body of evidence to suggest that mixtures are beneficial to crop tree growth on certain soils, provided of course that appropriate species are combined. This fact is causing foresters to rethink the case for mixtures, self-thinning systems being advocated quite widely. However, virtually all the information we have on the ecology of mixtures as compared with single species stands comes from overseas research. It is essential, therefore, that a major programme of work be initiated in Britain on the ecology of mixtures, including their effects on soil development and water quality and the population dynamics of key selected groups of plants and animals. It will be necessary to establish special replicated trials on a range of sites representing extremes of climate and soil types. They will need to be large to accommodate studies with birds and mammals and would hopefully be funded by, and available to, various organizations with an interest in mixtures research.

The role of deer in forestry, including their effects on other plants and animals as well as the crop trees, is a matter for much concern in those areas (much of Scotland and the north of England) where deer are a real or potential problem. A good deal of research has been and is being done but more is needed, especially on the effects of deer density on tree damage in different situations and on different soils. Work is also required on the feeding preferences of deer in plantations which will have a higher proportion of broadleaves than at present. Can palatable broadleaves such as willows be managed in clearings and along roads and rides so as to reduce damage to less palatable crop species? What will be the relative damage to birch and Sitka spruce in the proposed mixed plantings of these species?

Consideration of the conservation and amenity value of forests in social and economic terms is another area which has received inadequate consideration in Britain and which merits a major research initiative. We need to develop reliable methods for assessing peoples perceptions of the forests and determining their requirements and preferences in terms which can be related to forestry practice. The ecologists role in this is to identify the various habitats and species groupings comprising those features rated as desirable or undesirable and to determine how they may be encouraged or discouraged within the forest framework. Similarly, the ecologist can help the economist trying to put a revenue foregone estimation on the operations necessary to provide habitat for particular species or communities in production forests. It is time we grasped the nettle of costing conservation and amenity value in real money terms so that it can be properly offset against the positive gain provided. This would enable private foresters to get appropriate compensation for provisions made for wildlife conservation and amenity enhancement in their forests and would allow the Forestry Commission to show the extent of their provision for these activities, which are fully accepted by government as being appropriate to their function. Experience from similar research in continental Europe, North America and Australasia suggests that joint approaches involving social scientists and economists as well as foresters, ecologists and conservationists are essential if real progress is to be made in understanding and tackling these problems.

RESEARCH RECOMMENDATIONS

The three main priorities recommended for future research are as follows:

1. Mixtures

There should be a major new programme of work on the ecology of mixtures, including their effects on ground vegetation, shrub layer, soil development and water quality, numbers and species diversity of chosen groups of invertebrates birds and mammals. The trials will need to be large to accommodate studies with birds and mammals and will need to be replicated on a range of sites representing extremes of climate and soil types. Exact locations should be chosen to fit in as much as possible with centres of research expertise, bearing in mind that the trials will be available for use by anyone interested in mixtures research.

An advantage in starting from scratch with species trials would be the opportunity of approaching them with an open mind, prepared to consider unlikely as well as predictable combinations. Also there would be the considerable gain that the sites could be studied before planting and taken through the entire rotation and perhaps beyond. Proposing such long-term committments may be unfashionable at the present time but I can see no effective alternative means of investigating this subject which is of key importance to the long term as well as the immediate future of British plantation forestry.

2. Invertebrates

Our knowledge of invertebrates in plantations, both in their own right and as food for many birds and other higher animals, is abysmal. Studies of the effects of dynamic forest structure on insect diversity and abundance, of the type done for birds, should be initiated. Factors leading to insects becoming pests and the possible role of tree species mixtures in limiting pest outbreaks also demand urgent attention. Insects as essential food items in the diets of other animals, especially birds, should also be studied. This would probably be best approached by studying the feeding habits of a range of insectivorous birds.

3. Deer

More work is needed on the effects of deer in plantations, particularly effects of deer density on tree damage in different situations and on different soils. Work is also needed on the feeding preferences of deer in plantations which will have a higher proportion of broadleaves than at present. Can palatable broadleaves such as willows be managed in clearings and along rides so as to reduce damage to less palatable crop species? What will be the relative damage to birch and Sitka spruce in the proposed mixed plantings of these species?

Other priority projects

Soils and water

(a) Confusion remains over the extent and rate of soil acidification and podzolization effects with conifers. In particular, the mitigating effect of soil type, particularly with relation to drainage, needs investigation.

Ground vegetation

(a) Present studies of the pest status of rhododendron (ITE Project 794, Rhododendron in Snowdonia) should be extended to include an assessment of the potential for using conifers in its control, exclusion and eradication.

(b) Projects should be initiated in different forest types into management of rides and clearings to maximize floral diversity. They should include such novel approaches (for Britain) as the use of selective herbicides to control dominant species, e.g. bramble. The relevance of such projects to improvement of habitat for invertebrates is apparent.

(c) A project should be initiated to study population dynamics of particular clearfell pioneer plant species on the large scale. How do different species respond to the large and sudden availability of bare ground and how do their responses affect the patterns of colonization?

Invertebrates

(a) Chemical thinning is receiving a good deal of attention as a possible alternative to no-thinning in plantations susceptible to windthrow. Foresters are concerned that the resulting dead trees would provide unacceptable dispersed habitat for various actual and potential pest species. ITE should initiate a project to investigate the effects of chemical thinning on population dynamics of selected invertebrate species, linked to studies of its effects on bird diversity and abundance.

(b) Whittaker's group at Lancaster have shown that seemingly uniform moorland habitat actually consists of a range of different ones with different insect populations. Furthermore, the distribution of these insect populations directly influences distribution of higher animals (reptiles, amphibians, birds) feeding on them. How does afforestation and dynamic forest structure affect these communities? A project is required to investigate this important subject.

(c) Biting insects, especially midges, have a considerable effect on the recreational value of forests. A project is needed investigating the macro- and micro-climatic factors influencing their distribution and abundance in forests, with special reference to the effects of forest structure.

(e) Conflicting evidence emanates from Europe on the effects of forest fertilization on insect numbers, suggesting that different species fare differently depending on feeding habit. This is worth investigating under British conditions, perhaps involving nursery experiments as well as work in the forest.

(e) The effects of pesticides used in the forest on non-target species and through them on higher animals should be investigated.

Birds

(a) A study is needed of the relationship between area and isolation of plantations and their bird fauna.

(b) There is concern among farmers and landowners over the raised carrying capacity of forests for corvids and wood pigeons. More precise information is needed on numbers and feeding habits.

Mammals

(b) The effects of clearfelling on numbers of small mammals and their predators should be investigated. How does the method of brash handling affect numbers and accesibility to predators?

(c) There is considerable concern among farmers and landowners over increased numbers of foxes in plantations. In Wales this is the single biggest complaint against forestry. Further study of the influence of forest structure on fox numbers, breeding habits and feeding habits in plantations is required.

(d) Studies are needed of the occurrence and behaviour of Red deer/Sika deer hybrids.

Microclimate

(a) How does forest ride and clearance affect microclimate and hence distribution of plants and animals?

(b) Studies are needed relating stand age, tree density, canopy height and foliage density with precipitation interception.

Sylvicultural systems

(a) There is a need for comprehensive ecological studies as part of the current investigations of agroforestry systems. The ecological consequences of changing from agricultural land usage to sylvi-pastoral or sylvi-arable systems should be investigated.

(b) A study should be made of the ecological consequences of self-thinning systems, especially those involving Sitka spruce/birch mixtures.

Recreation and amenity aspects

(a) A study is needed, as outlined earlier in this Summary, investigating user perceptions and requirements in plantation forests in ecological terms. This would be done jointly with a social scientist and would be very likely to attract outside (possibly ESRC) funding.

(b) A programme is needed to quantify in real money terms the costs of providing recreational facilities (including landscape) in forests. The possibility of allowing private forest enterprises to offset provision of wildlife and recreational facilities against forest income for tax purposes should be investigated. The possibility of increasing forest revenues through sale of hunting, shooting and fishing licences in appropriate areas should be studied. The possibility of charging for forest use should also be investigated on the principle that 'user pays'. Computerised systems for calculating revenue foregone would be used to determine the effects of various options. This project would be undertaken jointly with forest economists.

1. INTRODUCTION

The aim of this review is to assess the contribution of past and present research in Britain and abroad to our understanding of possible ways of reconciling conservation and amenity with production forestry in Britain: to highlight research areas requiring further investigation: and to recommend appropriate research topics.

The review concentrates on the effects of forest structure, as influenced by site history, current management procedures, and time, on soils and soil water, fauna, flora, landscape and general recreational values of the forest. While considering lowland broadleaved forests to some extent, attention is focussed on upland forestry which in Britain has been, and is likely to remain, the chief area for expansion. A conceptual model has been devised to aid appreciation of the web of interrelated factors influencing conservation and amenity values of commercial forests (see Figure 1).

The limited time available for reviewing this extensive subject has not, unfortunately, permitted comprehensive coverage of the literature but it is believed that the range of research currently underway is covered. The bibliography is intended only to provide an informative guide to the seminal papers in each of the several major fields of work relevant to the review.

A high proportion of the cited papers on most topics refer to work in Continental Europe, including the Eastern Block countries, or to the United States: an indication of the relatively advanced stage of research reached in those countries compared with Britain. This difference is due chiefly to the fact that many of these countries remain well forested and have a long tradition of multi-use forestry in which wildlife conservation and use for public sport and recreation as well as timber and fuel production play a normal part (Marcstrom 1986; Niemeyer 1986). There has been a national awareness, varying in degree with country and time, of the importance of the forest resource and the need to develop an understanding of the way the forest functions as a prerequisite for effective multi-use management.

In Britain, on the other hand, the larger forest areas are mostly of recent origin and remote from centres of population. They were established in response to the realization in two World wars that our timber reserve was totally inadequate to meet even short term needs in times of emergency (Ministry of Reconstruction 1918; Forestry Commission 1943). Meeting the afforestation targets set in response to this awareness involved adopting an "agricultural" approach: getting as many trees as possible

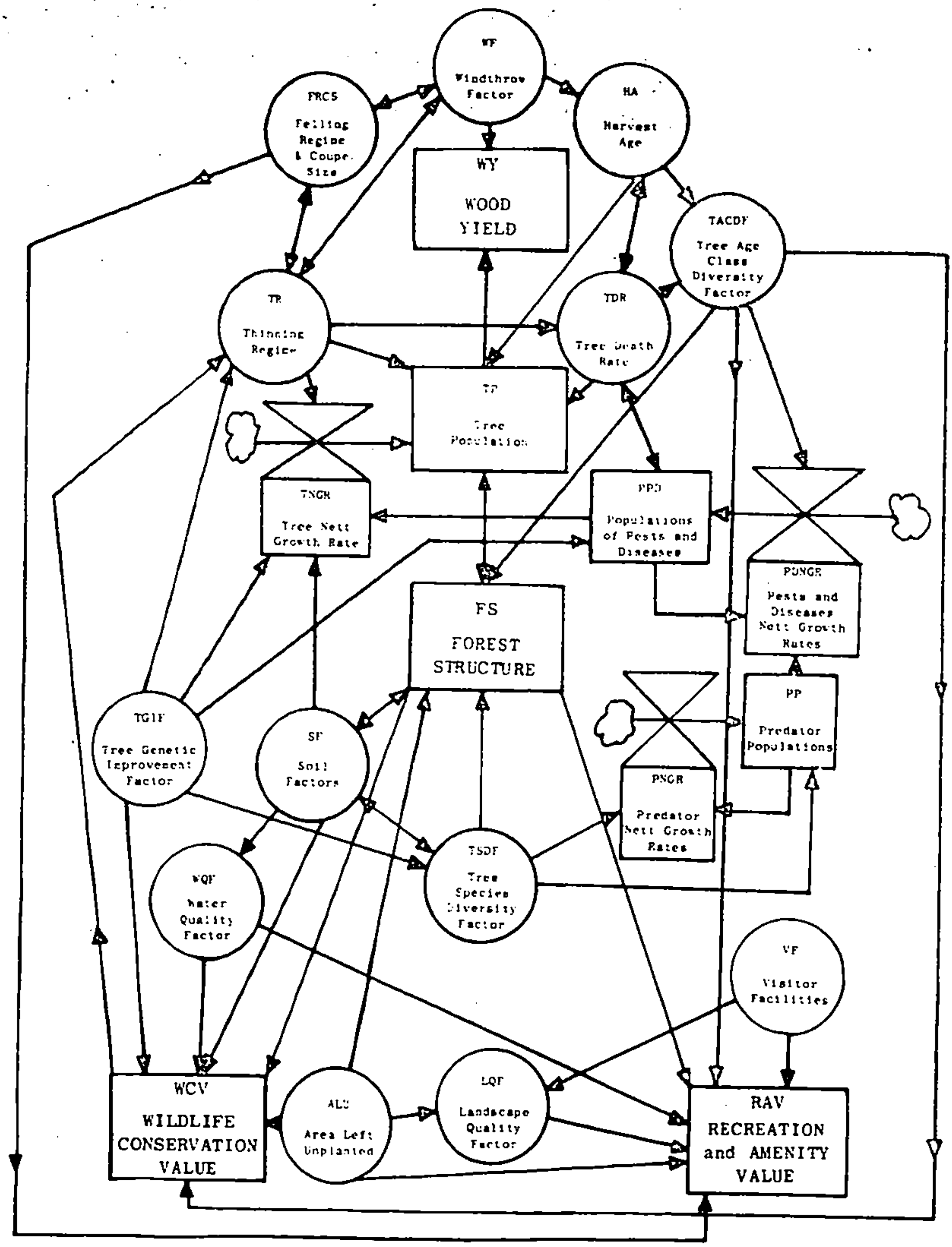

Figure 1. The interrelationships between forest structure and wood yield, wildlife conservation value, recreation and amenity value of clearfell plantation forests.

on the ground fast.

As Britain is a small heavily populated island already committed to intensive agriculture on the very limited amount of better land, it was the intention from the start that forestry should not compete but should be mainly restricted to the poorer soils and less favourable climates of the north and west. Given these limitations, and recurrent problems in obtaining sufficient suitable land for afforestation, few would disagree that the Forestry Commission and private forestry have done an excellent job in meeting their planting targets. Furthermore, it is natural, given such a clear remit for untramelled timber production, that other considerations, such as wildlife conservation and amenity, were pushed very much into the background. Species were planted and silvicultural methods developed which would ensure reliable establishment and maximum yields on the generally poor quality land available, with the result that even-aged monocultures of a few exotic conifers, notably Sitka spruce, have come to dominate British forestry (Rowan 1986).

Even now, with the 1943 planting targets reached, we as a nation still import more than 90% of our timber and wood product needs. While the development of nuclear weapons has largely removed the original strategic justification for large-scale afforestation to make up some of the shortfall, the huge annual cost of importing what we use (exceeding £4000 million at 1986 prices) is reason enough to banish any thoughts of complacency. Furthermore, despite our increasing level of home production the gap between output and consumption is increasing as it is throughout the EEC, and all this in the face of a predicted worsening world wood supply situation (Centre for Agricultural Strategy 1980; Campbell 1983). Understandably, such pessimistic predictions have led to the call for substantial further afforestation in Britain and throughout the EEC. The Centre for Agricultural Strategy suggest in their report (Strategy for the UK forest industry(1980)) that up to 2 million hectares (Mha) more should be afforested in addition to the 1.2Mha planted since 1919.

The recent concern with agricultural overproduction in the EEC and the escalating cost of subsidies to producers have led to increasing pressure to identify alternative uses for agricultural land. It might be supposed that this offers a golden opportunity for increasing the area of forest and thus killing two birds with one stone. There are those who favour this option, but for the time being the farming community, as represented by the national Farmers Union, does not appear to be convinced. The chief concern among farmers is the maintenance of incomes and there is resistance to afforestation of farmland on two counts: firstly that there is a period during forest establishment when the land will provide no income; secondly that land under trees cannot be quickly returned to agriculture and that such re-conversion is in any case expensive. There can be no doubt that subsidies to farmers to counteract these costs would be necessary if afforestation on the better agricultural land were to take place on any significant scale.

An alternative receiving much attention at present, and which amounts to a compromise, is agroforestry. The idea of combining wood production and agriculture on the same land concurrently, as is practised successfully in a number of other countries (New Zealand and Mexico are examples), is now recieving much attention in Britain. A good deal of research is underway or planned, mostly concentrating on upland silvopastoral systems involving sheep grazed under a widely spaced tree crop. In a co-ordinated series of experiments throughout Britain, Sycamore is the favoured principal species because of its tolerance of a wide range of soils and climatic conditions . There are also more limited investigations of systems involving deciduous trees undersown with arable crops which might be more attractive to those currently farming lowland arable land.

As a result of the changes in land use priorities resulting from EEC responses to unacceptable surpluses of agricultural commodities, a more flexible attitude to land use is becoming apparent. Included in this is a greater willingness all round to give greater attention to the potential of farmed and forested land for nature conservation and amenity provision. There is an accelerating realisation among those in the forest industry that public opposition to the earlier pattern of large-scale intrusive afforestation with conifers cannot be ignored. The appointment of Dame Sylvia Crowe as landscape consultant to the Forestry Commission in 1964 was a milestone in this respect and the principles of forest landscape set out by her (Crowe 1966) continue to provide sound basic guidance to foresters. Wildlife considerations have received more attention recently, the objectives and strategy for nature conservation in upland forestry having been stated clearly and in detail by Steele & Balfour (1979) and more recently in a major Nature Conservancy Council publication (NCC 1986). The 1984 amendment to the Wildlife and Countryside Act makes it a duty of the Forestry Commission to achieve a balance between the needs of timber production and other interests.

The Forestry Commission has responded in various ways to these changes in attitudes towards forestry. As a part of the recent reorganisation of its headquarters in Edinburgh it has brought together all those involved with environmental issues in one department (Forest environment) under the leadership of Mr Duncan Campbell. Mr Rod Leslie, a member of the RSPB Council, has been appointed to this department in charge of wildlife and conservation. In addition, each conservancy now has a Forest Environment Officer who gives advice both within the Commission and to private forestry. He is ultimately responsible to the department at headquarters. These changes have involved the establishment of a number of new posts and general funding has been improved.

New posts have also been created in the Commission's Research Division, with the establishment of a Conservation and Protection group headed by Dr P R Ratcliffe at the Southern Research Station at Alice Holt, Surrey. A new post in the same group has also been established at the Northern Research Station at Roslin, Midlothian. This group will have an advisory role in addition to its research function and it also has a remit to seek contract funds from private forestry for these activities. Dr Morton-Boyd, Formerly Director Scotland, NCC, has recently been employed by the Commission to carry out a review of the potential for nature conservation in forests and research needs to realise that potential.

It is clear, then, that the Forestry Commission sees itself as having a major and increasing role in research and advice on all environmental matters relating to forestry. At the same time it has been made very clear in my discussions with senior Commission research staff that ITE's research role is seen as being complementary to, rather than in competition with, their own. It is felt that, while the Commission will increasingly be able to tackle specific conservation and amenity issues as they arise, it has neither the staff nor the inclination to carry out longer-term research aimed at objective quantification of whole systems, nor that aimed at quantifying the scale (in terms of land area) required for conserving particular communities within forests.

While we may well not wish to be limited by others in determining our research priorities, it would seem to be sensible to determine the areas in which we are likely to be able to proceed with the Commission's approval and support and also those where active co-operation is feasible.

Another factor makes now an appropriate time to reassess ITE's role in this field. While the majority of the plantation forests of the last half century are still young, and therefore of necessity in a condition where little can be done to alter their shape, species composition, age-class or structure without major losses of revenue (Rowan 1986), an increasing proportion are at or approaching the end of their first rotation (Low 1984). In some cases this is as a result of their having reached normal maturity but in many others it is premature following windthrow. In either event, restocking offers many opportunities for altering forests so as to improve their landscape, recreational and wildlife conservation values (Low 1984). It is very important that the best possible knowledge be made available to the forestry industry to enable the most appropriate and cost effective prescriptions for improvement to be adopted. This in turn requires that the research effort, limited as it is by shortage of resources, be directed towards answering the most rewarding questions. The current FC/NCC funded ITE study of nature conservation in new conifer forests (ITE 1097), for which the author of this review is ITE Nominated Officer, is an example of a new initiative in this direction.

2. PAST AND PRESENT RESEARCH REVIEWED

In this section, research in fields relating to the reconciliation of conservation and amenity with production forestry are reviewed under subject headings and sub-headings, concentrating on the effects of dynamic forest structure. Gaps in knowledge are highlighted.

2.1. Soils and water

It may be thought surprising that in a review of conservation and amenity in production forestry, soils and water should be considered at all, let alone be given pride of place. In fact, however, as the conceptual model shows (see Figure 1), the influences of soil type on species choice and yield and the effects, in turn, of the trees themselves on the soils and on water yield and quality are of fundamental importance to any such analysis.

It requires only a moment's reflection to realise that if all of Britain were on fertile brown forest soils of the types found in many of the lowland areas and in much of continental Europe, we should not now be considering the problems posed by large-scale upland coniferous monocultures. The problems of modern forestry in Britain arise in large part from the fact that the soils available have been, and probably will chiefly remain, infertile, poorly buffered and often poorly drained (Pyatt 1970; 1982). Add to this the associated problems of high altitude: notably high average wind speeds, high rainfall and lowered temperatures, and you have a combination of adverse factors which have dominated species choice (Anderson 1950; Ogilvy 1986) and sylvicultural techniques (Stirling-Maxwell 1925; Zehetmayr 1954; Binns 1959; Toleman 1975; Booth 1977; Thompson 1979; McIntosh 1983; Low 1984; Sands 1984; Thompson 1984; Rowan 1986).

The effects of forests on water yield and water quality under British conditions are currently the subject of active research in the Institute of Hydrology and the Forestry Commission as well as in ITE (Projects 594, 625, 923). There is no doubt that forests do reduce water yield compared with grassland and that the losses can be serious (Clarke & McCulloch 1979). Once this is realised, however, it is not too difficult to devise sylvicultural management procedures which will substantially alleviate the problem (Binns 1979).

Soil acidification, leading in turn to acidification of watercourses, could be of major significance because of the very poor buffering of the siliceous soils through which much of the rainfall must pass after entering the forest (Hornung 1985; Miles 1986). This subject has received considerable attention in the last five years as a result of the acid rain controversy and is being actively researched by a number of university groups as well as by the Forestry Commission, Institute of Hydrology and ITE. Project 923 is specifically concerned with acidification of waters in forested and unforested catchments while project 1036 aims to compare soil and water acidity under different trees. A number of other projects (453, 594, 710, 791, 841, 893, 895, 924, 925, 959,), while primarily concerned with the occurrence of acid precipitation and its effects on trees may be considered to have a potential involvement in soil and water acidification. As will be made clear in the more detailed account below, there is a need for further process studies to clarify the mechanisms and rates of change on a range of soils and sites (Hornung 1985).

2.1.1. Soil types and forestry possibilities

Because of the fundamental sylvicultural need to know about soil types, much work has been done in this field and all that needs to be known with regard to cultivation of the existing major forestry species is known (Pyatt 1970; 1977; 1982; Toleman 1975). There may be some room for further research into the soil requirements of hitherto untried species which may have potential for use in British forestry and it could well fall to ITE to do such work in the absence of Forestry Commission interest. However, so successful has Sitka spruce been in the first rotation on most soil types that the tendency now is to plant Sitka on all of these and in particular to replace Lodgepole pine in the second rotation on deep peats (Ogilvy 1986).

2.1.2. Effects of trees on soils and water

A great deal of research has been done in this field both in continental Europe and latterly in Britain. Particular attention has been paid to the effects of different tree species and of mixtures, especially the decomposition of their litter and how this affects the soil. More recently, with concern about the possible adverse effects of afforestation on water yield from catchments and on water quality there has been a marked acceleration of research into these aspects.

2.1.2.a. Effects of trees on soils

Many of the world's remaining natural forests and woodlands are found on acid soils, e.g. the boreal forests, the temperate mixed forests, the acid oakwoods of western Europe (Hornung 1985). The acid soil-vegetation associations are the result of interlinked vegetation succession and pedogenesis. Thus the natural trend, on freely drained soils in northwest Europe at least, for progressive leaching to lead to soil acidification and eventual podzolization (Ball 1975) may be hastened and exacerbated by certain types of vegetation and perhaps slowed down or even reversed by others (Miles 1986).

The effect seems to vary considerably in rate and eventual degree depending on the initial soil characteristics and, to a lesser and by no means clearly defined extent, the type of vegetation. The most dramatic effects which have been clearly demonstrated are those caused by heather (Calluna vulgaris) (Gimingham 1960). Marked acidification can occur beneath this species within a decade and podzolization is promoted (Gimingham 1960; Dimbleby 1962). Indeed it has been suggested that all lowland and most upland podzols in Britain (excluding montane podzols and micropodzols) formed under heather (Miles 1985).

Many published studies suggest that a range of other species have similar effects, but the commonly held view that all conifers routinely cause soil acidification while broadleaves invariably have the reverse effect is not substantiated in the literature. The fact that conifers are frequently found on acid soils should not be taken to imply that they were responsible for the initial trend towards podzolization. Nevertheless, soil acidification and sometimes podzolization have been reported to occur under all the major coniferous species of British forestry, namely Sitka spruce (Page 1968; Hornung 1985), Norway spruce (Nykvist 1961; Grieve 1978), Scots pine (Bublinec 1971; 1977; Hussein 1974; Romans & Robertson 1975; Birse 1980; 1984;) Corsican pine (Ball & Williams 1974), Lodgepole pine (Zinke 1962; Williams et al. 1978), Douglas fir (Zinke 1962; Crampton 1982) and also European larch (Ashley 1965; Page 1968).

In a number of studies where acidification has been shown to occur beneath various conifers, a concentric zonation in soil properties related to the position of individual stems and canopies has been noted (Zinke 1962; Zinke & Crocker

1962; Crampton 1982). In most cases the soil was more acid, with lower base saturation, adjacent to the stem than beneath the edge of the canopy. This pattern is usually said to result from differences in chemistry between stemflow and throughfall, the former being significantly more acid (Ernst 1978). Some authors also note the importance of the accumulation of very acid bark-litter adjacent to the stems (Zinke & Crocker 1962; Ryan & McGarity 1983). The acidity of stemflow has been stressed in several recent papers on precipitation-tree canopy interactions. For example, Nicholson et al. (1980), reporting on ITE work on acid precipitation, report a mean stemflow pH of 3.3 below Scots pine with a minimum recorded value of pH 3.0. As Hornung (1985) says when reviewing this work, "Given such an acid input it would be hardly surprising if soil acidification resulted". More work is needed to determine the source of the acidity in throughfall and stemflow and the reasons for the greater acidity of the latter. Hornung considers (personal communication) that much of it may be atmospheric in origin, having been 'filtered' from the atmosphere by the canopy, but organic acids leached from the tree leaves and bark are also involved. Work is currently under way (ITE 923) to determine the sources of acidity in throughfall, stemflow and groundwater in a Sitka spruce plantation in S. Wales. A likely explanation for the greater acidity of stemflow as compared with throughfall is the greater contact time between the water and the source of acidity, but this has not been researched.

A marked feature of acid waters flowing from spruce plantations in Wales has been their high aluminium concentrations compared with those found in waters draining grassland (Stoner et al. 1984; Reynolds et al. 1986). It is believed that aluminium is mobilized in much the same way as the other mineral ions mentioned above. It is known that elevated aluminium concentrations in the range frequently found in this study are toxic to fish and other aquatic organisms (Cummins 1986; Ormerod et al. [in press]).

The acidification which can occur due to acid throughfall and stemflow may be supplemented by that resulting from breakdown of litter. Messenger (1980) suggests that the main contribution to the lower pH below Norway spruce stands in his study site may be organic acids produced from the litter. He also mentions a low rate of magnesium cycling, which could contribute to a lowering of pH. Several other studies suggest that the lowering of soil pH is due in the first place to increased H^+ ion production in litter which in turn results in mobilization of calcium and/or magnesium. Matzner & Ulrich (1981) showed a much greater mean annual production of H^+ ions in the humus layer and mineral soil below Norway spruce than below beech while Nys (1981) observed an increased rate of mineral weathering below Norway spruce compared to an oak (Quercus petraea) dominated hardwood stand. In the same study, leaching of calcium and magnesium from the A horizon below the spruce was almost double that in the oak woodland. In a catchment study in the Massif Central, Dupraz (1982) found almost double the output of calcium and magnesium in streams draining a catchment planted with conifers compared to one draining a beech forested catchment.

Not only are base cations lost from the ssoil by leaching, they are also accumulated in the tree crop and in the litter. The amount in the crop varies considerably with species. In a study at two sites in Minnesota, Perala & Alban (1982) found that aspen (Populus tremuloides) stemwood contained more than twice as much calcium as any of three conifer species, supporting earlier suggestions (Rennie 1955) that broadleaves accumulate more base cations than conifers. Similarly it is clear that the litter of different species can vary markedly in content of mineral nutrients (Swift et al. 1979) and that in general broadleaf litter contains higher levels than that of conifers when both are grown on similar soils. Since both broadleaves and conifers produce similar amounts of litter, at least above ground (Miller 1984) it might be thought that more base cations would be accumulated in the former. This does not take account of the fact, however, that conifer litter decomposes and is incorporated more slowly than that of broadleaved trees (Miller 1984). One reason for this is that conifer litter is more acid and has a higher tannin content, making it less palatable to earthworms and other litter feeders (Satchell 1967).

Base cation accumulation in both the tree crop and the litter is most marked during the early years of the forest when tree growth is most rapid and litter accumulation most marked (Nilsson et al. 1982). Litter depth in Sitka spruce in Britain was found by Page (1968) to reach a maximum at an average tree top height of 18-20m. Near the end of the rotation both litter depth and soil pH return to approximately their original values. These cyclic trends have been confirmed elsewhere, notably in Newfoundland (Page 1974). Thus it appears that much of the early acidification due to accumulation of base cations in mor-humus is reversed in the latter stages when litter decomposition rate exceeds accumulation rate.

Forest structure also influences litter accumulation and quality. Thus Saly (1980) found that in Norway spruce stands in Czechoslovakia, heavy thinning caused rapid changes in the surface humus from mor to mull with, at the same time, development of a rich surface vegetation of non-acidophyllic, frequently even nitrophyllic species. There are no reports of similar changes from elsewhere but this finding is sufficiently important to suggest that a project investigating the effects of a range of tree densities on soil chemistry, flora and fauna, as well as on ground flora and tree growth rate would be worth initiating

This somewhat unexpected result emphasizes the point that species can vary in their effects. If we remain with Norway spruce, which has been much investigated in Europe, we find a confusing and contradictory story. There is no doubt that it is generally regarded as among the most acidifying of trees, causing soil deterioration wherever it occurs naturally or is planted in central Europe (Krauss et al. 1939; Nykvist 1961;). Miles (1978) has collated data for the effects of planting this species and Scots pine in place of beech or oak in a number of European countries and produced a table which shows pH reductions ranging from 0.1 to about 1 unit. In most cases the acidification is restricted to near-surface horizons, often the top 10-20cm. Evidence to suggest that Norway spruce produces similar effects in Britain comes from the Forest of Dean where Grieve (1978) found that on acid brown earths it caused significant podzolization, thick mor humus replacing the mull which formerly existed under broadleaves. This change was associated with increased soil acidity and there were signs of developing structural breakdown. Studies on sandy moraine soils and on stiff water-holding clay in Denmark have, on the other hand, shown no significant changes in physical or chemical properties in second generation stands (Holmsgaard 1966). Similarly, changes from hardwoods to Norway spruce on clay moraines in Denmark did not affect the soil physical conditions, humus type, thickness of humus layer, or degree of podzolization (Holstener-Jorgensen 1968). Again, Gennsler (1959) found no sign of podzolization after 250 years of spruce in the Harz Mountains, though he did record surface acidification, while Saly & Obr (1965) recorded one instance where the pH of the surface soil under Norway spruce planted in place of beech in Czechoslovakia had increased from 3.9 (under beech) to 4.2.

Similar contradictions could be sited for other species, notably Scots pine, for which sufficient data is available, and likewise for the supposedly beneficial effects of various hardwoods in reversing trends towards podzolization. Thus, while birches (Betula spp.) seem generally to be soil improvers, causing a change from mor to mull humus when colonizing acid Calluna soils (Dimbleby 1952; Miles & Young 1980; Miles 1981), McVean & Ratcliffe (1962) and Rennie (1955) found that on nutrient-poor Calluna soils birch increased the depth of raw humus and litter, Rennie finding that large amounts of nitrogen, phosphorus and calcium were immobilized in the process. Malcolm (1957), on the other hand, concluded after extensive painstaking study that birch could prevent soil degradation and check its progress in natural Scots pine stands in Scotland after it had begun.

A number of factors would seem to contribute to these apparent inconsistencies. Several authors (Jones 1965; Stone 1975; Miles 1986) have pointed out that many published accounts, particularly the earlier ones, referred to contemporaneous studies of soil under different species assuming, without testing to find out, that the soil was initially homogeneous. The second, and probably more important factor, is related to the first in that it concerns the nature of the soils before afforestation. Thus, for example, non-calcareous soils with little clay content are poorly buffered and change faster, with or without vegetation cover, than well-buffered soils. In most upland areas of Britain, poorly buffered siliceous soils predominate, whereas in the lowlands and the upland areas of central Europe, well-buffered more base-rich soils are common. Intrinsically freely drained siliceous soils are the most susceptible of all to change, poorly drained types showing only superficial changes during the lifetime of a tree stand (Miles 1986). Management of the site in terms of cultivation, drainage and fertilization as well as of the trees in terms of density and age-class also has, as one would expect, a profound influence on the effects of the trees on the soil.

In a classic experiment, Ovington (1953) studied a large number of species, including conifers and hardwoods, on three sites in England. He found that the influence of the individual tree species on soil pH depended on initial site conditions and silvicultural management but concluded that the general trend was for conifers to intensify the increased acidity of the upper soil to a greater extent than the hardwoods. When Ovington's plots were re-sampled in 1974 to assess changes since the original 1951 sampling it was found (Howard & Howard 1984) that temporal change in pH varied both between species and between sites. In some cases, e.g. Quercus petraea at Bedgebury, an increase in soil pH was found while at the Abbotswood site a significant decrease in the 0-5cm pH was found below all seven species. Some of the most profound increases in soil acidity were found not below the conifers but beneath hardwood species, e.g Grey alder (Alnus incana). Howard & Howard conclude that the effects of different tree species on soils depend both on the nature of the soils and local site conditions, including management methods.

Having considered the complex and often contradictory effects of individual tree species on soils it is necessary to consider mixtures. It has been argued that since broadleaves such as birch (Miles & Young 1980; Miles 1981), aspen (Frank & Borchgrevink 1982) and holly (Dimbleby & Gill 1955; Malcolm 1957) generally produce rapidly decomposing mull humus which is soil improving they should reduce the soil degrading effects of conifers if planted in mixture. European evidence in general supports this view, litter decomposition rates being increased, acidity being reduced and nitrification being stimulated when hardwoods are mixed with softwoods (Gosz 1984). It is claimed that the beneficial effects of hardwood mixtures in spruce stands in Sweden may persist even after removal of the hardwoods (Lutz & Chandler 1946).

Likewise, there have been reports to the effect that the growth of conifers has been improved by growing them in mixture with birch (Shumakov 1958; Kovalev 1969; Blintsov 1971; Prudic 1972) but Miles in his review (Miles 1986) considers the supporting data unconvincing. However, more recent studies have shown that admixtures of Scots pine, Lodgepole pine and Japanese larch with Sitka spruce improve the latter's growth (O'Carroll 1978; McIntosh & Tabbush 1981; McIntosh 1983), apparently by improving its nitrogen nutrition. The Forestry Commission is currently involved, jointly with the Republic of Ireland Forest Service, the Macaulay Institute for Soil Research, and the University of Edinburgh, in an EEC funded project on the mechanisms involved. The key questions to be answered are, how do the nurse species growing on deep peats manage to obtain sufficient nitrogen for their needs while Sitka spruce cannot and how, having obtained the nitrogen they need, do these species 'give' it to the spruce?

In another study of mixtures, ITE work at Gisburn Forest (Brown & Harrison 1983) reported that mean height of 25 year-old Norway spruce was 9m in pure stands, 10m with a 50% mixture of Common alder and 11m with a 50% mixture of Scots pine. The processes underlying these effects are not known but are being investigated (ITE 367, 824). They are perhaps particularly unexpected in that the soil is a surface-water gley and thus not of a type generally considered to be susceptible to substantial change. Brown & Harrison estimate doubled earthworn biomass under spruce/alder compared with pure spruce and an amazing 5X biomass increase under spruce/Scots pine. Available N & P is increased in proportion to worm biomass and Brown & Harrison suggest that increased earthworm activity caused increased mineralization of N & P so leading to improved growth. However, (Miles 1986) considers it more likely that the increased earthworm numbers under mixtures are a result of the increased availability of N & P rather than its cause. He suggests that the improved yields of mixtures are probably largely a biological phenomenon, mainly independent of physical and chemical changes to the soil. Clearly much remains to be discovered concerning the effects of trees in mixture on soils and this should continue to be an area of major ITE research interest.

While the trees clearly have a very major impact on soil development in forests, the possible influences of the ground flora should not be ignored. We have already noted the dramatic acidification effects which Calluna can cause but it is easy to underestimate less obvious influences. Miles (1986) considers it likely that under forests of species such as beech and oak, which have rather neutral pedogenic effects, the field layer often determines whether the soil tends towards podzolization or the reverse. Similarly Lag (1959; 1971) has suggested that in Norwegian forests the field layer is in general more important than the tree stand in determining the direction of soil development. Again, there is very little known about this and there is a clear need for ITE reserarch to be initiated.

2.1.2.b. Effects of trees on soil water

Afforestation has many hydrological consequences, some of which have already been reviewed in relation to the effects of trees on soils. These consequences vary both in time as the forest matures and from place to place depending on climate, soil and topography, which all affect the afforestation techniques themselves. Many of the changes in the quantity and quality of water leaving a catchment are site-specific and therefore cannot be taken as a guide to what will happen elsewhere. This point highlights a major problem in trying to gain insights into the processes and mechanisms influencing water yield and quality. Such research generally involves intensive long-term studies requiring heavy investment in time and money for the installation of monitoring equipment. Inevitably this means that the research is limited to one or two sites. While it is possible, with a good deal of thought and reconnaisance, to choose the most representative sites available, it will never be possible to be fully confident that detailed findings gained at one or two sites will apply elsewhere.

It is clear, however, that an upland afforested catchment yields less water than a similar grass-covered catchment and the afforestation effect can be relatively easily predicted (Calder & Newson 1979; Pyatt 1984). Pyatt has produced a graph enabling the runoff to be calculated, given the average rainfall and proportion of the catchment afforested. It is suggested, as a first approximation, that deciduous species reduce runoff about half as much as conifers, and that a forest with a proportion of deciduous species would thus require a corresponding adjustment when making water yield calculations (Pyatt 1984), but more research is needed.

Forests use more water than pasture or other low vegetation for four reasons (Binns 1979). First, forest has a lower reflectivity so it absorbs more incoming radiation. Second, the forest canopy is rough and deep, which causes a greater mixing of the air passing through it. This results in more efficient transfer of water vapour and thus greater evaporation. Third, an appreciable proportion of any one storm is held on the needles or leaves of complete canopies and evaporates after the rain ceases. Finally, some forest trees are deeper rooting than other forms of vegetation and in droughts they will continue transpiring at the normal rate after shallow-rooted plants have been forced to reduce their transpiration rate. This does not greatly affect surface runoff or ground water supplies at the the time, but it leaves a greater soil moisture deficit to be made up when the drought ends.

Of course, the forest is not static, and water yield follows a cyclic pattern tied to forest structure (Binns 1979; Robinson 1980). Thus, when upland pasture is initially ploughed and/or drained to enable afforestation to take place, water yield increases as does the likelihood of 'flash' runoff following storms. Turbidity is also increased and, whether or not fertilizers are used to promote early tree growth, more nutrients enter the drainage water (Hornung & Newson 1986). Road construction will also temporarily increase erosion, and therefore suspended solids in the water (Stretton 1984). In severe cases, heavy siltation of reservoirs may occur, perhaps with algal blooming of the water if high concentrations of nitrogen and phosphorus occur.

While the effects of the extra nutrients on aquatic fauna and flora are not well understood, it is known that in static waters algal blooms are a frequent consequence (Gibson 1976; Richards 1984). In the case of suspended solids it is known that while fish may tolerate very high concentrations for short periods, sub-lethal effects may occur well within the concentration range commonly found on occasion in streams draining newly forested catchments (Allabaster & Lloyd 1980).

As the crop grows, the water yield falls and the catchment becomes less responsive to rainfall fluctuation than the original sheep pasture. Each thinning reduces water uptake, interception and transpiration, but because thinning is normally limited to small areas of any particular forest each year, the overall effect on the water yield is hidden. Traditionally, forests drains were maintained in a clean open condition by forest workers, but insufficient manual labour is now available and there is no suitable machine to do the work. Thus the tendency now is to let drains block up on the principle that by the time this has occurred the trees will be well grown and in most cases will be removing sufficient water from the soil to prevent waterlogging.

This change in practice is advantageous hydrologically because, while open drains maintain the 'flashy' characteristic imposed when they were first dug, filled drains smooth the hydrograph (Binns 1979). Recommended Forestry Commission drainage practice on afforestation sites involves cross-drainage networks, stopping plough furrows short of main drains to provide a filter for suspended solids. Current research thinking in the Commission tends to favour moving away from strip ribbon ploughing to subsoiling and mounding. However, there is some concern over the growth benefits of such systems and more herbicide usage and changes in drainage practice would be required.

When forests are clearfelled, runoff and leaching are immediately increased (Hibbert 1967) and nutrients normally absorbed by roots enter the drainage water along with suspended solids. Most of the latter are due to the soil-churning activity of harvesting machines. This runoff could lead to serious problems if large areas were to be clearfelled at one time but because of different growth rates on different soil types, and because of windblow, there are few sites where this is likely to be a serious problem in Britain. In any case, it is likely that

Interrelationships

It will be seen from Figure 1 that soil factors have indirect effects through tree nett growth rate on wood yield, and direct and indirect effects on wildlife conservation value and recreation and amenity value. The direct effects on wildlife conservation value refer to the effects of soil factors on soil and above-ground flora and fauna but soil factors can also have an effect via water quality, for example on the diversity of aquatic animals, and through forest structure.

2.2. Ground vegetation

Progressive changes occur in the composition of the field layer during the life of a stand whether the latter arose after disturbance in old forest (MacLean & Wein 1977; Brakenhielm & Persson 1980), replaced moorland (Hill 1979; Miles 1981; Sakura et al. 1985), blanket peat (Doyle & Moore 1982) or farmland (Brakenhielm 1977). The known effects of plantations on ground flora and succession in British plantation forests have been comprehensively reviewed by Hill (1983; 1986). It is important first to realise that our knowledge of the medium to long term effects is seriously limited by the fact that little data was collected before 1940. Thereafter, a few long-term data sets are available, for example from Caeo Forest, South Wales, where observations started in 1952 (Hill & Jones 1978), Ovington's plots (already mentioned in relation to the effects of trees on soils) established in 1952 (Ovington 1953; 1954; Anderson 1979;), the joint FC/ITE species trial started in 1955 at Gisburn (also already referred to), and the ITE study area at Stonechest in Cumbria which was established in 1972 (Sykes & Lowe 1986).

This shortage of long-term studies on a range of sites has been to some extent remedied by use of the chronosequence method. This involves comparing observations from supposedly similar sites which were planted at different dates in the hope that associated vegetation differences represent normal patterns of vegetation change with time in a single plantation. This method has been applied to studies of succession in Sitka spruce plantations (Hill 1979) and to regeneration of birch scrub on moorland (Miles 1981). See Hill (1986) for a discussion of the pitfalls in use of this method and checks that can be made on its validity in the present situation.

2.2.1. Vegetation changes in planted blocks

The changes, insofar as they are understood for British forest plantations, are described in detail by Hill (1979; 1983). The condensed version which follows, relating vegetation to the sequential stages of forest development, is closely based on Hill's 1986 review.

2.2.1.a. Establishment to canopy closure

Afforestation generally initially involves fencing to exclude grazing animals, ploughing and drainage. According to Hill, the associated vegetation changes, typically involving an increase in shrubby species, especially Calluna, and tussocky species such as Molinia are mainly due to drainage and cessation of grazing. He considers that ploughing produces much less effect, noting that ground exposed by deep ploughing often remains bare for 5 years, becoming dominated by lichens and moss. This is not universally the case, however, for Sykes & Lowe (1986) report that at Stone Chest, a flowering plant ground cover was complete within 2-3 years.

Fertilizer produces very little qualitative effect on ground vegetation at this stage, simply promoting the growth of plants that are already established.

The effects of herbicides, including their possible use to encourage certain species or communities at the expense of others merits further study. The problem in doing so is that herbicides are forever being changed as more effective, selective, easily applied or cheaper chemicals appear. Thus some sort of continuous testing and monitoring programme would be the most appropriate approach.

2.2.1.b. Canopy closure to clearfelling

Canopy closure has varying effects depending on the species in the plantation, soil type and altitude. On infertile soils in the uplands, under species which cast dense shade, such as Sitka spruce, Norway spruce, Douglas fir (Pseudotsuga menziesii) and Western hemlock (Tsuga heterophylla), little normally survives except mosses. In similar conditions under pines and larches, which cast a lighter shade, the response to canopy closure is less predictable, varying from almost complete ground cover to a barrenness reminiscent of spruce. Where there is appreciable survival during the early stages of closure there will almost certainly be good vigorous cover later since light penetration increases with thinning as the trees mature.

On more fertile soils in the lowlands, even such heavy shade casters as Sitka spruce can support quite a rich ground flora when mature and fully thinned. Under such conditions the state of forest development has a much more marked effect. Thus in his trials of different crop species, Ovington (1955) found large differences between the vegetation under broadleaves and shade-casting conifers at age 22. However, when Anderson (1979) re-visited the plots 22 years later it was the similarity of the ground flora under the differing species which struck him rather than the differences, real those these still were. Native oakwood species such as bramble (Rubus fruticosus), bracken (Pteridium aquilinum), English bluebell (Hyacinthoides non-scripta) and creeping soft-grass (Holcus mollis) occurred under all crop species.

2.2.1.c. Clearfelling and replanting

The pattern of events following clearfelling tends to be much more indeterminate than that following initial afforestation. This is because the vegetation that is able to establish between clearfelling and closure of the replant canopy depends to a considerable extent on the seed available to colonise the bare ground left after tree removal. If there was very little vegetation beneath the trees immediately prior to felling, early regrowth may be dominate£ by species that have lain dormant in the soil throughout the closed canopy stage of the crop, notably Calluna, foxglove (Digitalis purpurea), rushes (Juncus spp.), sedges (Carex spp.) and gorse (Ulex spp.) (Hill & Stevens 1981). Bird-dispersed seeds such as bilberry (Vaccinium myrtillus), bramble, raspberry (Rubus idaeus) and rowan (Sorbus aucuparia), which are introduced to the forest floor over a prolonged period by defaecation of birds roosting in the treetops, may also form an important component of the inter-rotational vegetation. Some species with very short-lived seeds, such as Wavy hairgrass

(*Deschampsia flexuosa*), seem to need a small population already established at clearfelling if they are to become abundant before canopy re-closure. Others, like bracken, are able to survive throughout the rotation as vegetative individuals along roads and rides and can spread some way back into planted blocks from there during the open period (Hill 1979).

If an appreciable vegetation cover exists beneath the canopy immediately prior to felling, the pattern of vegetation is likely to be quite different to that outlined above. The plants already present will have a considerable advantage over newcomers, however derived, and they and their offspring are likely to dominate the vegetation until, perhaps, increasing competition in the changed conditions forces species composition to alter.

Hill (1986) considers the most interesting topics for research in this area relate to the question of the overall survival and spread of plant populations in forested areas. Whereas change is, in the absence of catastrophic events such as fire, relatively gradual in the grasslands and shrublands that the new forests mostly replace, in the forest it is sudden and dramatic. Plant populations must constantly be on the move. How is this achieved by different species in different situations? What are the dynamics of plant populations on the larger scale as against those of the small local community within the forest? Answering these questions requires a combination of observations on permanently marked plots and repeated surveys in a range of representative forests.

Hill also considers that more information is still needed on the response of vegetation to differing crop species and site-types, especially in the period after clearfelling. Comparative studies of rate of litter breakdown and nutrient release from the forest floor and their effects on different species are needed.

An interesting example of the change brought about in the ground flora as a result of a change in tree species is described by Miles (1986). In a Scots pine plantation, part of which had been felled 20 years previously and colonized by birch, the soil under the birch was significantly less acid and had mull-like humus compared with the mor under pine. Many more species grew under the birch than the pine and half of those under birch were exclusive to it. Miles notes that it is difficult, if not impossible, to ascribe relative importance to factors in determining these differences. However, experiments have shown that seeds of a range of species sown experimentally on either heather moorland, or successively older birch stands which have replaced the former, were progressively more successful as the birch age increased. Some species

(*Geranium sylvaticum*, *Primula vulgaris*, *Prunella vulgaris*, *Viola riviniana*) were only successful on the oldest (40 yr) birch site. All these are species typically found on mull soils.

2.2.2. Vegetation changes in unplanted areas

Because of the shading out, and virtual elimination of all vegetation under spruce crops in the uplands, most species are able to survive only in the unplanted areas. Evans (1978) came to the conclusion, after extensive survey, that in North Wales roadsides were the most important habitat for survival of plants; bogs, streamsides and other unplanted areas also making a significant contribution. Rides generally contributed little because they were occupied almost exclusively by heather and tussocky coarse grasses. The importance of unplanted areas on wildlife conservation generally, as well as on recreation and amenity is indicated in the general model (see Figure 1).

Roads occupy only about 5% of the total area in forests (Evans 1978) and most of the more unusual plant species occurred on the verges which occupy only 1.6%, so it can be seen that a major proportion of the botanical (and presumably associated zoological) interest resides in a very small proportion of the total forest area. It would be possible, of course, to simulate roadside verge habitat in rides and forest clearings by management, and the above information suggests that this might be an extremely effective means of enhancing forest wildlife conservation value. Such management is already practised to a limited extent in some Forestry Commission forests, particularly those where there is a good deal of public access. Dr Hill's recently completed study in Newborough Forest, Anglesey, under contract to the Forestry Commission (ITE 1009) included a study of the effeccts of existing verge management procedures and makes recommendations for additional procedures to increase the diversity of road- and ride-side habitats.

Streams and lakes can also contribute substantially to the floristic diversity of forests, provided that suitably wide margins are left unplanted. Goldsmith (1981) studied forest streams and lakes in Galloway and showed that the unplanted zone needs to be at least 3m wide for any appreciable vegetation to survive and that full floristic diversity is achieved with a 6m margin. Fortunately, concerns about water yield and quality are leading the Forestry Commission to prescribe such margins in any case in new and second rotation planting. Design of watercourse margins is now a matter of major interest in the Commission and will be discussed later in this review under forest design.

Unplanted areas include hilltops too high to plant, bogs which would be costly to drain, rock outcrops and screes where trees would grow poorly, or farm fields within forested areas. These areas can provide habitats for interesting species which could not survive in the forest proper and are also, as we shall see in later sections, of considerable importance for birds, mammals and other animals. They are too, by definition, areas which can be given over to wildlife conservation and amenity interest without direct loss of forest revenue.

Unfortunately, in the higher rainfall zones in western Britain, some such areas, along with much woodland, moorland and poor grassland are under threat from rhodendron (Rhododendron ponticum) (Shaw 1984). Traditional landuse is incapable of excluding it and in many places in North Wales, the Lake District and western Scotland it threatens to reduce large areas to dense thickets, eliminating all ground vegetation as it does so. Conifer plantations, particulerly of heavy shade-casters such as spruce or hemlock, are one of the few places where rhododendron cannot thrive, although even there it can linger on in unplanted areas and, in a much suppressed, vegetative state, under the crop, ready to grow, flower and spread as soon as the trees are felled. It is impossible, as one who loves and has worked in N. Wales oakwoods infested with this pestilential weed and seen its spread through a wide range of habitats, not to consider its control and, where possible eradication, as a first priority in the conservation of semi-natural habitats wherever it is a threat. There is a need for increased research into the potential for using conifers in such control, eradication and exclusion programmes (Hill 1986).

2.2.3. The effects of sylvicultural management on vegetation

Because the planted blocks generally have little vegetational interest and are, in any case, doomed to a period during which vegetation will almost if not completely disappear, there is no need to manage them with conservation of the vegetation in mind. Much more important is the management of the roadsides, rides and other unplanted areas where it is possible to have a lasting influence on wildlife conservation and general amenity value. In the areas to be planted, the role of ground vegetation species as weeds is of more concern than their conservation value. In the uplands, heather is usually the only serious weed problem in the first rotation. Whether it will also be a problem in the second depends on the longevity of heather seed (currently unknown but probably >50 years) and the effectiveness with which its seeding is controlled in the period between clearfelling and closing of the replacement canopy. In many situations other woody species, such as birches and willows, may be more important after clearfelling and replanting, notably where mature individuals abound in the unplanted areas ready to provide a rain of widely dispersible, wind-borne seeds.

2.3. Epiphytic flora

The composition and distribution of epiphytic algae, lichens and bryophytes in forests appears to depend less upon particular plant associations, or even particular species of trees, than upon the structural conditions and the impact of climatic fctors operating through these (Barkman 1958). Epiphytic growth on trunks and branches is considerably affected by the nature of the bark surface (whether rough or smooth, chemical characteristics), but this is only one of a great many features that bring about variety and sometimes clear zonation in the cryptogamic covering. It is strongly influened by the degree of forest cover, the height within the micro-climatic gradient from ground to canopy (see section 2.7), the angle at which the trunk or branch rests, the climatic zone, and also by proximity to sources of toxic gaseous effluents (Elton 1966). Lichens have very complex micro-distribution, partly vertical, partly by aspect, or often inversely to the moss covering - i.e. they occur on the drier side of the trunk.

Conifers generally bear poor epiphyte floras compared with broadleaves (Elton 1966), though they have richer ones in Scotland (Rose 1974). The greater acidity of the bark of conifers and the heavy year-round shade that they cast on their own trunks are given by Rose as the chief reasons. Despite common supposition to the contrary, the great majority of epiphytic lichens, and to a rather lesser extent, bryophytes, are light-demanding. Again, the commonly voiced belief that some species of lichens are only found on very old trees, and that therefore such trees are of special lichen conservation value, does not seem to be strictly true. It is continuity of habitat that is of key importance, rather than the age of particular trees in the wood (Rose 1974).

Epiphytes are grazed by a variety of animals. For example, the alga Pleurococcus viridis, a very common species forming extensive thin coverings on a wide range of species including various conifers, is grazed by woodlice, millipedes, some molluscs, a few caterpillars and a good many Psocids (Elton 1966). Since it forms the algal portion of many lichens as well, there is a delicate balance between the two types of epiphytes.

The fact that there are currently no ITE projects in this field reflects an interesting difference in attitudes to cryptogamic as against vascular plants. Epiphytic habitat has been severely reduced in the past by deforestation, just as has that of woodland ground flora, but whereas there is almost universal interest and concern among conservationists for the latter, the interest in epiphytic algae, lichens, and to a lesser extent, bryophytes and pteridophytes is minimal. Fortunately, action taken to improve forest structure for general wildlife conservation is likely to favour forest epiphytes too, since they require the same higher light intensities and greater tree species diversity favoured by more "interesting" plants and animals.

2.4. Forest invertebrates

Two major points emerge from any discussion on invertebrates in British plantation forests: firstly that very little is known about them; secondly that this lack of knowledge is a severe hindrance to both their conservation and, where necessary, control, and to the conservation of the many other forest animals that, directly or indirectly, depend upon them for food. This dearth of knowledge compares very unfavourably with the much more detailed information available for lowland deciduous woods and, to a lesser extent, Scottish native pinewoods. The deficiency is due firstly to the fact that the professional forest entomologists have been preoccupied with pest species; secondly that academics have concentrated on individual species illustrating particular principles and thirdly to the fact that the bulk of references to forest impacts have been made by amateur entomologists on the basis of circumstantial or unpublished information (Young 1986).

With the exception of Alan Watt's continuing studies of the population ecology of the Pine beauty moth (*Panolis flammea*), which are revealing important general information on the factors influencing pest outbreaks and factors affecting their control (Watt 1986), ITE's own efforts in woodland entomology have concentrated, overmuch in this reviewer's opinion, on survey and monitoring, especially of "interesting" insects (notably butterflies) in lowland woods. It is encouraging that the greater interest shown by the NCC recently in the conservation value of lowland plantations, as evidenced by their willingness to fund ITE 948 (Invertebrate conservation in plantation woods), has been followed by a wish to know more about invertebrates in upland plantations, as shown by their concern that invertebrate studies shall comprise a major part of ITE 1097 (Nature conservation in new conifer forests).

2.4.1. Effects of afforestation on invertebrates.

2.4.1.a. The moorland invertebrate fauna

An important initial point which needs to be made is that not only is there little known in Britain about the invertebrates of upland plantation forests, but that our knowledge of the invertebrate communities of the mountains and moorlands which they replace is also far from adequate. Until the recent work of the Lancaster University group for the NCC on communities of peat and upland in the north of England (Coulson & Butterfield 1985), most information on the uplands had come from one site, Moor House National Nature Reserve in the northern Pennines (Cragg 1961; Coulson & Whittaker 1978).

Coulson & Butterfield (1985) point out that there has been a tendency in the past to regard all upland areas with an extensive heather cover as being essentially similar and, by implication, uninteresting, whereas in fact heather has a wide habitat tolerance, thriving on a range of peaty soils from dry heath, where the organic content of the soil is relatively low, to waterlogged blanket peat. The distribution of invertebrates is strongly influenced by such differences in the water and organic contents of the soil and a number of different invertebrate communities exist on areas that are generally referred to as moorland. In their study of 42 sites in the north of England they were able, using indicator species analysis, to identify 7 distinct communities, though there were of course numerous intergrades. One important point they confirmed was that mixed-moor, with a range of habitat diversity, carried a greater number of species than uniform moor.

Biomass was much greater on the dry mineral heaths and grasslands than on the bog heaths, mostly due to the presence of lumbricid worms on the former and their virtual exclusion from the latter. The blanket peats showed a very marked spring abundance of invertebrates with little available after June, reflecting the subarctic affinities of the fauna (Coulson & Whittaker 1978). On the grasslands and dry heaths the peak of abundance is, on the other hand, in July/August. In areas where deep peat abuts on heath or grassland, vertebrate predators can benefit from the prolonged availability of food. These interfaces tend to occur most frequently at the lower limits of blanket bog formation where the annual rainfall is c. 1300mm, usually at altitudes between 400-500m in northern England. A number of species are known to benefit from this situation - e.g. Meadow pipit, Common frog, and some Carabid beetles move off the blanket bog onto adjacent grassland after the spring emergence of insects on the peat has ended (Coulson & Whittaker 1978).

The Meadow pipit, the most numerous bird on moorlands and in newly established forestry plantations (Moss et al. 1979), declines at higher altitudes primarily because of its need to nest near the interface of peat and grassland areas (Coulson & Whittaker 1978). The first brood is fed almost entirely on the earlier emerging insects collected from the peat moor, while the second brood is fed on the later-emerging insects from grasslands or stream sides. The higher Meadow pipit density, together with the higher density of large Lepidoptera (and their caterpillars), probably explains the strong preference shown by the Merlin for nesting below 550m and for the presence of cuckoos on many of these moors.

This work is quoted in some detail because it shows the sort of integrated study which is needed, but has not been attempted, in British plantation forests. Rather than concentrating on species which are 'attractive' or 'interesting' these workers have pieced together a picture of how the animals of the moorland habitat interact. By such means are puzzling distributions and population cycles explained and the effects of habitat change understood. Now we need to know, in an equally fundamental way, what are the effects of imposing plantation forests on such systems.

2.4.1.b. The invertebrate fauna of particular tree species

There is a good deal of scattered information on the insects feeding on particular tree species, which has been brought together by the Phytophagous Insect Data Bank and Kennedy & Southwood (1984). Lists from Kennedy and Southwood for three major coniferous species with oaks, birches and willows for comparison follow:

Species	No. of phytophagous insects
Scots pine	82
Lodgepole pine	18
Sitka spruce	32
Oak (2 spp.)	423
Birch (2 spp.)	334
Willow	450

While the lists for exotic conifers should be regarded as incomplete, new records being added every year as more recording is done in plantations and as more species become adapted to them as host plants (Winter 1974; Carter 1983; Welch 1986), it is clear that some native broadleaves are substantially more species rich in invertebrates than even the native Scots pine. I have seen no satisfactory explanation of why this should be so, although it appears to be generally the case elsewhere as in Britain.

2.4.1.c. The invertebrate fauna of mixtures

In Finland, planting Norway spruce into meadows sparsely wooded with deciduous trees caused a serious decline in the diversity and total numbers of various invertebrate groups, the most obvious being butterflies (Heath 1981; Svensson 1982). Presumably the reverse operation, introducing or promoting broadleaves in conifer plantations, would have the opposite effect, but surprisingly very little is known about this here or abroad. Indeed, the whole subject of mixtures and their effects on insect populations, including those on actual and potential pest species, is of considerable interest and merits a much greater research input than it has received so far. Evidence from Europe suggests that the increase of several species to pest densities in European forestry is closely correlated with the increase in monoculture plantations (Ehnstrom et al. 1974; Brammanis 1975; Loyttyniemi et al. 1979; Langstrom 1980; Heliovaara 1982; Austara 1982; Austara et al. 1983; Heliovaara et al. 1983). Heliovaara & Vaisanen (1984) claim that any study of virgin forests will furnish proof that mixed stands are much safer against insect injury than pure stands, noting an observation (Lekander et al. 1977) that tree species which tend to form large, homogeneous stands also tend to have a rich and injurious bark beetle fauna. They also note that the numbers of such predators as Carabidae and Ichneumonidae in mixed species stands are higher than in pure stands on the same site (Szujecki 1979). They then go on to state, "In fact, it can safely be said that the greater the diversification of tree species, the less frequent insect outbreaks will be".

Watt (1986), referring to Pine beauty moth outbreaks on Lodgepole pine crops in Scotland, is less sanguine about this possibility and states, "...the reason for fewer pest problems in some polycultures is not diversity *per se* but some factor such as greater mortality during dispersal, or enhanced natural enemy action due to a predator or parasite being particularly associated with one of the plant species in the polyculture. These factors are not necessarily present in a species mixture which is chosen for conservation or amenity reasons." He goes on to point out that pest problems might in fact be exacerbated by mixed planting because some serious forest pests are both polyphagous and phenological specialists. The latter characteristic implies that they must hatch from the egg stage at a certain stage of the host's development if they are to survive. If two or more suitable host plants are available with different phenologies then they will present the pest with a larger 'phenological window' within which it must appear. Examples quoted are Pine beauty moth on Lodgepole and Scots pines, which flush at different times, and Winter moth (*Operophthera brumata*) and Vapourer moth (*Orygia antiqua*) which have extremely wide host ranges including both broadleaved and coniferous trees. Watt urges that any research into the management of forestry for wildlife, including assessments of species mixtures, should take great care to determine the likely effects on insect pests.

2.4.1.d. Dynamic forest structure and invertebrates

Young, in his paper given at the 1985 Banchory Symposium (Young 1986), stresses that even in the case of the Lepidoptera, the most studied insect group in woodlands, little is known of the habitat requirements of even the adult stage of most species. He suggests, therefore, that if habitat improvement in plantations is to be achieved on more than a hit-and-miss basis, monitoring of the requirements of different species and of the effects of different sylvicultural management procedures is necessary.

In the absence of knowledge to the contrary, it has been assumed that little change occurs in the invertebrate fauna of new plantations, excepting the addition of those species associated with the crop trees, until canopy closure takes place. However, now that it is known that there is close correlation between upland soil organic matter and water contents and invertebrate fauna (Coulson & Butterfield 1985), it cannot be doubted that the associated ploughing and/or drainage operations that take place have a major effect on the soil fauna at least. Research is needed in this area.

There is certainly no doubt that fertilizing the forest has important effects both on the soil fauna and on many of the invertebrates feeding on the trees. The most important factors in fertilizer effects are said to be nitrogen levels and pH (Marshall 1977; Lohm _et al_. 1977; Behan _et al_. 1978; Abrahamsen & Thomson 1979; Huhta _et al_. 1984). The significant role of pH for soil invertebrates has been recently experimentally demonstrated in several laboratory studies (Baath _et al_. 1980; Hagvar & Abrahamsen 1980; Hagvar & Amunsden 1981). Fertilization seems to decrease the number of Lumbricidae while having no effect on soil macroarthropods (Huhta _et al_. 1967; Lohm _et al_. 1977; Huhta _et al_. 1984;).

The effects of fertilization on several pest insects have been studied recently in Europe with apparently contradictory results. Populations of _Aradus cinnamomeus_, a sap-sucking insect living on young pines, have been recorded as being greater in fertilized than in unfertilized trees (Heliovaara _et al_. 1983). It is suggested that it is probably easier for the sucking insects to take sap from host trees which have a higher turgor pressure owing to fertilization. Loyttyniemi (1978) reported that nitrogen fertilization had little effect on pine shoot beetles and caused no essential changes in the level of damage. On the other hand, an analysis of a recent outbreak of the European pine sawfly (_Neodiprion sertifer_) on Scots pine in southern Sweden showed that the damage was _less_ severe in a fertilized stand (Larsson & Tenow 1984). It is suggested that the better nutrient status of fertilized stands probably implies an increase in available resources for allocation to processes other than growth, e.g. for synthesis of defensive chemicals. It would seem that the effect of fertilizer through increased tree vigour depends on the life style of the pest concerned, particularly its feeding behaviour, but much more information is needed.

Once the canopy has closed and ground flora has been almost, if not absolutely eliminated, the only species living wholly within the stand will be those whose life cycle is tied to the species comprising the crop and, in some cases, their parasites. The remainder of the invertebrate fauna, which is likely to comprise the overwhelming proportion of species, will be dependent on the tree crop, if at all, for secondary reasons, such as the shelter it may provide. As in the case of the ground flora (see section 2.2.2) it is, therefore, the unplanted land which is of major significance in invertebrate conservation terms.

In their natural woodland habitat, many of the butterflies and moths which only inhabit woodland feed as larvae on herbs, grasses or shrubs, rather than on the trees themselves. Many of these favour plants growing in clearings, rides and woodland margins. Even species using the trees as larval foodplants often require nectar or honeydew as adult food sources so may depend also upon flowers within the woods. For example Kelly (1983) studied the Chequered skipper butterfly (Carterocephalus palaemon), which occurs in open woodlands in western Scotland, and noted the adults feeding on a succession of flowers including English bluebell, Bugle (Ajuga pyramidalis) and Marsh thistles (Cirsium palustre). Clearly, anything which reduces the abundance and diversity of the flowering plant flora will adversely affect the insect community (Young 1986).

The major indirect effect of woodlands is undoubtedly their provision of a microclimate which seems to suit many insects. Kelly (1983) found that the glades in woodland in Argyll were less windy, more humid and warmer than the nearby open hillsides and he suggested that this favoured the Chequered skipper butterfly. However, if clearings or rides are too narrow they may remain in the shade and so stay cool and unattractive to the many insects that like sunlight and warmth, and if too straight they may act as 'wind tunnels' (Young 1986). On the other hand, some species, such as the Speckled wood butterfly (Pararge aegeria), require a mixture of light and shade such as would be found in mature deciduous woodland (Davies 1978). It would not be difficult to provide such conditions at the forest edge, along streamsides and in clearings as an alternative to the sharp delimitation between dense tree canopy and completely open vegetation. The point is that we need to know the requirements of different animals if we are to be able to provide their habitat needs. Once we do know, the provision is often relatively simple and inexpensive.

The dominance of young, single-species stands in British forestry (Rowan 1986) probably reduces their invertebrate diversity. In Sweden, the number of Arachnida species and individuals is lower in spruce plantations with closed canopy than in more open and maturer plantations with a field layer (Almquist 1982). Unfortunately, conditions in British forestry, notably the high incidence of windthrow, are reducing rotation ages so that few forests are likely to remain into maturity. This is disadvantageous as far as invertebrate conservation is concerned since many species are found only in mature woodland (Elton 1966). Others rely on dead trees or fallen timber and if this is absent not only will they be too (Heliovaara & Vaisanen 1984), but also those birds which feed upon them (Newton 1983). If groups of trees can be left, for example along watercourses, when the crop is felled, and especially if these groups can include some mature broadleaves as well as maturing conifers, the overall conservation value of the forest is likely to be substantially enhanced at little financial cost. If such groups can be included in the overall design of areas to be left unplanted in the next rotation (Low 1984), so much the better.

The information available on the effects of clearfelling on invertebrates mostly comes from abroad and largely refers to natural or semi-natural stands. Nevertheless, the same basic principles are likely to apply in clearfelled plantations. The direct effects of clearfelling, coupled with the modifications of microclimate that ensue, bring about great changes in forest and forest soil fauna. Specialized invertebrates are reduced in number or disappear, being replaced by species with considerable ecological plasticity (Szujecki 1979). However, the overall number of species increases because the influx of new ones exceeds the loss of forest specialists (Huhta et al. 1967). In the southern Appalachians, Lenski (1982) did not find any significant difference between forests and clear-cut areas in total carabid beetle species diversity. There was a decreas in genus diversity in the clear-cut areas and also a reduction in the numerical dominance of one species over its congeners. Coyle (1981), also working in the southern Appalachians, but on spiders, found that after clearfelling certain functional groups (e.g. web builders) were severely reduced, but within less affected groups (e.g. ground hunters) diversity increased. Similar effects can be found in northern Europe (Heliosaara & Vaisanen 1984).

The effect of clearfelling in allowing herbs such as Willow herb (Chamaenerion angustifolium) and Calamgrostis spp. to flourish is to favour their associated insects, e.g. the geometrid moth Sparagania bictuata on Chamaenerion (Svensson 1982). The stumps left at felling provide a new habitat which is unfortunately favoured by a range of beetles, including the so-called Pine weevil Hylobius abietis) and black pine beetles (Hylastes spp.), which breed in them but can also breed in and attack young plants of all coniferous species in restocking areas. Insecticidal protection of all planting stock by dipping is a routine requirement. Heavy brash can also provide breeding sites for these and other pest species as well as for harmless and helpful species (Heliovaara & Vaisanen 1984).

2.4.2. Control of harmful insects in forests

In an ideal world, all forests would be growing in healthy balance with their environment. Populations of pests and diseases would remain more or less in balance with predator populations (see Figure 1). While individual insects might reach pest proportions from time to time, perhaps as a result of some periodic perturbation such as unusual climatic conditions or fire, the trend would always be towards equilibrium - the dynamic balance which represents the status quo. Needless to say, our plantation forests are far removed from this utopian condition, and are likely to remain so, given the economic constraints of the real world of timber production. Thus it will be necessary to be eternally vigilant, monitoring the levels of existing pest species and the effectiveness of control procedures and watching for the signs of a hitherto harmless species getting out of hand.

At the same time there is everything to be said for pursuing the ecological approach to the control of pest species. This involves as a first essential the investigation of factors which influence the temporal and spatial population dynamics of the particular species (Watt 1986). Not only does such knowledge offer the prospect of altering forest structure and management so as to minimize the likelihood of pest outbreaks, it also enables such outbreaks to be predicted more accurately so that chemical control can be organized effectively. This in turn will enable better targetting of the insecticide, with lower overall dosages and, consequently, less damage to predators or harmless species.

As chemical insecticides are still the chief direct means of controlling insect pests, one priority is to improve their effectiveness and selectivity. Much has been achieved in this direction. Thus, in the control of Pine looper moth, there has been a progression to safer insecticides, from DDT in the outbreaks of the 1950's and 1963 to an organophosphorus insecticide (tetrachlorvinphos) in 1970 and 1971 and Dimilin (difubenzon) from 1979. Dimilin offers a real step forward since it is active only against the immature stages of invertebrates and thus has no significant mammalian toxicity, does no direct harm to fish, and does not kill the adult stages of insect predators and parasitoids (Stoakley 1986). Dimilin has also been used very successfully at ultra-low-volume (ULV) against Pine beauty moth in Forestry Commission trials in 1985 (Stoakley 1986), so there is hope that it will replace the more toxic organophosphorus insecticide, fenitrothion, in due course.

The effects of insecticides on non-target species have been studied extensively in Scandinavia and more recently in Britain. Although referring to various chemicals these studies reveal some general effects. Thus, the species living mainly on the soil surface and among litter, especially predatory ones (beetles, spiders, chilopods) seem to suffer most while the true soil fauna are less affected (Huhta et al 1967). The recolonization and replenishment of treated areas seems to take place relatively quickly (Zoebelein 1960).

Biological methods of insect pest control have not, so far, been conspicuously successful. An early attempt to control Pine beauty moth in Britain with a preparation of a bacterium (Bacillus thuringiensis) which is active only against the larvae of lepidoptera proved disastrously ineffective (Stoakley 1986). Nuclear poyhedrosis virus (NPV) has been used against pine sawfly (Neodiprion sertifer) in Norway (Bakke et al. 1983) and Finland (Nuorteva 1972). Though its killing effect on its target are indisputable, the application of the virus has hardly had any permanent influence on the abundance of N. sertifer. It has been suggested that this is because the latent stage of (NPV) disease is naturally present, especially in areas where where these diprionid sawflies have been abundant for several years (Nuorteva 1964; 1972). In experiments, the NPV disease of certain other insects has had no effect on other insect species or mammals (Ignoffo & Heimpel 1965; Heimpel 1966; Meinecke et al. 1970).

One reason for failure of earlier applications of NPV to have a major impact on sawfly populations may have been poor distribution of the virous within the affected trees. Investigations have been made by the Institute of Virology at Oxford into the use of the ultra-low-volume spray technique for application of Pine sawfly and Pine beauty moth viruses. These have been sufficiently successful for commercial-scale use of Pine beauty moth virus to be used for the first time in 1986.

Another possible method of control of insect pests involves the use of pheromone traps. Mass trapping of male bark beetles of the species _Ips typographus_ was carried out in 1979 and 1980 in Norway & Sweden. 800,000 pheromone-baited traps caught some 2.9 billion beetles in 1979 and 4.9 billion in 1980. Unfortunately many predators were also trapped, but this problem has largely been overcome latterly (Bakke _et al._ 1983). Whether the removal of several billion beetles had any effect in averting even more catastrophic losses than took place in those years remains open to conjecture (see Birch & Haynes 1982).

There is one functional group of insects which has not been mentioned so far, and on which little if any work has been done, but which have a major if not overriding influence on the amenity value of woodlands. These are the biting insects which attack men and include midges, horseflies and headflies. In some forests in the west of Britain these insects can be so troublesome in summer as to severely reduce their recreational value. While it will not be possible ever to eliminate these insects from the forest it might be feasible to alter the forest in such a way as to limit their numbers to tolerable levels. With the ever-increasing emphasis on the role of forests as providers of recreation it would be worth initiating a project to investigate the population dynamics of, in particular, midges in forests. It is likely that microclimatic factors would be of major significance in any such study.

2.5. Birds in plantation forests

Because of their popular appeal and the fact that they are relatively easily observed, birds have been studied in forests more than any other group of animals. For this reason less work remains to be done on birds than on other groups. There is currently considerable interest in plantations as habitat for game birds. ITE's commissioned project on Black grouse (ITE 764) complements the study of the same species recently initiated in Wales by the Forestry Commission. ITE also has a commissioned project on Capercaillie (ITE 442). The priority project (ITE 636) on songbird populations and woodland diversity continues a long-standing ITE involvement in research in this field. The Forestry Commission has initiated a study of the effects of afforestation on Dhu Lochan habitat in Sutherland and Caithness, concentrating on predation of waders by mammalian and avian predators living in surrounding plantations.

2.5.1. Effects of tree species on bird diversity and numbers

Some species (Hawfinch, Marsh tit, Garden warbler, Blackcap, Wood warbler, Chiffchaff, Pied flycatcher, Green woodpecker) are more or less confined to broadleaved woodland whereas others (Capercaillie, Crested tit, Crossbill) are restricted to conifers. Goldcrest, Coal tit and Siskin are much commoner in conifers than broadleaves (Newton 1986). The species restricted to conifers have, as might be expected, spread with the planting of conifers.

Tree species also influences density. According to Newton (1986), on similar sites in Finland, breeding birds are more abundant in birch/oak than in spruce, and more abundant in spruce than in pine. French et al. (1986) found, on the other hand, that in woods in the north-east of Scotland, conifers held more breeding birds than birch, although less than oak. Among mixed forests in Scandinavia, bird densities in spruce/pine are nearer to pine than spruce, whereas densities in birch/spruce are as high, or higher, than those in pure birch, and much higher than in pure spruce (Palmgren 1930; Merikallio 1946; Haapanen 1965). It is not clear why pine supports low densities but it may be because it has less foliage per unit area than do the other trees, and hence less habitat for insects. It also offers less good nesting sites than spruce and has cones which are more difficult to open (Newton 1986).

Mixtures of conifers and broadleaves increase bird species diversity partly by increasing structural diversity but mainly by providing habitat for species tied to one or the other tree type. French et al. (1986) found that maximum bird densities are achieved if the ratio of conifer:broadleaves lies between 1:3 and 1:5 in either direction, and if the sub-dominant component is present as clumps up to one hectare in area, rather than scattered evenly. Williamson (1972), in discussing bird life in lowland coniferous forests in Herefordshire, recommends the retention of broadleaved stands in an irregular pattern including some isolated broadleaved trees. He states that broadleaf blocks of under half a hectare in conifer forests are unattractive to birds and that two smaller blocks of a third to half a hectare are better. On the other hand, Bibby et al. (1986) have shown that in North Wales forests, small groups of broadleaves or even individual trees supported disproportionately large numbers of the bird species which require broadleaved habitat, suggesting that scattered broadleaves might be proportionately more effective than larger areas in increasing bird diversity in plantations.

What is needed to determine more precisely the effects of broadleaves in conifers, if indeed this is considered necessary, is the establishment of a series of replicated trials in conifer plantations on different soils and in different situations with broadleaf clumps of different sizes using a range of species. Such trials could be part of a wider series designed to investigate a range of forest wildlife conservation issues.

2.5.2. Effects of forest area on bird diversity and numbers

The larger the area of uniform woodland the lower the overall density of birds (Oelke 1969). This mysterious rule is widespread - oceanic islands often have astonishingly high densities of birds, as do small islands of habitat in mainland situations (MacArthur 1971). It is unlikely that this effect, like the positive effect of soil fertility on bird abundance (von Haartman 1971), can be explained in terms of increased biological productivity. One factor may be the so-called 'edge effect' (Odum 1959) by which birds are found at much greater density at the boundary between two habitats than within either one of them. The edge effect is apparent at the junction between different tree communities, but especially where a wood adjoins an open area. In this last situation, some species nesting on the forest edge, such as Crow, Woodpigeon, Kestrel, feed mainly in the surrounding open areas. Thus the density of nesting birds in the wood may be greater than could be sustained by the wood itself (Newton 1986). In this way some raptors, including Hen harrier, Buzzard, and locally Goshawk, have benefited from the patchy planting of upland in some areas. However, if the surrounding open land is later also planted, they will disappear, since open areas within the forest do not offer the same food supply as the sheepwalk and heather moor (Marquiss et al. 1978; Newton 1986).

While bird density is greater in small woods than large, the number of species in small woods is often less. Moore & Hooper (1975) found number of species became less with decreasing area and also with increasing distance from other woods. Newton (1986) suggests that the relationship between area and isolation of a wood and its bird fauna needs further quantification in the British context.

2.5.3. Effects of dynamic forest structure on bird diversity and numbers

2.5.3.a. Fencing to canopy closure

The first 10-15 years after afforestation can usually be regarded as productive (Ratcliffe 1980). Some species, especially certain moorland wading birds, disappear early on , but others increase in abundance and there is a colonization by species which need open scrub with good cover and scattered trees (Lack 1933; Reed 1982; Harris 1983; Newton 1984). The overall density of birds may also increase, as is to be expected from the increase in structural complexity of the habitat. The most noteworthy effect in the uplands is the increase in population density of Short-tailed field vole (Microtus agrestis), which in 2-3 years from fencing can reach densities 100-200 times greater than on the original sheepwalk (Charles 1981). This food source attracts open-ground predators such as Short-eared owl (Goddard 1935; Lockie 1955), Long-eared owl (Village 1981), Kestrel (Village 1982;1983) and, locally, Hen harrier (Ratcliffe 1986). Black grouse, Stonechat and Whinchat also typically increase and, at lower elevations, species such as Tree pipit, Grasshopper warbler and Willow warbler often appear.

2.5.3.b. Canopy closure to clearfelling

Once canopy closure occurs subsequent development of the avifauna depends on location and silvicultural practice. Tree density in the maturing forest is very important because it determines light penetration, which in turn affects the development of vegetation under the trees, and hence the associated animal communities. In the typical situation described earlier (section 2.2) in the western uplands, where virtually all vegetation is eliminated, birds become confined to the canopy and edges, and consist of species able to survive under these limited woodland conditions. A community dominated by songbirds replaces one in which waders are specially well represented (Moss 1978; Reed 1982). The sparrowhawk replaces the merlin as the most characteristic raptor and the Tawny owl takes over from the Short-eared (Ratcliffe 1986).

In a more open conifer forest, such as is sometimes found in the case of pinewoods in the more easterly and southerly parts of Britain, and which begins to approach the structure of natural high forest, a many-layered vegetation develops with a rich ground flora and a shrub layer, with perhaps a tree understorey. Such forest holds more bird species than a dense uniform stand in which all the trees are the same height (Newton 1986). In such forest, structural diversity is apparently more important than the number of tree species in influencing the number of bird species present (MacArthur & MacArthur 1961; Moss 1978; O'Connor 1981; Orians 1969; Recher 1969). Scottish pinewoods with a shrub layer hold slightly more species, and about double the density of birds, as do even-aged stands with no shrub layer (Newton & Moss 1978). French et al. (1986) found that in general an evergreen shrub layer, whether conifer or broadleaved, was consistently better for songbirds than a deciduous shrub layer and a mixed shrub layer, at least in combination with a mixed canopy, was better than either. They found that feral rhododendron, berated elsewhere in this review for its harmful effects on ground flora (see p. 21), was particularly good, removal resulting in "drastic" decrease in species richness.

The main reason why the complexity of the habitat has such a great influence on the bird community is that many woodland birds show a distinct vertical zonation in their feeding. Colquhoun & Morley (1941) distinguished 3 classes: ground feeders; tree and shrub species; upper canopy feeders. Among the tits, for example, in oakwoods Great tit feeds mainly on the ground, Marsh tit on the lower branches and shrub layer, and Blue tit largely in the canopy. French et al. (1986), as a result of combining information from literature sources with their own observations in Scottish woods, extended these to 7 classes: open ground birds; ground + shrub birds; stem and air birds; tall shrub birds; tall shrub + canopy birds; canopy birds; whole profile birds (either requiring, or able to use almost any level).

Structural complexity also has a horizontal component, many typical woodland birds being associated with openings of one sort or another. Some species, such as Willow warbler, prefer a broken canopy, while others, such as Tree pipit, prefer glades devoid of trees. Yet others, such as Whitethroats, require areas of low scrub. When considering those requiring areas devoid of trees, it is only a matter of degree before open-ground birds come into the reckoning, and in the ideal mature forest many of them would find a place.

Availability of nest sites is an important aspect of structure. In managed forests, where dead wood and scrub may be absent, densities of hole- and shrub-nesting species may be limited by shortage of nest sites. This has been shown in many studies where the provision of nest boxes or bunches of branches (tied and stuck up to look like bushes) resulted in marked (up to 10 X or more) increases in density of such species (Pfeifer 1953; 1963). Pied flycatcher, normally considered to be a bird more or less exclusive to broadleaved woodlands in Britain, will breed in pure conifer woods devoid of natural nest holes provided that nest boxes are available and the woods have a reasonably open structure (Newton 1986).

2.5.3.c. Clearfelling and replanting

The age at which the forest is clearfelled is important for bird conservation because mature and over-mature woodland provides habitat not available in the maturing plantation (Ratcliffe 1986). As we have seen earlier, economic constraints, allied with the problem of windthrow, mean that in practice few plantations are allowed to grow to maturity. Felling at age 30-35 years is now common practice in the west of Britain where windthrow is particularly prevalent and areas within plantations may succumb at an even earlier age than this. The replanting of windthrow areas has the positive advantage of increasing age-class diversity but does not make up in ecological terms for the loss of old trees and open mature canopy.

As we have seen earlier (section 2.2.1.c), vegetation between rotations is different from that at afforestation. Accordingly, the numbers of small mammals, notably Microtus agrestis, do not reach the same high levels and hence the high raptor numbers are not repeated. Deer (as we shall see later, section 2.6) have a dramatic impact on the vegetation between rotations. In areas, such as North Wales, where they are absent, rich soils are soon colonized by broadleaved seedlings and forbs which in turn support a diverse scrub-dwelling avifauna (Currie & Bamford 1981; Bibby et al. 1985). In Northumbria, on the other hand, where deer grazing results in grassy vegetation, the bird community was similar to that on newly-planted land, with Meadow pipit the most abundant species (Leslie 1981).

2.6. Mammals in plantation forests

As a result of early post-glacial separation from the continent of Europe, Britain is depauperate in mammals (Staines 1983). Most of those indigenous species that we do have are by nature woodland or woodland edge dwellers so the removal over the centuries of most of our native woodland has reduced their numbers. Conversely, the recent re-afforestation has, by and large benefited them, particularly where forest has replaced open moorland and sheepwalk. Many of the larger carnivores have increased their range since the turn of the century, especially in Scotland. These include Pine marten (Lockie 1964; Verlanders 1983), Wild cat (Jenkins 1962; Corbett 1979) and Red fox (Lloyd 1981). Langley & Yalden (1977) reviewed the possible reasons for the decline of the rarer carnivores during the nineteenth century and their subsequent recovery in Britain as a whole. They concluded that the revival was mainly due to less persecution, since it coincided with a decrease in the number of gamekeepers (particularly during and immediately after the first World War) and preceeded the development of large-scale afforestation. Hewson & Kolb (1974), on the other hand, found that the number of foxes killed at a forest in south Scotland increased with afforestation even though fox control was vigorous.

ITE research on mammals in woodlands is currently restricted to five projects on Red deer (ITE 54, 104, 111, 479, 528), the last two of which are priority ones specifically concerning deer in forests, and two priority projects on suirrels. One of these (ITE 606) is concerned with damage caused to forests by Grey squirrel, the other (ITE 811) with foraging and reserve storage in Red and Grey squirrels. The Forestry Commission Wildlife Branch has a project in hand reviewing habitat requirements of Red squirrel. Additional research projects on mammals which should be considered are emphasized in the text that follows.

2.6.1. Effects of tree species on mammal diversity and numbers

The effects of tree species on mammal diversity and abundance is poorly understood compared with what we know for birds. However it is reasonable to suppose that, as in the case of birds, forest structure is, in general, of more importance than species composition. This supposition rests on the fact that most mammalian herbivores are catholic in their choice of foods while carnivores will tend to flourish provided that a food source is available along with nearby cover and suitable breeding sites (Staines 1986). Some species prefer particular types of woodland, however, for example bats such as the Noctule (Nyctalus noctula) and Leisler's (Nyctalus leisleri) which need old hardwood trees with holes for roosting and nesting.

In Britain the Red squirrel (Sciurus vulgaris) is most abundant in large Scots pine woods in Scotland (Tittensor 1970) and eastern England (Reynolds 1981) but they will also occupy pure broadleaved or mixed woods (Spark 1936; Gurnell 1983) and the seeds of deciduous trees and shrubs are important food items at certain times of the year (Moller 1982). No quantitative information is available on the densities or ecology of Red squirrels in the upland Sitka spruce forests but elsewhere in northern Europe spruce appears to be preferred to pine (Pulliainen 1973), the seeds of spruce having a higher calorific value than those of pines and being easier to strip off the cones (Danilov 1938). Most of this work on Red squirrels in Europe was done in mixed Norway spruce and Scots pine forests, where it is relatively esay for them to switch from the dependable but less nutritious food supply of pine seed to the sporadic but more nutritious supply of spruce seeds in years of abundance. In Britain, where spruce and pine are usually segregated in different (often distant) plantations, Red squirrels in pine forests cannot necessarily use the irregular bumper crops of spruce seeds. Nor can the low density populations supported by spruce forests make use of the dependable crop of pine seed. It would seem, therefore, that effective conservation of Red squirrels in Britain could best be achieved either by lengthening the rotation of spruce to provide larger biomass of seeds or by planting more mixtures of pine and spruce (Ratcliffe & Petty 1986). As we have seen earlier, rotation extension is extremely unlikely to occur because of increased risk of windthrow with increasing tree height (Busby 1974) and economic constraints (Hamilton & Christie 1971; Busby & Grayson 1981), but increased use of Scots pine, although disadvantageous financially, may take place because it meets a range of wildlife conservation and aesthetic amenity requirements (Ratcliffe & Petty 1986).

2.6.2. Effects of forest structure on mammal diversity and numbers.

Following afforestation, the seral stages of the forest provide various combinations of food and cover which affect species differently, but the young forest stages before canopy closure provide the key habitats for most species (Staines 1986).

2.6.2.a. Fencing to canopy closure

Exclusion of domestic grazing stock is usual in all plantations, but in 55% of afforested areas, mainly in north and central Scotland, Red deer (Cervus elaphus) are also excluded by fencing (Ratcliffe 1984). As we have already seen, the resultant increase in vegetation biomass leads to an enormous increase in vole numbers (Charles 1981). These provide a ready source of food not only for raptorian birds but also for mammalian predators, such as Red fox (Vulpes vulpes), Wild cat (Felis sylvestris) and Weasel (Mustela nivalis). Where Red and Roe deer (Capreolus capreolus) have not been effectively excluded, they will make substantial use of these areas for feeding, markedly reducing the botanical diversity at densities as low as 3 Red deer per square kilometre (Krauss 1985), a density commonly exceeded in Scottish forests (Ratcliffe 1984; 1985a).

Roe deer became extinct in the Scottish lowlands and in England and Wales by the end of the 17th century (Bewick 1800; Ritchie 1920), and were restricted to Ross, Inverness, Argyll and Perthshire (Ritchie 1920). Having increased steadily in the late eighteenth and throughout the nineteenth centuries they are now the most widespread deer species. Roe reach their highest densities in young plantations or in the early stages of re-stocked forests (Loudon 1980; Staines & Welch 1984) and may reach 25/100ha in 5-15 years old spruce forests.

Red deer, which were previously restricted to open-hill ground, have colonized most large coniferous plantations in the Scottish uplands except, so far, those in the borders. They are resident throughout the year, reaching comparable densities to those on the open hill, generally ranging between 5-15/100ha. They, like Roe, need an intimitate mixture of open ground for food, and cover, but prefer older thickets for cover, especially when the growth of the conifers is in heather check (Staines & Welch 1984). Body weights and reproductive rates of forest deer are frequently higher than those of deer living on open moorland (compare Mitchell *et al.* 1977 with Mitchell *et al.* 1981 and Ratcliffe 1984) and with puberty reached earlier and adult females breeding every year, population turnover is high.

Japanese Sika deer (*Cervus nippon*), which were introduced to Britain in 1860, are now feral and widespread throughout much of the north and west of Scotland (Ratcliffe 1986). Their increase is related to the expansion of commercial forestry as they are, more than Red deer, a woodland species. There is concern over the fact that they hybridize with Red deer, creating a threat to the genetic conservation of the native species (Lowe & Gardiner 1975; Harrington 1982). They appear to favour much the same forest conditions as Red deer, but have not been studied as intensively.

2.6.2.b. Canopy closure to clearfelling

Closure of the canopy, and the associated elimination of the ground flora, terminates the period of high vole numbers except in clearings and rides. As a result, carnivore numbers decline. However, very large areas of uniform growth are uncommon, many forests having developed an uneven height and tree density by the thicket stage due to local variations in site quality and weed suppression. The resulting structural diversity, with small vegetated glades within thickets provides ideal conditions for Red deer, which reach their highest densities found in Britain (Ratcliffe 1984). Roe deer are less favoured and in the later thicket stage they tend to decline in numbers (Staines & Welch 1984).

As the tree crop ages, it usually becomes more open as a result of death of suppressed trees, thinning, and in some situations, windthrow. The limited field layer that may develop is, however, of low quality for herbivores, and deer use this stage less than any other. When the trees begin to produce seed Red squirrels may begin to colonize. (Tittensor 1975).

2.6.2.c. Clearfelling and restocking

Felling coupe size depends upon economic and environmental considerations, modified to a greater or lesser degree by actual or expected windthrow damage (Low 1984). In practice the areas are usually much smaller than areas being planted for the first time. Thus in the second rotation, and presumably even more in subsequent ones, a mosaic of open areas with forest of various ages between is established, adding considerably to the general wildlife conservation and amenity values of the forest. There will be a greater amount of forest edge habitats and a greater area of young forest. This is because the proportion of a plantation before canopy closure is related to the length of the first rotation (Konig & Gossow 1979). With rotations averaging only 45-55 years predicted for many spruce forests in Britain (Ratcliffe & Petty 1986), 40% of the forest will be in the 1-15 years age group; compared with 10% in a forest of 100 years rotation.

This predominance of young forest will favour most mammals provided that the relationships between animal abundance and habitat types are similar in subsequent rotations to what they are in the first (Staines 1986). What we know with regard to deer suggests that they, in particular, will do even better in later rotations. Red and Roe numbers can reach very high levels in restock areas with adjacent cover. On larger sites, Red deer tend to keep close to cover, using the centres of such areas less than the edges (Thirgood 1984). Few studies have been made of other species in re-stocked areas and more research is needed into this increasingly important habitat type. For example, if vole numbers increase in re-stocked areas as they do in newly afforested areas, will mammalian predators show similar increases or will the brash and other debris limit their hunting efficiency? Perhaps it will limit the efficiency of some predators more than others so shifting population balances?

2.6.3. Mammals as forest pests and their control

As we have seen above, plantation forests often carry abnormally high numbers of a wide range of mammals compared with the open moorland or sheepwalk that they replace. Unfortunately, this can lead to severe conflicts of interest between conservationists, foresters and farmers (Staines 1980, 1983). Carnivores, particularly foxes, are thought to affect farming and game interests. In a survey of farmer's attitudes to forestry in Wales, increased incidence of foxes was cited most often as the main disadvantage of forest plantations (Thomas & McLean 1984). Farmers were generally willing to accept forestry if they got something in return, such as landscape improvement, monetary gain or employment, but not if the increased incidence of foxes caused a nuisance. Likewise, there is concern that in grouse moor areas, foxes use the forest as a breeding refuge and feed on ground nesting birds, notably Red grouse, on the surrounding moor (Ratcliffe 1986). There does not seem to be any hard evidence to support this supposition.

In the case of herbivores, notably deer, there is concern not only about the undoubted damage they do in forests but also among agricultural landowners that, using the forest as a refuge, they too move out onto the surrounding moorland where they compete with livestock for grazing (Staines 1986). It is well known that selective grazing by high densities of deer causes damage to commercial tree crops (Burdekin & Ratcliffe 1985) and drastically reduces botanical diversity (Krauss 1985). Pines are more susceptible than spruces (Mitchell et al. 1977). In Norway spruce, Walker (1979) found that although increment was not affected by bark stripping, the usable bole length was reduced by 2m, largely due to fungal rots, staining and resin and bark inclusion. This resulted in a 30% loss of timber volume and 45% loss in revenue from the crop. Surprisingly, no comparable study has been done on Sitka spruce: an important gap in knowledge that should be filled. As regards browsing: the growth of Norway spruce is clearly retarded by heavy browsing, but Staines (1986) believes that Sitka spruce on fertile sites may be little affected. Multiple leading stem production, a common response to browsing in Sitka (Welch et al. 1983; Staines & Welch 1984), does reduce timber value however. Here, as in the case of bark stripping, insufficient is known of the long-term effects at different deer densities and in different forest situations.

There is no doubt that in areas (increasing all the time) where deer are a problem in forestry, controlling them effectively represents one of the stiffest challenges to woodland managers. It is clear from the flow diagram showing the factors influencing deer numbers in forests (Figure 2) that the food ratio (FR) of food available per deer (FPD) to food required per deer for normal growth (NFPD) has a key influence on deer nett growth rate (DNGR) and hence deer population. If there is a growing population of deer and the trees offer a palatable source of food when other more palatable sources are inadequate to meet the deer's requirement for normal growth, be it only at certain times of the year, the trees will be damaged and deer numbers will tend to continue to increase. One obvious way to reduce damage is to reduce deer density which may be done in a number of ways. Sensitive plantations may, as at present, be fenced against deer. Alternatively planting, or encouragement of natural development of more palatable species (such as willow) in unplanted areas, combined with rigorous control by shooting would seem to be an attractive option.

The problems of controlling deer should be anticipated at the afforestation and re-stocking phases and sites for high seats (Rowe 1979) and deer control clearings or glades should be selected throughout the forest. These should, where possible, be located in areas naturally favoured by deer (Ratcliffe 1985). Carefully sited glades may be beneficial to landscaping and wildlife conservation as well as aiding effective deer control by rifle. Ogilvy (1986) considers that if more extensive forests are established, using good internal design for deer control, it will be possible to do away with deer fences. There will be no

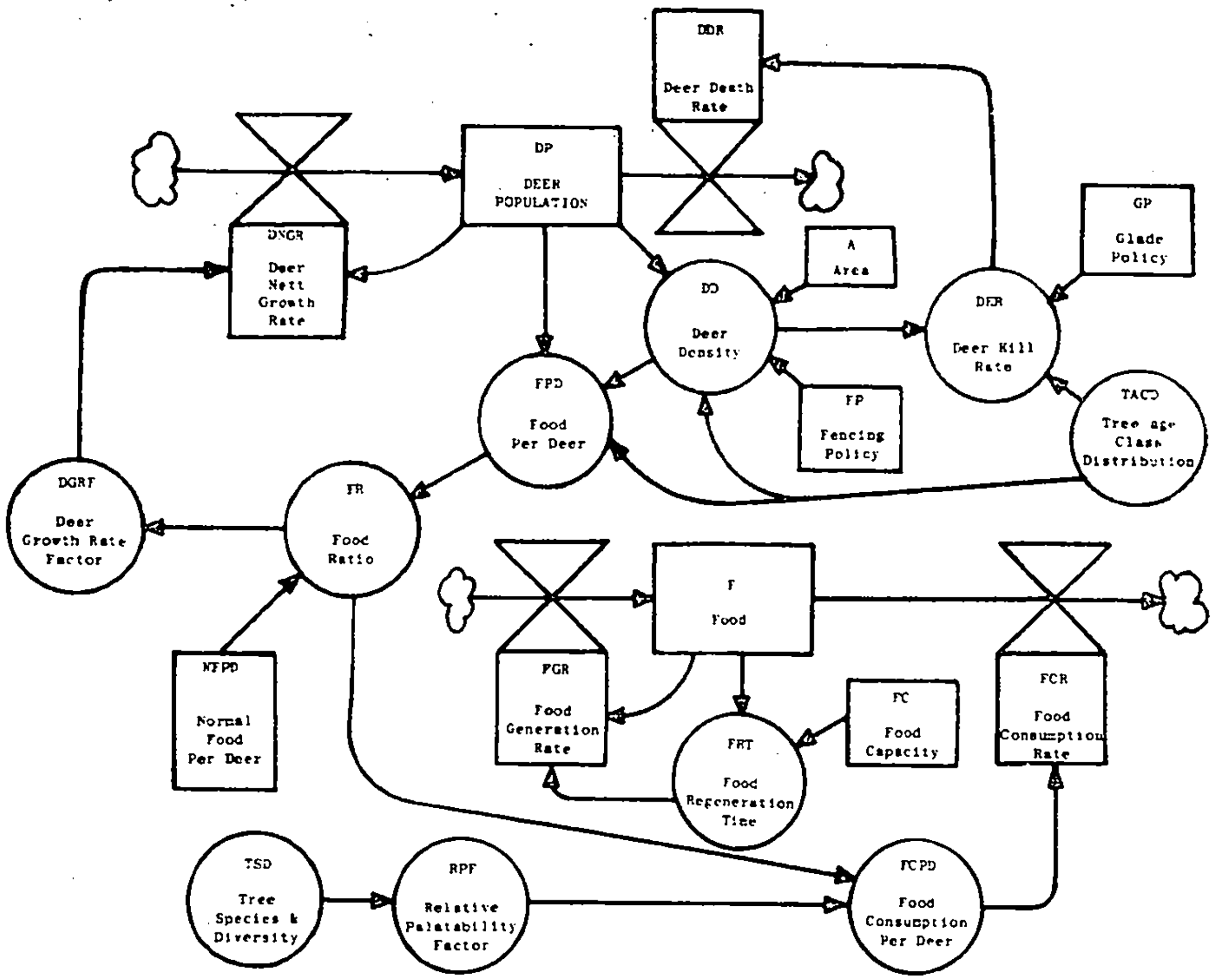

Figure 2. Flow diagram of deer in conifer Plantations.

distinction between deer and forest land, the deer moving freely between forest and hill with both deer and stalker adapting to a truly integrated environment.

2.7. Dynamic forest structure and forest microclimate

Much has been made throughout this review of the effects of forest structure, changing with time, on the species diversity and abundance of various groups of plants and animals and on soils and soil waters. We have seen that water yield is greatly influenced by forest structure as are, for example, composition and productivity of the ground vegetation, insect abundance and diversity, and deer fecundity. What are the controlling factors in each case and how does the developing structure of the forest, interacting with the wider environment beyond, and the more enclosed environment within, affect them? We may know that shelter and sunlight are both essential habitat components for many woodland Lepidoptera, but what are the actual wind speed reductions in plantations of particular structure and how does crown shape influence light interception and shadow cast? By answering these and similar questions, while at the same time quantifying more precisely the physical habitat requirements of particular species or groups of organisms, progress is made towards achieving greater control for particular ends through forest management.

This field of research is a very active one which has attracted physicists and micrometeorologists as well as plant physiologists. Much of the research involves building and testing complex mathematical simulation models for forest atmosphere interactions. Most studies are single-site oriented and involve costly installation of sophisticated instrumentation including microcomputer-based automatic data acquisition and handling systems (Hutchison & Hicks 1985). While the detailed information coming from such studies may, if combined with that from other studies at other sites, produce important guidance to those trying to quantify forest environment in relation to the occurrence and abundance of particular species or groups of plants or animals, it is not, in itself, relevant to the present review. It is proposed here, therefore, to simplify matters by reporting in a much abbreviated form what is known of the dynamics of plantation growth and the effects of dynamic forest structure on differrent forest environmental phenomena.

ITE's main research thrust in this field has been through the extensive lon-term studies carried out in a young Sitka spruce stand at the Rivox site in S. Scotland. Over a period of 15 years, much information has been gained on forest-atmosphere interactions during the period from pre-thicket to closed canopy. This work contines under priority project 831 (Modelling of transpiration in Sitka spruce). Much work has also been done at this site on patterns of root growth and this is continuing under project 801 (Radial growth of Sitka spruce roots). Increasing interest in the problem of windthrow has led to the initiation of two new projects (ITE 1003 and 1042) investigating the mechanics of the phenomenon.

2.7.1. Fundamental processes which determine microclimate

For much of what follows I am indebted to an excellent review by Ford (1984).

The microclimate of a site is determined by its pattern of heat and water balance. While total inputs of radiation and precipitation and world climatic systems set limits, both heat and water balance are strongly influenced by soil and vegetation properties.

2.7.1.a. Heat balance

Of the total solar radiation received, some is reflected and scattered and some is emitted as long-wave radiation. That remaining which is available for energy transformations is the nett radiation. This is partitioned in four ways (see Thom 1975 for a comprehensive account).

1. Heat is transferred to the atmosphere by direct warming of the surrounding air. This is termed "sensible" heat transfer and occurs either by natural convection, where surface to air temperature differences create air movement, or forced convection as a result of wind-driven turbulent exchange. Forced convection is the stronger process (Gates 1962) and is the chief means by which heat and water vapour are exchanged between canopy and atmosphere. The way in which individual leaves and branches shelter each other in a canopy determines the efficiency of exchange. The rougher the surface the greater the exchange.

2. Water is evaporated. Maintaining a high rate of evaporation depends upon maintaining a water supply to the evaporating surface and rapid removal of water vapour into the atmosphere by turbulent exchange.

3. Heat is stored in the vegetation. The rate of exchange depends primarily upon temperature differences between air and vegetation, the heat conductivity of the vegetation and the mass of vegetation.

4. Heat is transferred to the soil. The rate of transfer depends upon the heat conductivity of the soil and its temperature gradient with depth. The steeper the gradient the greater the conduction for the same soil heat conductivity.

The relative values of these processes varies with meteorological conditions and between day and night.

2.7.1.b. Water balance

Precipitation may be evaporated into the atmosphere, stored in the soil or vegetation, or drained from the catchment (see Rutter 1975). Evaporation links the heat and water balances and is of fundamental importance in determining the character of the microclimate and, therefore, the conditions for plant growth. It has three components which must be carefully distinguished:

1. Interception loss - precipitation which evaporates directly back to the atmosphere from the surface of the vegetation. Its magnitude depends upon both the size and water retention capacity of the vegetation and on the meteorological conditions prevailing during and immediately following precipitation.

2. Transpiration - depends upon the energy available for evaporation, canopy size and ventilation, and factors controlling the rate of water supply to the foliage (Jarvis & Stewart 1979).

3. Evaporation from the soil surface. Once standing water has evaporated, then evaporation rate depends upon the upward movement of water through the soil by capillary action or the diffusion of water vapour through the soil pores. These processes vary between different types of forest soil (Pritchett 1979).

The properties of stand and site which determine patterns of heat and water balance fall into three groups: the size and mass of the vegetation, the physiological properties of the trees, and the soil characteristics. These may all change as the plantation grows and so come to have different relative importance in determining the microclimate.

2.7.2. Plantation development and forest microclimate

2.7.2.a. Windspeed

It is obvious to anyone who has entered a mature forest from open country on a windy day that reduced windspeed is one of the most marked characteristics of forest. It is one of the most attractive features of woodland from the amenity point of view and one which makes it particularly attractive to wild animals requiring shelter from high winds, e.g. most butterflies and moths (see section 2.4.1.d). The obvious effect of forest structure on windspeed and the fact that it is relatively easy to measure have caused it to be the most frequently measured and discussed environmental forest variable. Within the canopy, large differences in windspeed profiles occur as a result of differences in the structure and density of the canopy. Higher within-canopy windspeeds are associated with more open canopies. In a typical 14m high Sitka spruce plantation in Scotland, Jarvis et al. (1976) found that in the middle of a sunny summers day, windspeed fell away fairly gradually for the first 2m below the canopy surface, then falling sharply until at 8m above the ground the air was virtually still. Windspeed then gradually increased again towards the ground with a sharp peak at about 30cm above ground level, falling away again to zero. The presence of an understorey would undoubtedly alter this profile, but in what precise way is not known.

Wind profiles are markedly affected by the wind characteristics of the area surrounding the forest. Topography will affect air circulation, upslope and upvalley winds generally occurring during daylight, drainage winds at night. Drainage winds are usually cool, humid and laminar in nature while upslope and upvalley winds are generally warmer, less humid, and more turbulent. The time of cross-over between these wind movements depends upon the orientation and size of the valleys and slopes and the nature of the surfaces (trees, grass, water, rock etc.). If the forest is located on a ridge or plateau, more vertical flow divergence and convergence will occur compared with in a valley forest. These phenomena will probably affect wind direction, temperature and humidity more than other variables.

Wind blowing into a forest from a clearing is reduced to an equilibrium state within quite a short distance provided the forest edge is fully developed with a "wall" of foliage to near ground level. Fritschen et al. (1969) quote figures of equilibrium with forest ambient windspeed being achieved within 2-3 tree heights of the forest wall. This windspeed reduction zone is much larger if there has been recent clearfelling and the forest wall has not had a chance to regrow. When wind is blowing in the opposite direction, there appears to be an acceleration of wind through the crowns next to the forest wall. This has been confirmed in wind tunnel studies which showed the acceleration zone to exist for the last 10 tree heights (Meroney & Yang 1969). Boundary conditions affecting forest environmental phenomena have been fully described in a recent review (Fritschen 1985).

2.7.2.b. Air temperature

In the same Sitka spruce forest referred to above in relation to windspeed, Jarvis et al. (1976) found that air temperature increased steadily from the canopy surface to about half the canopy height where a zero gradient was reached as in the case of windspeed. Temperature then fell away sharply for about a metre before achieving a steady fall to ground level. This profile is expected , since the soil and tree trunks are sinks for sensible heat. The differences in air temperature within the profile are actually quite small (about 1.5oC in the Sitka spruce example quoted), but the absence of wind in the same area of the profile would reduce heat loss of animals spending much of their time there.

2.7.2.c. Radiation

Conifer canopies absorb a higher proportion of the solar radiation that falls upon them than agricultural crops, hence the failure of ground vegetation to thrive, or even in the case of heavy shade-casters, survive beneath them. Interception by forest canopies has been measured many times to define the radiation environment for the ground flora, but such measurements have rarely been accompanied by measurements of the area of leaf present in the overstorey because of the obvious practical difficulties in making such measurements. Regarding the quality of the light reaching the forest floor; it seems that, regardless almost of species, conifers behave like a neutral filter in the blue part of the spectrum (Jarvis et al. 1976), reducing irradiance but not markedly changing its composition. Depletion in the blue is greater under broadleaves. Such differences, while small, may be important in determining the balance of species in the ground vegetation beneath different tree types where light penetration is sufficient to allow growth.

The radiation interception rate is essentially a function of height development of the total forest canopy, almost exclusively so in the case of closed conifer canopies, but other factors must be taken into account where broadleaved forests are concerned. The difference in interception between the foliated and leafless period is less than one would imagine because the reflectance (albedo) of trunks and branches is generally higher than that of leaves.

2.7.2.d. Water balance

Precipitation interception loss from conifer crops with full canopies can proceed at three times the rate for grass (Calder 1979). This difference is due to a combination of low canopy resistance, which increases potential evaporation, together with a large capacity to hold intercepted water, which reflects the large surface area of forests. Thus when a light summer rain shower falls on such a canopy, all of the precipitation may well be evaporated back into the atmosphere, none reaching the forest floor.

Generally, as would be expected, annual interception loss is greater for evergreen than for deciduous forest (Helvey 1967), but we have no information for changes in interception with stand age in British plantations. One study on *Pinus strobus* stands in N. Carolina showed that interception increased with age (Helvey 1967), but no information was presented on foliage densities so the results are difficult to interpret. Studies relating stand age, tree density, canopy height and foliage density with precipitation interception are required.

While interception is generally greater for forest than for agricultural crops, transpiration is generally less. Jarvis & Stewart (1979) suggest that transpiration from well-watered short vegetation may be two or three times higher than that from plantation forests. This is largely because of the characteristically high leaf resistance to transfer of water vapour into the air shown by trees which makes them conservative of stored water.

Water passing through the canopy can reach the ground either as throughfall or stemflow. We saw in section 2.1.2.a that stemflow is the more acidic and noted the suggestion that it may be a major cause of increased soil and soil water acidity under conifer crops. It was also noted that soil acidifcation was most marked in the early to middle years of the crop, declining as it approached maturity. In the light of this knowledge it is interesting to note that in a young (14 yr old) Sitka spruce plantation Ford and Deans (1977) found that 40% Of the summer water flux to the soil occurred as stemflow and that a large proportion of throughfall was also shed close to the main stem, whereas in older Norway spruce Aussenac (1970) found the reverse pattern with a lower proportion of stemflow and increasing throughfall amount at increasing distance from the trunk. Ford (1984) suggests that the difference reflects differences in branching habit between young and old trees. In young, dense plantations, the top-most branches tend to be erect, and so conduct water towards the main stem, whereas in older stands a large proportion of the total branch length becomes angled away from the tree, favouring throughfall.

The uneven pattern of distribution of water through the canopy is reflected in tree root distribution. Ford & Deans (1977) found greater concentrations of fine roots in regions of high throughfall and stemflow in the Sitka spruce plantation referred to above, than in drier parts of the soil. As a result of the higher root biomass more water is withdrawn from these areas and, in times of drought, there is very substantial root death (Deans 1979). Thus the soil beneath the trees, far from being homogeneous as regards water content and root biomass, is patterned, with areas receiving relatively little precipitation input having relatively few roots and relatively constant soil moisture tension and those reciving large inputs having large and fluctuating root biomass and associated large variations in soil moisture tension. The situation is a good deal more complex than this, however. Stemflow contains a higher concentration of nutrients than throughfall (Parker 1983), so nutrient uptake is probably greater by the roots in the wetter areas which receive more of it. Also, the rate of mineralization of organic matter in the soil surface layers is likely to be higher where soil moisture deficits are lower (Brix 1979).

2.8. Tree species and sylvicultural systems

As this is not a review of forestry from the wood production point of view it would be inappropriate to discuss in detail the merits of different species and species combinations and of different sylvicultural systems with regard to yield and timber quality. It is appropriate, however, to consider their merits from the conservation and amenity points of view.

2.8.1 Tree species choice and mixtures

There is no doubt from what has been said so far in this review that increased use of native species, especially broadleaves, is highly desirable in British forestry from the conservation and amenity viewpoints. Broadleaved forest, being leafless in winter, allows the development of a rich ground flora and understorey (Hill 1983). It also supports many more species of insects (Kennedy & Southwood 1984) and more birds (Newton 1986) than either native or introduced conifers. This is partly because the broadleaved trees themselve provide a more palatable food source than conifer needles; partly because the ground flora and understorey supplement this and provide (for mature insects) sources of nectar (Young 1986); and partly because they provide a more diverse structure and thus a greater range of habitat (Elton 1966; Massey 1974; Moss 1978; Almquist 1982). It is assumed, although with little hard information to support the assumption, that mixing hardwoods with conifers also leads to increased biological diversity. As was noted earlier (section 2.4.1.c), this is an area in which much more research is needed. Certainly as far as birds are concerned, the structural diversity inherent in mixtures will favour species diversity (Williamson 1972; Bibby et al. 1986; French et al. 1986).

The use of broadleaves and of species mixtures is unlikely to win much more than token support from foresters while maximising the value of the forest is seen by many only in terms of producing the maximum volume of timber of the best possible quality in the shortest possible time. While this attitude prevails, Sitka spruce is likely to remain the dominant tree in British upland forestry. It outperforms all other tested species on a wide range of sites both in terms of productivity and timber quality (Anderson 1950). The recent discovery (see section 2.1.2.a) that it can be effectively nursed by species such as Scots pine, Lodgepole pine and Japanese larch on deep peats deficient in nitrogen, where it would suffer heather check if grown alone, suggest that it will be even more widely grown in future, although in this instance at least, in mixture.

The fact that Sitka is so pre-eminent as a timber tree in the UK has focussed attention on its improvement through tree breeding, and improved plants are now beginning to become avialable for forest use - an additional reason for planting it still more. While such breeding has so far concentrated on yield and form there is potential for integrating advanced tree breeding with intensive silvicultural technologies (Daniels 1984). The combined approach, e.g. breeding to improve fertilizer response (Smith & Goddard 1973; Ballard 1980), may have a more than additive benefit, perhaps justifying intensive inputs on sites which previously did not merit them. Intensified management on a portion of the forest can be more productive and cost effective than a lower level of management of the whole (Staebler 1972; Silen 1982). By maximizing yield of Sitka on the best forest land it might be possible to adopt a more flexible approach to the rest, either managing it at a lower level of intensity primarily for timber production, or leaving it primarily for alternative uses such as nature conservation and recreation. In the latter two cases there would be scope for growing a higher proportion of less productive species, including broadleaves, either alone or in mixtures with conifers.

Several authors have suggested such a zoning approach (Kardell 1969; Schuler & Meadows 1975; Clawson 1981). Clawson proposes a new economic classification of United States commercial forests, based on both economic and conservation criteria. He envisages three classes of commercial forests: (A) most productive - no serious conservation or environmental restrictions on timber production and harvesting; (B) intermediate productivity - capable of growing industrial wood under extensive management for harvest on relatively long rotations; (C) least productive - lack sufficient productive potential to justify investment in timber management or pose environmental or conservation hazards too great to permit timber harvest. Clawson estimates that in the U.S. 70% of wood production could come from class A forests, which would comprise less than 30% of commercial forest area and less than 20% of total U.S. forest lands.

Of course, Britain is not the United States, and we have the fundamental problems of shortage of good quality land for timber production, plus the desire for a great increase in output to reduce our dependence on imported timber supplies (see section 1). But that does not necessarily invalidate the approach Clawson and others have adopted as far as Britain is concerned. If, as seems inevitable, there is to be an increasing need to meet conservation and recreation demands in our forested areas, then a zoning approach merits consideration. This sort of approach has been questioned by those who consider that the management of all forests should involve the optimisation of environmental and recreational functions in addition to timber production (Perina 1973; Michal 1974; van Migroet 1975). van Migroet points out that strict functional zoning leads to a damaging split between the executive branches responsible for timber production and social, cultural and scientific uses of the forest. Perina (1973), in favouring multiple-use forestry, expresses concern that there is insufficient reliable data which may be effectively applied by the forest manager when selecting a suitable sylvicultural system.

2.8.2. Sylvicultural systems

There are many different ways of growing and harvesting trees, which have been reviewed by, among others, Troup (1952) and Helliwell (1982). Factors determining choice of sylvicultural system include the species which it is desired to grow, climate, soils, economic factors and, increasingly in Britain, public acceptability. Economic constraints have been, and are likely to remain, the overriding factor, but as we shall see later in this review (section 2.9), efficient timber production need not necessarily be the sole yardstick for judging the economic viability of a forest enterprise. All sylvicultural systems are capable of some modification if this is felt to be necessary to accommodate changed circumstances.

Sylvicultural systems can be divided into two main types: even-aged and uneven-aged.

2.8.2.a. Even-aged silvicultural systems

In even-aged systems, as the name implies, all the trees in the crop are the same age. This situation can be achieved in various ways. Starting from scratch, as in the afforestation of open moorland, trees of the same age are planted at the same time, grow up together, are thinned or not thinned according to prescription and, when they reach the most profitable age for harvesting (or before if windthrow intervenes), are felled. The felling may be clearfelling, as in Britain, in which case a new crop is planted and the cycle repeated, or shelterwood felling, as happens commonly in continental Europe, whereby most of the trees are felled at one time but a few chosen seed trees are left for anything from 5-30 years to provide the means of natural regeneration and shelter to the new crop in its early stages. When the new crop is established, the remainder of the mature trees are removed.

Assuming that the same species are used and that a full rate of stocking is achieved by both means, there is probably little to choose between clearfelling and shelterwood systems as far as conservation and amenity are concerned, except in the regeneration phase. With the clearfelling system, the sudden removal of the entire crop produces not only a very sudden and marked visual change but also the dramatic soil, flora and fauna changes that have been outlined earlier in this review. With the shelterwood system, the young trees in the new crop are quite well established by the time the mature trees are removed, so that there is no sudden loss of woodland cover, with its associated disadvantages. Also, the mature trees left to provide seed and shelter offer a much more open mature woodland facie than ever occurs with the clearfelling system.

The great disadvantage of the shelterwood system for British conditions is that the mature trees left at the end of the rotation are very prone to windthrow on all but the most sheltered sites.

There is room to maoeuvre within the even-aged clearfelling sylvicultural system and a number of alternatives to the normal system have been proposed. Their main attributes have been summarised by Ogilvy (1986):

<u>Oceanic forestry</u>

The plantation is established at normal density but opened up early to give selected stems room to develop. This produces the premium value, large diameter sawlog sooner but at the expense of quality, with high taper, large proportion of juvenile wood, and large knots. There does not seem to be much support for this system at present.

<u>No-Thinning regimes</u>

Trees are planted at a normal spacing of around 2300 - 2500 per hectare; wide enough to give adequate individual stem size yet close enough to obtain minimum knot size and fine growth through early branch suppression and close competition. This system is receiving a good deal of attention because of the everpresent threat of windthrow. There would probably be little or no difference in conservation and amenity value between these woods and normally thinned plantations.

Re-spacing systems

The aim is to maintain maximum growth rate throughout by planting at normal close spacing but thinning as soon as growth rate indicates that the trees are in competition, which may be only a few years after planting. Further re-spacing takes place when competition again threatens growth rate. There is a natural reluctance of foresters to spend money removing trees so soon after they have been planted. There is some interest in this system, but more with relation to the respacing of dense, naturally-regenerated Sitka spruce obtained fortuitously at the end of the first rotation (Low 1984) than in planted situations. ITE has a priority project (ITE 773) on the sylviculture of respacing Sitka spruce. It is unlikely that such a system would offer great benefits in wildlife conservation and amenity terms, since the aim would be to establish a closed canopy as soon as possible and then maintain it in a just-closed condition until clearfelling. Ground vegetation would probably be regarded as being in competition with the trees and would therefore be discouraged.

Chemical thinning

This is not so much a different system as an adaptation of the traditional thinning system whereby the trees to be "removed" are killed with herbicides and left in situ instead of being removed by mechanical means. It is being researched by the Forestry Commission at present in the hope that it may allow thinning of stands where physical removal might result in instability. Its use in re-spacing fortuitous natural regeneration has been described by Low 1984). Where trees are small (<1m at the time of respacing) the stand may be sprayed with herbicide either in bands or using two passes at right angles to leave small clumps at 2m centres. The resultant alleyways will give easy access to carry out selective respacing at a later date. In older, previously unthinned crops, there will be difficulty in getting to the trees to apply the herbicide and hence costs will be much higher. There is concern that the dead trees left after chemical thinning may provide well dispersed breeding material for forest pests and pathogens. Ironically, this disadvantage from the foresters point of view coincides with the main potential advantage of this system from the wildlife conservationists viewpoint: the provision of dead timber habitat in forests which would otherwise be largely devoid of it.

Self-thinning

The idea here is to plant the main crop species in mixture with a nurse species which will be suppressed naturally by the crop once its job has been done, although competing sufficiently in the early stages to shape and clean the timber. It is a system receiving a good deal of favour at the moment since the discovery of the nursing capabilities of Scots pine, Lodgepole pine and Japanese larch towards Sitka spruce on deep peats. Advocates believe that it will enable heather (Calluna) check to be avoided; will allow lower levels of nitrogen fertilization; will result in greater total productivity because of improved site utilisation resulting from different but complementary rooting patterns; will reduce the risk of total loss by forest pests and pathogens (Ogilvy 1986).

Additionally it is claimed that it will provide conservation benefits through allowing increased light to reach the forest floor, so favouring ground flora and associated animals, and that it will be more acceptable aesthetically than monocultures of Sitka spruce. Although the use of birch as a nurse has not been much discussed, given its known soil improving characteristics (see section 2.1.2) there would seem to be potential for its use in this way also, and it would have a strong conservation and amenity appeal. The ecological effects of these, and as yet untried self-thinning systems, have so far received no attention. This should be remedied immediately, as there is a real chance that such systems will be established on a large scale on deep peats in the second rotation.

2.8.2.b. Uneven-aged sylvicultural systems

These systems work on the principle that instead of replacing the crop all at once when it reaches maturity, a programme of continuous replacement is adopted. A proportion of the mature trees are felled at any one time and their place is taken by either the naturally regenerated seedlings springing up in their place from seed provided by the remaining mature trees, or by planted seedlings. There are two main uneven-aged systems; group selection and individual tree selection.

Group selection

In effect this resembles a small-scale clearfelling system in which each stand or compartment of the forest has, ideally, a full range of age classes, distributed in small groups. The size of the groups may vary from as little as two or three mature trees to as much as a quarter or half hectare (Helliwell 1982). The great advantage of this system from the wildlife conservation and amenity points of view is that the forest is a mosaic of habitats, all age classes with their different characteristics being available side by side. There is also the visual advantage that individual coupe size is by definition small and that this results in the forest having an appearance of continuity. Unfortunately this aspect adds greatly to the cost of harvesting the crop, although this might not be the case were foresters geared to the idea of continuous small scale harvesting over a whole forest rather than occassional large-scale felling in individual compartments.

Malcolm (1971) describes an experimental system of this type at Corrour in Inverness-shire with a wide range of species. The total area is 54ha, arranged in 6 blocks of 9ha each. Each year one block is 100% enumerated (the so-called 'check' system) and a thinning/felling marked on individual trees. Thinning has been of a heavy crown type designed to break up the stand into groups of trees of different size classes. Malcolm considers that there are two possible applications for this type of system: (i) in areas where clearfelling is not practicable due to amenity pressures or where protection of site or regenerated stands is important. These may coincide as in certain watersheds; (ii) in areas where site conditions are highly variable (e.g. glaciated country) where it might be possible to predict yields of extensive areas from sample compartments.

Individual tree selection

This is simply group selection taken to its logical conclusion, the individual mature tree being the unit of sylvicultural treatment. Each forest compartment is visited about every 5-10 years, according to the rate of growth of the trees and the numbers felled after the previous visit, and selected trees marked for removal, including some large trees and some small ones, the best trees being favoured for the ensuing growth period. Restocking is a continuous process also and is usually obtained from natural seeding, although planting may be necessary on occasion. This system, as I have seen it in French oakwoods, produces a visually attractive forest with a range of trees of different sizes and is almost universally admired by conservationists as well as foresters who see it for the first time. It requires skilled management and continuity of forest policy as the product is a slow-grown, high quality one which may or may not be economic to produce at any particular time. Such a system is, unfortunately, totally impractical for all but the best sites in Britain.

2.8.2.c. Coppice

Coppicing is really a regeneration system rather than a sylvicultural system but it is sufficiently separate from other forestry techniques to merit individual consideration. Where it differs from other systems, of course, is that regeneration is by vegetative means from the stools rather than by seed. The frequency of the coppice cycle depends on the species involved, the fertility of the site, and the end-use of the product. There may or not be older trees (Standards) dispersed between the coppice stools.

The system has traditionally been used for certain species of hardwoods only (most conifers and some hardwoods will not regrow from a cut stump) grown for specific purposes (agricultural use, hurdle manufacture, fuelwood) near to the site of use or manufacture. More recently it has received a good deal of attention as a possible source of rapidly-grown, high-yielding pulpwood or fuelwood, but for this to be economic large areas of fertile level ground suited to mechanical harvesting would be needed. There is just a possibility that with current and predicted changes in the EEC agricultural support system leading to reduction or withdrawal of subsidies for certain crops, such land may become available. If it does, then coppice harvesting would have to compete with 'traditional' forestry and agroforestry systems as possible alternative land uses.

2.8.2.d. Agroforestry

This is not an appropriate place to investigate agroforestry in any detail, but it is necessary to consider the possibility of its assuming a significant role as a multi-use, forest-based system in the future. As the name implies, agroforestry systems all involve some form of agriculture/forestry arrangement whereby trees are grown at sufficiently wide spacings to allow cultivation of an agricultural crop beneath. This may be grass grazed by herbivores, in which case the system is sylvi-pastoral, or an arable crop (sylvi-arable). It is envisaged that in Britain, at least on the marginal land most widely tipped for agroforestry usage, grazing animals on improved grass would be the most likely agricultural usage. Experiments are currently underway and planned to test the feasibility of operating such systems in the uplands. Different tree species grown alone and in mixtures, with various grazing regimes, are involved.

There is a need for comprehensive ecological studies as a part of the investigations of agroforestry systems, including their effects on soils, flora and fauna. Comparisons of various agroforestry possibilities with traditional and novel plantation forestry systems and with prevailing agricultural land use practices on similar sites are also needed. ITE staff at Bangor, Bush and Merlewood have been involved in the discussions about these trials and in their establishment and various ecological studies are planned. It is essential, however, that if ITE is to play the key role in agroforestry research which is surely appropriate, given the Institute's historical and continuing interest in land use change, that a coordinated programme of work be quickly established.

2.9. Recreation and amenity

There are really two levels of perception of forests with regard to recreation and amenity: the view of the forest from outside in relation to the broader landscape: the experience, including visual amenity, within. To many who rarely if ever enter a forest the former of these is all important. It is what the forest looks like rather than what it is that concerns them (Burton & Muir 1979). Does it fit into the overall landscape pattern? Does it look natural? Is it a blot on the landscape? This aspect will almost certainly also be of importance to the person who uses the forest for recreation, but in addition he or she will be concerned about the forest itself (Brush 1976). Is it accessible? Does it provide those "facilities" which it is hoped to enjoy? Is it a nice place to be?

2.9.1. Forests and the broader landscape

It might be thought that people would have many different perceptions and preferences where landscape is concerned and that it would therefore be impossible to reach reasonable compromises when designing forests to take account of their varying requirements. While it is true that preferences vary among special interest groups within individual cultures (Hendee et al. 1968), and probably to a greater extent between groups having different racial or cultural characteristics (Tips & Savasdisara 1986), there appear to be some attributes of landscape which find common acceptance. In particular, "natural" landscapes are generally preferred to those containing obviously man-made elements (Zube et al. 1974), but at the same time variety is preferred to uniformity (Rapoport & Kantor 1967) provided that the varied components support rather than conflict with one another. Permanence of appearance is preferred to sudden change, which is regarded as disruptive and unsettling (Tuan 1974; Zube et al. 1974).

Designing forests to satisfy even these generalized requirements is not easy, and is made a good deal more difficult where they must be accommodated in an otherwise open upland landscape. This is mainly because the vertical elevation in hill country exposes the whole plantation to a map-like view (Crowe 1986). Thus, whereas on flat land rectangular blocks look appropriate, particularly where the fields are laid out in geometric patterns, in hilly country the contoured landscape cannot accept them. These and other problems and suggested solutions have been eloquently presented by Crowe (1979) and provide the basis upon which Forestry Commission forest design is based.

The main aim is to harmonize the forest with the landscape by emphasizing features such as hollows, convex slopes, rock outcrops, streams, rather than running the forest over them all in a uniform manner. Thus, for example, rock outcrops and sufficient area below to allow them to remain visible when the trees are mature, are left unplanted; larches are planted on convex slopes to emphasize them, with broadleaves in the hollows and alongside the streams that run through them. A key feature in determining whether the end result is satisfactory is scale. What looks right from a long distance, or from below in the case of an upland view, may look quite incongruous from close to or above, and vice versa. Generally speaking, to be effective scale should increase with vertical height and distance to the observer (Low 1984). The problem comes when the same piece of forest is viewed both from close too and a distance, but in most cases reasonable compromises can be reached provided the problems are considered in advance.

The introduction of diversity into coniferous plantations, particularly by the use of larch to introduce the element of colour and texture change associated with a deciduous species, should be done carefully. Sharp, straight boundaries between larch and other species can be just as artificial in the landscape as similarly discordant forest or felling coupe boundaries. It is easy, with the best of intentions, to produce something akin to a park bedding scheme writ large on the hillside.

Clearfelling presents the greatest challenge to the forest designer intent on reconciling his forest with the broader landscape. Large felling coupes may be thought to be the most visually disturbing, but some consider that small coupes scattered through the forest can create an even less attractive, moth-eaten appearance which is particularly inappropriate in very large-scale, open landscapes. The best way to minimize the visual discord of clearfelling is to take great care with the edges, adopting the same principles in their shaping as are used in designing the forest in the first place: coupe boundaries should have winfirm edges that are sympathetically shaped to landform. Skylines should either appear completely open or as solid forest; diffuse belts and scattered trees appear out of scale and should be avoided (Low 1984). Groups of trees left standing can do much to reduce the visual impact of felling coupes and have the added advantage of providing some older trees in the following crop which will increase structural diversity and break up the visual uniformity of the crop surface. Equally they can look out of place and may be more obtrusive than the developing restocked plantations among which they remain, so care must be taken to retain individuals or groups in relation to terrain features such as rock outcrops and valley bottoms.

2.9.2. Recreation and amenity within the forest

Perceptions of recreation and amenity potential of a forest among users depend on their expectations and requirements. These have been researched in Britain (Goodall & Whittow 1975; Good 1976; Anon. 1978; Goodall 1978) and abroad (Clawson & Knetsch 1966; Cook 1972; Heino 1974; Decourt and Souchon 1975; Hultman 1976; How 1982; Telishevskii 1976) using observation, interview and postal questionnaire techniques. For the great majority of the population, who use the forest casually for family outings, picnics and other essentially non-forest-specific activities (user-based as defined by Clawson & Knetsch 1966), accessibility by car is of the first importance, with the provision of a good network of clearly marked routes through the forest scored highly also. Most studies reveal a desire for variety, in terms of views, topography, tree size and tree type (conifer and broadleaves). Water, whether in the form of rivers, streams, lakes or pools is always appreciated and access to the waterside is eagerly sought. Many visitors regard experience of wildlife - particularly birds, mammals and flowering plants - as an essential part of the recreational experience. Since, as we have seen earlier in this review, tree species and age class and the management of unplanted areas are all of key importance in determining wildlife value (see Figure 1), it follows that they are also of central importance to these visitors.

In countries, such as those in Fenno-Scandinavia, with a large area of forest and a continuous tradition of forest use for recreation, "naturalness" of the forest is regarded as being very important. Anything which threatens to destroy this "naturalness", such as even-aged monocultures (Ammer 1977) or forest roads (Hofstad 1976), is disliked. There is less evidence of such concern in Britain where there is no tradition of recreation in large, undisturbed forests.

In addition to user-based activities, Clawson & Knetsch (1966) working in the united States distinguished resource-based activities in the forest. Such activities are more remote and rely on availability of suitable resources, e.g. cliff faces for rock climbing, wilderness areas with few, if any, man-made intrusions. Compared with user-based types of recreation they were considered to depend less on accessibility and more on the "quality" of the resource.

Goodall & Whittow (1975) and Goodall (1978) compared the recreation potential of different Forestry Commission forests for different users by means of a well planned and carefully executed questionnaire employed both in the field among people using forests for recreation and by post to a wide range of recreational organizations. It revealed common elements among user requirements enabling a Forest Recreational Potential Index to be developed. The exercise was then repeated as a desk study using surrogate map data in place of the questionnaire information and it was shown that field and desk studies produced consistent results. It was concluded that the desk approach could safely be used as a priority ranking device in the formulation of Forestry Commission recreation strategies at the national and conservancy levels. An important general finding of the study was that positive forest characteristics associated with high amenity ratings could not be used to offset negative characteristics to any great extent. The presence of one or two adverse physical factors (poor climate, inadequate roads or footpaths, uniform aged dense stands of conifers) would lead to a low amenity rating regardless of the presence of other highly desirable features.

An extensive study in Scotland between 1972-78 (Anon 1978) confirmed most of these findings. It suggested, however, that greater effort should be made to assess user demands - potential as well as actual - so that gaps in provision for recreation could be considered and, where possible, met. It concluded that amenity could and should be catered for like any other demand and that by meeting the public's needs the forestry industry might go a long way towards improving its image and that of production forestry. There has in fact been a great increase in the provision of recreational facilities (car parks, picnic sites, campsites, cabin and chalet developments, information centres, forest walks, orienteering courses, canoeing) in public forests in recent years (Baylis 1987) and partly because of this and partly, it seems, as a result of a general increase in public demand for outdoor recreational facilities, use of F.C. forests by the public has increased greatly also. There is some evidence, however, that this use peaked in the late 1970's, at least in Wales (Baylis 1987), perhaps as a result of the recession coupled with an increase in the availability of cheap continental package holidays and a series of poor summers. The general feeling in both the Forestry Commission and among private foresters appears to be that there is still an enormous untapped potential for forest-based tourism but that a greater financial input and general commitment to determining and then satisfying the needs of all potential visitors is necessary. "Standards of reception and presentation of recreation facilities in the countryside have greatly improved during the 80's. Stately homes, historic places, country parks and nature reserves commonly exhibit to the visitor a generous welcome and a professionalism in presentation which extend beyond tidy car parks and explicit signing .... By comparison the reticent, unobtrusive style of the Forestry Commission often seems less effective" (Baylis 1987).

There is every reason to hope that if the forests were improved for wildlife conservation and amenity in the ways recommended in this review, some of which require further investigation for their effective development, there would be a much greater wish among the public to use them. Is it too much to hope that over the coming years our plantation forests may become the new multi-use forest resource which our people have lacked for centuries?

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APPENDIX 1

Ranking of relevent ITE projects in their previous core groups on the basis of their present or potential importance in an overall programme of work on conservation and amenity aspects of production forestry: 1 - HIGH PRIORITY, 2 - INTERMEDIATE PRIORITY, 3 - LOW PRIORITY.

Programme 1. FOREST & WOODLAND ECOLOGY

Commissioned research projects

948	Invertebrate conservation in plantation woods	E	Pollard	1
1006	Forest decline and atmospheric pollutants	(F T	Last)	3
1009	Forestry & nature conservation at Newborough	M O	Hill	1
1097	Nature conservation in new conifer forests	J E G	Good	1

Priority projects

9	Monitoring at Stonechest	J M	Sykes	2
389	Management effect in lowland coppices	A H F	Brown	3
479	Red deer in production forests	B W	Staines	1
528	Red deer populations in woodland habitats	(B	Mitchell)	1
1003	Quasi-static model for wind overturning	R	Milne	3
606	Grey squirrel damage and management	R E	Kenward	1
721	Dry matter in forests: world review	M G R	Cannell	3
773	Silviculture of respacing Sitka spruce	J D	Deans	2
820	Regional aspects of forest dynamics in Europe	P	Ineson	3
933	Succession under birchwoods	A J	Hester	2

Non-priority projects

417	Silvicultural systems - N. Ireland expt.	A H F	Brown	2
454	Monitoring of woodlands	J M	Sykes	3
517	Primary productivity in woodlands	(J N R	Jeffers)	2
574	Potential for fuel cropping in upland Wales	D I	Thomas	3
746	Grazing in woodlands	T W	Ashenden	3
991	Effects of waterlogging on mycorrhizal seeds	J	Dighton	3

Programme 2. FRESHWATER ECOLOGY

Commissioned research projects

967	Acidification & freshwater plants & inverts.	K H	Morris	3

Programme 3. REHABILITATION OF DISTURBED ECOSYSTEMS

Priority projects

360	Tree planting on opencast sites	J E G	Good	3
707	Plant establishment in woodland	L A	Boorman	2

Programme 4. MANAGEMENT OF NATURAL AND MAN-MADE HABITATS

Priority projects

599	Heathland management research	R H	Marrs	2
794	Rhododendron in Snowdonia	M W	Shaw	2

Non-priority projects

674	Plant species for energy in Great Britain	T V	Calleghan	3

Programme 5. SURVEY AND MONITORING

Priority project

906	Ecological data unit	G L	Radford	3

Programme 6. AIRBORNE POLLUTANTS, INCLUDING RADIONUCLIDES

Commissioned research projects

837	Fish populations and acid precipitation	(P S	Maitland)	2
841	Throughfall and stemflow under different trees	I A	Nicholson	2
845	Effects of acid rain on vegetation in Wales	T W	Ashenden	3
893	Effects of acid rain on forest trees	J	Dighton	2
924	Acid mist and tree injury	A	Crossley	2
925	Variation of acid deposition with altitude	D	Fowler	3
959	Acid deposition and groundwater chemistry	B G	Bell	3

Priority projects

895	Chemical composition of rainfall	I A	Nicholson	3
380	Monitoring atmospheric SO2 and NOx at Devilla	I A	Nicholson	3
453	SO2 dry deposition in Scots pine forest	D	Fowler	2
710	Airborne pollutants and Scots pine	J N	Cape	2
1036	Soil and water acidity under different trees	J	Miles	1

Non-priority project

791	Effect of acid rain on Sitka spruce	D	Fowler	2

Programme 7. PLANT PHYSIOLOGY AND GENETICS

Priority projects

702	Selection of frost-hardy trees	M G R	Cannell	3
717	Birch variation and environmental differences	J	Pelham	2
770	Evaluation of conifer clones and progenies	M G R	Cannell	3
805	Effects of mycorrhizas on assimilation	E J	White	3
801	Radial growth of Sitka spruce roots	J D	Deans	2
831	Modelling of transpiration in Sitka spruce	R	Milne	3
872	Effect of mycorrhizas on metal uptake in Betula	H J	Denny	3
935	Evaluation of Red alder	L J	Sheppard	2

Non-priority projects

898	Light use efficiency of coppice	M G R	Cannell	3
1042	Mechanics of windthrow in commercial forests	R	Milne	3

Programme 8. ECOPHYSIOLOGY AND POLLUTION IN ANIMALS

Priority project

811	Foraging & reserve storage in Red & Grey squirrel	R E	Kenward	2

Programme 9. PLANT POPULATION ECOLOGY

Priority project

793	Ecotypic variation in oak	M W	Shaw	2

Non-priority project

512	Birch gene-bank	(J	Pelham)	3

Programme 10. AUTECOLOGY OF ANIMALS

Commissioned research projects

204	Assessing butterfly abundance	E	Pollard	3
291	Population ecology of bats	R E	Stebbings	2
292	Specialist advice on bats	R E	Stebbings	2
442	Population ecology of Capercaillie	R	Moss	2
764	Habitat requirements of Black grouse	N	Picozzi	2

Priority projects

862	Population ecology of Pine Beauty moth	A D	Watt	2
568	Subcortical fauna in oak	M G	Yates	3

Non-priority projects

54	Ecology of red deer on the Isle of Rhum	V P W	Lowe	2
104	Distribution and segregation of Red deer	B W	Staines	2
111	Population dynamics of Red deer at Glen Feshie	(B	Mitchell)	2
131	Golden plover populations	R A	Parr	3

Programme 11. ANIMAL SPECIES INTERACTIONS AND COMMUNITIES

Priority projects

636	Songbird populations and woodland diversity	D D	French	1
826	Fauna of native and introduced trees	R C	Welch	1
309	Phytophagous insect data bank	L K	Ward	2

Non-priority projects

405	Fauna of pasture woodlands	P T	Harding	3

Programme 12. CYCLING OF NUTRIENTS

Commissioned research projects

594	Geochemical cycling in the uplands	M	Hornung	2
625	Effects of clear felling in upland forests	M O	Hill	1
923	Acidification of waters in Wales	M	Hornung	1
1060	Effect of forest management on soil	M	Hornung	1

Priority projects

90	Birch on moorland soil and vegetation	J	Miles	1
367	The Gisburn experiment	A H F	Brown	1
654	Status of mycorrhizas in the soil ecosystem	J	Dighton	3
695	Effects of mycorrhiza on tree growth	(F T	Last)	3
824	Cycling of key nutrients in forest soils	A F	Harrison	1
865	Mycorrhizal toadstools in coniferous plantations	J	Wilson	3
929	Effects of altitude on nitrogen mineralization	R H	Marrs	3
934	Vegetation dynamics and soils	J	Miles	2
714	Role of forest vegetation in pedogenesis	P J A	Howard	1
971	Nitrogen metabolism of decomposer fungi	R A	Johnston	3
1039	Soil change under birch	A J	Ramsay	1

Non-priority projects

561	Soil fertility	A F	Harrison	3
589	Microbial characteristics in soils	P M	Latter	3
645	Effects of soil chemistry on decomposition	D D	French	3
939	Liming and earthworm inoculation in forest soil	A F	Harrison	2

Programme 13. LAND RESOURCES AND LAND USES

Priority projects

424	Ecological survey of Britain	R G H	Bunce	3
534	National land characterisation & classification	D F	Ball	3
909	Changes in the rural environment	C J	Barr	3
973	Environmental and socioeconomic effects of CAP	M	Bell	2
377	Historical aspects of environmental perception	J	Sheail	3

Non-priority projects

4	Soil classification methods	P J A	Howard	3

Programme 15. SYSTEMS ANALYSIS AND BIOMETRICS

Non-priority projects

663	Estimation of abundance of populations	M D	Mountford	3
777	Estimation of population parameters	K H	Lakhani	3
846	Influence of events on population growth	I R	Smith	2

Programme 16. AGRICULTURE AND THE ENVIRONMENT

Commissioned research projects

1010	Countryside implications of changes in CAP	R G H Bunce	2