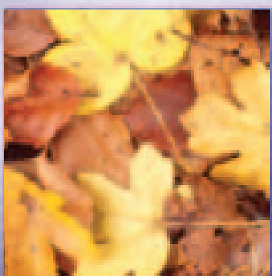
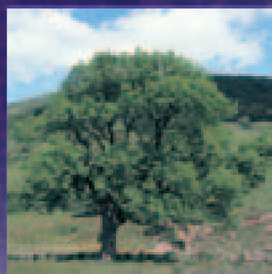
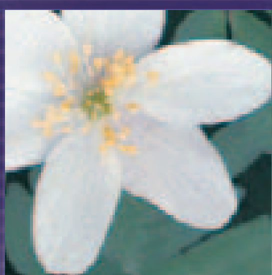
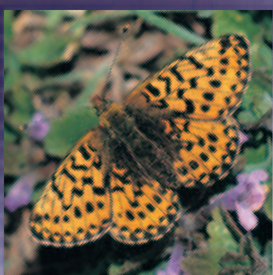
Forest Research

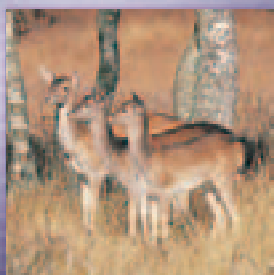
Annual Report and Accounts 2001–2002











Forest Research
An Agency of the Forestry Commission

Forest Research
Annual Report and Accounts 2001–2002

Together with the Comptroller and Auditor General's Report on the Accounts

Presented to Parliament in pursuance of Section 45 of the Forestry Act 1967
and Section 5 of the Exchequer and Audit Departments Act 1921

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Forest Research
An Agency of the Forestry Commission

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Forest Research Organisation Spring 2002

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Forest Research (FR) is an agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research.

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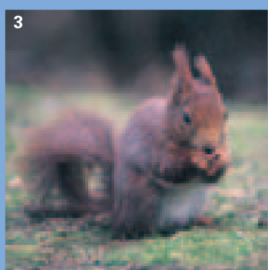

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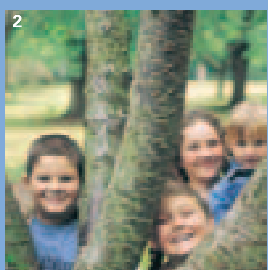

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1. Beech tree seeds in autumn.
2. Children in the Mersey Forest.
3. Red squirrel.
4. Time and motion felling study.

AIMS AND OBJECTIVES

Aims

To provide research, development, surveys and related services to the forest industry and to provide authoritative advice in support of the development and implementation of the Government's forestry policies.

Objectives

- To meet customers' needs and respond to changing customer demands.
- To satisfy current standards for the quality of research.
- To increase competitiveness and efficiency and demonstrate value for money.
- To recover the full economic costs of the Agency from charges to customers.

CUSTOMERS

Most of our work is funded by the Forestry Commission with the Policy and Practice Division of the FC acting as purchaser of research and other services in support of forestry in Britain, including the particular needs of England, Scotland and Wales. Forest Enterprise, the agency responsible for managing the FC estate, purchases research, development and surveys specifically related to this estate. Other customers include the Department of Environment, Food and Rural Affairs, the Department of Trade and Industry, the Department for Transport, Local Government and Regions[a], the European Union, commercial organisations, private individuals, land owners and charities. All our customers are free to purchase their research from Forest Research or from other sources.

ACTIVITIES

FR's research covers a broad range of topics from genetic improvement of trees, through tree seed, tree establishment, stand management and threats to tree health. The species covered include all the main native trees as well as the commercially important introduced conifer species. Much of the research effort is directed at increasing the environmental and social benefits of trees, including biodiversity and recreation, and ensuring compliance with international agreements on the sustainable management of forests. The Agency also carries out method studies, product evaluations, crop inventory, surveys and monitoring.

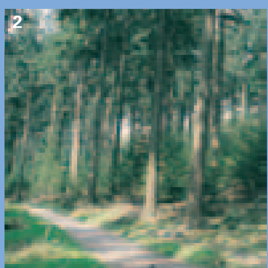
RESOURCES

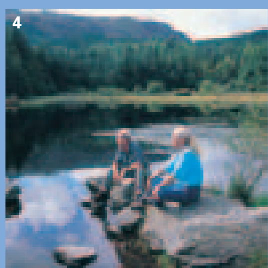
The Agency has two main research stations, Alice Holt Lodge in Hampshire and the Northern Research Station on the Bush Estate south of Edinburgh. The main office of Technical Development Branch is located at Ae in Dumfriesshire with subsidiary offices in the English Midlands and Wales. The Agency also has 10 field stations from which an extensive network of field trials, sample plots and monitoring sites is assessed. A list of addresses and telephone numbers is given on the inside back cover. The Agency employs 260 staff, not including visiting scientists and sandwich students. The Agency has published a Corporate Plan for the period 2001–2005. Copies are available from the Library at Alice Holt Lodge.

[a] **Editorial update**
Since 29 May 2003, The Office of the Deputy Prime Minister (ODPM).

Chief Executive's Introduction

I am pleased to report that the Agency has again achieved all its key targets. While it could be argued that the targets might have been more demanding, consideration of the record over 5 years since the Agency was launched shows a steady improvement in levels of customer satisfaction, output of peer reviewed papers and reductions in unit costs. Full cost recovery has been consistently achieved despite declining income from the main Forestry Commission customer. This record owes much to the commitment and hard work of the staff of the Agency and I thank them for their support.





1. Assessing stem straightness in Sitka spruce.
2. Douglas fir at Longleat Estate, Wiltshire.
3. Trees and branches create channels and dams to slow down flood flows.
4. Mountain lake walk, Beddgelert Forest.

QUINQUENNIAL REVIEW

In accordance with the normal management of agencies a team, led by Duncan Macniven of the Forestry Commission, is conducting a quinquennial review of Forest Research. A consultation exercise showed that there was a high level of satisfaction amongst stakeholders in the quality of the work done by the Agency but there was scope for improving customer involvement in developing the FC R&D strategy. A plea was also made for a greater emphasis on knowledge transfer.

The first stage of the review concluded that there was a continuing need for the activities carried out by Forest Research and that the best means of delivering this was for Forest Research to remain as an agency of the Forestry Commission. Ministers have accepted this recommendation. The second stage of the review will address other issues raised by consultees.

RESEARCH HIGHLIGHTS

Our research aims to protect Britain's trees and woodlands from pests, disease and other threats; to increase the contribution of trees and woodlands make to improving quality of life including environment and social benefits; and to increase the competitiveness of British grown forest products and their contribution to wealth creation. The research highlights which follow here provide an update on significant developments across the range of our activities. The six main articles (on pages 16-85) then give a comprehensive account of selected subjects where important issues have arisen, and where there has been major progress in recent years.

Evaluation of the threat from the new *Phytophthora (P. ramorum)*

Evidence from FR scientists suggest that the *Phytophthora* causing widespread mortality of oaks in California (Sudden Oak Death) is the same as the newly described *Phytophthora ramorum* found infecting Rhododendron and Viburnum in parts of Europe. Research to assess the threat this pathogen might pose to trees in the UK has concluded that *P. ramorum* is not involved in oak decline in Britain. Preliminary pathogenicity tests on a limited range of hosts, carried out under quarantine containment conditions, have indicated that European oaks are more resistant to this pathogen than American oaks, although European beech may be susceptible. Studies of *P. ramorum* have also shown it has two mating types (A1 and A2), with the A2 only apparently present in the USA and the A1 in Europe. This raises questions about the geographic origin of this new pathogen and its potential for genetic change.

Targeting of stump treatment against *Heterobasidion annosum*

Research has already shown that the need for stump treatment to protect Sitka spruce from *Heterobasidion annosum* is least on peat soils and where rainfall is high. This information has now been refined using additional information on soil type and climatic variation (i.e. rainfall and temperature ranges), which is then combined with various management options (e.g. species selection or thinning) to estimate the risk posed by *H. annosum*. A GIS decision support system is being developed to allow managers to predict risk and assess the benefits of stump treatment.

Integrated Forest Management

There has been continuing progress in the development of the Integrated Forest Management (IFM) system for managing the threat posed by restocking pests, mainly *Hylobius abietis*. Results of trials of simple monitoring regimes indicate that predictions based on the relationship between time of felling, proximity to other felling coupes and size of the immigrant *H. abietis* population can aid local decision-making. This has particular significance in offering a range of options for the forest manager, options include: whether or not to treat transplants with insecticides before planting or at intervals after planting and altering the duration of follow periods. Predictions of the decline in weevil populations on a forest-wide scale combined with selective application of insect parasitic nematodes may be the key to IFM of this pest. Results from trials of alternative insecticides suggest that alpha-cypermethrin is the most suitable, and data are now being gathered for registration of both electrodyn pre-plant applications and water-based post-plant applications.

Increasing and unusual insect pests

Although most attention is focused on the major pests of current concern *(H. abietis, Dendroctonus micans* and *Elatobium abietinum)*, research has also been carried out on pests that are showing unusual or increased activity. An unusual outbreak of pine looper moth *Bupalus piniaria* in the North of Scotland, described later in this report, serves to emphasise that, even when a pest has been well studied in the past, it can still provide surprises. Similarly, the increase in activity of the hornet clearwing moth *Sesia apiformis*, also described in this report, confirms that the interactions between insects and their host trees are dynamic balances and that a complex of factors, including tree species, site characteristics and climatic variables, determine whether pest populations develop.

The threat posed by Asian longhorn beetle *Anoplophora glabripennis* has already been highlighted in the three most recent annual reports and Entomology Branch continues to work with Plant Health Service staff to keep the pest out of Britain. Measures put in place in 1999 have helped in reducing the number of interceptions discovered in imported wood from China. However, the finding of a population of the beetle breeding in trees in Austria has confirmed that it can breed successfully in Europe, and that it can remain undetected for several years before being found. Awareness of the general health of our trees and the need to obtain specialist advice to investigate unusual symptoms is an important part of plant health strategy in relation to detection and management of exotic organisms.

Climate and environmental change

The conclusion of a number of years of intensive research, *Climate change: impacts on UK Forests,* was published as a Forestry Commission Bulletin in February 2002. Edited by Mark Broadmeadow, this publication brings evidence and conclusions on likely future climatic conditions in the UK, and their effects on the forest ecosystem. It also includes a discussion about possible responses for the UK forestry industry. The publication provides valuable guidance on the possible magnitude of climate change impacts, and is the catalyst for further targeted research to reduce those remaining uncertainties identified in its compilation.

Originally set up to monitor and study the effects of acidic atmospheric pollution on forests, environmental monitoring in forest ecosystems using the EU Level I and Level II networks is being strengthened to give important information on the forest response to climate change and ozone, and the monitoring of carbon stocks and biodiversity. The number of Level II sites (those more intensively monitored) has been extended to include beech, and meteorological and ozone measurements are being made continuously at or near all sites. In addition, analysis of the Level II dataset is revealing evidence of recovery of some sites from the effects of acidification. The development of the Level II network is in recognition of its ability to provide information on the state of the nation's woodlands and trees. Further development is expected with the likely implementation of a new EC Regulation on environmental monitoring in forest ecosystems in 2003.

A new carbon dynamics research programme has been established to formalise the work being carried out as part of the yield modelling and climate change programmes. One of only two forestry long-term carbon flux stations in the UK has operated under the programme since 1998, providing data for model calibration and validation and for interpreting inter-annual variation in individual elements of the ecosystem carbon flux. Data from the mensuration sample plot network have been used to improve estimates of the contribution of forestry to the national carbon emissions inventory, together with development of the CARBINE carbon accounting model. The role of existing FR monitoring networks in monitoring carbon stocks will be assessed in the coming year, including recommendations on modifications to improve delivery of carbon inventories.

As part of the European Union's Quality of Life Framework 5 Programme, Forest Research is co-ordinating a project entitled 'Forecasting the dynamic response of timber quality to management and environmental change: an integrated approach'. The consortium includes partners from Belgium (Universities of Antwerp and Gent), Germany (Technical University of Berlin), Italy (University of Viterbo), Finland (European Forestry Institute) and United Kingdom (Building Research Establishment).

This project aims to increase understanding of the relationships between site conditions and growth, timber quality and production for current and future scenarios of atmospheric change, and to encompass such understanding within an integrated modelling framework. This system will assist forest managers, the timber industry and policy makers to decide whether management of forests should be principally for production, conservation or amenity outputs, within the context of multi-purpose forest policies.

Such a forecasting system will support the future reshaping of European forestry through policies aimed at the optimisation of sustainable management, the provision of renewable resources and the protection of the global and local environment, in particular the role of forestry in the carbon cycle.

The Social Research Unit

In January 2002 the appointment of a further project leader with social sciences research experience heralded the formation of FR's Social Research Unit. The unit is developing research projects to increase the understanding of the social aspects of sustainable forest management. Work is currently being undertaken in themes covering values, health, participation, recreation and governance.

A research project was started to investigate the social value of woodlands in England with data collection undertaken in the northwest and the southeast through a series of focus groups and in-depth interviews. A dissertation called 'Public Money for Public Good: public participation in the development of long term forest plans' was produced as part of a one-year MSc course at University College London. This project will develop qualitative assessments of public participatory processes in forestry.

A trial of a decision framework for public involvement in forest planning was initiated in three FE forest districts. This process of 'ground-truthing' the framework is ensuring that the guidance delivered to forest managers through the framework is consistent with their needs and the expectations of forest stakeholders. The understanding gained through this project is proving useful to the FC in the development of consultation procedures for the Woodland Grant Scheme.

In March 2002, *Trees are company* was published. This provides the proceedings from a major conference held at Cardiff University in June 2001 on Social Science Research into Woodlands and the Natural Environment and focused on three main themes:

- Culture, values and meanings of woodlands and trees;
- Monitoring and modelling approaches to forest management and sustainability, and;
- Community involvement in decision-making and management.

Woodland ecology

Provision of deadwood in managed stands can make an important contribution to forest biodiversity. The best available knowledge, and its application to the range of stand types was summarised in an advisory poster and booklet, in collaboration with Forest Enterprise. A training course has been developed to support the publication.

There is considerable concern for the future of capercaillie *(Tetrao urogallus)* populations in Scotland. FC Scotland (with funding from the Scottish Executive) mounted a Challenge Fund over winter 2001/02 to remove or mark deer fencing likely to cause problems close to known capercaillie sites (leks). FR prepared specifications for deer fencing designed to be more visible to capercaillie, produced advisory material jointly with RSPB and installed demonstration and research sites; the durability of the options will be monitored.

The range and size of populations of red squirrels are declining in many areas, and there is need to target the implementation of conservation measures to the best sites. We have aided this decision-making by implementing a set of rules identifying suitable sites for red squirrel conservation. By combining these rules with maps of woodland cover for the whole of Scotland and North England we were able to prioritise areas. A report was presented to the Scotland Squirrel Forum and GIS data overlays have been provided to guide grant-aided support for conservation measures.

Uneven-aged silviculture

The use of uneven-aged silvicultural systems is recommended for use in different types of semi-natural woodlands by Forestry Commission Management Guides for semi-natural woodland. However, many forest managers in Britain lack experience of uneven-aged silviculture and insufficient guidance is available to assist them. A recent project funded by the Forestry Commission and the EU INTERREG programme has investigated methods for using uneven-aged silviculture in coppice-with-standards woodlands in East Sussex. Data on species composition and diameter distribution were collected from nine woodlands and then negative exponential distributions were fitted to each. This information was also used to generate a suite of target distributions to guide management of the woodlands surveyed and which may have much wider application. The work has been written up as a scientific paper (Kerr, to be published 2003) and as a guide for forest managers (Kerr, to be published 2002).

Stability/Forest GALES

The major effort this year has been in the rewriting of ForestGALES into Object Orientated Code and the linking with ArcView geographic information software. Object Orientated Code allows much easier coupling of ForestGALES with other models and is more resource efficient. The link with ArcView GIS allows the risk to stands to be displayed at the press of a button. FE will begin trials in one of their districts during 2002. We have also completed a report on the validation of ForestGALES based on data from eight monitoring areas. The results shows that ForestGALES is correct 70% of the time in predicting the presence or absence of wind damage.

Timber quality

A large body of field work was completed this year as part of a survey of Sitka spruce stem straightness in Wales, conversion work in Scotland and the EU Compression Wood project. The Welsh straightness survey gave very similar results to previous surveys in Scotland and Northern England, although the overall straightness was higher. A number of seminars and a conference in Perth were organised to publicise the work and findings of the Timber Quality team and were attended by growers and representatives of the timber processing sector.

Tree genetics

The first full-sib families of Sitka spruce planted in 1985 (both mother and father selected based on first cycle genetic testing) have provided mature field-based data for density, straightness and vigour. As a result of this, for the first time, seed from one outstanding family was reproduced through controlled pollination and sold to a commercial nursery. It is intended that this will be the first of a restricted number of superior families to be marketed over the next 5 years.

Forest operations research

The development of improved techniques of ground preparation on restock sites using excavators has been a major project over the past two years and some particularly effective solutions to deal with the problem of low stocking and uneven spacing caused by brash and spoil trenches have been developed. The practices of rowing brash or heaping brash into individual mounds was found to cause wide spacing regularly throughout the restock site. Selection of appropriate bucket design, techniques of raking directly through brash mats, the identification of a disciplined procedure for the sequence of mounding and estimation of spacing distances have been combined to enable regular spacing to be achieved on the majority of sites. Findings to date were delivered through a series of seminars to forest managers, supervisors and contractors during 2001.

Techniques for the extraction of timber on deep peats have been developed and evaluated. Options included different methods of brash mat construction, the use of straw, brash bales, woodchips and geotextile matting with successful solutions being identified. These additions can significantly extend the durability of the extraction route particularly on sites where there may be low tree stocking and limited brash available for extraction route construction. The results of work on ground preparation and wet ground working will be published during 2002/03.

ADVISORY COMMITTEE ON FOREST RESEARCH

The Advisory Committee provides guidance to the Agency on the quality and direction of its research. The Committee met on two occasions and appointed two Visiting Groups of scientists to review the work of Pathology Branch and of Environmental Research Branch.

Professor David Ingram (Chairman), Professor John Lucas and David Burdekin looked at the work of Pathology Branch. The Visiting Group concluded that the overall quality and customer relevance of the research were very good and provided excellent value for money. The Group was impressed by the scope and quality of Pathology's work, and noted that a significant proportion of the research is innovative and of international quality. None of the Branch's programmes were considered to be failing to meet the needs of their customers. The Group was concerned about the critical mass of the team and its ability to respond to future demands and felt that careful succession planning and recruitment will be vital to sustain the Branch's research and advisory role. Other recommendations were that the customer-contractor relationship should be clarified, that the Branch's programmes could be better integrated both north and south and with other FR Branches and finally that the Pathology laboratories at NRS required upgrading.

Professor Brian Wilkinson (Chairman), Professor Ted Farrell and Professor Howard Griffiths looked at the work of Environmental Research Branch. In addition to review and evaluation of the Branch's research programmes, the Visiting Group commented specifically on funding, personnel and Branch management. The Group noted that many new areas of research were being identified by the Branch, that opportunities for developing sources of external funding should be encouraged and that FC funding arrangements should be less prescriptive with more responsibilities given to project leaders. It concluded that there should be a modest growth in the activities of the Branch.

The Group endorsed the need for a promotion panel, recommended more flexibility to streamline and speed up appointment procedures and suggested the establishment of a structured scholarship programme for studentships. The Group were impressed with the overall management of Environmental Research but suggested interdisciplinary research. The Group concluded that all of the Branch's programmes fully meet customer expectations and were making a useful contribution to national policy and practice. Seventeen specific recommendations were made.

Dr Rod Griffin has resigned from the Committee on his return to work in Australia. Particular thanks go to Rod for his contribution over a number of years. He will be replaced by Dr Christine Cahalan. We are grateful to the members of the Advisory Committee and of the Visiting Groups for their valuable advice.

FINANCE

Overall Income was slightly higher than the previous year. Within this small increase income from non-FC sources was up by 13% while income from Policy & Practice Division was down by 3.5% and other parts of the Commission increased their spend with us by 18%. Total expenditure increased by less than one half of a percent containing a 2% increase in payroll costs. The target operating surplus for the year was set at £520,000 but this increased to £556,000 due to substantial upward revaluation of the Roslin and Alice Holt sites. None the less, the operating surplus generated was sufficient to cover the increased capital charges leaving a net surplus for the year of £13,000 remaining.

Capital investment for the year was £513,000. Investment covered a wide range of scientific equipment, laboratory refurbishments and site and staff facility enhancements. A continuing programme of capital investment is essential if Forest Research is to continue to maintain high quality and cost effectiveness in its research.

VISITORS AND EVENTS

Deputy Minister for Rural Affairs Rhona Brankin, accompanied by Director General David Bills, visited the Northern Research Station in July and showed interest in the full range of our activities and very much enjoyed the visit. Members of the Timber Growers' Association (now the Forestry and Timber Association) and the Institute of Chartered Foresters attended Research Update Seminars at Alice Holt in July and NRS in November. A new initiative to establish regional research seminars was launched with events at Newton Rigg, Milton Keynes and Inverness which were well attended by a wide-ranging audience. Other workshops and seminars were also held at the research stations and on forest sites; these included Continuous Cover Forestry, Tree Doctor (a user-friendly CD for identification of tree disorders) and Ecological Site Classification.

Forestry Commissioners visited Alice Holt in April and their visit included a presentation about selected research programmes; this was followed later in the year by a visit from new FC Chairman, Lord Clark.

The Agency maintained its links with forestry organisations worldwide by hosting groups and individual visitors from many countries, including France, Sweden, Denmark, Chile, New Zealand, Fiji, Yale (Connecticut, USA) and British Columbia (Canada). Alice Holt and NRS also welcomed visitors from the Woodland Trust, the Northmoor Trust, FC England, University of Dublin, DTLR, and groups of students from Wye College University of London, and Reading University.

PEOPLE

The total number of staff employed by the Agency at year end excluding sandwich students and visiting scientists was 260 full-time equivalents.

In the Queen's Birthday Honours, Jim Pratt of Pathology Branch was awarded an MBE in recognition of his services to forestry. Roger Trout of Woodland Ecology Branch was elected to the Council of the Mammal Society. Clive Brasier of Pathology Branch, was confirmed at IMP2 by the Joint Research Council Committee responsible for administration of Individual Merit Promotion (IMP). David Lonsdale, Pathology Branch, was one of two UK winners of the International Society of Arboriculture Merit Award, an annual award for outstanding contributions to the promotion of arboricultural knowledge.

Several staff were awarded PhDs: Laura Forrest of Tree Improvement Branch for 'A phylogeny of Begoniaceae Bercht. & J. Presl.' from the University of Glasgow, for work carried out at the Royal Botanic Garden Edinburgh; Gary Kerr of Silviculture and Seed Research Branch for 'Factors affecting the early growth and form of *Fraxinus excelsior* L. in Britain', from the University of Wales, Bangor; Liz O'Brien of Silviculture and Seed Research Branch for 'Organisation, landowner and former management in the conservation of blanket mires' from the University of Central Lancashire; Chris Quine of Woodland Ecology Branch for 'The role of wind in the ecology and naturalisation of Sitka spruce in upland Britain', from the University of Edinburgh. Paul Tabbush of Silviculture and Seed Research Branch was awarded a distinction for his MSc in Public understanding of Environmental Change by University College, London. Peter Freer-Smith was awarded a DSc from Lancaster University.

BSc degrees were awarded to: Hugh MacKay of TSU Newton, in Forestry and Conservation from Inverness College (Stirling University accredited); Colin Edwards of Silviculture North Branch, in Natural Sciences from the Open University, in addition to diplomas in Biological Sciences and Natural Sciences. Alan Harrison of TSU (North), Bill Jones of Technical Development Branch and Colin Edwards of Silviculture (North) attained BASIS Certification in Crop Protection and are now qualified to give advice on the use of pesticides in forestry.

Robin Jackson of Woodland Ecology Branch (Forest Research funded CASE student), was awarded a PhD by Southampton University for a thesis on remote-sensing of forest gaps. Caroline Gorton of Pathology Branch (FR funded student) was awarded a PhD for her work on 'Biological control of bluestain in Pine' by Imperial College, London. John Dolwin (supervised by Pathology Branch) was awarded a PhD by Reading University for evaluating and developing devices for the assessment of decay in trees. Matt Wood (supervised by Environmental Research Branch) achieved a PhD from Southampton University for his work on 'The effects of mechanised forest harvesting on soil physical properties'.

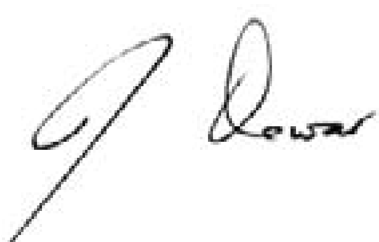
David Lonsdale of Pathology Branch retired after 26 years of service, including internationally recognised work on beech bark disease, Phytophthora disease of alders, prevention and decay in amenity trees and tree hazard assessment. Iain Forest of Tree Improvement Branch also retired after 30 years of service working mainly on genetic variation at the biochemical level and through these techniques establishing patterns of variation between populations of Scots pine indigenous to the Scottish Highlands.

New appointments to the Agency included Dr David Williams to work on entopathogenic nematodes, Dr Sarah Green to work on establishment problems in native hardwoods, Anna Brown on continuous cover forestry and herbicides, Keven Watts on landscape ecology, Paul Taylor to work on the Forest Research database, Matthew Griffiths as GIS officer and Jenny Claridge as Publications Officer.

This is my last Annual Report as Chief Executive of Forest Research. Over the last 5 years the Agency and before that the Research Division of the Forestry Commission has developed in response to the changing demands of our customers and owners and the changing environment in which we operate. This could not have been achieved without the hard work of staff in the Agency and particularly my colleagues on the Forest Research Management Board. I wish them and my successor well for the future.

TARGETS AND ACHIEVEMENTS

Performance measure		1997/98	1998/99	1999/00	2000/01	2001/02	
Customer satisfaction	Target	85%	92%	95%	96%	96%	TARGET MET
	Achieved	90%	94%	96%	97%	97%	
Peer-reviewed papers	Target	29	35	38	43	48	TARGET MET
	Achieved	33	40	43	48	48	
Unit cost/research day 96/97 = 100	Target	98	96	94	94	94	TARGET MET
	Achieved	98	94	94	94	92	
Unit cost of support services	Target	-	-	98	94	96	TARGET MET
	Achieved	-	100	98	96	94	
Cost recovery	Target	100%	100%	100%	100%	99%	TARGET MET
	Achieved	101%	103%	100%	101%	100%	

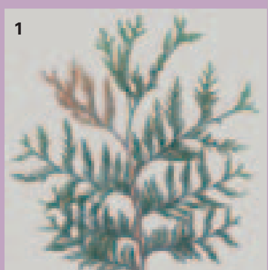


Jim Dewar
Chief Executive, Forest Research

Joan Webber and Hugh Evans

Pests and diseases

It has long been recognised that climatic conditions influence the epidemiology and incidence of many pests and diseases. Now, with the growing acceptance that man's activities are causing a gradual change in the global climate, there is an increasing need for research into the climate dependency of pathogen and insect outbreaks. Over the next century climate change is likely to have both direct and indirect effects on the environment and, in consequence, to alter the way we manage our forests and also how we combat the damage caused by pests and diseases. Some of these issues are highlighted in a recently published Forestry Commission Bulletin (Broadmeadow, 2002), which contains several chapters authored by Forest Research entomologists and forest pathologists.




1. Foliage browning and shoot dieback in Leyland cypress caused by *Kabatina thujae.*
2. *Monochamus* beetle.
3. *Ips* bark beetle.
4. Fruit bodies of *Pholiota* (a cause of root and butt rot) on *Prunus.*

INTRODUCTION

When considering the potential impact of climate change, the UK has the benefit of some of the best climate data series in the world. These data indicate that the UK climate has been warming at a rate of 0.1 to 0.2°C per decade, with fewer cold days and more frequent hot days (Hulme, 2002). Indeed, the 90s decade – 1990 to 1999 – was the warmest since records began in the 16th century. The growing season has also lengthened. There is a strong likelihood of further alterations in temperature and precipitation; possibly also wetter winters and more severe winter gales resulting in more episodes of flooding and wind damage. The major expansion of forestry in Britain in the 20th century led to the widespread use of exotic species, principally conifers from western North America, continental Europe and Asia. Because of this, the forests of Britain may be more vulnerable to weather-induced injury than those in other countries that rely more on native species and local provenances.

The accidental transfer of plant pests and pathogens to new regions of the world is always of concern but likely to be even more significant in the face of climate change. One much quoted example is *Phytophthora cinnamomi*, which probably originated in the Pacific Celibes, but now occurs in Australasia, North America and Europe. Its pathogenic activity is greatest at 25–30°C, making it especially destructive in sub-tropical and Mediterranean climates. In the current climate of Britain, it causes occasional disease outbreaks on a wide range of broadleaved hosts but is likely to become more prevalent with global warming (Brasier and Scott, 1994). Evidence from pests and diseases involving native hosts also suggests that damage is likely to be exacerbated by stresses brought about by extremes of weather, especially drought during the growing season. Bark beetles for example, which often act as vectors of sapstain fungal pathogens, are likely to be favoured by the stresses induced by climate change. Rates of development are linked to spring and summer temperatures, so increased temperatures would lead to decreased generation time and a northerly shift in distribution. In particular, beetles such as *Ips typographus*, which are not established in Britain but pose a considerable threat, would undoubtedly respond positively to higher average temperatures, and any drought-induced stress would make it easier for the beetles to overcome host defences as they mass attack trees to breed.

Over the years there has clearly been a strong link between international trade and the movement of pests and diseases and the damage they cause. Now, the potential role of climate change in aiding establishment and in determining the impact of pests and diseases also needs to be taken into consideration.

THREATS FROM ABROAD

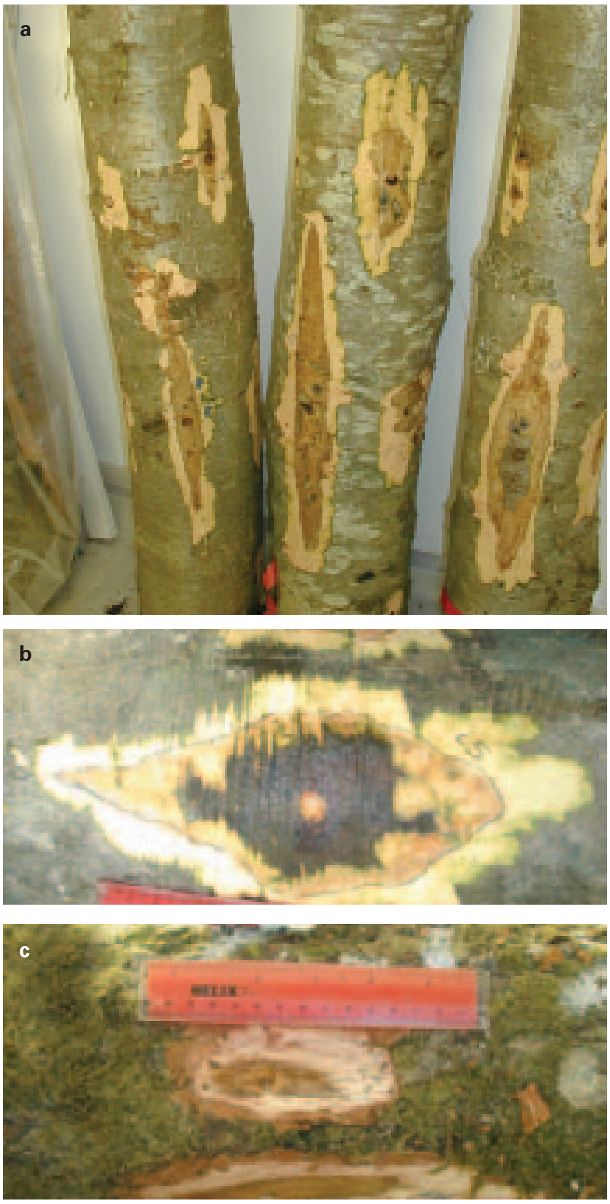
Sudden Oak Death

Last year's report on Pests and Diseases (Evans and Webber, 2002) described the risk posed by a new fungal pathogen, *Phytophthora ramorum*. This is currently the cause of widespread mortality of oaks in coastal areas of California, USA, and the rapid onset of symptoms frequently seen in infected trees has led to the disease name 'Sudden Oak Death' or SOD. The same fungus has also been found sporadically in the Netherlands and Germany where it causes a twig blight of rhododendron and has also been found killing nursery plants of viburnums and rhododendron (Werres *et al.*, 2001).

In June 2001 an information leaflet was prepared describing the symptoms caused by SOD on oaks in California, and the possible symptoms that might be seen if UK oaks were infected. Over 2000 copies of this Exotic Pest Alert were circulated to arborists, tree officers and foresters. As British oaks are already subject to a widespread but low level mortality and dieback known as 'oak decline' (caused by a complex of root infecting fungi, recurrent droughts and insect defoliation), there was concern that decline symptoms could be masking the somewhat similar symptoms of SOD. To assess whether *P. ramorum* could be infecting oaks in Britain a range of oak decline sites were re-surveyed for any signs of SOD, with particular attention given to sites where rhodendron was a component of

Plate 1 (a), (b) and (c)

Lesions on logs 5 weeks after inoculation with *Phytophthora ramorum* and other *Phytophthora* species: (a) entire logs with some bark removed to show lesions; (b) *P. ramorum* lesion in *Fagus sylvatica* and (c) *P. ramorum* lesion in *Quercus robur*.



the surrounding vegetation. However, no evidence of the disease was obtained, and all visible symptoms could be attributed to known problems of oak dieback.

To evaluate in more detail the risk that SOD might pose to oaks (and possibly other trees species) in the UK, pathogenicity tests were undertaken with *P. ramorum* under licence in high security quarantine containment chambers. Freshly felled logs cut from a range of broadleaved species, but with particular emphasis on *Quercus* species, were inoculated with isolates of *P. ramorum* obtained from Europe and California. After a few weeks the extent of lesion development in the bark and sapwood around the inoculation point was taken as an indicator of pathogenicity (see Plate 1 (a), (b) and (c)). The results of these tests were promising in that *Quercus robur* appeared relatively resistant to the fungus and only small, limited lesions developed. However, *Q. rubra* (American red oak) and *Fagus sylvatica* (European beech) showed signs of greater susceptibility to *P. ramorum* and further tests are planned. Closer study of the pathogen has also revealed that it has two mating types (A1 and A2), with the A2 only apparently present in the USA and the A1 in Europe. This raises questions about the geographic origin of this new pathogen and its potential for genetic change through sexual recombination. More information about this research is available on the Forest Research website or from one of the authors (joan.webber@forestry.gsi.gov.uk).

Coleoptera intercepted in port inspections and in pheromone traps

As part of the service that Entomology Branch provides for the Forestry Commission Plant Health Service, rapid identification is carried out of insects intercepted during port inspections and which are captured in pheromone traps at ports and timber yards. There were relatively few significant interceptions during 2001 but among the list are Coleoptera of high quarantine significance (Table 1).

Table 1

Interception of Coleoptera of quarantine significance

Family	Species	Tree genera	Country of origin	UK species?
Identifications from port inspections				
Scolytidae	*Hylurgops palliatus*	*Picea, Pinus*	Latvia	Yes
	Ips calligraphus	*Pinus*	USA	No
	Ips typographus	*Picea*	Europe	No
	Pityogenes chalcographus	*Pinus*	Germany	Yes
	Tomicus piniperda	*Pinus*	Germany	Yes
	Ips grandicollis	*Pinus*	Canada, USA	No
	Tomicus minor	*Pinus*	Italy	Yes
	Hylastes spp.	*Pinus*	Spain	Yes
Cerambycidae	*Monochamus titillator*	*Pinus*	USA	No
	Monochamus galloprovincialis	*Pinus*	Europe	No
	Arhopalus tristis	Conifers	Guernsey	Yes
Bostrychidae	Species not determined. Known as false powderpost beetles	Hardwoods	Vietnam, India, Zimbabwe	No
Identifications from pheromone traps				
Scolytidae	*Ips typographus*	*Picea*	7 specimens at 5 locations	No (European)
	Ips sexdentatus	*Pinus*	21 specimens at 5 locations	Yes
	Hylurgops ligniperda	*Pinus*	1 specimen	No (European)
	Ips cembrae	*Larix*	1 specimen	Yes
	Tomicus piniperda	*Pinus*	1 specimen	Yes
	Hylastes brunneus	*Pinus*	1 specimen	Yes

The eight-toothed European spruce bark beetle, *Ips typographus*, has been regularly intercepted and poses one of the most serious threats to spruce forests in this country. It was found during regular inspections by Plant Health Service staff and in pheromone traps at five different locations. Among the other bark beetles, several are already present in Britain but their interception indicates that there were infringements to the quarantine requirement that all bark should be removed from sawn timber. Two species of *Ips* from North America were also intercepted. Although neither species is regarded as a serious pest in the country of origin, their potential impacts in new locations may be less predictable. For example, *I. grandicollis* has established in Australia (Berisford and Dahlsten, 1989) where it has caused significant damage to radiata pine *(Pinus radiata)*.

The recent finding of pinewood nematode, *Bursaphelenchus xylophilus,* in Portugal (see Gibbs and Evans, 2001) has raised awareness of this important pest in Europe and has confirmed the role of longhorn beetles in the genus *Monochamus* as vectors of the disease. There are no *Monochamus* species in Britain but, as indicated in Table 1, interceptions of two species, *M. titillator* from North America and *M. galloprovincialis* from Europe, confirms that movement via wooden packing material takes place in international trade. Both species of *Monochamus* are known vectors of *B. xylophilus* in North America and Portugal, respectively. Contact christine.tilbury@forestry.gsi.gov.uk for further information.

ESTABLISHED PEST AND DISEASE PROBLEMS

Pine looper moth, *Bupalus piniaria*

Pine looper moth, *Bupalus piniaria*, has been studied intensively in Britain and continental Europe over many years. Within Britain, the Forestry Commission has carried out annual surveys of population trends at selected sites since 1953. With the exception of a single outbreak on young lodgepole pine, *Pinus contorta,* trees in 1979, the moth has reached significant population levels only on Scots pine, *Pinus sylvestris,* on well-drained sites. Usually the moth does not give rise directly to tree mortality but weakens Scots pine sufficiently for pine shoot beetle, *Tomicus piniperda,* to launch successful attacks that can kill the trees.

However, during the past 2–3 years an unusual increase in populations of *B. piniaria* has been noted in a plantation at Achrugan in Sutherland. Lodgepole pines have been attacked heavily and, for the first time in Britain, appear to have been killed by the direct action of the moth as no significant presence of pine shoot beetle has been noted. Studies on population trends in a number of forests in the north of Scotland have been carried out by Forest Research staff and by Dr David Barbour on contract to Forest Enterprise. Pheromone lures were supplied by Professor David Hall of Natural Resources Institute of the University of Greenwich and were deployed at most of the forest locations. Results from the pheromone counts correlated with the areas showing highest signs of the moth recorded by other means such as pupal densities, egg densities and defoliation scores. Within Achrugan forest approximately one-third of the crop has been severely defoliated, with a high proportion of trees killed.

A further one-third was heavily defoliated, while the remainder was relatively untouched. Pheromone trap counts from these three areas revealed mean counts of 1432 (range 727–2391), 811 (384–840) and 622 (186–1999), respectively. Defoliation scores ranged from 12.5% to 31.9% in the moderate and from 0% to 13.1% in the undefoliated/lightly defoliated area (the heavy defoliation area was not formally assessed because there was so little foliage left). Egg counts averaged 3109 (range1495–5342) and 441 (163–879) in the moderate and light defoliation areas respectively.

Although there was a link between pheromone trap catches and numbers of eggs subsequently laid on the trees, the correlation was low. However, data from pheromone trapping at six other forests representing non-outbreak sites on Scots pine (two forests) and lodgepole pine (four forests) gave counts ranging from 119 to 702. The highest count was at Dalharrold, the forest closest to Rimsdale Forest which had recorded a high pupal count in 2000. These data indicate that deployment of pheromone traps may provide a means of assessing significant differences in population levels of *B. piniaria* between forests but not necessarily for detecting local differences in population levels within forests. Further work is needed to confirm and extend these initial data. Contact stuart.heritage@forestry.gsi.gov.uk for more information.

Hornet clearwing moth *(Sesia apiformis)* and dieback of poplars

Dieback in poplar trees in the region of Bedford (Plate 2), Milton Keynes and Northampton has been of concern for several years, and has been associated with attack by the hornet clearwing moth, *Sesia apiformis* (Lepidoptera: Sesiidae). The moth (Plate 3) is usually considered a secondary agent, but there were suggestions that in this region the insect was acting as a primary pest and killing healthy trees. In 1999, a survey was carried out to establish more clearly the relationship between tree health and moth attack, and whether dieback and infestation could be related to particular environmental and habitat factors. The survey was conducted by Mr John Arundell as part of his MSc course in arboriculture at the University of Middlesex and was supervised by Dr Nigel Straw.

Plate 2

Dieback in poplar [Nigel Straw].

The 1999 survey of around 800 trees demonstrated that there was a correlation between dieback and the severity of infestation as measured by the number of moth emergence holes at the base of the stem (Plate 4). However there was considerable variation in the relationship and a significant number of trees showed severe dieback but no evidence of moth attack (Arundell and Straw, 2001). Dieback in many trees could not be attributed, therefore, to *S. apiformis*. Careful examination of the data indicated that the moth was most likely acting as a secondary agent. The primary cause of tree decline was probably drought in earlier years and perhaps human influences that affected water availability.

A re-survey of the same trees during 2001 was designed to identify more clearly the possible role of the moth in causing dieback. In total, 674 trees from the 1999 survey were re-surveyed during August and early September 2001, although a number of trees had been lost because of thinning work or safety felling, and some were inaccessible due to foot and mouth disease restrictions.

Preliminary results indicated that the condition of the poplar trees in the re-survey was very similar to that recorded in the original survey, indicating minimal crown recovery over the past two years (Table 2).

Average crown dieback of the *P. x euramericana*, the largest taxonomic group and the taxon most heavily infested with *S. apiformis*, remained at 31.4%. Crown condition at individual sites showed little change (Figure 1). Mean rates of dieback in the other poplar varieties and species that were included in the surveys also remained much the same or increased only very slightly (Table 2).

Plate 3

Adult hornet clearwing moth *(Sesia apiformis)* [Kimmo Silvonen].

Plate 4

Exit holes of adult *S. apiformis* at the base of a poplar tree [Nigel Straw].

Table 2

Differences in % crown dieback between poplar species and varieties in the original survey in 1999 and in the re-survey in 2001.

Species/variety	1999 survey all trees		1999 survey: same trees as 2001 survey		Re-survey in 2001	
	mean % crown dieback	*n*	mean % crown dieback	*n*	mean % crown dieback	*n*
Black poplars						
P. nigra	20.0 –	10	20.0 –	10	23.0 (±1.5)	10
P. x euramericana	34.6 (±0.9)	601	31.4 (±0.9)	480	31.4 (±0.9)	480
P. nigra var. *italica*	14.4 (±1.0)	111	14.2 (±1.0)	107	14.4 (±1.1)	107
Balsam poplar *(P. trichocarpa)*	18.1 (±5.3)	27	12.4 (±3.7)	25	12.0 (±3.4)	25
White poplar *(P. alba)*	10.0 –	12	10.0 –	12	10.0 –	12
Grey poplar *(P. canescens)*	37.4 (±4.6)	40	37.4 (±4.6)	40	38.3 (±4.6)	40

Analysis of the exit hole data for *P. x euramericana* showed that the number of new holes per tree was related to the total number of exit holes recorded in 1999 (Figure 2). This is not unexpected, as heavily infested trees are likely to continue to produce large numbers of adult moths for several years. However,

Figure 1

Site means of % crown dieback for *P. x euramericana* in 2001 plotted against the site mean % crown dieback in 1999.

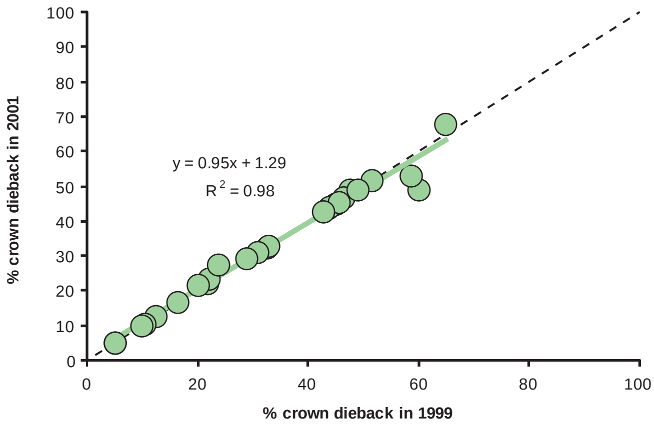
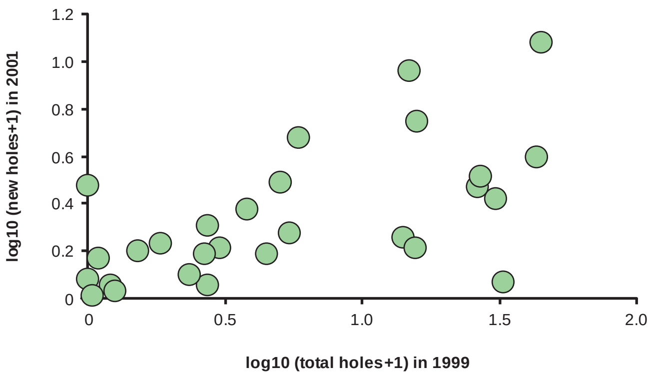


Figure 2

Relationship between the number of new holes appearing in 2000–2001 and the total number of *S. apiformis* exit holes recorded in 1999.



there was considerable variation in the number of new exit holes appearing and moth production showed no obvious relationship with previous infestation, crown dieback or tree size.

Higher numbers of new *S. apiformis* exit holes were recorded on trees growing in rough grass areas, and where there was dense tall weed, bramble and scrub vegetation. Few new holes were found on trees growing in hedges or in short, mown grass. These trends follow the pattern of infestation observed in the 1999 survey.

In the original survey, 160 *P. x euramericana* trees showed no evidence of moth attack, despite showing signs of moderate or severe dieback in the crown. During the 2001 survey, 134 of these trees were re-examined and 37 had exit holes. Despite the appearance of *S. apiformis* exit holes in many of the trees that had not shown signs of attack in 1999, the amount of dieback in the crown of the trees remained exactly the same between the surveys. Consequently, the development of infestation in the stem did not have a very immediate effect on crown condition.

Conclusions and recommendations

Crown condition did not change sufficiently between 1999 and 2001 for the re-survey to show how tree recovery or decline might be related to *S. apiformis* infestation, or habitat and environmental variables. Evidently, a longer period of time is required to monitor changes in crown condition and tree health. However, the re-survey did demonstrate increases and decreases in *S. apiformis* infestation, and these data, and the observation that crown condition changed little, allow a number of important points to be made:

- Crown dieback does not progress rapidly in trees infested with *S. apiformis*, nor are infested trees doomed to die rapidly.
- A few trees, with up to 14 new and 45 old exit holes, showed reduced dieback and slightly improved condition after two years. Hence some trees appear to be recovering despite infestation.

Further assessment of the same trees in 2–3 years time will add value to these observations, and will indicate more clearly under what conditions trees are more likely to recover or decline, and what may predispose uninfested trees to attack. Contact nigel.straw@forestry.gsi.gov.uk for further information about this work.

BIRCH DIEBACK IN SCOTLAND

Birch is a major component of native woodlands throughout Scotland, and it is valued increasingly as a resource for conservation, habitat and landscape purposes. Recently there has also been interest in the potential of silver birch *(Betula pendula)* as a timber species in the UK (Malcolm and Worrell, 2001; Varley, 2001). Silver birch and downy birch *(B. pubescens)* are two of the more important broadleaved species in new native woodland planting and natural regeneration schemes in Scotland, of which 50 000 ha were created during the 1990s (Forestry Commission, 2000). The area of native woodlands is projected to increase further over the next 5–10 years with continued take-up of the new native woodland grant schemes (Forestry Commission, 2000). As a result, there are now large numbers of young birch trees on a wide variety of site types across Scotland.

During the past 2–3 years there have been reports of widespread dieback of young, planted birch in Scotland. Although factors such as unsuitable provenance and site selection, poor silvicultural management, and climatic damage may be contributing to this dieback, attack by fungal pathogens is thought to be an important element in the demise of the trees. A number of fungal pathogens have been found to cause shoot and stem lesions on birch in Finland and Canada, resulting in dieback (Hahn and Eno, 1956; Arnold, 1967; Romakkaniemi, 1986; Lilja *et al.,* 1996; Paavolainen, 2001). However, very little information is currently available on the fungal pathogens associated with shoots and stems of birch in the UK.

In August and September 2001, visits were made to nine sites in Scotland where dieback of young birch had been reported. Affected trees appeared to be dying back from the lower crown upwards, and from the outer crown inwards (Plate 5). Symptoms included: discrete lesions and tip dieback on current shoots; darkened, sunken lesions on older shoots and on the main stem (Plate 6); and bark cracking associated with lesions at the stem base. The ascomycete fungus, *Anisogramma virgultorum*, was found to be very abundant, particularly on downy birch. This fungus forms black 'stroma' on current shoots (Plate 7), which develop into large, deep fissures, causing older shoots and whole branches to die back. Other fungi isolated from lesions include a *Phomopsis* sp., *Melanconium* sp., *Marssonina* sp., *Fusarium* spp. and a fungus tentatively identified as a *Godronia* sp., the latter being previously unrecorded in the UK. The life cycle and degree of pathogenicity of these fungi on birch is not yet known. Pathogenicity tests are being conducted on birch seedlings of Scottish provenance in the greenhouse. The field survey for fungal pathogens associated with birch dieback will continue in the summer of 2002; contact sarah.green@forestry.gsi.gov.uk for more details about this research.

Plate 5

(a) and (b) Dieback in the lower crowns of young birch [Sarah Green].

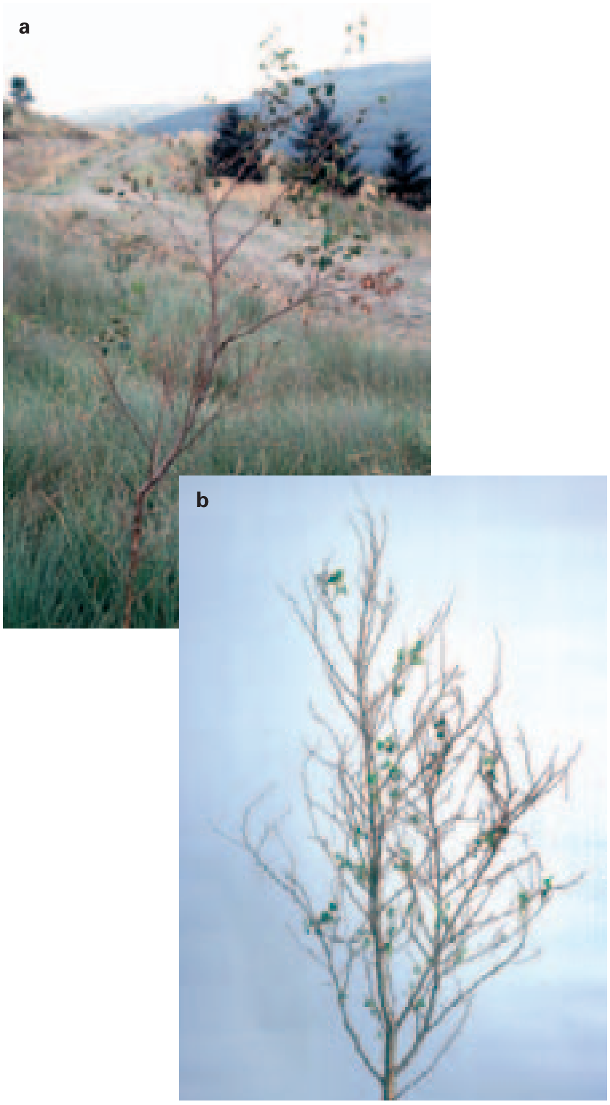


Plate 6

Dark sunken lesions on one of the older shoots of an affected birch.

Plate 7

Black stroma formed by *Anisogramma virgultorum* on the current shoots of downy birch *(Betula pubescens).*

WEATHER-RELATED AND PERIODIC DAMAGE

The past few years have seen a marked increase in the incidence of various pests and diseases and the change is often weather related. This alteration may also represent a new pattern of behaviour brought about by climate change. A wide range of leaf and shoot infecting pathogens show marked annual fluctuations in their incidence and severity of attack and climate change could be expected to influence their frequency of occurrence in the long term. In the UK, one of the most striking pathological phenomena of recent years has been the prevalence and severity of scab on willow caused by *Venturia (Pollaccia) saliciperda* (Lonsdale and Gibbs, 2002) which defoliates and can kill the most susceptible species such as crack willow. The consistently wet weather in April 2001 coupled with periods of heavy rainfall during May in southern England, once again encouraged the development of this disease. The increase in disease severity apparently results from a sequence of cool wet springs – which has favoured the development of several other foliar diseases. Red band needle blight *(Mycosphaerella pini)*, which attacks Corsican pine continued to show an upsurge in frequency and severity in the south of England. This has caused such severe defoliation and growth reduction that an area of 10 ha had to be clearfelled. The increased incidence of this disease (which is even more marked in France) is thought to be associated with climate change as well as altered management regimes.

There were also a number of deaths due to waterlogging, as in 2000, again involving mostly cherry, beech and Douglas fir. With the warmer conditions in July and August, *Phytophthora* diseases were once again widely reported. The species most affected were yew and silver fir with *Phytophthora citricola* being most frequently isolated. Douglas fir from an area of new planting near Bristol were also found to have suffered root-killing by *P. megasperma*.

In Scotland heavy snow fell at the beginning and end of February 2001 accompanied by low temperatures and strong winds. These conditions are likely to have been associated with directional foliage browning and shoot dieback noticed on roadside Leyland cypress at several locations in the Scottish Borders. The fungus *Kabatina thujae*, which is a weak wound pathogen, was found on the affected shoots (see Plate 8). During spring 2001, a combination of planting at high elevation and strong winds led to several reports of browning and loss of older needles on young Scots pine planted under New Native Woodland Grant Schemes. Some of the browning was due to the needle cast fungus *Lophodermium seditiosum* – the most widespread of pine needle-cast diseases. These trees, which are already stressed, will remain susceptible to further climatic damage and attacks by secondary pests and pathogens.

NOTABLE RECORDS

Disease Diagnostic Advisory Services (DDAS) at the two FR research stations respond to hundreds of enquiries related to tree health each year. Several unusual problems were encountered over the year. Contact david.rose@forestry.gsi.gov.uk and sarah.green@forestry.gsi.gov.uk for more information about the DDAS.

Continuous cover forestry

One of the recent changes in forest practice has been the introduction of continuous cover forestry and the management of natural regeneration (Mason *et al.*, 1999). These changes in practice and site conditions may present new risks to trees. *Armillaria* (honey fungus) was the cause of death of 76-year-old Scots pine trees in a long-term transformation site in south Scotland. Some of the dead trees had fruit bodies on their stems up to a height of 2 m, and several trees which had healthy crowns but decayed roots blew over in gales. As *Armillaria* was widespread on this site it is likely that a high proportion of regenerating pine will become infected over time.

Christmas trees

The Christmas tree market has recently expanded in Britain, with 7 million trees sold in 2001. This is a speciality crop where appearance is of high importance and any damage to the foliage affects the value of the crop. One foliar pathogen that caused concern in a Forest Enterprise-owned Christmas tree nursery producing Scots pine was the rust *Coleosporium tussilaginis*. There is no practical control measure for this pathogen except management in the form of removing the alternate weedy host species. The rust *Melamsporella caryophyllacearum* caused foliage browning and needle loss on *Abies* species at another Christmas tree nursery. There were also three records of the needle rust *Pucciniastrum epilobii* on *Abies nordmanniana*. This rust is not commonly encountered in England and Wales and its appearance in three separate locations in southern Britain is very unusual.

Plate 8

Shoot dieback in Leyland cypress caused by *Kabatina thujae.*

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Helen Armstrong, Robin Gill, Brenda Mayle and Roger Trout

Protecting trees from deer: an overview of current knowledge and future work

There are six deer species in the UK: red, roe, sika, fallow, muntjac and Chinese water deer. Numbers of all, except perhaps Chinese water deer, are increasing and populations are expanding their range.

1. Group of fallow does in birch woodland [Forest Life Picture Library].
2. Red deer on the open hill [Alastair Baxter].
3. Sika stag in a spruce plantation [Norman Healy].
4. Muntjac doe in a grassy ride [Ian Wyllie].

INTRODUCTION

Deer browse young trees, fray saplings with their antlers and strip the bark from older trees (Plates 1, 2 and 3). This article provides an overview of how forest managers can protect young trees from deer. We discuss the reliability and application of different methods and the likely role of each in different woodland management scenarios. Details of many of the techniques can be found in various Forestry Commission publications listed in the References.

INITIAL QUESTIONS

In any situation there are three questions to be answered to determine the best approach to protecting trees from deer.

1. What are the objectives for the woodland?
2. Are deer likely to hinder the achievement of the objectives, either now or in the future?
3. If the answer is yes, which are the most applicable and affordable tools for reducing their impact?

At this stage, if the initial objectives are thought to be unattainable, it may be necessary to reconsider them. We will expand on each of these areas.

To determine whether success has been attained in any endeavour there must be a clear statement of what is to be achieved, and by when. This may be a very precise, quantifiable objective or it may be more imprecise and subjective, for example:

- 1100 oak seedlings per ha (plus or minus 100) at a height greater than 50 cm in three years' time;
- no more than 10% (plus or minus 5%) of restocked Sitka spruce saplings to have their leaders browsed by deer in any one year;
- young trees to be visible to a casual observer when walking through the woodland in two years' time.

The success or failure in achieving the objective has to be measured in some way. This might involve the use of either a formal measurement technique or a simple observational method. The choice will depend on the nature of the objective and on the precision required by the manager. Ferris-Kaan and Patterson (1992) and Pepper (1998) present methods for quantitatively sampling vegetation and planted saplings, respectively, to determine impacts by deer. Further guidance is being developed by Forest Research on methods of measuring, and estimating, deer impacts on a range of woodland features, including ground vegetation (see Plate 4), naturally regenerated seedlings and saplings, planted saplings and older trees.

Plate 1

Browsing damage by roe and red deer [Forest Life Picture Library].

Plate 2

Fraying to Scots pine by roe deer (a) and fallow deer (b).

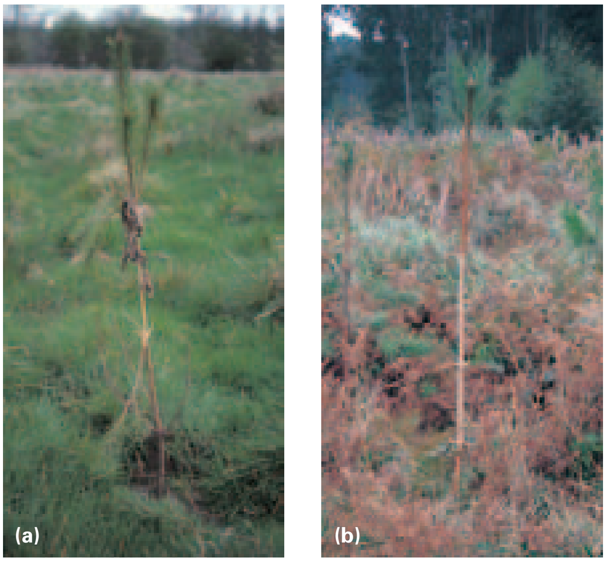


Plate 3

Stripping damage by sika deer in south Scotland to larch (a), examples indicated by arrows, and (b), and Sitka spruce (c).

(a) (b) (c)

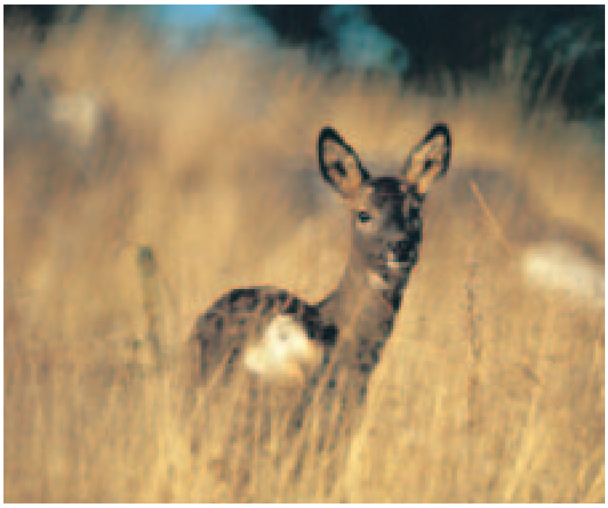
If the objectives need to be fulfilled immediately then the next step is to use the most appropriate impact assessment method to determine whether there is currently a deer problem. If the objectives are to be obtained in future years, e.g. when regeneration or restocking is planned, then looking for current impacts will be of no use and the manager will need to predict the likelihood of deer becoming a problem. This will require information not only about deer densities and movements but also about the attractiveness of the site, and the trees, to the deer species present (see Plate 5). Managers who have many years' experience of their site and of deer impacts under a range of woodland management conditions and deer densities can often make very good predictions. However, for others, such predictions are difficult because of the large number of factors involved. In this case computer models can be useful in helping to make best use of current knowledge on deer population dynamics, movements and foraging behaviour. Forest Research has recently produced a simple spreadsheet model to help managers to predict the effect of different culling strategies on future deer populations (Armstrong, 2000). In the coming years we plan to improve on this model and to add site-specific predictions of deer movements, foraging behaviour, browsing rates and tree responses (see Predicting the Impacts of Management, page 37).

Plate 4

Bluebells browsed by muntjac deer in Monks Wood [A. Cooke].

Plate 5

Roe deer in restock/prethicket habitat [Forest Life Picture Library].



MANAGEMENT OPTIONS

If there is, or is likely to be, a problem with deer, the following are the four main options for protecting trees:

- reduce deer numbers
- physically protect trees from deer
- reduce the significance of deer damage
- reduce the attractiveness of trees to deer.

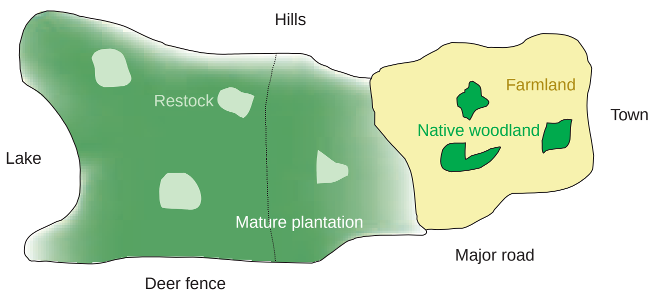
TOOLS TO REDUCE DEER NUMBERS

Culling is the obvious method of reducing the impact of deer on trees but may not always be possible where deer cannot be controlled over the whole deer range. Figure 1 illustrates the factors likely to constrain a deer range. Where the manager does not have control over the whole range it may be possible to join, or start up, a Deer Management Group and to obtain agreement from all members to cull the required number of deer. However, in some cases, different owners have different management objectives or some have inadequate resources to put into deer control. Safety might also rule out culling in areas used heavily by the public. To aid culling and extraction, forests should be designed with adequate glades and rides (Ratcliffe, 1985).

Where culling has the potential to have a significant impact on deer numbers in the problem area, there are various tools available to help with cull setting. The approach recommended by Forest Research for red and roe deer is outlined in Ratcliffe (1987) and Ratcliffe and Mayle (1992) respectively. This involves estimating initial deer population size, age structure and sex ratio as well as natural mortality and recruitment rates. Future populations can then be predicted using a simple model (Armstrong, 2000). The culling rate needed to achieve a particular deer density can then be determined. Where culling is unselective, the age

Figure 1

Schematic representation of a hypothetical deer management unit showing a range of habitats and potential barriers to deer movement.



structure of the deer population can be estimated from the age of culled animals. Field observations can be used to estimate sex ratio and recruitment rate. Ratcliffe (1987) and Ratcliffe and Mayle (1992) suggest appropriate natural mortality rates.

There are various methods of directly or indirectly assessing deer population size (Gill *et al.*, 1997; Mayle *et al.*, 1999). Direct methods include vantage point counts during daylight and distance sampling along transects at night using a thermal imager. The former requires locations within the woodland from where all deer are likely to be visible. The latter gives best results where there is a good network of roads and where there is a large component of open ground and/or the woodland is open. These methods give a value for deer numbers present at the time of counting. Indirect methods give an estimate of the average number of deer using the area sampled over a period of time. The most common indirect method is assessing the density of deer dung accumulated over a period that is either known or is estimated from dung decay trials. These methods are discussed in more detail in Mayle *et al.* (1999).

If the whole of a deer range is sampled then an estimate of the total number of deer in a population can be obtained. However, in many cases the manager is interested in only a small part of the deer range and it is impractical or too expensive to sample the whole deer range. Since deer use different habitats to varying degrees in summer and winter, any estimate of deer density that does not cover the whole range is likely to be affected by season. However, if repeated in one or more years at the same time of year, it can give a good indication of any changes in deer usage. It can also be useful when estimating the degree of immigration to an area. If culls are set at a level that should reduce the population and this does not happen, then the difference between the predicted and the measured population is likely to be due to immigration. Density assessment can therefore be a useful tool in assessing the numbers of immigrating deer.

Deer impacts need to be assessed to determine whether culling has been successful in achieving not only a reduction in deer numbers but also impact levels that are acceptable. Pepper (1998) describes a method of measuring rates of browsing on young trees and Ferris-Kaan and Patterson (1992) describe methods of monitoring the condition of ground vegetation. The method should be tailored to the objectives and the level of precision required. Forest Research is currently working to provide further guidance on a range of methods (see Initial Questions, page 29).

Another potential method of reducing deer numbers is through immuno-contraception. There has been considerable work and some success with a range of species, but especially white-tailed and fallow deer in the USA and Canada (Kirkpatrick and Turner, 1997; Muller *et al.*, 1997; Fraker *et al.*, in press). However, to date, no practical means of using immuno-contraception on wild deer populations has yet been developed in Britain.

TOOLS TO PHYSICALLY PROTECT TREES FROM DEER

Methods for physically protecting trees from deer include tree guards (Pepper *et al.*, 1985; Pepper, 1987; Hodge and Pepper, 1998; Potter, 1991), fences (Pepper, 1992; Pepper *et al.*, 1992; Pepper, 1999) and 'natural' protection. There are many types of tree guard on the market, however the efficacy of the latest designs has not yet been tested. Tree guards are usually too expensive for anything other than amenity planting or small woodlands. Hodge and Pepper (1998) provide a comparison of the cost of using fencing and tree guards for different sizes and shapes of woodland.

Permanent fencing can also be expensive and the fence specification needs to be tailored to the deer species present and the management objective (Pepper, 1992, currently being updated). Alternative, lower cost, fence specifications have been developed for temporary and reusable fencing (Pepper, 1999). To date, electric fences have been found to be of limited use against roe deer (Pepper *et al.*, 2001) but they may be more effective against red deer if there is a reliable electricity supply and the fence can be checked daily. Forest Research plans to investigate their use as short-term protection for coppiced lowland woods.

Fences may have other drawbacks, however; they are a barrier to walkers and the straight edges caused by fences can have significant landscape effects if badly positioned. It is recommended that where fences will result in a visual intrusion, they should be set within the edge of the woodland or trees should not be planted up against the entire length of the fence (Forestry Authority, 1994). Complete removal of large grazing animals by fencing may also cause a decline in woodland biodiversity over a number of years (Gill, 2000). In some parts of Britain, mortality of capercaillie and black grouse through collision with fences can be significant unless a visible fence marking system is used (Petty, 1995). Summers and Dugan (2001) provide advice on a number of such systems and further work is ongoing.

Brushwood 'hedging', made from cut branches, has protected small areas of coppice against roe and fallow for up to 18 months (Mayle, 1999a) but it is ineffective against muntjac as they push through the bottom of the hedge. Brash 'fences', made of piled up brash, have recently been found useful in some circumstances (RTS Ltd, 2002). Both these 'fence' types could provide useful habitats and are unlikely to cause woodland grouse mortality. Brash 'fences' can also be cheaper than ordinary fences if the brash has to be removed anyway. However, their durability is not yet known, they have the same landscape and biodiversity drawbacks of other fence types, they may harbour rabbit populations and are not easy to modify to provide deer-proof access to the fenced area. Covering coppice stumps with brash can reduce browsing rates on re-growing shoots.

In native woodlands, there is some anecdotal evidence that piles of dead branches formed when old trees fall over, or patches of blackthorn, hawthorn, dog rose, juniper, holly, bramble or even bracken can protect young, naturally regenerated trees from deer browsing (Sanderson, 1996; Hamard and Ballon, 1998). In native woodlands where there is insufficient natural regeneration, it might be worth considering the possibility of increasing the amount of these features. However, bramble and holly are also preferred browse species so may be difficult to establish at high deer densities and increased amounts might attract more deer to the site. Bracken can inhibit the seedlings of some tree species, such as oak (Humphrey and Swaine, 1997). There is an increasing body of opinion that in large, unmanaged native woodlands, where deadwood and shrubs have not been removed, 'natural' protection may allow enough trees to regenerate to maintain the woodland (Sanderson, 1996; Vera, 2000). However, this approach has not been tested as a management tool and we know little about the conditions under which it might be feasible.

TOOLS TO REDUCE THE SIGNIFICANCE OF DEER DAMAGE

In some cases, successful natural regeneration might be achieved by increasing the density of young trees rather than by decreasing the rate of browsing. In closed canopy woodland some thinning of adult trees may achieve this. Where there is dense ground vegetation, grazing animals can help break this up and so create additional germination sites. Pigs can do this job, as can cattle at the right densities (Mayle, 1999b). Both species can, however, damage woodland biodiversity if stocked at too high a density. We are currently concluding a survey of cattle grazed woodlands to improve our guidance on appropriate cattle management systems.

For planted trees, increasing the density of planting may increase the chances of the required number remaining undamaged but will increase the expense. However, it is difficult to predict how browsing rates change with the density of young trees and, in some cases, the proportion of trees browsed may increase if the density of trees increases. This approach is more likely to have the desired effect when applied to the less preferred tree species (Table 1) but is an expensive approach to take when there is little certainty of success.

Healthy trees are likely to suffer fewer lasting effects of browsing than less healthy ones. The significance of browsing impacts on planted trees can therefore be reduced by ensuring that the planting stock are healthy and carefully handled.

Table 1

Relative preferences of deer for saplings of different tree species (adapted from Ferris and Carter, 2000). The species are listed in order of preference with the most preferred at the top. Preferences vary with deer species, season, site type and with the amount and quality of other food sources available, therefore this is only an approximate guide. Preferences for coppice shoots may differ from those given here for saplings.

Broadleaf browsing	Conifer browsing	Bark stripping
Aspen	Silver fir	Willows
Willows	Douglas fir	Ash
Oak	Larch	Rowan
Rowan	Norway spruce	Aspen
Norway maple	Scots pine	Lodgepole pine
Sycamore	Sitka spruce	Beech
Beech	Lodgepole pine	Norway spruce
Lime	Corsican pine	Scots pine
Hornbeam		Larch
Birch		Douglas fir
Alder		Sitka spruce
		Silver fir
		Oak
		Alder
		Birch

TOOLS TO REDUCE THE ATTRACTIVENESS OF TREES TO DEER

If trees are being planted, the manager can consider choosing species that are less attractive to deer (Table 1). However, browsing preference is relative and whether a tree is eaten or not depends not only on the number and species of other trees present but also on the quality and quantity of ground vegetation available. Even the most unattractive species will be eaten if there is nothing else to eat.

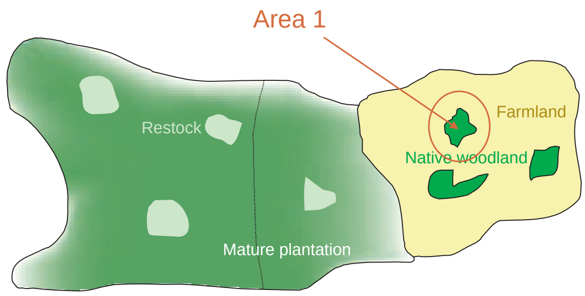
The only effective and approved chemical repellent is Aaprotect (Pepper *et al.*, 1996). This protects against winter browsing by rabbits as well as deer, but can only be used during the dormant season as it is phytotoxic. Generally, most repellents do not work for long enough to be useful other than to protect an area in the short term while more permanent measures are organised.

All chemical repellents need to be reapplied at least annually to protect new growth. There is a continuing need to test new materials as they become available.

Alternative shelter and diversionary feeding are potential methods of reducing the attractiveness of trees to deer. In theory, if deer are being attracted to a site for either shelter or feed, the provision of a better alternative may divert them. Most woodland deer are not short of shelter hence the provision of alternative shelter is unlikely to be successful. Diversionary feeding, however, has been used successfully in other countries though not in Britain (Gill, 1992). It is more likely to work with deer species, such as red deer, that have a large range and that will move long distances between shelter and regular feeding sites. Roe and muntjac deer, on the other hand, are territorial and generally remain in their own territories regardless of the quality of the forage available there. In the long term, if the population is not being culled appropriately, diversionary feeding will be counterproductive since it will result in a higher deer density. Currently, it is very difficult to predict the effect of such alternative food supplies on deer behaviour since many factors, which vary from site to site, will affect the outcome. Forest Research's planned modelling work will help with these predictions (see Predicting the Impacts of Management, page 37).

Figure 2

Scenario 1: the area to be managed is one of three patches of native woodland surrounded by farmland and near to a large commercial plantation.



CHOOSING THE RIGHT TOOLS

One of the major factors affecting which tools are appropriate or possible is the proportion of the deer range over which they can be appropriately controlled. This determines whether reducing deer numbers is likely to be feasible. The range of a deer population is likely to be bounded by water, mountain ranges, deer fences, railways, major roads (if fenced) or built up areas (Figure 1, page 31). Within that range, deer can move freely. We will discuss three scenarios, each of which will require a different approach.

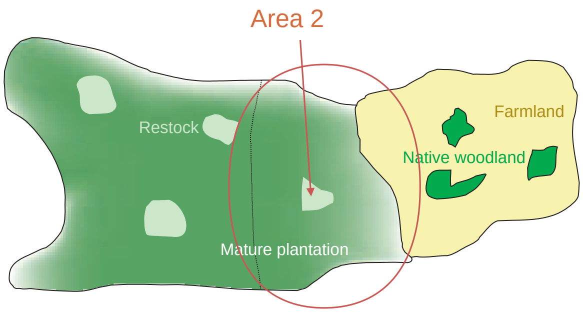
In **scenario 1** shown in Figure 2, the manager has control over a very small piece of native woodland surrounded by agricultural land. Close by is a large area of mature plantation with a few restock coupes. The aim is to achieve significant natural regeneration of broadleaved species. Firstly, the manager has to decide on the density of different tree species that are needed. Secondly, the adequacy of current levels of regeneration must be assessed and, if they are not high enough, whether deer damage is likely to be the limiting factor. This will be aided by a field visit to record density, height and damage to young trees as well as canopy cover and ground cover. This can be done quantitatively or by visual assessment depending on how accurate the result needs to be.

It might be possible to cull deer but it is likely to have very little effect on the overall population and hence on damage to trees. If it is not possible to work with the neighbouring landowners to control deer then this leaves the options of protecting trees from damage using a fence, tree guards or 'natural' protection. Cost, effects on biodiversity and accessibility to other woodland users are likely to determine whether any of these will be suitable. Alternatively, it may be possible to increase the density of young trees through scarification or opening up the canopy and /or accept that only the less attractive species will regenerate successfully.

In **scenario 2** shown in Figure 3, the manager wants to restock a clearfelled area of a conifer plantation. He/she has control over a significant proportion of the deer range but not over the whole area. The chances of getting significant damage depend on the density of deer and on the availability of alternative feed through the year. Culling is an option but if the neighbouring land owners are not also culling at a high rate then replacement of culled deer with deer from the neighbouring areas may be a problem. Assessing the initial deer density in the area, recording numbers, sex and age of culled animals, running a population model (Armstrong, 2000) and reassessing the deer density in later years can help in determining whether significant immigration is occurring or not. This can help to persuade neighbours that there is a problem. A cull of 25–30% is usually needed to reduce deer numbers but, even with this level of cull, it will take several years to achieve a significant reduction. This approach can work where the restock area is not attractive to deer relative to surrounding areas. This is likely to be the case in southern England where winters are relatively mild and where there is always alternative food around. It would also apply to a red deer hind wintering range where immigration of hinds from another range may be very slow. Assessing damage levels will determine whether the approach is working or not. However, it is impossible to be sure that this approach will work until it has been tried and it is expensive to carry out the culling and monitoring required.

Figure 3

Scenario 2: the area to be managed is a recently felled stand within a large plantation forest, which is soon to be planted with young trees.

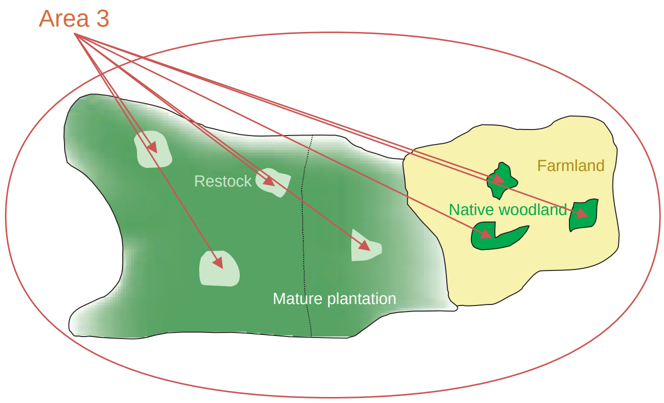


It might be possible to increase the planting density and accept the losses but it is hard to predict what the losses will be and how increasing the density of trees might affect this. Alternatively the manager might be able to plant a less attractive species of tree but that depends on objectives and site type. This is probably the most difficult type of site for which to decide on the best approach and is where a predictive model would be of most use.

In **scenario 3** shown in Figure 4, the manager has control over a whole deer range and has a variety of objectives for different areas, from natural regeneration in native woodland to restocking areas of a conifer plantation. In this case culling deer will normally be the most viable option. The approach to deer management outlined above can be used to set the cull and monitor populations and damage. Once deer numbers are at the appropriate level a 'holding' cull can be implemented. But predicting the density of deer that will allow the woodland objectives to be achieved is not easy since

Figure 4

Scenario 3: the area to be managed includes three small patches of native woodland surrounded by farmland as well as four stands within an adjacent plantation that are to be replanted.



there is not always a direct relationship between deer density and degree of damage (Putman, 1996; Hester *et al.*, 2000). Forest Research currently has a large-scale experiment in progress to improve knowledge of the factors that affect the relationship between deer density and damage. Again, it will normally take several years to get a population of deer that has been unculled, or lightly culled, down to a suitable level unless very high culling rates can be applied. So forward planning is needed. Predictive models will help to set appropriate cull targets and target populations and to predict how long it will take to reach the target population (see Predicting the Impacts of Management, page 37).

Fencing and tree guards may be the best option for particularly sensitive areas, but will normally be too expensive and unsuitable for use in all restock areas at this type of site. It might be possible to also increase the density of naturally regenerated trees in the native woodland by opening up the canopy or by creating regeneration niches. But this can result in too much regeneration of the wrong sort such as a flush of dense birch regeneration where pines are wanted.

PREDICTING THE IMPACTS OF MANAGEMENT

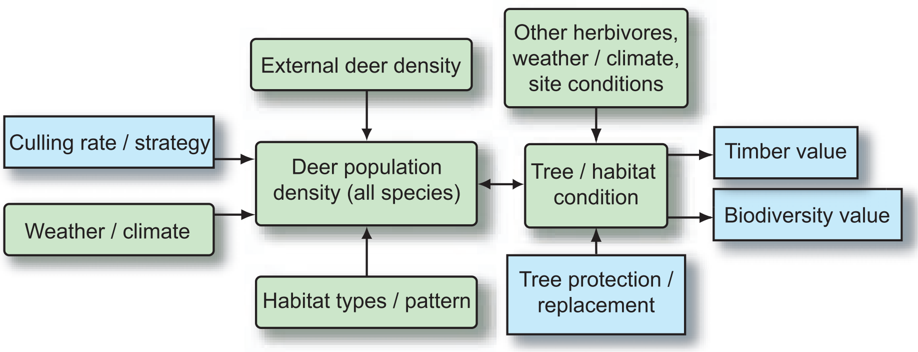
To decide on the most cost-effective approach to protecting trees from deer, woodland managers need to know if the resources required will pay off in terms of the final outputs. Figure 5 illustrates the factors that influence the impact that deer management and tree protection measures will have on final woodland outputs. Every site is different, so, as noted above, it is usually not possible to give general advice. There are also usually too many factors for the manager to be able to predict the outcome without many years of detailed knowledge. Our aim is to remedy this by building a computer model that incorporates all the factors illustrated in Figure 5. Eventually, it will predict not only the economic impact of a given approach but also the impact on biodiversity and nature conservation value. Our intention is to make this new model spatially based so that it can be linked to GIS-based stand and habitat maps and co-ordinated with production forecasting. The model will form the core of a computer-based decision support tool.

In making its site-specific predictions, the decision support system would make use of all existing knowledge, both of the general processes that influence the interactions between deer, trees and vegetation and of their current state at the site in question. Managers would then be able to readily assess the likely consequences of different deer management regimes as well as of changes in woodland management systems such as a change towards continuous cover forestry. Without modelling, optimal management can only be arrived at by years of trial and error at each site.

Current knowledge is far from perfect but it will be more cost-effective to use it to make site-specific predictions than to try out each approach by trial and error at each site over many years. Information coming from operational site monitoring will provide practical tests of the model. The use of the site monitoring methods that we have provided, and will continue to improve upon (see Initial Questions, page 29), will help to ensure that monitoring is carried out to as high a standard as possible, given the objectives, and resources available, at any site. The model will also help to highlight key gaps in our knowledge, which we will then address. As our knowledge increases we will improve and refine the model leading to increased confidence in its predictions. In the meantime, decisions on best practice in protecting trees from deer require detailed site information and a good knowledge of deer numbers and behaviour as well as tree responses.

Figure 5

The elements of a deer management decision support system. Blue boxes represent resource inputs and outputs from the system. Green boxes represent other elements of the system that have to be understood and modelled to predict the effect of changing inputs on outputs.



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Duncan Ray and Alice Broome

Ecological Site Classification – supporting decisions from the stand to the landscape scale

In the decade since the first Earth Summit in Rio de Janeiro (Anon., 1992) and the Helsinki ministerial conference to discuss the protection of forests in Europe (Anon., 1993), a number of measures have been introduced to improve sustainable forestry and conserve and enhance forest biodiversity. The measures include the *UK Forestry Standard* (Anon., 1998), the *UK Woodland Assurance Scheme* (Anon., 2000), *Native Woodland Habitat Action Plans* (Department of the Environment, 1996) and national forestry strategy documents (Anon., 1999a, 1999b, 2001).

1. Stand of mature Japanese larch with a broad buckler-fern-dominated field layer in Glentress Forest, Scottish Borders.
2. Investigating a surface-water gley soil profile.
3. Yellow pimpernel indicates a Soil Nutrient Regime of Rich.
4. ESC decision support system version 1.7 on CD.

INTRODUCTION

The first step towards sustainable forest management, on which all other decisions depend, is to ensure that the tree species are suited to the site conditions, whether the aim is a timber plantation or a native woodland community. The professional ability of the forester to 'read' the site conditions and select well-suited tree species is of fundamental importance. Commercial considerations dominated forestry practice in the UK in the middle to latter part of the 20th century. Forest managers tended to select from a short list of species and adjust the site conditions (ground preparation and fertilisation) to ensure optimal growth, so that the skill of matching species to site type declined.

Ecological Site Classification (ESC) has been developed to rekindle these skills and to draw together the accumulated knowledge of site suitability, for a range of species. ESC is a decision support system that brings together site-related information, presenting it in a format for the forest manager to use and decide on species choice, and assist the development of a woodland management plan that stems from species selection. The ESC classification has been designed in a similar way to forest classification systems used in other countries, for example Biogeoclimatic Ecosystem Classification (BEC) in British Columbia (Pojar *et al.*, 1987). However, since Britain has no natural forest, the methodology predicts suitable National Vegetation Classification (NVC) woodland communities and a range of native and exotic timber species for any site.

METHOD

The method uses six factors (Pyatt *et al.*, 2001) as criteria for testing site suitability:

- four climatic factors: accumulated temperature, moisture deficit, windiness and continentality;
- two soil quality factors: soil moisture regime (SMR) and soil nutrient regime (SNR).

ESC–DSS (Ray, 2001) calculates the climatic indices from the grid reference and elevation of the site. Soil quality is estimated from a combination of soil type and associated measurements, and an analysis of the field layer plant indicator species occurring. The ESC suitability models assess which factor is likely to limit suitability and growth on any particular site. The method assumes that any number of suitable or very suitable factors cannot compensate for an unsuitable factor. The approach also offers a sensitivity analysis to assess the effect of varying one or more factors on the results.

USING ESC AT DIFFERENT SCALES

ESC was designed to be used at the stand scale. ESC–DSS (Ray, 2001) allows the user to input basic site information and obtain results for a single location; more detailed information can refine the predictions. However, over the last 5 years there has been a rapid increase in the use of Geographical Information System (GIS) technology for forest and woodland management. This GIS revolution has enabled the development of ESC as an extension to ArcView GIS (ESRI, Redlands, California) in which the suitability of tree species (timber) and NVC woodland communities are analysed spatially using the same six factors (Clare and Ray, 2001; Ray *et al.*, in press). The ESC–GIS model derives climate factors from a digital elevation model, and calculates default values of soil quality (SMR and SNR) from digital soil maps, or vegetation community maps that have been validated by field survey. Ideally, a soil map surveyed at a scale of 1:10 000 should be used to provide soil quality for an ESC analysis at the forest landscape scale. However, soil or vegetation information surveyed at a scale of 1:25 000 would provide reasonable soil quality information for a regional ESC analysis (Ray *et al.*, in press).

It is therefore possible to use ESC analyses at three different scales: stand, forest landscape and regional.

At the stand scale the forester would check species or woodland community suitability from surveyed information prior to management operations within a coupe. Forest landscape scale analyses would be useful for more general forest planning, such as the production of design plan scenarios and site yield assessments. At the regional scale of forest planning, the Indicative Forestry Strategy scenarios (Quine *et al.*, 2002) or the effects of climate change on tree species suitability can be explored. In the three sections that follow ESC case studies are presented to illustrate these uses.

ESC FOR STAND ANALYSIS

In this example ESC has been used to answer the question: which native woodland NVC community is suitable for the site type? Table 1 shows site details for an ESC demonstration site, a 10 ha sub-compartment on an elevated ridge of the Pennant sandstone within the Forest of Dean. In the summer of 2000, the sub-compartment contained Scots pine, Corsican pine, European larch and birch.

Table 1

Forest of Dean site details.

Site name	Barnhill Plantation
Grid reference	SO 597106
Elevation	190 m
Geology	Pennant sandstone
Soil type (FC classification)	1z - Podzolic brown earth
Slope	10 degrees – east aspect
Rooting depth	80 cm
Stoniness	1%
Soil texture	Sandy loam
Humus form	Moder like mull

The site location and elevation were entered into ESC–DSS, and climate models calculated AT, MD, windiness and continentality (see Table 2). These data show that the area is relatively warm and quite dry for an elevation of nearly 200 m in western England. In addition the windiness score shows the east facing site is quite sheltered, and has an average continentality score between the lower (Conrad) scores of coastal sites (milder winters and cooler summers) and the higher scores of central England (colder winters and warmer summers).

Table 2

Climatic and soil quality data calculated in ESC for the Forest of Dean site.

ESC climate factor	
Accumulated Temperature (day-degrees above 5°C)	1579
Moisture Deficit (mm)	139
Windiness (DAMS)	10
Continentality (Conrad Index)	8
Soil Moisture Regime	Slightly Dry
Soil Nutrient Regime	Poor

The soil type, texture, stoniness and rooting depth were entered into ESC–DSS which calculated the SMR as Slightly Dry. The recorded field layer (Table 3) comprised plants indicating a range of conditions, for example, Very Poor SNR (e.g. *Vaccinium myrtillus, Calluna vulgaris*), Poor SNR (e.g. *Blechnum spicant, Deschampsia flexuosa, Agrostis capillaris*) and Medium SNR (*Holcus mollis, Rubus fruticosus*). ESC–DSS weights the contribution of individual species to the SNR calculation by the proportion in which they occur on the site, resulting in a site classification of Poor SNR.

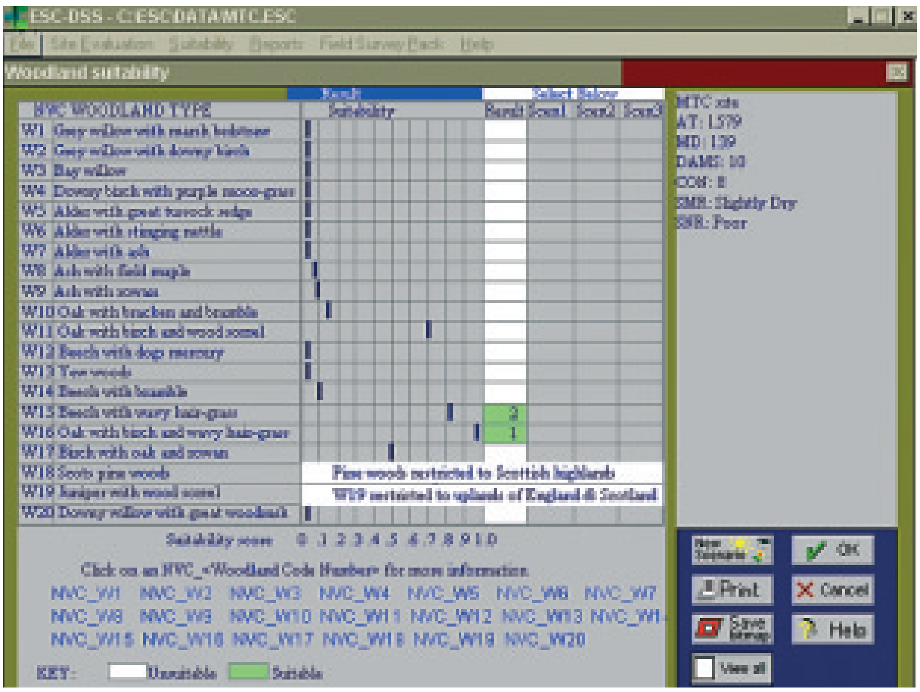
Table 3

Plant indicator species at the Forest of Dean site.

Indicator species	Quadrat – % cover									
	1	2	3	4	5	6	7	8	9	10
Deschampsia flexuosa	65	5	30		30		60	70		40
Agrostis capillaris	15						5	10		
Vaccinium myrtillus	5					65		30	2	
Rubus fruticosus	10	20	60	50	20	20	15	15	60	30
Pteridium aquilinum	5	25	25	50	80	1	10	25		20
Dryopteris dilitata			5			5			10	2
Blechnum spicant			1					2		
Calluna vulgaris							2			
Holcus mollis									10	

ESC–DSS identified that a *Quercus* sp.–*Betula* sp.–*Deschampsia flexuosa* woodland (W16 oak–birch with wavy hair-grass) community was best suited to the site (Figure 1) with the *Fagus sylvatica*–*Deschampsia flexuosa* woodland community (W15 beech with wavy hair-grass) less well suited. But both NVC woodland communities are suited to the site conditions, providing some flexibility in the management options. The analysis methodology is transparent, the rules contained in the model for species or woodland suitability can be examined, and further details on soil type and indicator plant identification keys are contained within the help system of ESC–DSS.

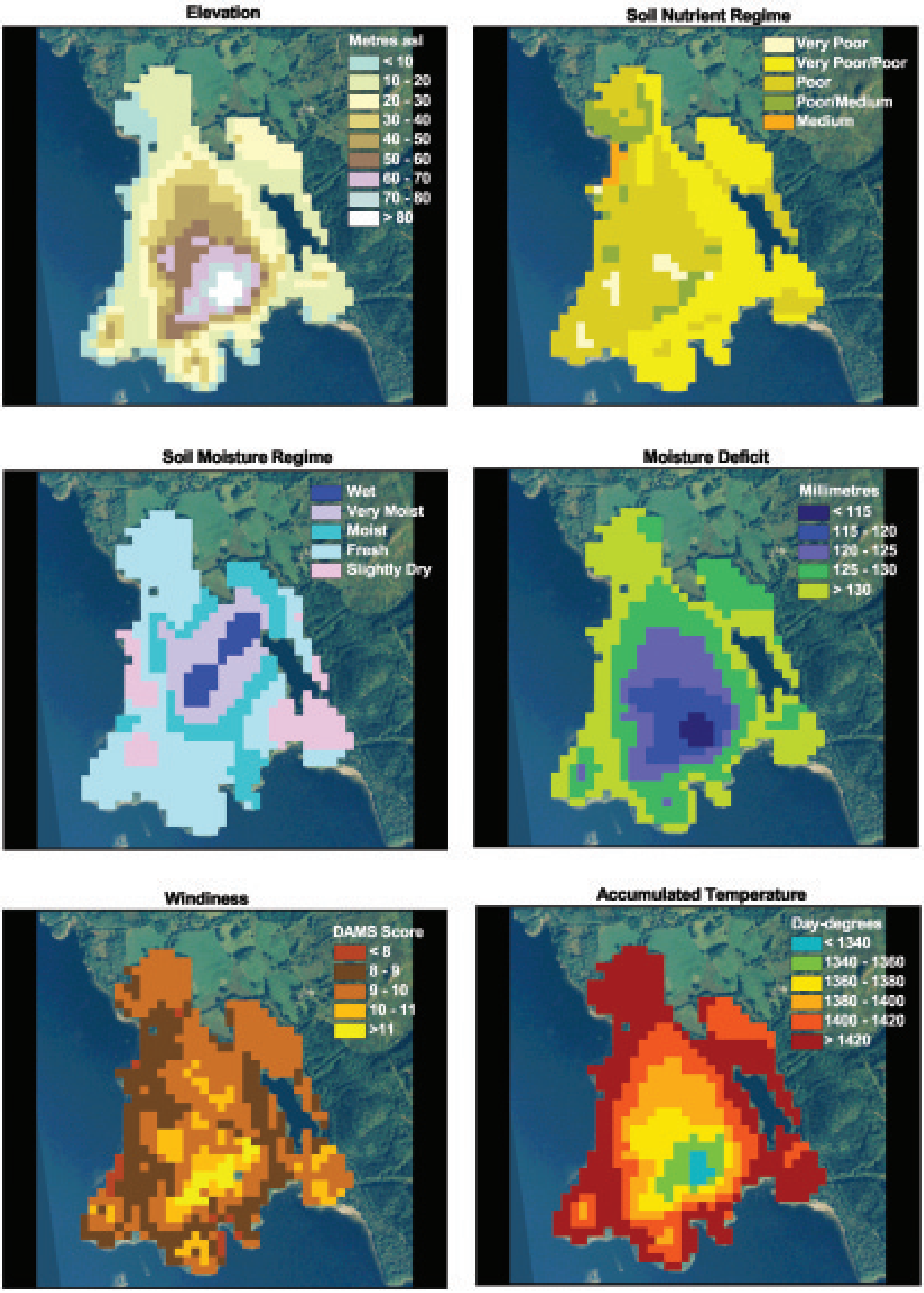
Figure 1



Output analysis of NVC woodland community suitability from ESC–DSS for a site in the Forest of Dean.

Figure 2

ESC factors at Ross Wood on the eastern shore of Loch Lomond overlaid on orthorectified aerial photographs.



ESC FOR FOREST LANDSCAPE ANALYSIS

In this example the ESC–GIS analysis is used to assess the options of restoration to native woodland at the forest landscape scale. Ross Wood on the eastern shore of Loch Lomond was assessed as part of the EU Natura Life Project on Atlantic Oakwoods. ESC–GIS was used to answer the question: are upland oak woodlands (NVC woodland communities 11 and 17) suited to the site types currently planted with exotic conifer stands within the north-western part of Ross Wood? The vegetation communities and soil types were surveyed, recorded and mapped, providing information for detailed soil quality maps of the SMR and SNR. The climate data were calculated using the ESC–GIS climate models and data were provided by a 50 m resolution digital elevation model (DEM) as shown in Figure 2.

The ESC–GIS analysis shows that Ross Wood is suitable for three NVC woodland communities (Rodwell, 1991) as shown in Figure 3, and the distribution is defined by the soil quality. The native woodland types predicted are: downy birch wet woodland NVC type W4, upland oak/birch woodland NVC type W11 and birch woodland NVC type W17.

ESC FOR STRATEGIC REGIONAL ANALYSIS

In this example, ESC is used to consider the impact of climate change scenarios on ESC climate factors and the consequent tree species suitability. The UKCIP98 medium-high climate scenario predictions (Hulme and Jenkins, 1998) for the 30-year periods 2010–2039, 2040–2069 and 2070–2099 have been used to calculate new ESC AT (Figure 4) and MD (Figure 5) (Ray *et al.*, 2002).

Figure 3

Suitable NVC woodland communities in Ross Wood, overlaid on an orthorectified aerial photograph (resolution is 50 m).

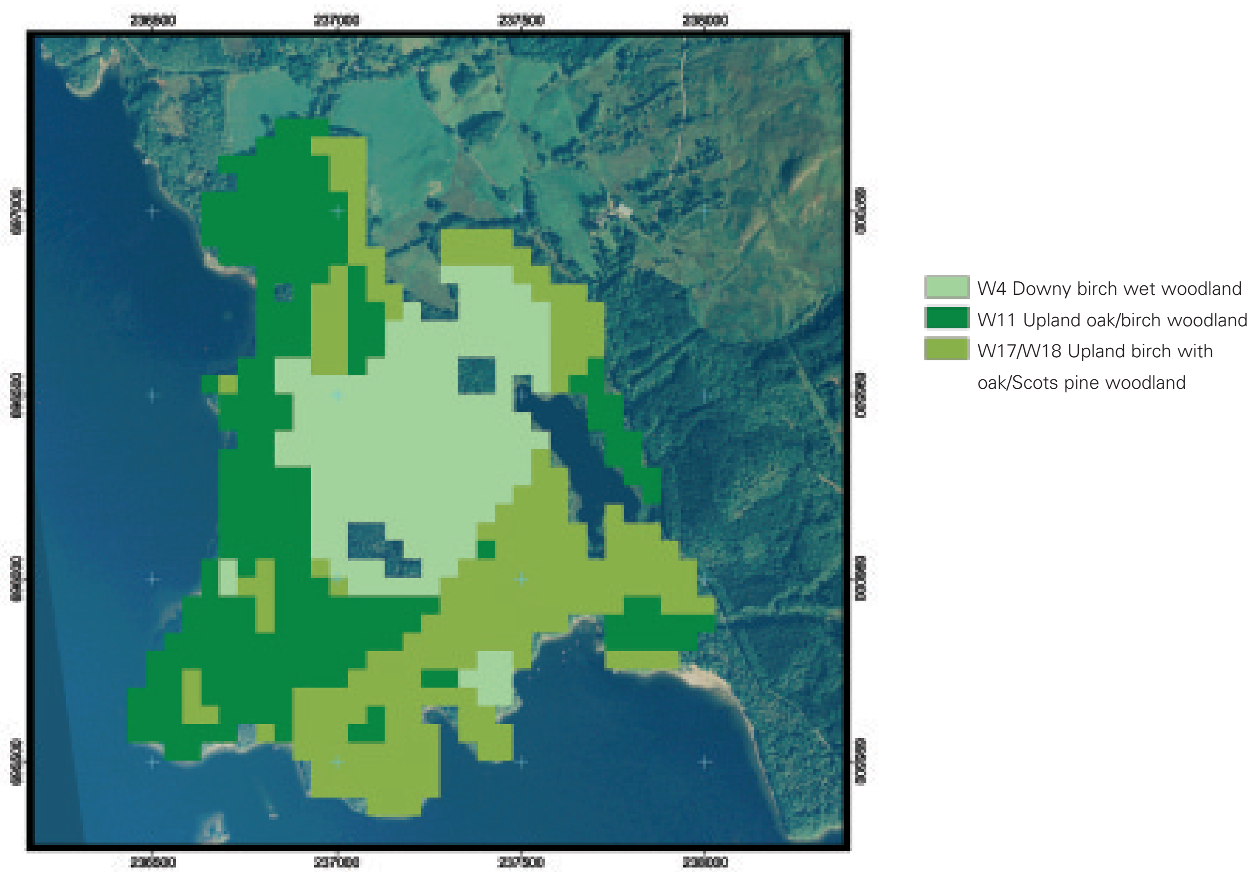


Figure 4

Accumulated Temperature (day-degrees above 5˚C) for the baseline (1961–90; current) and predicted climates of the 21st century.

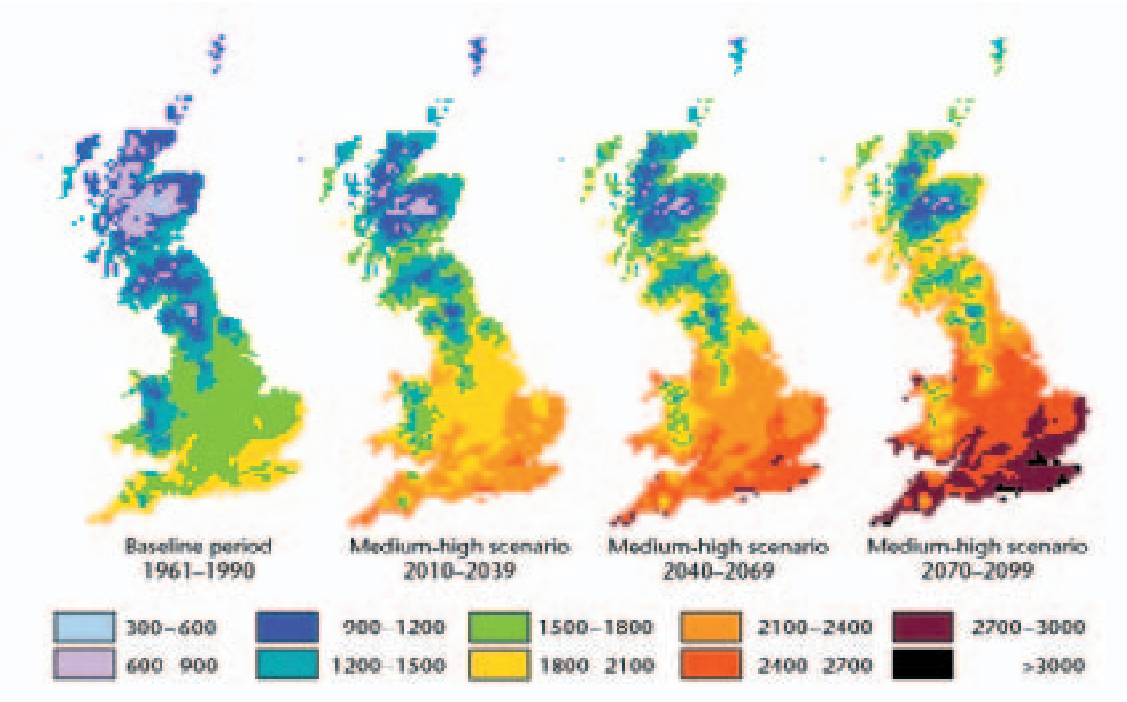
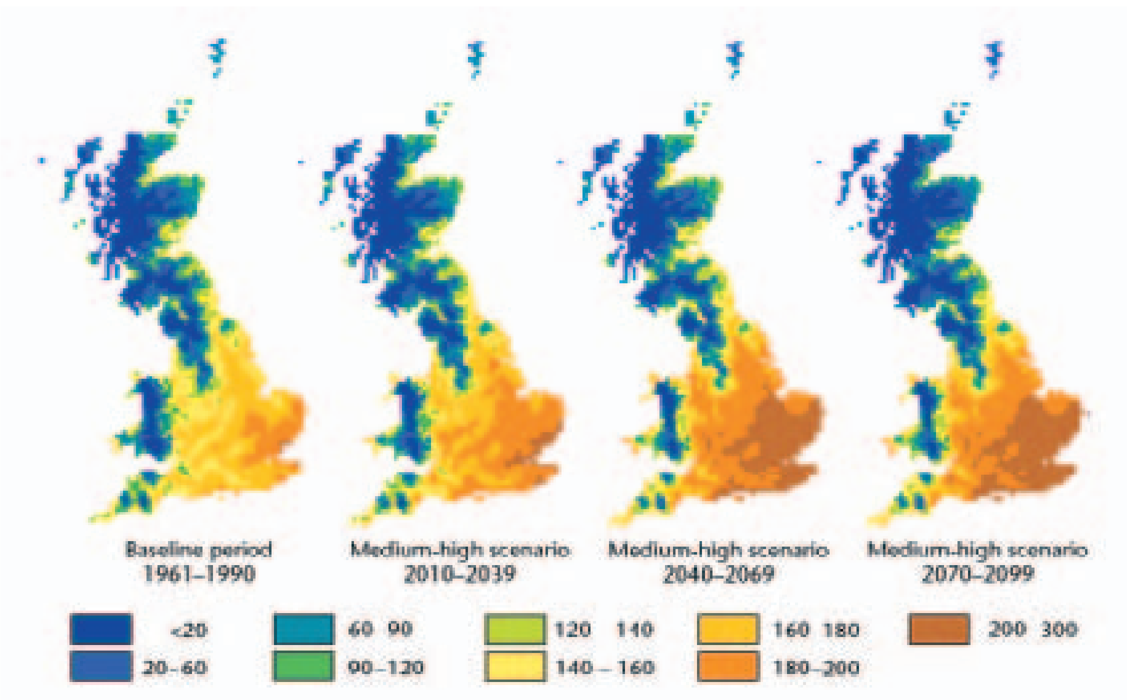


Figure 5

Moisture Deficit (mm) for the baseline (1961–90; current) and predicted climates of the 21st century.



The sequence of maps in Figure 4, from the baseline to the 2070–2099 period, show the ESC climate factor AT increasing throughout the century across Britain. The increased AT reflects the warmer summers but also longer growing seasons. The extent of cool montane climates, with an AT less than about 600 day-degrees, is reduced to a few 10 km squares covering the central Grampian Mountains. Eastern and central Scotland, northern England and central Wales are likely to experience increased warmth of 600 day-degrees over the next century, whereas in central and southern England and south-west Wales an AT of over 3000 day-degrees is predicted, representing a 50% increase on the baseline value.

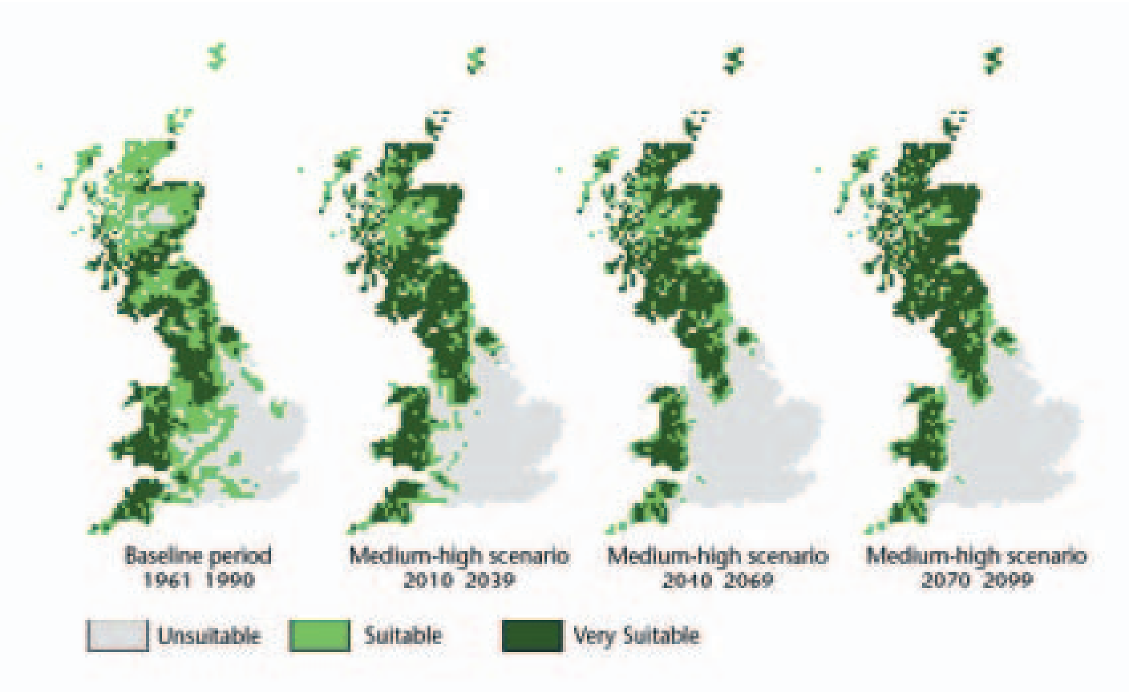
Figure 5 shows the predicted ESC climate factor MD from the baseline to the 2070–2099 period. In the north and east of Scotland a reduction in the MD reflects the prediction for slightly wetter summers, whereas in southern Scotland and northern England there is very little change in MD. In central and southern England, in west Wales and the western peninsula, where summers are predicted to be drier, MD will increase substantially.

The ESC model has been used with these revised climate layers to predict the broad suitability of tree species. Note that in this form of ESC climate suitability analysis, the assumption is that the soil quality is very suitable for growing any particular species, and that climatic factors impose the only restrictions on the species distribution. The ESC definitions of species suitability (Pyatt *et al.*, 2001) suggest that, in approximate terms, where one of the ESC climate factors is unsuitable for a species, it will have a yield class of half, or less than half, the maximum yield class for that species in Britain. Very suitable climates enable the species to achieve a yield class in the upper quartile of its yield range. This type of analysis must be treated with caution. Aside from the uncertainties in the climate predictions and the lack of soil information, the ESC MD factor has been predicted on the basis of assumptions linking the relative rates of potential and actual evaporation, and no adjustment has been made for increased CO_2 levels.

With this cautionary note in mind, Figure 6 shows the predicted change in the climatic suitability of Sitka spruce in Britain. The species is a native of the Pacific Northwest, where it grows well along a narrow coastal strip, featuring a humid oceanic climate. The two main provenances of Sitka spruce widely planted in Britain (Queen Charlotte Islands and Washington) are regarded as unsuitable wherever MD exceeds about 180 mm. In the baseline climate, Sitka spruce is unsuitable in the relatively dry central and southern parts of England. By 2080, this area is predicted to expand northwards and westwards across much of England south of the Humber and Mersey Rivers. In the southwest peninsula and in southwest Wales where a substantial increase in AT, but only a small increase in MD, is predicted, Sitka spruce should remain at least suitable. Throughout Scotland and northern England the climatic suitability should improve, with warmer and wetter climates, and in particular, increased summer precipitation leading to a reduced MD by 2080. The recently published UKCIP02 climate scenario predictions (Hulme *et al.*, 2002), provide an opportunity to modify the ESC climate factors and further develop tree species suitability scenarios.

Figure 6

Climatic suitability for Sitka spruce.



CONCLUSIONS AND FUTURE DEVELOPMENTS

ESC can provide decision support for forest planning at a range of scales using ESC–DSS or ESC–GIS. The examples have illustrated the application of the ESC methodology, to species or native woodland suitability at the stand scale (ESC–DSS), the development of forest design plans (ESC–GIS), and the assessment of the strategic futures of forestry at a national or regional scale in a changed climate. At each level of use, and despite the different types of data being used, ESC uses a common terminology that is consistent between the users. This brings transparency to the forest planning process, also enabling users to assess and make sense of the variation that occurs when moving from one scale of application to another.

The ESC–GIS decision support system is at an advanced stage of development, and following testing by FE Forest Districts and others will be released in 2003. A major constraint in the use of ESC–GIS is access to digital soil or vegetation community data at a resolution consistent with the use of the analysis. Digitised soil types, phases and lithology mapped at a scale of 1:10 000 is ideal but coverage is incomplete. Research has begun to establish whether soil quality for ESC can be derived from alternative sources, such as satellite imagery and models based on topography and coarse soil maps.

An ESC-DSS version 2 for detailed stand scale work is planned for 2004. The upgrade will include more plant indicator species for open managed habitats, a soil key (Kennedy, 2002), suitability models for open habitats and an NVC type assessment program.

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Richard Thompson, Colin Edwards and Bill Mason

Silviculture of upland native woodlands

Recognition of the value of native woodlands, particularly Ancient Woodlands, has been increasing in recent years. At an international level the importance of such natural habitats was emphasised at the Rio Earth Summit in 1992 and in the resolutions of the Ministerial Conferences on Protection of Forests in Europe at Helsinki in 1993 and Lisbon in 1998.


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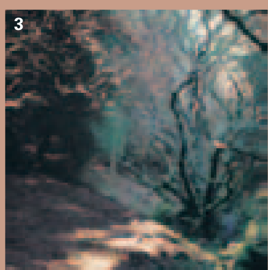
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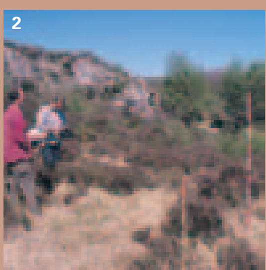
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4

1. Improvement: management for natural regeneration, upland oakwood, mid Wales.
2. Expansion: predicting colonisation of upland birchwoods, Wester-Ross.
3. Restoration: remnants of a former ancient woodland within a Sitka spruce plantation, Argyll.
4. Woodland history: assessing the impact of charcoal production on oakwood structure, Argyll.

INTRODUCTION

The improvement, restoration and expansion of native woodlands is a prominent element in the *UK Biodiversity Action Plan* (Anon., 1994). This is reflected in the recent English, Welsh and Scottish forestry strategies and complying with these objectives forms one of the preconditions for certification under the UK Woodland Assurance Scheme.

These initiatives have generated a renewed interest in the management of native woodlands. Some 50 000 hectares of new native woodland were established in the uplands during the 1990s through natural colonisation and planting. The majority of these new woodlands were created in the Scottish Highlands (Anon., 2000). In addition, there have been extensive schemes where the aim has been to restore native woodlands on Ancient Woodland sites previously planted with non-native conifers. Habitat Action Plans (HAPs) have been published for the main upland native woodland types (see Table 1) with targets for expanding the current area of each type. This rapid development of native woodland management in the uplands has generated a series of questions on the most appropriate management techniques to use and improved guidance is needed. However, as Box 1 shows, there are a range of issues to be considered and guidance needs to be

Table 1

Native woodland types in the uplands.

Habitat	FPGs[a]	NVC[b]	Approximate area (000 ha)
Upland oakwoods	5	W11 W17 W10e	70–100
Native pinewoods (+ juniper woods)	7	W18 (+W19)	16
Upland birchwoods	6	W11 W17 (W4a & b)	40–64
Upland mixed ashwoods	4	W9 W8d-g (W7c)	65
Wet woodlands	8	W1–3, W5–7	50–70[c]

[a] Forest Practice Guides for the management of semi-natural woodlands. [b] National Vegetation Classification. [c] Includes lowland wet woodlands.

Box 1

Some of the issues that influence research in upland native woodlands.

- The uplands of Great Britain range from the cool boreal north-east to the oceanic western seaboard. The range of climatic and edaphic conditions has resulted in a diversity of woodland types which generates a need for a range of management options.
- Many upland native woods experienced a period of intensive management, particularly in the 17th to 19th centuries. A variety of stand structures can be observed depending upon management history. Appropriate management will depend on inherited stand structures, from minimum intervention to managed high forest for a range of objectives including production of timber.
- Traditionally, upland native woodlands were used to shelter low numbers of livestock (usually cattle). Today, there are frequently high numbers of sheep and cattle found in these woodlands. The deer population has also increased dramatically in the last 30 years, e.g. 185 000 red deer in Scotland in 1969 compared with 350 000 today (MacKenzie, 1989; Deer Commission for Scotland, 2000). Regeneration of existing woodlands is often very difficult to achieve, not only due to the direct impact of grazing animals but also to their effect on the quality of ground conditions for seedling germination (e.g. lack of leaf litter in upland oakwoods and competitive grasses in upland birchwoods).
- High grazing pressure and regular burning of upland heaths and mires has significantly impoverished soil conditions for establishment of new native woodlands. Sufficiently robust establishment techniques are needed which will cause minimal impact to the site and the wider environment.
- Between the 1930s and the early 1980s approximately 40% of ancient semi-natural woodlands were converted into plantations of predominantly non-native coniferous species. The understorey of many broadleaved woodlands have been gradually colonised by invasive species such as *Rhododendron ponticum*.

appropriate to a particular site and woodland type. In order to deliver practical solutions we need to improve our understanding of underlying processes influencing the development of native woodlands in the uplands of Britain.

Until the early 1990s, with the exception of some intermittent studies in native pinewoods (see Nixon and Edwards, 1997), very little applied silvicultural research had been undertaken in upland native woodlands. This article presents recent findings from three areas of our work with emphasis on the native pinewoods and the upland oakwoods. In the first section we discuss stand dynamics in a range of minimum intervention stands, in the second we consider natural regeneration within existing woodlands as a consequence of site treatments, and lastly we consider some results from experiments on the planting of native woodlands.

NON-INTERVENTION RESERVES

Age structure of upland oakwoods

This study was undertaken to highlight the influence of woodland history on inherited stand structures and the consequences for future management.

Records suggest that many upland oakwood stands were worked intensively for coppice production, some of these having been planted originally. Other stands retain large trees which appear to be relics of pastoral management systems. Work has been undertaken in the past on the historical ecology of upland oakwoods, particularly in Scotland and Wales (e.g. Lindsay, 1975; Linnard, 2000), but the relationship between past management and current conservation value has not always been fully recognised in the development of management recommendations.

A study was carried out (partly funded by LIFE Nature) to determine age structure profiles in a number of Atlantic oak stands, i.e. upland oakwoods on the western seaboard. Results are presented from two stands in western Scotland (Duntaynish and Barr Mor) and from Coed Cymerau in north-west Wales which illustrate contrasting structures and woodland histories. In each case a plot of around 1.0 ha was established and cores taken from trees within the stand.

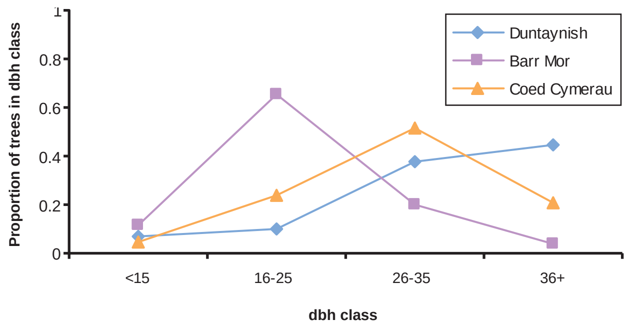
Results

Diameter distributions: comparison of the three sites

Trees were classified into four dbh classes: <15 cm, 16–25 cm, 26–35 cm and >36 cm. Data were analysed as a two-way contingency table with site and dbh class as the two factors. There was a highly significant (p<0.001) difference in the distribution of trees among dbh classes between sites. Duntaynish has a higher proportion of trees in the two larger dbh classes, with Barr Mor reaching a peak in the 16–25 cm class and Coed Cymerau in the 26–35 cm class (Figure 1).

Figure 1

Proportion of trees in four dbh classes at three sites.



Duntaynish stand description

This stand at Duntaynish (Plate 1) has a very irregular structure and an open canopy with a basal area of 19.5 m^2 ha^{-1} in 1999. Oaks are composed of old coppice and maiden trees with a range of diameters. The stand also contains frequent birch, rowan and hazel, many of which are senescent. There is a well-developed lichen flora on the larger maiden trees (>40 cm dbh) including a range of lichens characteristic of old growth stands, e.g. three species of *Lobaria*. Smaller maiden trees (< 35 cm) had poorer lichen communities, suggesting that they have seeded in after coppicing ceased.

Plate 1

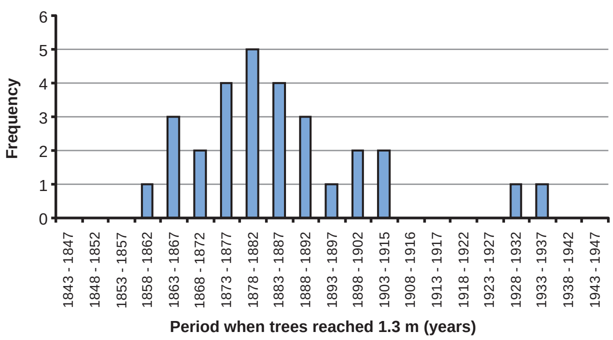
Upland oakwood stand at Duntaynish, western Scotland.

The age-class profile (Figure 2) indicates a 55-year regeneration period from 1860 to 1915. Some of the older trees have smaller diameters and these probably originate from coppiced stems. The small number of younger trees probably regenerated due to relaxation of grazing in the 1920s and 1930s.

The plot contains an old trackway and boundary walls which appear to date from an early period. There are no archeological features to suggest intensive woodland management which, combined with the irregular stand structure, indicate that this stand was not managed as intensive coppice. Some of the plot appears to have been managed as wood pasture with other areas subject to informal exploitation of coppice material.

Figure 2

Histogram of oak age classes – Duntaynish.



Barr Mor stand description

There are striking differences between Barr Mor and Duntaynish, despite both occurring in the same woodland complex. This stand at Barr Mor (Plate 2) has a uniform structure with a closed canopy of singled oak coppice and a basal area of 30.6 m^2 ha^{-1}. There are few maiden stems and no veteran trees. There is a complete lack of *Lobaria* lichen species within this plot which (in the context of Taynish) indicates a lack of ecological continuity. Other lichens are largely limited to species characteristic of early successional habitat.

The age profile (Figure 3) indicates that coppicing declined from around 1850 to 1860, with the majority of coppice regrowth reaching 1.3 m by 1900. However, there was continued recruitment to the stand until the 1940s.

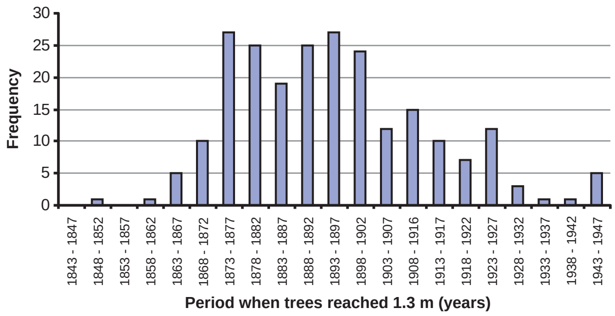
Archeological features suggest a history of intensive woodland management with a number of very obvious charcoal hearths or platforms and interconnecting pony tracks seen within the stand. The uniformity of the stand, lack of veteran trees, relatively poor lichen flora and archeological remains suggest that this stand developed after a period of intensive coppice management when ecological continuity was lost.

Plate 2

Upland oakwood stand at Barr Mor, western Scotland.

Figure 3

Histogram of oak age classes – Barr Mor.



Coed Cymerau stand description

The age of the oldest trees at Coed Cymerau (shown in Plate 3) is greater than at either of the Scottish sites (Figure 4). Reduction in grazing pressure following fencing in the 1960s has resulted in a substantial change in vegetation since extensive swards of *Deschampsia flexuosa* have been replaced by *Vaccinium myrtillus* (W. Shaw, personal communication). There has also been the recruitment of natural regeneration on an area at the top of the bank (known to have been treeless in the early 1960s) and the development of an understorey in much of the wood. Stems on the middle bank are competing for space and going through a stem exclusion phase (i.e. suppressed and sub-dominant trees are dying due to competition from dominants and co-dominants). At the same time, a substantial recruitment of saplings is taking place in the understorey. In the lower bank (where the slope becomes shallower, soils become moister, light levels and temperatures are lower), several isolated dominant and co-dominant oak trees are dying or dead. Some of these are on the river terrace which occasionally floods. Gaps created are filling with rowan from the understorey. There were no signs of *Lobaria* lichen species either within the plot, on trees around the edge of the wood or elsewhere within the woodland.

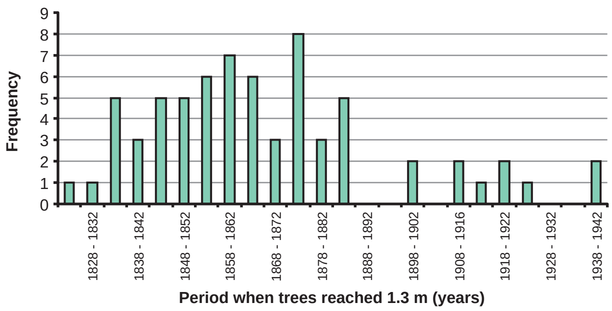
The only archeological features observed within Coed Cymerau were dry stone walls thought to date back to the enclosure period. Timber from the local Maentwrog oakwoods is known to have been used largely for ship building from the late 1700s until 1820. A photograph in Linnard (2000) shows a merchant vessel being constructed from Maentwrog oak at Porthmadog, with the bark being used at a tannery on the southern edge of Coed Cymerau. Other records show that timber from the estate went to the Pembrokeshire collieries and that some was used for charcoal. Many of the woodlands in the Vale of Ffestiniog may have been planted since 1807. Merioneth Quarter Sessions records indicate that local landowners were encouraging new plantations (Gwyn, 2001). The local estate owner was recognised for the active management of his woods, and there was a tree nursery 1 mile east of the wood. Records suggest that trees from here were used to plant up clearings after felling. It is possible that planting was restricted to the more accessible sites with better soils and that poorer sites were left for grazing or to regenerate naturally after felling. Further work is required to discover the extent to which planting or regeneration determined the current overstorey structure in this woodland.

Plate 3

Upland oakwood stand at Coed Cymerau, north-west Wales.

Figure 4

Histogram of oak age classes – Coed Cymerau.



Age structure and development of native pinewoods

Natural regeneration is the preferred method for increasing the area of existing pinewood stands. Managers are looking for more information on the natural recruitment rates and dynamics of pinewood stands, and the effect management operations have on speeding the establishment of future cohorts of seedlings. Some guidance can be obtained from a series of non-intervention pinewood reserves established between 1930 and 1950 (Edwards and Mason, 2000).

The Black Wood of Rannoch is an 800 ha Native Scots pine reserve situated on the southern shores of Loch Rannoch in Perthshire. Felling operations and disturbance events are known to have occurred regularly from the 17th century, the last being in 1940/41 by the Canadian Forestry Corps (Wonders, 1996). Deer browsing is known to be a significant cause of seeding loss (Miles and Kinnaird, 1979a and b). This has been reduced substantially since 1945 by a combination of fencing and rigorous culling (Arkle and Nixon, 1996).

Several 0.81 ha plots were established in Rannoch in 1948 to study structural changes and natural regeneration succession. Plots were assessed in 1948, 1956, 1983/84 and 1993/94 when tree and seedling establishment or mortality was recorded. Tree height, dbh, crown depth and crown width in two directions were recorded. Trees >10 cm dbh were aged by taking increment cores. Seedling (<10 cm dbh, <1.3 m in height) positions and species were also recorded. The research focus has been to examine whether the pinewood could recover and regenerate sufficiently without management intervention and the speed of the recovery process.

Results

Recruitment of both Scots pine and birch exceeded mortality between 1948 and 1994 (Figure 5), resulting in substantial increases in tree population size. New seedlings (<1.3 m tall) were recorded in all plots in 1994 at a density of around 170 seedlings ha^{-1}, showing that recruitment is still continuing. Over 90 per cent of seedlings were of Scots pine, with the balance being made up by birch, rowan and willow.

The age distribution pattern for plot 4 differs markedly from the other plots in the study (Figure 6). There is a peak of individuals in the 120 years age-class with lower frequency in all younger age-classes. In addition, plot 4 has a greater basal area than any of the other plots (Table 2) and is the only plot where mortality exceeds recruitment (not shown). In plots 5, 6 and 7 there is a higher frequency of individuals in the youngest age classes (Figure 6). Recruitment probably occurred as stands recovered from disturbance during felling operations in the period 1940–1942. Either advance regeneration was released by the felling operation or new seedling germination occurred, or both.

In parts of the Black Wood reserve, seedlings established following ground disturbance and canopy removal have taken an average of 16 years to reach 1 m height in good growing conditions (Edwards, unpublished). Scott *et al.* (2000) predict Scots pine saplings will require 22 years to grow from <10 cm height to >1.5 m in good conditions, and > 50 years on poor sites. This is in general agreement with seedling growth at Rannoch.

Figure 5

Mortality and recruitment rates for Scots pine and birch in all plots (1948–1994). Values indicate mean number of trees ha^{-1} present on each assessment date, and the mortality and recruitment rates between each successive assessment date.

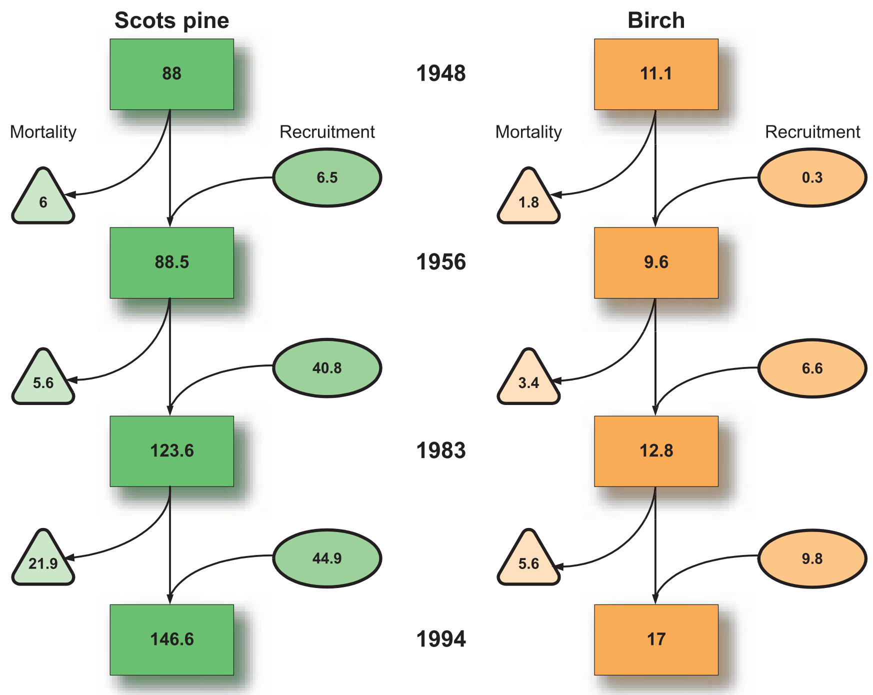


Table 2

Tree species data from the four permanent assessment plots in the Black Wood of Rannoch (excluding areas disturbed by fences and power lines).

	Number of Scots pine trees in 1994 (>1.3 m height, >10 cm dbh)	Basal area[a] (m^2 ha^{-1})	Mean height (m)	Mean age[b] (yr)	Age range (yr)
Plot 4	130	27.3	15.7	119	23–263
Plot 5	58	21.2	14.4	80	13–204
Plot 6	81	14.9	11.0	37	9–140
Plot 7	114	25.7	14.3	57	14–153

[a] Basal area calculation includes birch, rowan and pine trees.

[b] Age is taken from cores at 1.0 m height above ground level.

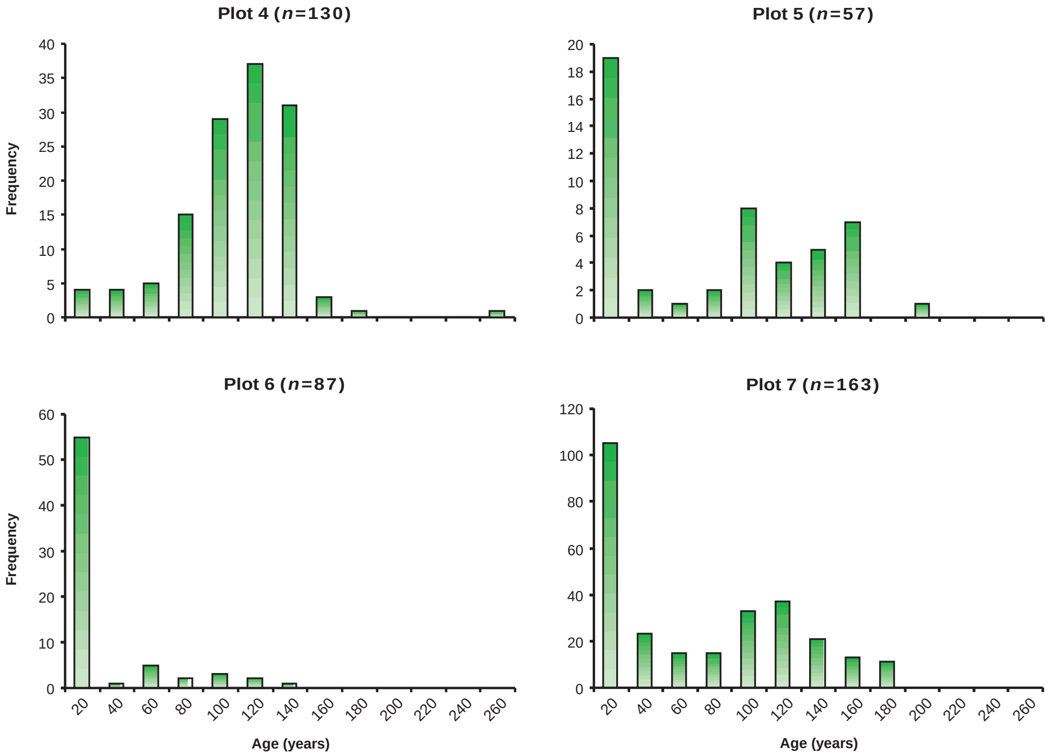
Management recommendations

These stands exemplify the following management recommendations.

- Each stand should be examined and treated as an individual unit. Consider how its structure has developed, the effects of past management, and the interactions between management and site type.
- The most uniform upland oakwood stands tend to be those that have been managed intensively in the past. In such stands, management intervention may be desirable to increase structural diversity, particularly in small woods where natural disturbance is unreliable. Silvicultural operations should avoid large scale disturbance, and aim to maintain woodland conditions.

Figure 6

Age class distribution for pine and birch > 10 cm dbh in the four permanent assessment plots, the Black Wood of Rannoch.



- Before any intervention, assess the conservation value of stems carefully, and do not assume that small trees are of lower value for biodiversity. In some stands, many of the older trees are sub-dominant and have well-developed epiphytic communities, valuable deadwood and associated species of fungi and invertebrates.
- Stands often take a long time to recover from disturbance and it can take 50–100 years or more before new seedlings form part of the forest canopy.

GROUND PREPARATION FOR REGENERATION

Upland oakwoods

A series of experiments was set up during 1991–92 within group fellings in oakwoods in Kilmichael (Argyll), Gilling (North York Moors) and Brechfa (mid Wales). The aim was to assess the effect of different ground preparation treatments on the natural regeneration of oak.

Method

Each site consisted of three group fellings (25 m or about 1.5 tree heights in diameter). A randomised block design was used with six replicates of the treatments described in Table 3. Plots of 0.002 ha were sown with 200 acorns (equivalent to 100 000 ha^{-1}, representing typical acorn densities in a mast year). Seedling counts were carried out in years 1, 5 and 10 for North York Moors 73, years 1, 6 and 10 for Kilmichael 28 and years 1, 5 and 11 for Llandovery 2 (Brechfa). Data from each year were analysed by Analysis of Variance using a square root transformation. Plot layout is shown in Figure 7.

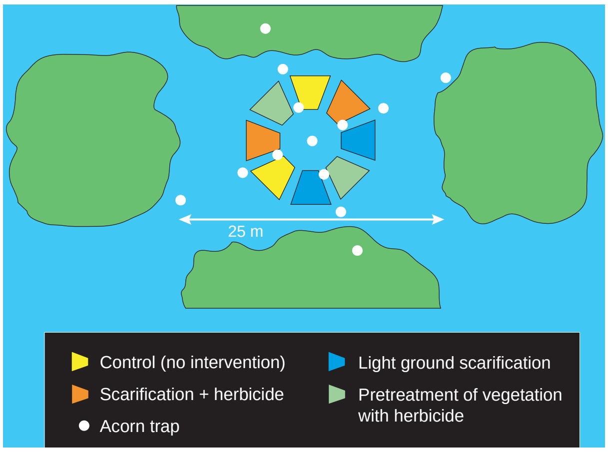
Table 3

List of treatments in the oakwood regeneration studies.

Control (O)	Removal of existing tree seedlings, sowing acorns onto otherwise undisturbed sward.
Scarify (S)	Simulated scarification with hand tools, burying sown acorns 5 cm deep.
Herbicide (H)	Application of herbicide prior to sowing of acorns.
Scarify, herbicide (SH)	Application of herbicide prior to sowing of acorns followed by simulated scarification with hand tools, burying sown acorns 5 cm deep.

Figure 7

Layout of treatments in upland oakwood ground preparation experiments.



Results for Kilmichael

First year results (Table 4) showed significant positive effects of the scarification treatment (p<0.001) and the herbicide treatment (p<0.05). The general drop in the number of seedlings by year 6 is attributable to development of a dense sward of bracken in 4 out of 6 blocks which negated the initial herbicide effect, so that at 10 years the only significant effect was due to scarification (p<0.001). Birch showed a similar response to oak (data not shown), regenerating better on treatments with an element of scarification.

Results for North York Moors

This site suffered severe predation of acorns in the first year which was particularly bad in treatments with herbicide (the herbicide treatment showed a significant negative effect (p<0.01; Table 4). There was a good mast year for oak in 1995 and new seedlings established in all plots, but especially where scarification had occurred; however, no effects showed statistical significance. By year 10 scarification alone showed significant improvements over the others (p<0.05). There was no advantage from application of herbicide.

Birch regeneration (data not shown) was most abundant where treatments had an element of herbicide application; the addition of scarification (i.e. the SH treatment) showed slight advantages over herbicide alone (i.e. the H treatment).

Results for Brechfa

No effects reached statistical significance in this experiment although a similar pattern of beneficial effects of scarification was observed (Table 4). The increase in seedling numbers by year 6 can be attributed to the 1995 mast year. Year 11 results indicate a general decline in seedling numbers and a lack of treatment effect due to weed competition.

Table 4

Mean plot counts from three upland oakwood regeneration experiments. Data were transformed before analysis and values in parentheses are the untransformed means.

Treatment	North York Moors			Kilmichael			Brechfa		
	Year 1	Year 5	Year 10	Year 1	Year 6	Year 10	Year 1	Year 5	Year 11
S	0.87 (1.17)	3.00 (12.50)	2.45 (9.00)	2.83 (8.67)	2.23 (5.67)	1.61 (4.17)	2.53 (7.33)	3.16 (11.50)	1.64 (4.30)
H	0.40 (0.50)	1.48 (2.30)	0.81 (1.33)	2.03 (4.33)	1.04 (1.33)	0.80 (1.00)	1.34 (2.50)	1.87 (3.80)	1.22 (2.50)
SH	0.00 (0.00)	1.45 (3.30)	1.87 (3.83)	3.12 (10.17)	1.94 (5.67)	1.99 (4.50)	2.28 (5.83)	3.21 (14.00)	1.95 (5.80)
O	1.48	1.91	1.49	0.50	0.17	0.00	2.03	2.34	1.53
	(3.00)	(4.00)	(3.17)	(0.83)	(0.17)	(0.00)	(5.33)	(6.80)	(4.20)
SED[a]	0.37	0.71	0.55	0.46	0.52	0.43	0.55	0.74	0.86
LSD (5%)[b]	0.80	1.51	1.17	0.99	1.10	0.92	1.18	1.57	1.83

[a] SED: Standard Error of Difference between mean.

[b] LSD: Least Significant Difference test.

Discussion

The only treatment to provide consistent benefits was shallow scarification, with herbicide effects being very short lived. Ground preparation to encourage regeneration in upland oakwoods will be particularly relevant where high densities of seedlings are desired for timber production objectives.

On all but the most infertile sites and those in northerly latitudes, ground preparation to encourage natural regeneration of oak should be done in a mast year under an intact canopy, with group felling or heavy thinning undertaken later when seedlings are at most 2–3 years old. Group fellings prior to achieving advanced regeneration may develop a dense sward of competitive vegetation before the next mast year.

Native pinewoods

An experiment was established in the 1930s in Glenmore Forest Park in Inverness-shire to test the effects of eight methods of ground preparation or vegetation manipulation upon the natural regeneration of Scots pine. The soils are predominately shallow to deep peaty podzols overlying fluvio-glacial deposits. Topography is generally level with slight hummocks causing changes in micro-topography. A deer fence was erected in 1930 prior to treatments being applied and this fence was maintained until 1972. In 1930, the basal area of the Scots pine overstorey was between 17 and 22 m^2 ha^{-1}, and in 1998 there were 261 trees ha^{-1} with a basal area still at around 22 m^2 ha^{-1}. Rank *Calluna vulgaris* and *Vaccinium myrtillus* and *V. vitis-idaea* now dominate the area with various bryophytes forming a thick mat in the intervening spaces and under the *Calluna* canopy. Early results were reported by Macdonald (1952) who concluded that the best results were obtained after cultivation. This has been confirmed in other studies by Booth (1984) and Low (1988).

Twenty treatment plots, out of 64 originally established, were relocated for assessment in 1999 forming an area approximately 100 m x 80 m. The assessment distinguished between trees (>10 cm dbh), saplings (> 1.3 m tall; < 10 cm dbh) and seedlings (< 1.3 m tall). From each tree an increment core was removed from 1.0 m above ground level, mounted onto wooden holders and used for determination of tree age at that height following the methodology of Stokes and Smiley (1968). We made the assumption that trees aged < 60 years would have been recruited by any of the 1930s treatments. Saplings are considered younger than 60 years. Any trees > 60 years when cored were assumed to have been recruited prior to the 1930s, and have been designated 'mature' to distinguish them from the latter recruitment phase.

Results

In all treatments there was an increase in seedling numbers between 1943 and 1959 assessments (Table 5). The increase was much greater after strip cultivation than for any other treatment. This effect was still evident in 1999 when strip cultivation plots had significantly greater numbers of saplings and seedlings ($p < 0.05$) than all other plots (significance assessed using ANOVA). This treatment also gave rise to a much higher number of young trees. The control treatment eventually resulted in more young trees than patch cultivation, possibly because of reinvigorated vegetation competition in the latter. There are no visible differences in ground vegetation between the various treatments 70 years after the start of the experiment.

Conclusions

Cultivation of the ground in and around large canopy gaps when seed is abundant is the most reliable method of recruiting high numbers of seedlings in pinewoods. Non-intervention can also recruit new trees into a stand, but will only occur in limited numbers over an extended time period and when browsing pressure is controlled.

Table 5

Comparison of mean numbers of seedlings, saplings and young trees of Scots pine in treatment plots in Glenmore in 1943, 1959 and 1999.

	Treatments (date of application)	Number of plots assessed	Mean number of seedlings (gross ha^{-1})		Mean number of seedlings and saplings (gross ha^{-1})	Mean number of trees <60 years (gross ha^{-1})
			1943	1959	1999	1999
A	Control (1930)	6	0	197	133	104
B	Brash cover (1930)	2	0	161	175	50
E	Patch burning (1930)	2	111	37	138	62
D / D(r)	Patch cultivation (1930 and 39) / Patch cultivation (1930, 36 and 39)	2	457	284	162	0
J	Burning pre-strip cultivation (1930 and 39)	2	1185	1679	1212	225
C	Strip cultivation (1930 and 39)	3	1210	1703	1158	242
C(r)	Strip cultivation (1930, 36 and 39)	3	2329	3333	1220	467

PLANTING OF NATIVE WOODLANDS

Native pinewoods

Recent guidance to managers on creating new native pinewoods has recommended the use of the minimum cultivation commensurate with satisfactory establishment (Anon., 1994). However, establishment success is known to result from the interaction between cultivation, fertiliser input and plant quality, and it can be difficult to determine what is the appropriate strategy on a given site. An experimental area was established in the mid-1990s on Dava Moor near Grantown-on-Spey to explore some of these aspects.

The site is at 285 m a.s.l. on a sharply defined exposed ridge, with gentle to moderate southwest facing slopes. The soils are podzolic ironpans with various depths of overlying peat, depending on microtopography. There is a heathland vegetation, principally *Calluna vulgaris, Erica tetralix* and *Scirpus cespitosus*. The site was formerly managed as a grouse moor with sheep grazing, and was regularly burnt. The nearest pine seed source is over 1 km distant. Natural regeneration of pine and birch has occurred sporadically, but was suppressed by the grazing and burning. The experimental area was deer fenced before cultivation and planting.

Effects of phosphate at planting at Moray 47 P95

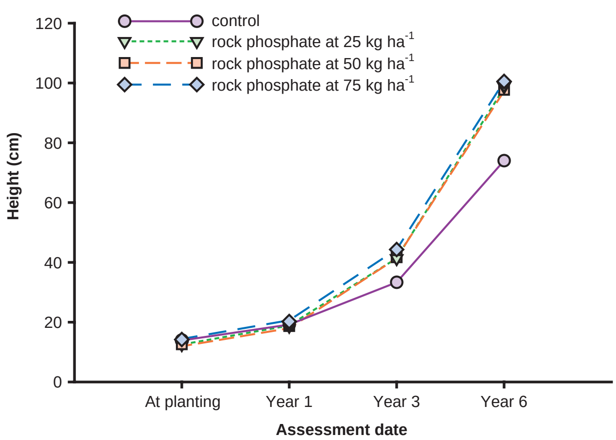
The site was cultivated by a MacLarty continuous mounder in March 1995, and planted with Abernethy origin native Scots pine in May 1995. Fertiliser, as ground rock phosphate, was applied at three rates (25–75 kg ha^{-1}) as spot applications plus an untreated control to an area approximately 1 m^2 round the base of each tree, in July 1995. No herbicide was applied to this experiment. Foliar nutrient concentrations were tested in 1996; 20 needles were collected from sample trees in each treatment and sent to the Foliar Analysis Service, Environmental Research Branch at Alice Holt for standard analysis.

Results

There were no significant differences in plant survival at the end of years 1, 3 or 6 with all treatments having over 95 per cent survival. Foliar N concentrations were significantly ($p<0.05$) greater in all fertiliser treatments compared with the control (an average of 1.8 vs 1.6 for the control). Plant heights were not significantly different between any treatment up to and including year 3. By year 6 all three fertiliser treatments were significantly taller ($p<0.001$) than the control, but there was no difference between fertiliser rates (see Figure 8).

Figure 8

Moray 47 P95: height response of native Scots pine to various rates of rock phosphate fertiliser applied at time of planting.



Minimal cultivation at Moray 51 P96

Seven different cultivation treatments (Table 6) were compared. Herbicide in the form of glyphosate was applied once to all treatments that included a weeding component. The site was planted with native Scots pine of Abernethy origin in late April to early May 1996.

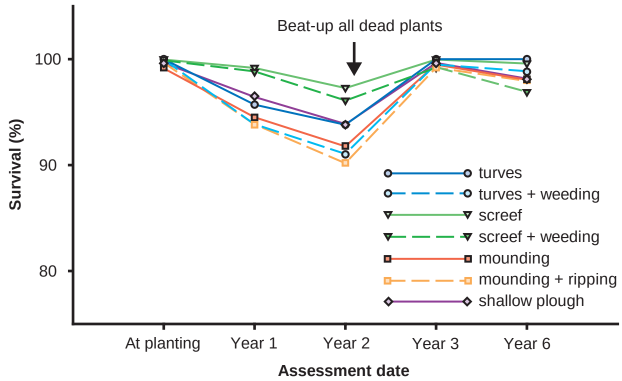
Table 6

Cultivation treatments used in experiment Moray 51.

Code	Treatment description
S	Direct planting into hand-screefed spot
SW	Direct planting into hand-screefed spot plus weed control
T	Direct planting onto hand-cut inverted turves
TW	Direct planting onto hand-cut inverted turves plus weed control
M	Continuous mounding by MacLarty continuous mounder
MR	Continuous mounding by MacLarty continuous mounder with ripping
SP	Shallow double mould board ploughing (D45 T60)

Figure 9

Moray 51: plant survival in difficult cultivation intensities. All dead plants were replaced with native Scots pine 1 + 1s in March 1988.



Results

Survival after 6 years was very good, with no treatment with > 5% mortality (see Figure 9). One year after planting, mean seedling heights in the hand-screefed treatments with and without herbicide were significantly taller (p<0.05) than all other treatments except hand cut turves with herbicide. Plants on hand cut turves were the smallest (Table 7). After 6 years growth, the order had changed with significantly taller plants in the mounding plus ripping and shallow ploughing treatments (p<0.05). The smallest plants were to be found in the hand-screefed treatments with or without herbicide.

Conclusions

In the absence of browsing, early survival was very good and not affected by either fertiliser or by cultivation. However, height growth was improved by more intensive cultivation and/or by fertiliser, supporting earlier studies on establishment of trees on heathlands (Zehetmayr, 1960).

Table 7

Mean seedling heights in the different cultivation treatments in Moray 51, assessed at planting and four other dates.

Assessment date	S	SW	T	TW	M	MR	SP	LSD (5%)
				Cultivation treatment				
At planting	10.2	9.0	9.6	9.9	9.5	10.3	9.4	**n.s**[a]
Year 1	18.8	18.2	15.9	17.0	16.3	16.1	16.3	**1.7**
Year 2	21.6	20.7	18.9	19.5	19.6	20.3	20.4	**1.6**
Year 3	26.1	25.3	23.2	24.3	24.4	27.4	28.5	**4.8**
Year 6	38.5	39.3	44.5	44.9	50.3	60.1	59.2	**7.0**

[a] n.s.: no significant differences between the heights of seedlings in any of the treatments at planting.

Restoration of upland oakwoods

In 1996 an experiment was established in Gisburn Forest, northern Lancashire, to examine the comparative performance of a range of broadleaved species for restoring native woodlands following clearfelling of the previous conifer stand. The site is located at 350 m a.s.l on a peaty gley soil. The site is exposed with a Detailed Aspect Method of Scoring (Quine, 2000) score of 16, although the south-easterly aspect provides some topographic shelter. The previous stand was 34-year-old Sitka spruce which was felled in late spring 1995. Site analysis after felling, using guidance in Rodwell and Patterson (1994), suggested that the upper part of the site lay within the NVC W4 native woodland type (birch with purple moor-grass) whereas the lower part fell into the NVC W17 type (upland oak–birch with bilberry).

The experiment contrasts the performance of pure plots of downy birch and of sessile oak with a 1:1 mixture of both species, and with plots containing the species mixtures recommended by Rodwell and Patterson (1994) for creating W4 and W17 types. All species were of local seed sources. Unplanted control plots were also included to examine the potential for natural colonisation. A randomised block design with four replicates was used.

All plots were 0.07 ha in size to allow the possibility of examining long-term stand development. On half of the plots brash from the conifer clearfelling was removed from the site while on the other half it was retained in windrowed strips.

At time of planting there was no ground vegetation as a result of the dense shade cast by the previous Sitka spruce stand. Six years later, although there was still much bare ground, there had been appreciable development of grasses and herbs characteristic of upland sites. Dominant species were *Deschampsia flexuosa, Juncus effusus* and *J. squarrosus, Molinia caerulea* and *Galium saxatile*. There was very little natural colonisation by trees after 6 years when an assessment of the control plots gave a total count of 39 seedlings (15 birch, 12 rowan, 8 Sitka spruce, 3 holly and 1 Norway spruce). The lack of any adjacent seed sources is the probable reason for the limited colonisation to date.

Five years after planting, the most notable trend was the poorer growth and comparatively low survival of the sessile oak plots compared to the other treatments (Table 8). There was no effect of brash removal upon growth or survival. Most of the minor species planted in either the W4 or the W17 treatments (rowan, silver birch, holly, common alder, goat willow, grey sallow) showed as good survival as the main species; the only exceptions were the two willows where the figures were around 30 per cent.

Although this experiment is still in its early stages, some preliminary conclusions can be drawn from this and sister experiments established in upland Britain since the mid 1990s. Firstly, planting will generally be necessary for rapid restoration of native woodland tree cover on sites that were planted with conifers, if there is no native tree seed source within close proximity. Secondly, the planting of more varied mixtures of native tree species as recommended by Rodwell and Patterson (1994) does not appear to cause major problems in terms of higher establishment costs. Thirdly, it is easy to be overoptimistic about the fertility of a site and to plant species that are not well suited to the location as is shown by the comparatively poor performance of the sessile oak in the Gisburn experiment.

Table 8

Five year height (cm) and survival (%) of a range of native woodland treatments planted in the Gisburn experiment.

Treatment	Height	Survival[2]
Sessile oak	14.9[d]	67.3[c,d]
Downy birch	100.7[a]	78.3[a,b]
Oak/birch mixture	55.0[c]	74.2[b,c]
W4 mixture	66.3[d]	60.3[d]
W17 mixture	83.2[b]	83.0[a]
Significance[1]	***	**
LSD (5%)	13.3	5.7

1. ***p*<0.01; ****p*<0.001.

2. Data were transformed before analysis but are presented here as percentages for ease of interpretation. LSD values refer to these transformed data.

Height and survival responses with common superscript letters are not significantly different.

OVERALL CONCLUSIONS

We believe that some general conclusions can be drawn from these studies:

1. *Management options.* A range of management options is normally available for each native woodland stand and the use of routine prescriptions should be avoided. The options should be carefully evaluated in the light of objectives, management history, practical opportunities and constraints.
2. *Sustaining conditions.* Maintaining woodland conditions (e.g. avoiding the large scale disturbance associated with clearfelling) frequently enhances biodiversity at the stand level and improves the prospects for successful natural regeneration and/or enrichment planting.
3. *Levels of intervention.* With adequate long-term control of browsing pressure, low densities of seedlings sufficient to ensure stand survival can be established with limited inputs. However, wherever timber production is an objective, more intensive site management may be necessary to ensure adequate regeneration.

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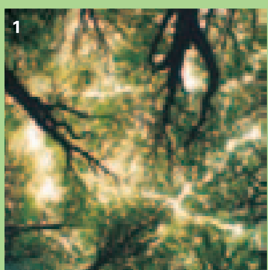
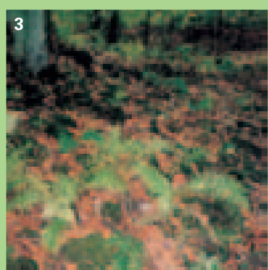
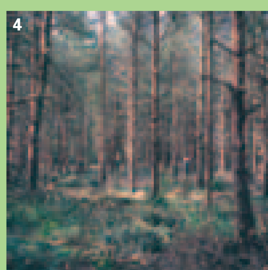
Fiona Kennedy

How extensive are the impacts of nitrogen pollution in Great Britain's forests?

Protecting our forests from pollutant deposition is and has been a topical issue for some time. Nitrogen, as well as being an essential nutrient for trees, is one of the most important of these pollutants. This article discusses the extent and severity of the issues associated with nitrogen pollution in our forests.







1. Canopy chemistry reflects nitrogen status: beech canopy at Myherin Woodland, Ceredigion.
2. Fungi thriving under beech woodland.
3. Ground flora under beech woodland at Bolton Abbey, Yorkshire.
4. Nitrate leaching is known to be high at this Intensive Monitoring plot at Thetford, Norfolk.

INTRODUCTION

Since the 1940s atmospheric nitrogen pollution has steadily increased, primarily as a consequence of the combustion of fossil fuels and agricultural intensification (Hornung and Langan, 1999). Nitrogen is an essential nutrient for plant growth, so why is nitrogen pollution an issue? While increases in the deposition of atmospheric nitrogen pollutants are likely to have contributed to improved forest productivity during the 20th century (Cannell, 2002), it is possible for a forest ecosystem to receive too much nitrogen.

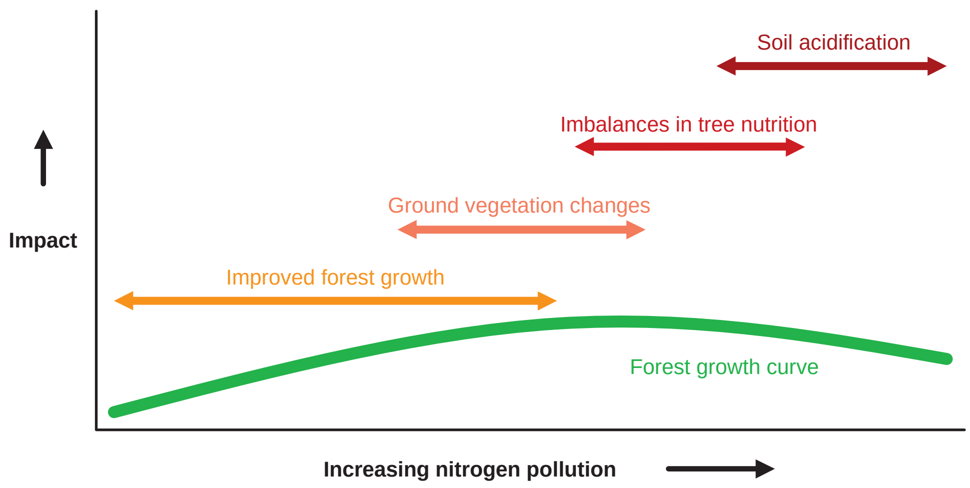
Gundersen (1999) has schematically summarised the effects of increasing nitrogen deposition on forests (Figure 1). Initially the forest canopy intercepts nitrogen and uses it for growth. As pollution levels increase, the nitrogen breaks through the canopy and reaches the forest floor. Here changes in response to nitrogen tend to be observed in the non-woody herbaceous ground flora first, due to their short life cycles in comparison to trees. Nitrophiles (nitrogen loving species) out-compete plants with lower nitrogen requirements, so in the first instance nitrogen deposition can impact upon biodiversity. Further increases in nitrogen deposition can result in imbalances in tree nutrition and when this occurs forest growth may be detrimentally affected relative to that under optimal nitrogen nutrition. Trees take up the nitrogen in excess, leading to deficiencies in other nutrients and increased susceptibility to insect attack and drought (Bobbink *et al.*, 1996). Finally, should nitrogen deposition reach a level at which inputs to the forest ecosystem are in excess of both biological demand and the storage capacity of the soil, then nitrate will begin to 'leak' out of the soil below the rooting zone. This state, which has been termed 'nitrogen saturation' (Aber *et al.*, 1989), has two key detrimental effects.

- Nitrate leakage disrupts the ion balance in the soil causing soil acidification, base cation depletion and increased aluminium toxicity to tree roots.
- The migration of nitrate out of the soil profile has the potential to contaminate surface and groundwater supplies, resulting in problems of eutrophication and algal growth.

The onset of changes in ground vegetation composition in Figure 1 overlaps with the 'improved forest growth' zone. This has important implications for the interpretation of national critical loads maps which identify thresholds of pollutant input that specific elements of the environment can withstand. The thresholds used to derive the critical loads for nutrient nitrogen in Great Britain and Northern Ireland are specifically aimed at protecting ground flora and epiphytic mosses and lichens. Thus a woodland located in an area in which the critical load for nutrient nitrogen deposition is currently exceeded will not necessarily have unhealthy trees or poor growth.

Figure 1

A schematic representation of the impacts of increased pollution on forest ecosystems (Gundersen, 1999).



THE GB SITUATION

Where do the forests in Great Britain (GB) sit on the schematic curve in Figure 1? Critical load maps for nutrient nitrogen are set to protect the most sensitive components of the forest ecosystem but how accurate are they? What percentage of GB forests are showing signs of nutrient imbalance? If nitrogen saturation is not necessarily occurring in all of the exceeded squares on the national critical load maps, how extensively is it occurring?

Changes in ground vegetation

In Europe there is now a considerable body of literature documenting changes in the species composition of woodland ground flora, macrofungi and mycorrhizae that are related to increased nitrogen deposition (Bobbink *et al.*, 1996). Fewer studies have been undertaken in Great Britain but these have found similar effects. Pitcairn *et al.* (1998) surveyed the wooded areas surrounding four livestock farms (which are significant point sources of nitrogen) in Scotland. These included a Scots pine plantation, two conifer shelter belts and some mixed deciduous woodlands with large beech and birch components. They found that species diversity in ground flora declined within 300 m of the emission source.

In autumn 2001 a survey of 20 beech woodlands distributed throughout Great Britain (Figure 2) was undertaken by the Environmental Research Branch of Forest Research. Results showed that changes in ground flora could be predicted by measuring the average distance from the centre of a 20 x 20 m survey plot to the edge of the woodland. The closer the woodland edge, the more nitrogen demanding the ground flora (Figure 3). The data show that the Ellenberg indicator values, which weight species on the basis of their nitrogen requirements (Hill *et al.*,1999), rise significantly as the distance to the edge of the wood declines. Unfortunately there are no data points in Figure 3 between 500 and 740 m, but on the basis of the available data, high Ellenberg values certainly begin to occur at sites within an average distance of 500 m from the woodland edge.

Much of the scatter in Figure 3 is because the distance to the edge of a woodland does not always represent the distance to a source of agricultural emissions of nitrogen from either livestock or fertilised arable farmland. However, it is still of interest to calculate the proportion of forest area in GB that is within 500 m of the edge of non-forested land. A calculation using data from a national survey of the size distribution of forests in Great Britain, which omits woodland types that tend to be densely planted and have minimal ground flora, places ~60% of the remaining GB woodlands within 400 m of woodland edges. This is a very approximate approach to quantifying the problem and suggests, as a rough estimate, that 60% of GB woodland ground flora could potentially have been altered. The current national critical load map for nutrient nitrogen estimates the extent of the problem using a different approach, namely comparing modelled maps of nitrogen deposition to a threshold based on expert opinion. This approach suggests that an area of over 80% may be affected (NEGTAP, 2001). The two estimates are considerably different, demonstrating that the uncertainty in any calculation of this nature is large. However, both estimates are high, indicating that nitrogen-enhanced changes in the composition of ground flora in GB forests are likely to be widespread and to have developed as agriculture has intensified and vehicle numbers have increased.

Imbalances in foliar nutrition and their effects

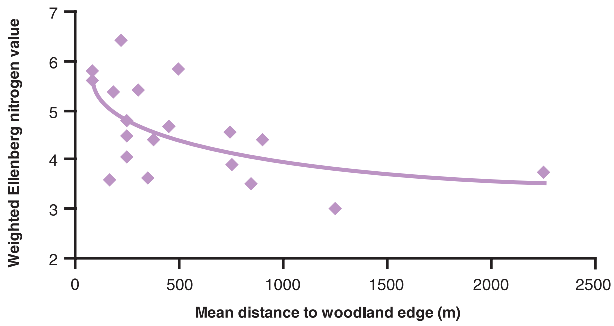
The best way to quantify tree nutrition at a large number of sites is to take foliar samples for chemical analysis. The largest survey of foliage chemistry undertaken in Great Britain in recent years was in 1995 when approximately 60 of the Forest Condition (Level I) monitoring plots, located throughout England, Scotland and Wales, were sampled under a European initiative (Stefan *et al.*, 1997). To provide as much information as possible, the foliar nitrogen data from the conifer sites in this survey have been combined in Figure 4 with those from the Intensive (Level II) monitoring plots (Durrant, 2000) and other surveys undertaken in recent years.

Figure 2

Locations of the 20 beech woodlands surveyed in 2001.

Figure 3

Changes in the nitrogen demand of beech woodland ground flora with proximity to the woodland edge; $R^2 = 0.35$, $p = 0.025$.



A foliar N content of >1.8% in Scots pine was found by Aronsson (1980) to increase frost damage but the value of 1.7 % is more widely used to indicate nutrient imbalance in conifers (Gundersen, 1999). It should be noted that this 'critical value' is close to the threshold for optimal nutrition (1.4%: Taylor, 1991), a key factor in site productivity. The results in Figure 4 show that approximately three-quarters of the Scots pine plots had nitrogen concentrations in needles in excess of 1.7%. Perhaps more significantly, there is a positive relationship between the estimated nitrogen deposition at the Scots pine plots (taken from the national 5 km x 5 km database for 1995-97; Fowler, personal communication) and foliar N content. Thus nitrogen pollution does appear to be a strong contributory factor in causing increased foliar N concentrations at the Scots pine sites. Increases in estimated nitrogen deposition also appear to impact upon foliar N concentrations at the Norway spruce plots, although the effect is less acute and, more crucially, the range of N contents is much lower. Only a quarter of all spruce plots (Sitka and Norway) were above the 1.7% threshold. There was no relationship between nitrogen deposition and foliar nitrogen concentrations in Sitka spruce.

Figure 4

Relationships between nitrogen deposition and foliar nitrogen in three conifer species in GB; Norway spruce: $R^2 = 0.43$, $p = 0.011$; Scots pine: $R^2 = 0.65$, $p = 0.003$.

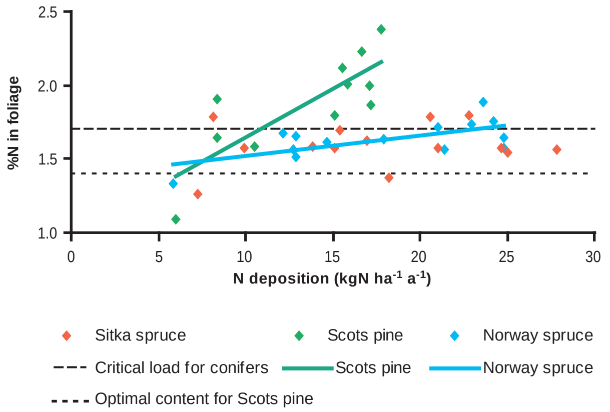
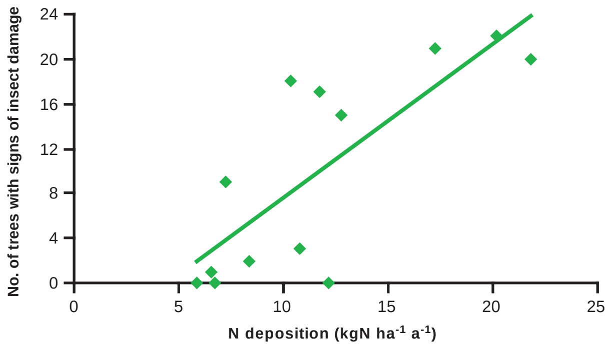


Figure 5

Relationship between nitrogen deposition and the occurrence of insect damage in Scots pine in Scotland in 1999 (24 trees assessed in each plot); $R^2 = 0.61$, $p = 0.002$.



There is evidence that the high N concentrations in Scots pine needles are detrimental to forest health in some areas of Great Britain but not others. Figures 5 and 6, derived from forest condition data for the Level I plots, show both an increased occurrence of insect damage and a reduction in needle retention with increasing nitrogen deposition to Scots pine in Scotland. These relationships did not hold for either Norway or Sitka spruce (with the exception of a very weak decline in needle retention in Norway spruce). However, the relationships in both figures are, inexplicably, only apparent in Scotland. If the English and Welsh sites are included in the analysis both trends disappear and in England and Wales alone, needle retention improves with increasing nitrogen deposition. It is possible that these different responses are due to site quality; broadly speaking, the soils in England and Wales are more nutrient rich than those of Scotland. The possibility that nitrogen deposition in Figures 5 and 6 is acting as a surrogate for a temperature effect has been tested and rejected.

There is no evidence that nitrogen deposition is damaging the health of broadleaved plots. The phosphorus (P) concentration (Figure 7) and the N:P ratio (a useful nutritional indicator) increased in line with nitrogen deposition. There were no relationships between foliar P and N deposition in the conifers; in fact foliar P in Norway spruce fell slightly with increased N deposition. Unlike other countries such as Switzerland, where deposition levels have reached as high as 30–40 kgN ha^{-1} a^{-1} and detrimental effects on beech have been observed (Flückiger and Braun, 1998), it appears that nitrogen inputs are having a beneficial effect on broadleaved species in England and Wales. It can be speculated that the additional nitrogen has improved root growth and the ability of trees to obtain phosphorus. Whatever the mechanism, there are no detrimental effects of nitrogen deposition on foliar chemistry and, consequently, no detrimental effects on forest condition could be found when data for oak were investigated. This is perhaps not surprising as broadleaves naturally have higher nitrogen concentrations in their foliage than conifers and it is conceivable that the same level of nitrogen deposition would be beneficial to broadleaves and detrimental to conifers.

In summary, the health of Scots pine in some areas of Scotland is likely to have been detrimentally affected by nitrogen pollution. There is no evidence of detrimental health effects caused by nitrogen pollution in any of the other species investigated except possibly Norway spruce.

Figure 6

Relationship between nitrogen deposition and needle retention in Scots pine in Scotland in 1999 (24 trees assessed in each plot); $R^2=0.42$, $p=0.017$.

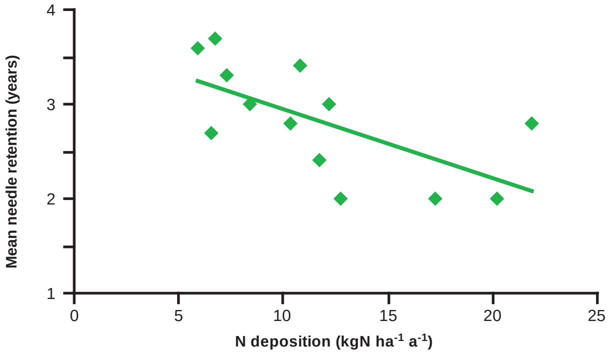
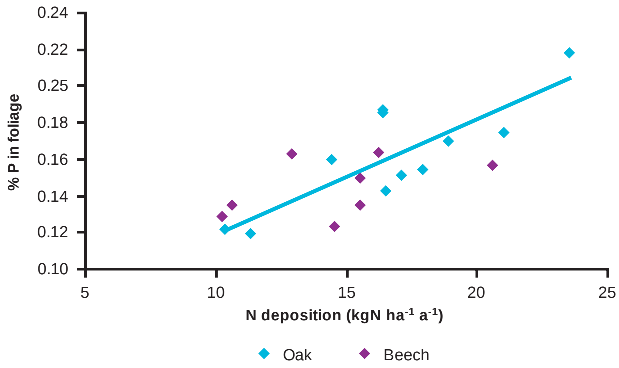


Figure 7

Relationship between nitrogen deposition and foliar phosphorus in oak and beech in England and Wales; $R^2=0.68$, $p=0.001$.



Nitrogen leakage

The dramatic differences in nitrogen concentrations that occur below the rooting zones of N saturated and unsaturated forests are demonstrated by data collected in the Level II Intensive Forest Health Monitoring network. Figure 8 shows that concentrations in soil solution at the site in Thetford Forest, Suffolk, can reach more than 100 times those recorded at the plot near Llyn Brianne reservoir in Dyfed. To some degree these differences in concentration are exaggerated by the considerably lower rainfall at Thetford, but a calculation of the fluxes of nitrate leaving the rooting zone in 1995/1996 revealed a leakage rate of 24 kgN ha^{-1} a^{-1} at Thetford and zero at Llyn Brianne.

A key threshold with regard to nitrogen leakage in the lowlands is the EC drinking water limit of 11.3 mg l^{-1}. At the seven Intensive Forest Health Monitoring sites at which subsoil water is collected, this limit is only exceeded in Thetford Forest. That we only see this at one out of seven of the plots is reassuring, but with data from so few sites, predictions cannot be made about the national extent of the problem. Furthermore, in the uplands of GB, where a number of the Level II plots are situated, soil and stream water acidification caused by the leaching of nitrate is also of concern.

The difficulty in assessing the extent of nitrate leaching is that the collection of data such as those presented in Figure 8 is labour and cost intensive. There are two ways to circumvent this problem. One is to collect data intensively at a larger number of sites, but for only a relatively short period of time, e.g. one to two years. The other is to collect one-off samples of subsoil water at a large number of sites during a sensitive period when nitrate levels are likely to be higher. (Note the seasonal cycle at Thetford Forest in Figure 8.) Three such surveys have been undertaken in recent years. These have concentrated on Sitka spruce (Emmett *et al.*, 1993; Emmett *et al.*, 1995) and more recently oak (Emmett, personal communication) and beech (Figure 2).

The Sitka spruce study was centred on stagnopodzols in upland Wales. Significant nitrogen leaching (in excess of that expected from known pristine sites located in northern Scandinavia) was found to occur at sites where the forest was over 30 years old and this was attributed to a decrease in nitrogen demand as the stand ages. From woodland inventories we know that Sitka spruce stands over 30 years old make up approximately 24% of the forest area in Wales, but these forests will cover a wide variety of soil types, not all of which will necessarily respond in the same way as the stagnopodzols in the study. In the more recent

Figure 8

Contrasting nitrate levels in the soil solution at 0.5 m depth at two of the sites belonging to the Level II Intensive Forest Health Monitoring network.

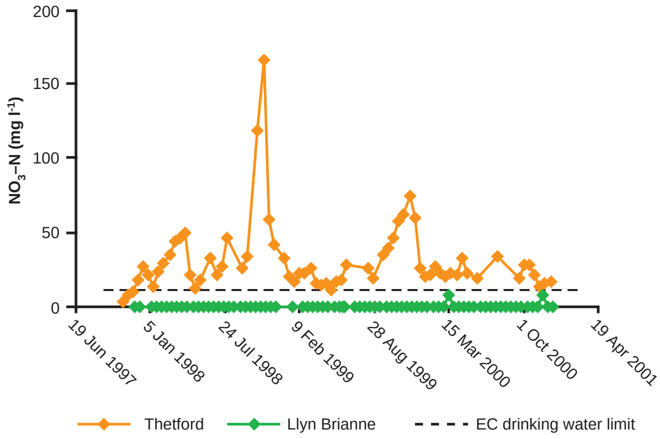
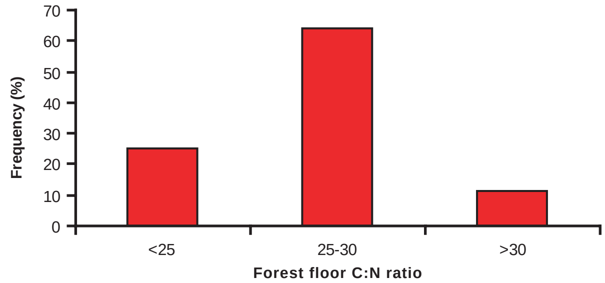


Figure 9

The distribution of C:N ratios in the forest floor of 36 Level I conifer plots in GB.



surveys of broadleaved species, Emmett (personal communication) found nitrogen leaching at three out of 19 oak plots in Wales and the northwest of England, and the beech survey on brown earth soils showed very similar results; nitrate leaching was observed in three out of 20 plots. These surveys all indicate that an estimate of 15–20% may be realistic for the fraction of woodlands experiencing nitrate leakage in England and Wales. Too few studies in Scotland have been undertaken to warrant even an estimate being made.

Using relationships between nitrate leaching and a more readily accessible indicator precludes the need for surveys such as those described above. Results using this approach can be compared to the above estimates with mixed success. For example, the ratio of carbon to nitrogen in the forest floor is often used as an indicator for nitrate leaching in conifer stands (Gundersen *et al.*, 1998). High nitrogen levels, and thus low carbon to nitrogen ratios, tend to indicate that the organic fraction of a soil no longer has the capacity to assimilate all incoming nitrogen and prevent it from leaching below the rooting zone. Data from a soil survey of 36 of the coniferous Forest Condition (Level I) plots in 1995 show that 25% had C:N ratios below the threshold value of 25 (Figure 9). This agrees well with the Welsh Sitka spruce study above, but unfortunately there is a 'grey' zone for C:N ratios, between 25 and 30, in which some sites leak nitrogen and others do not (Wilson and Emmett, 1999). There are various possible reasons for this but, as yet, there is no consensus as to the causal factors. Since most of the C:N ratios derived for the Level I sites sit in this grey zone, it is possible that more than 25% of coniferous sites are leaching nitrogen below the rooting zone, but how much more and in what fraction of these the nitrate reaches the stream water we currently cannot say.

IMPLICATIONS FOR FOREST DESIGN AND MANAGEMENT

As a consequence of pollution abatement agreements such as the Gothenburg Protocol and its predecessors, the deposition of nitrogen oxides in Great Britain has declined by 16% from its peak in 1990. Although this has had relatively little effect on total nitrogen deposition (which is dominated by ammonia) to date, declines are anticipated (NEGTAP, 2001). However, although this means improvements can be anticipated in the longer term, we cannot be sure how forest ecosystems will respond in the short to medium term. Even as nitrogen deposition begins to decline due to its historical accumulation in forests, it may still build up in the system and lead to further increases in leaching before we see signs of recovery.

Forest design and management can have a significant influence on the nitrogen status of woodlands. An effective course of action to combat nitrogen-related changes in ground vegetation would be to increase the size of woodlands, thus decreasing the relative area of 'edge'. This is not a new concept; Peterken and Game (1984) proposed a similar scheme. The de-fragmentation of woodlands would also go some way to reducing the occurrence of nitrate leaching.

Two further management options can also contribute to this reduction.

- It is known that in spruce stands of uniform age the occurrence of nitrate leaching is related to the age of the plantation (Emmett *et al.*, 1993). As vigorous early growth diminishes, so the use of nitrogen falls and it is more likely to leak from beneath the rooting zone. Recent moves for the expansion of mixed age plantations, such as those outlined in *Woodlands for Wales: The National Assembly for Wales strategy for trees and woodlands* (Forestry Commission, 2001), may improve the current situation. However, the potential effects of uneven-aged stands on air turbulence that could enhance deposition remain unquantified.
- The maintenance of a cover of ground vegetation can help to reduce nitrate leaching considerably. The survey of beech woodlands (Figure 2) demonstrated that nitrate leaching was only observed in the subsoil where the ground vegetation cover was less than 30%. However, in practice, establishing and maintaining ground vegetation is not necessarily straightforward or compatible with best practice for forest establishment. To this end, experimentation has begun to investigate the practicalities of establishing ground cover. In addition, the protection of watercourses from excess nitrate is best achieved through the recognised practice of establishing effective buffer and riparian zones (Forestry Commission, 2000).

CONCLUSIONS

Nitrogen deposition impacts on different elements of forest ecosystems to different degrees. While reductions in the species diversity of ground vegetation are undoubtedly widespread in Great Britain, it is thought that they are not as extensive as national critical loads maps may indicate.

Research suggests that the health of some Scots pine stands in Scotland (but not England and Wales) has been detrimentally affected by nitrogen deposition levels but whether this has impacted upon growth is not known. Some effect on the health of a small fraction of Norway spruce stands also cannot be ruled out, but Sitka spruce has remained unaffected to date. In contrast, the condition of oak and beech appears to have improved as a consequence of nitrogen deposition in GB. While there is little possibility of further increases in nitrogen deposition, it is unlikely that we will see the detrimental effects recorded in some continental European countries where pollution levels are higher (Flückiger and Braun, 1998).

A state of nitrogen saturation, and thus nitrate leaching, may occur in some 15% of broadleaved woodlands in Great Britain. While the incidence is probably slightly higher for conifers, we cannot be sure by how much. The difference between woodland types is thought to be due to the presence or absence of a cover of ground vegetation (its presence increases the overall biological demand for nitrogen) and soil characteristics.

While we can expect background levels of nitrogen deposition to fall over the next decade, we can also anticipate a lag effect in recovery due to the historical accumulation of nitrogen which has already occurred. Forest management can aid the recovery process by a move towards more mixed age and less fragmented crops, a reduction in large scale clearfelling, and the establishment of native woodland riparian buffer areas and woodland ground vegetation.

Finally, the need to continue monitoring forest condition, both intensively and extensively, is imperative if potentially complex responses to emission controls are to be detected, understood and used to guide changes in forest management.

Acknowledgements

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Jim Pratt

Stump treatment against Fomes

The Forestry Commission had a policy of ubiquitous treatment of stumps to prevent their infection by *Heterobasidion annosum*. During the past few years, Forest Research has established where the risk from the disease no longer justifies stump treatment, has obtained statutory approval for the use of two chemical and one biological treatment agents, and has identified weaknesses in existing application systems mounted on harvesters. The consequences of this work are now described and the potential for increasing the scope of biological control onto spruce stumps is also discussed.

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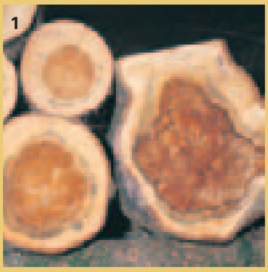

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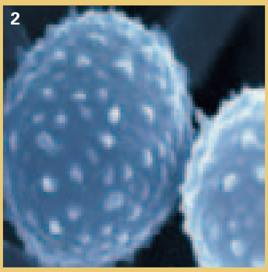

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1. Fomes decay in Norway spruce heartwood.
2. Basidiospores of *H.annosum*.
3. Measuring stump treatment applied by harvesting machine [Jim Pratt].
4. Testing the effect of incomplete coverage of a control agent in a stump treatment trial.

BACKGROUND

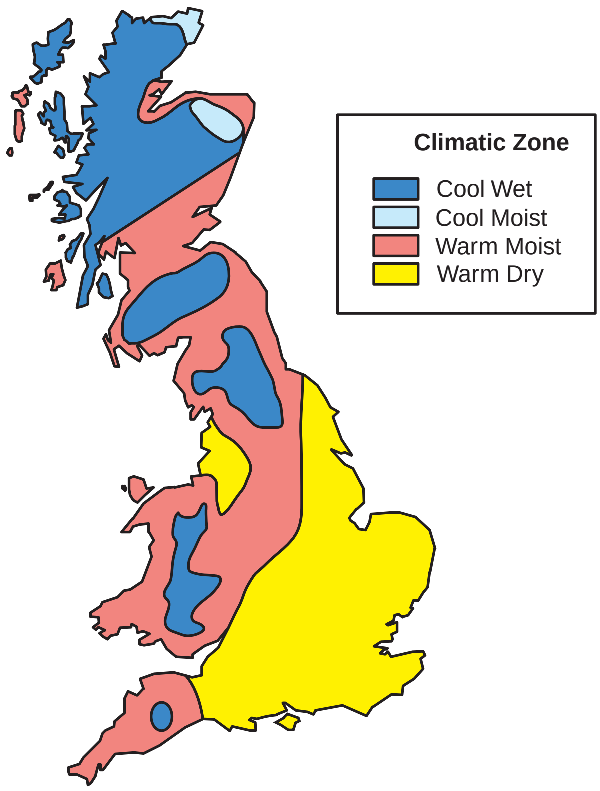
Heterobasidion annosum (more commonly known as Fomes) is a pathogenic fungus that kills the roots and decays the heartwood of most species of conifer used in commercial forestry. Up to 40% of the value of standing trees can be lost in a few years (Pratt, 1979). In Britain, airborne spores of the fungus are present throughout the year. These infect freshly cut stumps during thinning or felling operations, and provide the fungus with the means to initiate disease in new plantations. Once the role of stumps in the infection cycle of *H. annosum* was recognised in the 1950s (Rishbeth, 1949), opportunities for controlling the disease were quickly realised. Chemicals which prevented infection by airborne basidiospores when applied to fresh stumps were identified and brought into use in conifer stands in about 1960. A biological stump treatment based on a competing fungus *(Phlebiopsis gigantea)* was also developed (Rishbeth, 1963) for use on pine. When mechanised felling started in the 1980s, the need to apply these materials by harvesters became evident: however, by 2000 it was clear that the application systems were unsatisfactory and required improvement if the treatments were to be considered environmentally acceptable and economically justifiable (Pratt and Thor, 2001). At the same time, external factors including forest certification, European pressures to adopt GPPP (Good Plant Protection Practice; Jørgensen, 2001) and financial stringency within the forest industry combined to reduce the use of pesticides. These pressures are having a profound effect upon attitudes towards stump treatment. This article reviews the crucial elements of an emerging policy and how it may be implemented.

WHERE TO TREAT

The Forestry Commission adopted ubiquitous stump treatment within its conifer woodland 40 years ago, as an insurance until research could demonstrate the actual size of the risks involved. Experiments designed to assess the hazard to Sitka spruce from *H.annosum* in crops on peat and mineral soils have clearly demonstrated that the risk on peat soils is very low (Redfern, 2001) because fungal transmission from stump to tree is inhibited by this soil. Redfern also reported that survival of the fungus in Sitka spruce stumps is attenuated in high rainfall areas, regardless of the soil type. These and other observations made in Britain and elsewhere (e.g. Ross, 1973) make it clear that the pathogen thrives best and grows fastest under mild conditions where the soil is well-drained, and they lend support to the view that the risk of serious outbreaks of the disease in many of our upland forests is much lower than was forecast when stump treatment was introduced. However, the effect of soil is not independent of climate, and a soil that presents a high hazard in one area may be less hazardous where temperatures are lower and rainfall is higher. Parameters that capture these climatic conditions include *accumulated temperature* and *soil moisture deficit*, which have been amalgamated (Figure 1) into a number of UK climatic zones (Pyatt *et al.*, 2001).

Figure 1

Climatic zones of Great Britain: based on accumulated temperature (day-degrees above 5°C) and annual soil moisture deficit (mm). Adapted from Pyatt *et al.*, 2001.



Disease hazards based on a combination of soil type and climatic zone have been allocated to three classes, namely high (score 3), medium (score 2) and low (score 1). These classes are based on estimates of the amount of disease that might develop in the absence of stump treatment in a stand over two consecutive rotations, as derived from the computer model of Pratt *et al.* (1988), modified to take account of recent thinnings practices (Methley and Friar, 2001), and an assessment of the risk from clearfelling stumps (Pratt, unpublished). Thus, there is considered to be a high probability that more than 5% of trees will be affected in high-hazard stands, 1–5% in medium-hazard stands, and less than 1% in low-hazard stands. The relationships between climate and soil and these hazard classes are summarised in Table 1.

Note that in Table 1 two phases of soil described as peaty gley are recognised, based on the depth of peat overlying the gleyed mineral horizons: the shallower form (soil type 6) has peat 5–25 cm deep, compared to

Figure 2

Soil types in an area of conifer forest in Scottish Borders.

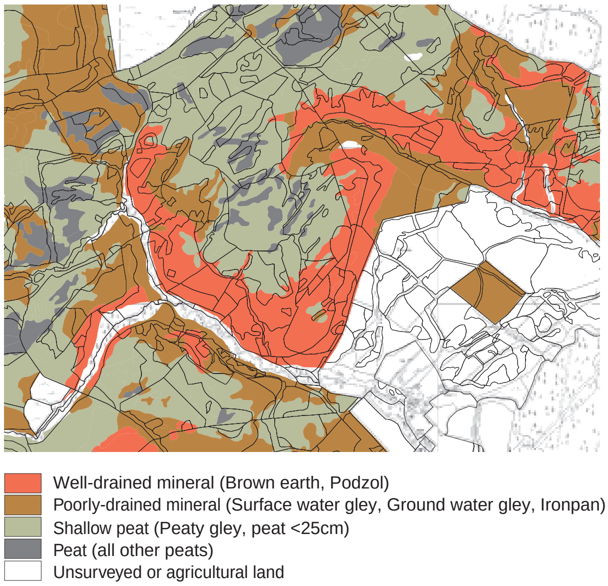


Table 1

H.annosum **hazards associated with soil types and climatic zones. Notations and soil numbers as in Pyatt** ***et al.*** **(2001).**

Fomes hazard class	Climate zone				
	Cool Wet	Cool Moist	Warm Wet	Warm Moist	Warm Dry
High (3)	Nil	Calc soils, littorals 12,15	BE, Podzol, Calc soils, littorals 1,3, 13 b,z: 12,15	BE, Podzol, Calc soils, littorals 1,3, 13 b ,z: 12,15	BE, Podzol, Calc soils, littorals, ironpans, GWG SWG 1,3, 13 b,z: 12,15,5,7.
Medium (2)	Calc soils, littorals 12,15	BE, Podzol, SWG 1,3, 7,13 b,z	Ironpans, GWG, SWG 4,5,7	Ironpans, GWG, PG (shallow), SWG 4,5,6,7	PG (shallow) 6
Low (1)	BE, Podzol, Ironpans, GWG, PG (all phases), SWG, Peat 1,3,4,5,6, 6p, 7,8,9,10,11,13 b,,z, 14	Ironpans, GWG, PG (all phases), Peat 4,5,6, 6p,8,9,10,11,13p, 14	PG (all phases), Peat 6, 6p,8,9,10,11,13p, 14	Peat, PG (deep) 6p,8,9,10,11,13p, 14	Peat, PG (deep) 6p,8,9,10,11,13p, 14

BE = brown earth; Calc = calcareous pH > 6.0; GWG = ground water gleys; PG = peaty gleys; PG (shallow) = peaty gley with peat layer 15 cm or less; PG (deep) = peaty gley with peat layer greater than 15 cm; SWG = surface water gleys; Peat = peats deeper than 15 cm.

the deeper form (soil type 6p), where peat is between 25 and 45 cm thick. Observation suggests that in practice the hazard from Fomes is greater in peaty gley where peat horizons are thinner than 15 cm, since at greater thicknesses the majority of roots are likely to be growing entirely in peat. However, 15 cm is not recognised as a threshold depth for identifying a separate peaty-gley phase in standard soil mapping. Where the suspected depth of peat is seen as a critical factor in determining hazard, judgement should be used in deciding whether peaty gleys are classified as soil type 6 or as the lower-hazard type 6p.

Examples of disease hazards derived from a knowledge of soil and climate are shown in Figure 3 (page 81). Soil types in a sample of woodland have been amalgamated into four major soil groups as shown in Figure 2, each of which will pose a different hazard. Figure 3 shows the estimated hazard ratings for each of these soil groups, and assumes that the woodland block is in one of four climate zones, namely cool wet and moist, and warm moist and dry. Nearly 60% of Forest Enterprise high forest exists in the former (cool) areas, and 37% in the two 'warm' zones.

The actual risk from *H.annosum* on a site of known hazard is determined both by the hazard *per se*, and by the management options. Thus, if risky options are selected for a high-hazard site, the losses that will occur will probably be higher in the long term than on other, less-hazardous sites. The risk can, of course, be minimised by stump treatment. In general terms, high-risk management options would involve the exposure of large numbers of stumps that are susceptible to infection by Fomes spores and which spread the disease to trees that are prone to it. Examples of risk associated with management operations are grouped under four disease risk classes in Table 2.

The scores associated with disease hazard and disease risk are mutually independent, and can thus be multiplied together to produce an overall risk score that can be used to inform decisions on stump treatment (Table 3).

Table 2

Disease risks associated with management practices.

	Disease risk			
Operation	**High risk (3)**	**Medium risk (2)**	**Low risk (1)**	**No risk (0)**
Thinning	Thin regularly, early and heavily	Reduce frequency and intensity of thinning	Non-thin	None
Stump treatment	No stump treatment	Allow poor practice	Practice high-quality stump treatment, treatments especially in early thinnings	None (no stump treatment is always 100% effective)
Remedial treatment of badly diseased sites.	No stump removal	Remove only rotted stumps, or stumps from the clear-fell	Remove all stumps	None. Stump removal cannot be 100 % effective
Species selection in next rotation: 1. following pine	Pure spruce, larch or DF	Hardwoods in mixture with spruce, larch or DF	Pine[a], grand fir, hardwoods	Hardwoods
2. following spruce, larch or DF	Western hemlock, larch	Spruce, DF	Pine[a], grand fir, hardwoods	Hardwoods

[a] Generally, pine is not at risk from Fomes except in soils where the pH exceeds 6.5–7.0; under these conditions, it is very susceptible and can be killed in large numbers at any age. Pine stumps are very susceptible to infection by Fomes spores, and readily pass on the disease to other species in mixtures. DF: Douglas fir.

Table 3

Assessing the need for stump treatment.

Management risk	Site hazard High (3)	Site hazard Medium (2)	Site hazard Low (1)
High (3)	HH (9)	HM (6)	HL (3)
Medium (2)	MH (6)	MM (4)	ML (2)
Low (1)	LH (3)	LM (2)	LL (1)
Nil (0)	NH (0)	NM (0)	NL (0)

Stands with a score of 6 or higher will justify stump treatment, while stands with a score of 3 or less do not. There are a number of options for dealing with other stands where the decision is not clear-cut:

- Relate the decision to treat or not to the value of the stand.
- Adopt low-risk policies for the stand.
- Assess the likelihood of stump infection from local spore sources, and adjust score accordingly.

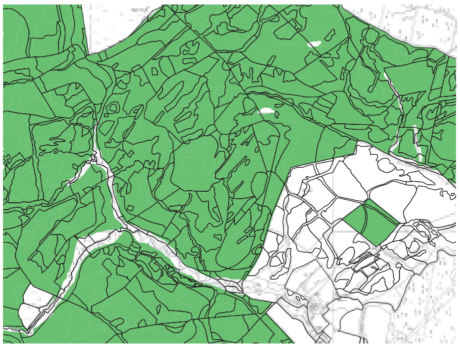
The scale at which decisions on investing in stump treatment are taken can be varied depending on intensity of management and the degree of site variation. The key to the decision is to accept that some losses in value will inevitably occur in the absence of effective prophylactic treatment, but as long as they are smaller than the savings made by not treating stumps, a policy of non-treatment is justifiable. The investment decisions that are taken in relation to stump treatment are long term (Pratt, 1998), and should extend to at least two rotations, during which expenditure on control will be offset by the benefits of an absence of disease. The use of standard discounting methods for measuring the economic benefits of stump treatment has proved difficult, because of the need to reconcile a stream of costs with a stream of losses over a long time period. However, an adequate approximation of the relative size of the benefits can be obtained by making simple assumptions on the costs of treatment and the value of the timber that would be saved, using current values for both. If the accumulated costs over two rotations are lower than the predicted losses over the same period, treatment is probably justifiable. In the following example, an average cost of 30p/m^3 has been selected for treatment. Timber values have been variable, but a 10-year weighted average of £15/m^3 was used. The losses caused by decay can be simply estimated by assuming that each decayed tree will lose 30% of its volume, or 40% of its value. Although these relationships were established for Sitka spruce (Pratt, 1979), similar losses through decay can be expected to occur to all other butt-rot susceptible species (with the exception of Grand fir: see Redfern and MacAskill, in press). Applying the ‘40%’ rule shows that in high-hazard crops where at least 5% of trees may become diseased, the losses would be more than 2% of value, and thus close to the notional cost of treatment (30p/m^3) and treatment would be justified. In medium hazard crops, between 1% and 5% of trees may become decayed, with losses in value of between 0.4% and 2%. Here, the decision to treat or not is marginal, and is likely to be affected by factors other than those of strict economics. Losses in low hazard crops are unlikely to exceed 0.4% of value, and cannot justify treatment.

STUMP TREATMENT MATERIALS

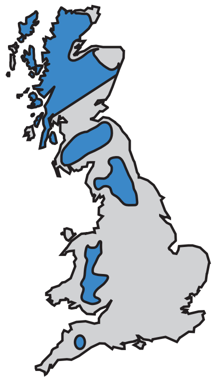
The materials available for stump treatment were all identified by Rishbeth in the 1950s (Rishbeth, 1959a, 1959b, 1963). He recognised the need for substances that were inexpensive, readily available and safe to apply in the forest. The first, creosote, was discarded when it became clear that this unpleasant chemical exacerbated the disease by preventing fungal competition within stumps. Sodium nitrite was selected as a successor, but after a number of years of use, it too was abandoned because of its inherent toxicity and explosive potential. The third choice fell on the nitrogenous fertiliser urea, which had shown promise in trials on pine stumps. Urea is inexpensive, widely available and of low mammalian toxicity and was approved for use in 1988 and again in 2001. It is effective for stump treatment only while it is being hydrolysed by bacterial action within stump tissues into ammonia (Rishbeth, 1959b). During this process, the pH of urea-treated wood rises above a threshold that is toxic to *H. annosum* (Johansson *et al.*, 2002). Hydrolysis occurs more readily in pine than in spruce stumps, the

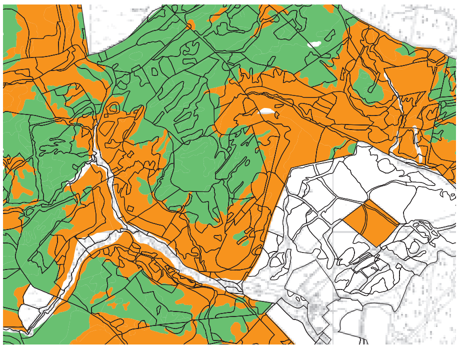
Figure 3

Disease hazard derived from climate and soil, for the area of forest shown in Figure 2, assuming it is located in each of four climatic zones from Figure 1. The proportion of the forest area within each disease hazard class is tabulated.

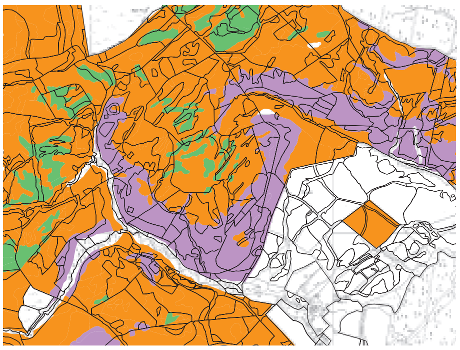


Climatic zone	COOL, WET		
Fomes hazard	Low	Medium	High
Per cent of area	100	0	0

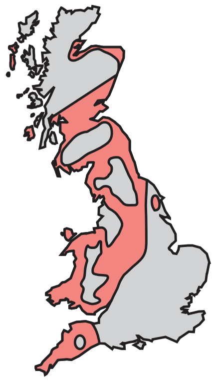


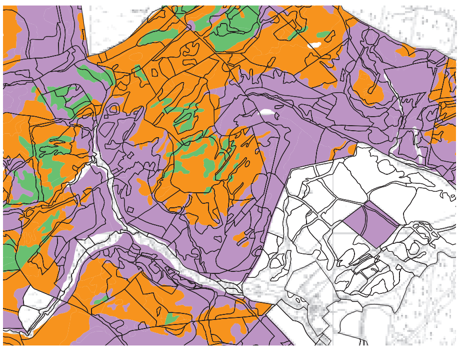


Climatic zone	COOL, MOIST		
Fomes hazard	Low	Medium	High
Per cent of area	51	49	0

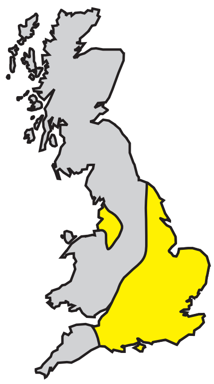


Climatic zone	WARM, MOIST		
Fomes hazard	Low	Medium	High
Per cent of area	12	56	32





Climatic zone	WARM, DRY		
Fomes hazard	Low	Medium	High
Per cent of area	12	23	65



rate being temperature dependent. This may explain why the efficacy of urea on stumps of Sitka spruce in upland Britain has been variable: in the absence of hydrolysis, urea acts as a fertiliser and it may even enhance the growth of the pathogen in diseased stumps (Pratt and Redfern, 2001). Large doses of urea are needed for the active process of hydrolysis to be maintained throughout the weeks when stumps remain susceptible to infection. In practice, however, the amount absorbed at the stump surface is limited by the dryness of the stumps during treatment, and it is rarely possible to apply more than 1 litre of fluid to each square metre of stump. Mechanised application at this rate has proved to be difficult, wasteful of material and responsible for unacceptable collateral damage to local vegetation (Westlund and Nohrstedt, 2000). In addition to these problems, urea is corrosive and is not a material well-fitted for use with modern harvesting equipment. As a consequence, an alternative chemical based on boron, namely disodium octaborate tetrahydrate (DOT), has been evaluated and approved for use in Britain (Pratt, 1994, 1996; Pratt and Lloyd, 1996; Pratt and Quill, 1996). Although DOT has many attributes that make it more acceptable than urea, the harmonisation of pesticides under European rules makes it unlikely that it will be available for stump treatment after 2003. There are currently no alternative chemicals other than urea.

The third material approved for stump treatment is biological, and relies on the ability of a saprotrophic fungus, *Phlebiopsis gigantea*, to decay the wood of stumps more rapidly than the pathogen, and thus exclude it. This form of treatment was devised in the 1960s (Rishbeth, 1963) and was the world's first commercially available biological agent for the control of a plant disease. The British-made product, PG Suspension, was approved for use on pine in Britain in 1998 and is manufactured on licence to the Forestry Commission by Omex Environmental Ltd, Kings Lynn. There would clearly be an advantage to have a biological agent for use on spruce as well, but extensive research has failed to find a British isolate of *P. gigantea* on species other than pine. However, a stump treatment product using an isolate of *P. gigantea* that grows on Norway spruce is manufactured in Finland and marketed in Scandinavia as Rotstop®. As a first step in its evaluation for use in Britain, pathogenicity trials of Rotstop® on living Sitka spruce were carried out in Denmark (Thomsen and Pratt, unpublished) and population studies using DNA markers (Vainio and Hantula, 2000; Webber and Thorpe, in press) were undertaken in Britain. Neither indicate that introducing this isolate into Britain and Ireland would involve unacceptable risk, and field trials are planned to determine its efficacy on Sitka spruce, Douglas fir and larch stumps. Following on from the work of Skrzecz (1994), the potential for Rotstop to affect populations of breeding weevils *(Hylobius abietis)* is being studied in both the UK and Ireland.

The high costs associated with testing and obtaining statutory approval of pesticides (about £5 million) does not encourage the development of new stump treatment materials. It is likely therefore that the forest industry will need to use and adapt those which are already available.

IMPROVING THE QUALITY OF TREATMENT

The general standard of harvester-applied stump treatment in Britain needs improvement. The chemical treatment (urea) crystallises at both high and low temperatures, corrodes all but a few metals and increases the cost of maintenance of the harvesting machines. It is awkward and bulky to handle and the equipment for applying it from harvesters has hardly changed during the past 15 years. Without close supervision there is little incentive for operators to achieve high standards of application and it is generally accepted that the quality of stump treatment in Britain is variable.

To improve the standard of treatment, there are three remedies:

- Ensure that machine operators and harvesting managers are familiar with the reasons why stump treatment is important.
- Apply treatment only where it is needed.
- Improve the equipment and the materials available for treatment.

The first issue is being tackled by means of a demonstration video (Whistler and Rushton, 2002), commissioned as part of a joint Forest Enterprise/Forest Research project. This will be used in training courses, and will also be made available to the private sector. A plan for meeting the second remedy using a decision support system for assessing the need for treatment is described above. Thirdly, changes that need to be made to equipment to improve the application system are considered below.

To qualify as best practice, stump protection requires that an appropriate dose be applied without compromising the safety of the machine operator, reducing the productivity of the harvesting operation or threatening the integrity of the environment. Application systems on harvesters are tending to become standardised for delivery of the protectant, which is pumped on demand from a storage tank to the felling head whence it is discharged onto the stump surface via holes spaced along the length of the chain saw bar. Sophisticated computer control systems may be fitted which determine when the pump is activated, and this affects the volumes discharged. The volumes applied to stumps will always be less than the total volumes discharged, since treatment inevitably produces waste that is sprayed onto the ground surrounding the target stump. The objective of further development must be to limit this waste to an acceptable minimum. Equipment has been developed to measure both the rate of discharge and its distribution (Pratt and Thor, 2001), and a standard has been devised to act as a benchmark (Table 4).

The two factors that contribute most to poor treatment are the over-capacity of pumps, and the arrangement of the delivery holes in the standard treatment bars (Pratt *et al*., 2001). The former can only be modified once the performance of the delivery bars is improved, and work by Forest Research (Pratt *et al*., in press) has demonstrated the beneficial effects of reducing the numbers of delivery holes, and of placing them more intelligently. Adequate coverage with less waste was achieved using bars with fewer holes that were positioned on either side of the centre of the cutting arc. In addition, the doses required were significantly

Table 4

Proposed minimum standards for stump treatment.

Application rate (l m^{-2})	1.0	0.5
Maximum consumption (l m^{-2})	1.5	1.0
Minimum coverage per stump	90% of surface, with no area greater than 10 cm^2 untreated per stump	
Minimum incidence of stumps treated to this standard	95%	

reduced and there was less collateral waste (Table 5).

These findings have been taken up by the major bar manufacturers (Oregon® Cutting Systems) and are being incorporated in new designs (G. Carruthers, personal communication, 2002). These will provide bars of superior performance, with prolonged life and reduced running costs. One such is a solid bar where the treatment holes are punched by the operator (Plate 1).

Plate 1

Protype harvester bar being punched by the operator to provide treatment holes in optimum positions.

DISCUSSION

The susceptibility of all our conifers to *H.annosum* has been clearly demonstrated in the UK (Greig *et al*., 2001), and as long as commercial forestry is practised, prophylactic treatment will be required to maintain relatively disease-free stands. The problem is to arrange this form of control so that it is economically justified, ecologically acceptable and meets our commitments to long-term sustainability. Research over the past three decades has provided some of the answers. Firstly, we now have a means of predicting the likely progress of the disease on most sites, albeit

Table 5

Comparison between standard and modified bars: volumes applied, wastage and stump surface coverage. Means of 10 (or 5) samples per treatment.

Stump diameter (cm)	Bar type	Number and length of array of holes	Waste as a % of discharged volume	Volume applied to stump surfaces (l m^{-2})	Coverage (mean %)
22	Standard	42, 53 cm	48	2.4	100
(*n*=10)	Modified	3, 13 cm	32	1.6	97
44	Standard	42, 53 cm	18	1.71	100
(*n*=5)	Modified	4, 46 cm	8	1.07	92

with a low precision. Using this knowledge, it is possible to select options for treatment which are appropriate to the site.The climatic zones developed for ESC offer a sensitive means of identifying sites where the hazards from the disease depend on soil type, and decisions on the need for prophylactic control are enabled. The widescale use of this GIS-based system will require that data on climatic zones and soils are (or soon will be) widely available. Secondly, three materials suitable for stump treatment have been tested and approved. However, a move away from chemicals towards biologically based materials is a clearly stated long-term aim of the Forestry Commission, and there is much scope for improvement of the existing biocontrol agent, since virtually no research has been undertaken on methods of enhancing the growth or formulation of stump-inhabiting fungi, or for determining their collateral effect on other pests such as *Hylobius*. Unfortunately, the future development of chemical or biological pesticides for markets as small and specialised as those in forestry will be increasingly inhibited by the costs of providing data to the regulatory authorities and by the complexity of the data that are required. Thirdly, means of improving mechanised treatment have been identified and are being implemented. However, there is a relatively small market for stump treatment equipment and little competitive pressure for its development: improvements will not be fast. Finally, the need to provide harvester operators and managers with training in the treatment of stumps has been recognised and is in hand.

Acknowledgements

Almost none of the research that underpins these recommendations on stump treatment was made without considerable help from Grace MacAskill, to whom I offer my thanks.

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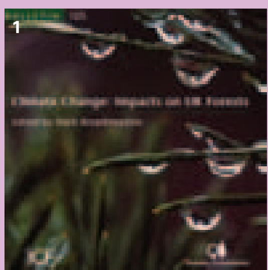
Publications, research programmes, contracts and people



1. New Bulletin on climate change and UK forests.
2. Labelling of cut battens from sawmill.
3. Modelling and forecasting yield and quality in Europe (MEFYQUE): information leaflet.
4. Common dormouse: an Action Plan species studied in connection with the restoration of planted ancient woodland sites [Chris Pierce/Sussex Wildlife Trust].

FORESTRY COMMISSION TECHNICAL PUBLICATIONS

The following titles were published during the year ending 31 March 2002

Report

Forest Research annual report and accounts 2000–2001. (£16.70)

Miscellaneous

Ecological Site Classification: a pc-based decision support CD/manual system for British Forests (v1.7). (£1.00)

Sustainable forest management: the international framework. (free)

Social forestry: questions and issues, compiled by Liz O'Brien. (free)

Trees are company: social science research into woodlands and the natural environment, edited by Liz O'Brien and Jenny Claridge. (£15.00)

The various series of technical publications listed below are published for the Forestry Commission by Policy and Practice Division. New titles are listed here as authors are predominantly from Forest Research. Authors outwith the Agency are indicated by an asterisk.

Bulletins

125 Climate change: impacts on UK forests, edited by Mark Broadmeadow. (£25.00)

124 An ecological site classification for Great Britain, by Graham Pyatt, Duncan Ray and Jane Fletcher. (£12.50)

Guideline Note (free)

2 Short rotation coppice in the landscape, by Simon Bell and Liz McIntosh

Information Notes (free)

38 The assessment of site characteristics as part of a management strategy to reduce damage by *Hylobius,* by Stuart Heritage and Roger Moore

39 Protocol for stem straightness assessment in Sitka spruce, by Elspeth MacDonald, Shaun Mochan and Thomas Connolly

40 Transforming even-aged conifer stands to continuous cover management, by Bill Mason and Gary Kerr

41 Forest Condition 2000, by Steven Hendry, Roger Boswell and John Proudfoot

Practice Note (free)

11 Practical techniques for surveying and monitoring squirrels, by John Gurnell*, Peter Lurz and Harry Pepper

Technical Paper

18 Perceptions, attitudes and preferences in forest and woodlands, by Terence R. Lee*. (£15.00)

32 Deforesting and restoring peat bogs: a review, by Russell Anderson. (£7.50)

Inventory Reports

National Inventory of Woodland & Trees – Scotland: Highland Region. (£5.00)

National Inventory of Woodland & Trees – Scotland: Western Isles. (£5.00)

National Inventory of Woodland and Trees – England. (£15.00)

National Inventory of Woodland and Trees – England Wallchart. (free)

National Inventory of Woodland and Trees – England: North East Region. (£15.00)

National Inventory of Woodland and Trees – England: Yorkshire & the Humber Region. (£15.00)

National Inventory of Woodland and Trees – England: West Midlands Region. (£15.00)

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National Inventory of Woodland and Trees – England: South West Region. (£15.00)

National Inventory of Woodland and Trees – England: East of England Region. (£15.00)

National Inventory of Woodland and Trees – Scotland. (£15.00)

National Inventory of Woodland and Trees – Scotland Wallchart. (free)

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Brasier, C.M. (2000)
The role of Phytophthora pathogens in forests and semi-natural communities in Europe and Africa. In: *Phytophthora diseases of forest trees. Proceedings from the first international meeting on phytophthoras in forest and wildland systems, Grants Pass, Oregon, USA, 30 August to 3 September 1999*, eds E. M. Hansen and W. Sutton. International Union of Forestry Research Organisations; Forest Research Laboratory, Oregon State University, USA. Oregon State University, Corvallis, Oregon, 6–13.

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Wainhouse, D., Ashburner, R. and Boswell, R. (2001)
Reproductive development and maternal effects in the pine weevil *Hylobius abietis*. *Ecological Entomology* **26**(6), 655–661.

Willoughby, I. and [Clay, D.] (2002)
Natural product herbicides in forestry: what are the prospects? What alternatives are there to synthetic pesticides? Ian Willoughby and David Clay look at whether natural product herbicides may play a role. *Forestry & British Timber* **31**(2), February 2002, 22, 24–25.

MAJOR RESEARCH PROGRAMMES FUNDED BY THE FORESTRY COMMISSION

Entomology Branch

Plant health
Hugh Evans, Nick Fielding and Christine Tilbury
Research into the risks from indigenous and non-indigenous forest insect species. Co-ordination and implementation of surveys in relation to retention of EU Protected Zone status for named bark beetle pests. The use of Pest Risk Analysis techniques to determine contingency options for potential pests. Research into alternatives to methyl bromide as a quarantine and remedial treatment against exotic pests (part EU-funded).

Restocking pests
Stuart Heritage
Research into the effective use of chemical pesticides for control of restocking pests, notably *Hylobius abietis*. Research into and development of insect parasitic nematodes for biological control of larval stages in stumps and provide direct intervention options within the Integrated Forest Management programme being developed in the Branch.

Impact of insects on tree growth
Nigel Straw
Investigate quantitative relationships between insect population pressure and the growth of trees attacked by those insects. An important aim is to separate the direct effects of damage from other biotic and abiotic variables that might mask the impacts of pest insects. The target species is green spruce aphid, *Elatobium abietinum*, which severely defoliates both Norway and Sitka spruces.

Integrated Forest Management
David Wainhouse, Roger Moore and Hugh Evans
Develop the concepts and science of Integrated Forest Management (IFM) to underpin sustainable forestry with particular emphasis on reductions in chemical pesticides. Study the population dynamics of *Hylobius abietis* and use the data to develop decision support systems for management of the restocking problem. Investigate the variability in quality of both stumps and transplants in relation to performance of *H. abietis* and use the data to refine management options within the IFM programme. Develop a decision support system for sustainable reduction of *H. abietis* populations towards the acceptable damage threshold predicted by the population dynamics models.

Mechanisms of tree resistance to insect attack
David Wainhouse
Investigate mechanisms of resistance of young conifers to the pine weevil. Determine the relative importance of genetic and environmental factors in resistance expression. Develop these aspects to contribute to an Integrated Forest Management (IFM) approach for control of pine weevil.

Advisory services
Christine Tilbury
Provide identification services for both pest and beneficial insects and provide advice on pest management and control.

Environmental Research Branch

Soil sustainability
Fiona Kennedy
Research to identify and evaluate the potential impacts of both forest management and air pollution on soil status and dynamics. Develop and advise upon sustainable practices.

Reclamation of man-made sites for forestry
Andy Moffat, Kirsten Foot and Tony Hutchings
Improve methods of establishing woodland and management practices on disturbed (brown field) sites, taking into account changes in forestry and land-use policy, planting opportunity, environmental impacts, mining practices and technology. Develop best practice guidelines.

Forest hydrology
Tom Nisbet
Study the impacts of forests and forestry management practices on water quality and quantity. Develop and assess guidance on best management practice for the protection of the freshwater environment within forests. Provide expert advice on forestry–water issues.

Effects of air pollution on trees
Dave Durrant and Andy Moffat
Determine the role of air pollution in forest condition and growth through long-term intensive environmental monitoring in forest ecosystems, in compliance with EC regulations. Provide data under the Convention on Transboundary Air Pollution for the calculation and mapping of critical loads.

Climate change
Mark Broadmeadow
Predict and model the impacts of environmental and climate change on tree growth by experimental work in open-top chambers and in forest stands. Identify interactions between forestry and a changing global environment, e.g. exchange of greenhouse gases.

Environmental change network
Sue Benham
Monitor and understand environmental change and its impact on terrestrial ecosystems. Manage one of the national network of terrestrial sites of the ECN network.

Archaeology
Peter Crow
Evaluate the impact of tree growth and forest operations on features of archeological interest. Examine how forest practices can be manipulated to minimise the risk to archeological features by practical research.

Mensuration Branch

Sample plots
Janet Methley and John Proudfoot
Develop and maintain national reserve of periodic growth and yield data to support measurement, growth and yield studies using a network of permanent and temporary sample plots. Current focus: contemporary silvicultural practices, uneven-aged planting mixtures, modern planting and harvesting systems, long-term environmental change monitoring.

Yield models
Robert Matthews
Improve methods and models for forecasting growth and yield of forests. Current focus: development of interactive stand-level yield model software, site:yield relationships, biomass yield models.

Measurement
Janet Methley
Develop and promote measurement systems and instruments for the accurate and efficient measurement of trees and timber to support industry, national and international standards. Provide independent expert advice in cases of measurement dispute.

Core model
Sam Evans
Integrate modelling initiatives within Forest Research by developing a framework of existing and new models and relevant datasets. Taking growth models as a starting point, the core model programme aims to provide modelling tools at appropriate scales of resolution to support and promote the implementation of multi-purpose sustainable forestry policy in the UK.

Pathology Branch

Tree disease and decay: diagnosis and provision of advice
David Rose, David Lonsdale and Sarah Green
Diagnose disease in trees and provide advice and information on disease identification, management and control. Provide information on decay in standing trees, and on management of veteran trees.

Tree health monitoring
Steven Hendry
Monitor the health of the nation's trees and raise awareness of tree health issues.

Risks from altered pathogens
Clive Brasier
Investigate changes in pathogen behaviour and evaluate the potential impact of such changes in relation to plant health and Pest Risk Analysis.

Non-chemical protection
Joan Webber
Research and evaluate the potential for biological control of tree diseases, with special emphasis on root rot pathogens and the fungi that cause vascular wilts and stain and decay.

Fomes root and butt rot of conifers
Jim Pratt
Conduct research on root and butt rot of conifers caused by *Heterobasidion annosum* and investigate approaches to management and control.

Phytophthora diseases of trees
Clive Brasier, Joan Webber and David Lonsdale
Investigate pathogenic *Phytophthora* species of alder and oak to determine their impact and the opportunities for management and control.

Silviculture (North) Branch

Forest nutrition and sustainability
Steve Smith
Investigate the influence of site fertility on tree productivity and how forest operations affect sustainability of forest site fertility, including nutrient cycling and tree growth response to fertiliser trials.

Plant quality and establishment
Steve Smith, Mike Perks and Colin McEvoy
Integrated studies of the effect of nursery practice, seedling physiology, plant handling methods, site preparation and maintenance upon plantation establishment.

Silvicultural effects upon timber quality
Barry Gardiner, Jason Hubert, Elspeth Macdonald and Shaun Mochan
Investigate the impact of silvicultural practices on timber quality in conifers, especially spruce. Main emphasis is impact of site factors (e.g. exposure, fertility) on quality.

Silviculture of upland native woodlands
Richard Thompson and Colin Edwards
Research into the structure, dynamics and silviculture of native woodland ecosystems in northern and western Britain to support restoration and extension for ecological and economic benefits. Emphasis is on Scots pine forests, birchwoods and the Atlantic oakwoods.

Alternative silvicultural systems in conifer forests
Bill Mason, Colin Edwards and Sophie Hale
Evaluate canopy structure manipulation to promote suitable microclimates for seedling establishment and facilitate natural regeneration to enable wider use of alternative silvicultural systems to patch clearfelling.

Stability of stands

Barry Gardiner, Bruce Nicoll and Juan Suárez

Research to reduce wind damage to British forests using a GIS-based windthrow risk model for predicting the probability of windthrow in Sitka spruce forests. Carry out studies of root development and architecture in support of the model.

Shelter forestry

Max Hislop and Barry Gardiner

Research into the design and management of woodlands for shelter and the development of techniques for assessing the potential benefit that they provide.

Silviculture and Seed Research Branch

Alternative establishment systems

Ian Willoughby and Richard Jinks

Investigate alternatives to conventional establishment systems for new planting and regenerating existing woodlands, including vegetation management, reducing synthetic chemical inputs and direct seeding.

Energy coppice

Ian Tubby

Investigate dry matter yields of willow and poplar coppice grown for renewable energy.

Lowland native woods

Ralph Harmer

Examine methods for managing, regenerating and extending lowland native woodlands.

Poplars

Paul Tabbush

Evaluate poplar clones with potential for timber production.

Silvicultural systems

Gary Kerr

Examine the potential for diversifying the range of silvicultural systems used in native woodlands.

Seed and seedling biology

Peter Gosling

Improve tree seed quality and performance to reduce costs and increase reliability of direct seeding and natural regeneration.

Social research unit (inter-Branch)

Paul Tabbush and Elizabeth O'Brien (SSRB, Alice Holt)
Max Hislop and Suzanne Martin (Silv(N), NRS)

Examine relationships between communities and woodlands in support of FC policies on sustainable forest management. Work concentrates on community involvement, publicly held values, health and well-being, criteria and indications of sustainability, recreation, access and rural development.

Technical Development Branch

Large-scale forestry harvesting

Colin Saunders

Evaluate machinery and equipment, produce output guidance and investigate operational techniques relevant to large-scale forestry work in harvesting.

Large-scale ground preparation, seed sowing and planting

Steve Morgan, Andy Hall and Bill J. Jones

Evaluate machinery and equipment, produce output guidance and investigate operational techniques relevant to large-scale forestry work in ground preparation and planting.

Farm and small-scale silviculture/harvesting and utilisation of small woodlands

Andy Hall

Develop methods and assess equipment with low environmental impact suitable for use in small, generally broadleaved woodlands, and suitable for use by farmers and small contracting firms.

Forestry operations on derelict and reclaimed land

Bill J. Jones

Undertake focused research into the cost-effectiveness of restoration techniques, with an emphasis on system and cost advice on techniques recommended by scientists.

Wood for energy

Andy Hall and Paul Webster

Develop methods for using short rotation coppice, single-stemmed short rotation forestry, forestry residues and existing undermanaged woodlands for small-scale heating and small- or large-scale electricity generation.

Chemical weeding

Bill J. Jones

Evaluate equipment, application techniques and safety.

Tree Improvement Branch

Selection and testing of conifers
Steve Lee
Undertake plus-tree selection, progeny testing. Breeding/production populations. Demonstration of realised gain. Development of techniques for marker aided selection. Species: Sitka spruce, Scots pine, Corsican pine, Douglas fir, larch.

Breeding and production of conifers
Steve Lee
Clonal archives: conservation, advanced breeding material. Improved seed: controlled pollination, seed orchards.

Improvement of broadleaves
Ned Cundall
Selection/testing of selections at population, family and clonal level. Species: oak, ash, sycamore, beech, birch.

Origin and provenance of conifers
Sam Samuel
Identification of suitable origins of conifer species. Key species: Sitka spruce, Douglas fir.

Genetic Conservation
Ian Forrest and Joan Cottrell
Study of genetic variation and gene flow in natural populations.

In vitro propagation and phase-change biotechnologies
Allan John
Investigate tissue culture systems for multiplication of Sitka spruce and hybrid larch.

Forest Reproductive Material Regulations
Sam Samuel
Devise methods for inspection of material proposed for registration. Maintain the National Register of Basic Material.

Woodland Ecology Branch

Biodiversity evaluation and indicators
Jonathan Humphrey
Synthesise datasets from the biodiversity assessment project, identify potential biodiversity indicators, and disseminate findings.

Forest habitat management
Jonathan Humphrey, Russell Anderson and Helen Armstrong
Investigate and provide guidance on the management of forests for biodiversity through developing old growth stands, utilising cattle grazing and managing open ground habitats.

Species Action Plans
Alice Broome, Roger Trout, Chris Quine and Brenda Mayle
Undertake research in support of Forestry Commission commitments to the species Biodiversity Action Plans and provide advice on appropriate management of woodland habitats for these species.

Landscape ecology
Kevin Watts and Chris Quine
Improve understanding of how biodiversity responds to management at the landscape scale, and translate this into practical management guidance for forest design.

Ecological site classification and decision support systems
Duncan Ray
Research, build and test models that predict the effect of forest management on forest ecology, and develop decision-making tools for ecological site classification and forest biodiversity.

Squirrel management
Brenda Mayle
Develop cost-effective means of managing the impact of grey squirrels on timber production. Investigate the impact of grey squirrels on woodland biodiversity.

Deer population ecology and management
Robin Gill, Helen Armstrong and Brenda Mayle
Provide a sustainable basis for deer management in UK woodlands by investigating and developing new techniques and models of impacts and damage, population dynamics of deer, and deer density assessment.

Tree protection
Roger Trout
Develop techniques and materials for cost-effective protection of trees and woodlands from vertebrate damage.

Woodland Surveys Branch

National inventory of woodlands and trees
Steve Smith
Undertake the FC national survey of woodlands and trees, assessing the woodland cover. Update key statistics on forest type, species, age-class, management and ownership.

Inventory GIS development
Graham Bull
Create the digital woodland map for Britain. Develop the use of GIS for providing spatially referenced data on the woodland cover of Great Britain.

Private sector production forecast
Justin Gilbert
Develop and produce the private sector production forecast incorporating new woodland data from the national inventory.

CONTRACT WORK UNDERTAKEN BY FOREST RESEARCH FOR EXTERNAL CUSTOMERS

Some projects may also be part-funded by FC customers.

Anglia WoodNet
Mobile sawmilling guide.
Coppice working methods.

British Biogen
Energy production network.

CABI
Nematodes.

Cranfield University
Biomass production of landfill.

Department of the Environment, Transport and the Regions
Monitoring the health of non-woodland trees.

Potential for woodland establishment on landfill sites.

Department of the Environment, Transport and the Regions/Loughborough University
Trees and drought in lowland England.

Department of the Environment, Transport and the Regions/Natural Environment Research Council
Cause–effect relationships for pollutant inputs to UK woodland ecosystems.

Department of Trade and Industry
Yield models for energy coppice of poplar and willow.

English Nature
Woodland restoration.

European Commission
Alternatives to methyl bromide for quarantine treatment.

Application of cDNA Microarray Technology for unravelling molecular events underlying dormancy and cold hardiness in forest tree seedlings.

Bark and wood boring insects in living trees.

Ash for the future: defining European ash populations for conservation and regeneration.

Compression wood in conifers.

Control of decay.

Demonstration of sustainable forestry to protect water quality and aquatic biodiversity.

Eco-engineering and conservation of slopes for long-term protection from erosion, landslides and storms.

Forecasting the dynamic response of timber quality to management and environmental change.

Forest condition surveys.

Gene flow in oaks.

Improving ash productivity for European needs by testing selection, propagation and promotion of improved genetic resources.

Improving protection and resistance of forests to the spruce aphid.

Integrating ecosystem function into river quality assessment and management.

Intensive monitoring of forest ecosystems.
Larch wood chain.

Modelling of *Heterobasidion* infection in European forests.

Native black poplar genetic resources in Europe.

Natural regeneration of oak.

Phytophthora in European oak decline.

Use of excavator base machines in forestry.

Use of excavators and backhoe loaders in forestry.

Upgrading the Level II protocol for physiological modelling of cause–effect relationships: a pilot study.

Editorial note
Since the June 2001 Election, work for Department of the Environment, Transport and Regions (DETR) and Ministry of Agriculture, Fisheries and Food (MAFF) is now covered by the new Department for the Environment, Food and Rural Affairs (DEFRA) and Department of Transport, Land and the Regions (DTLR).

EC/Highland Birchwoods
Conservation of native oakwoods.

EC/Scottish Natural Heritage
Restoration of wet woods.

Health and Safety Executive
Mobile elevated working platforms.

ITE
Terrestrial effects of acid pollutants.

UK emissions by sources.

Kemira Fertilisers
Slow release fertilisers for cell-grown seedlings.

Madeira National Park
Mammal control.

Macfarlane Smith
Vertebrate repellents.

Ministry of Agriculture, Fisheries and Food
Development of a site-specific yield model for ash in lowland England and Wales.

Provenance testing of broadleaved species in farm forestry.

Yield models for energy coppice of poplar and willow.

Natural Environment Research Council/Imperial College
Variation in the Dutch elm disease pathogens.

Terrestrial carbon dynamics.

National Forest Company
Research and demonstration in the National Forest.

Raleigh International
Conservation of the huemul deer in Chile.

Southampton University
Short rotation coppice (poplar).

Scotland and Northern Ireland Forum for Environmental Research
A coupled soil–forest–atmosphere dynamic model for predicting evapotranspiration demands at the plot and landscape scales in the UK.

Effect of riparian forest management on the freshwater environment.

Scottish Forestry Trust/UK Forest Products Association/Tilhill Economic Forestry/Scottish Woodland Owners Association
Assessing log quality in Sitka spruce.

RESEARCH CONTRACTS AWARDED BY FOREST RESEARCH

Avon Vegetation Research
Forestry herbicide evaluation.

Butterfly Conservation
Study of small pearl-bordered fritillary populations in Clocaenog Forest.

Cranfield University, BHR Group
Development and production of prototype systems to separate insect parasitic nematodes from rearing media.

Environment Agency (Wales)
Effects of forestry on surface water acidification.

Fountain Forestry
Water monitoring, Halladale.

Freshwater Fisheries Laboratory
Effects of riparian forest clearance on fish populations.

Imperial College, London
Control of decay in utility poles.
Development of a biological control agent for Dutch elm disease.

Macaulay Land Use Research Institute
Sustainability of afforestation development, Halladale.

Mountain Environments
Investigation of the long-term effects of forest management on upland catchments (Balquhidder).

Scottish Environment Protection Agency
Effects of forestry on freshwater fauna.

University of Aberdeen/University of Durham
Population dynamics in a predator–prey system.

University of Abertay, Dundee
Cryopresentation of Sitka spruce tissues.

University of Birmingham
Woody debris in forest aquatic habitats.

University of Durham
Habitat–predator–prey relationships, Kielder.

University of Leeds
Atmospheric boundary layer over forests.
Chemical transport in forests.

University of Reading
Tree root response to acidification.
Soil variability.

University of Southampton
Water and fine sediment transport in rivers with wooded floodplains.

University of Stirling
Habitat use of working forest by capercaillie.
Paleoecology of Glen Affric.

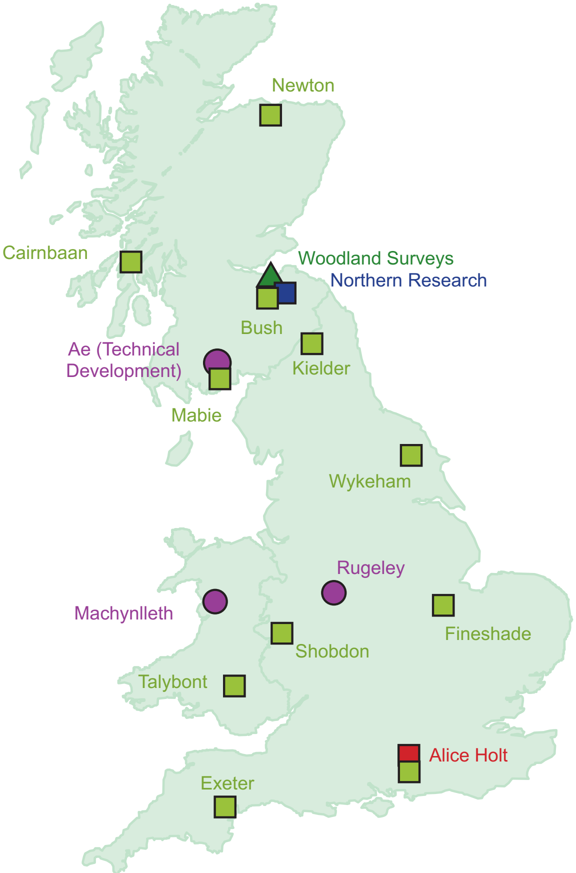
University of Sussex
Biochemical mechanisms for plants to act as sinks for atmospheric pollutants.
Drought tolerance in poplars.

University of Ulster
Feeding ecology of the large pine weevil.
Impact of defoliating insects on forests.

FOREST RESEARCH PEOPLE

Staff as at 31 March 2002, in Branches, Sections and Technical Support Units based at:

- **Alice Holt**
- **Northern Research Station**
- **Ae Village, Midlands and Wales**
- **Silvan House, Edinburgh**
- **Field Stations**



Chief Executive
- Jim Dewar, BSc, MICFor

Personal Secretary
- Madge Holmes

Chief Research Officer
and **Acting Chief Executive** from May 2002
- Peter Freer-Smith, BSc, PhD, DSc

Personal Secretary
- Claire Holmes*
- Sue Jones, BA, MA*

*Denotes part-time.

ADMINISTRATION BRANCH

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- Mandy Sennet*
- Amanda Smith*
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- John Williams

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- Eleanor Harland, MA, DipLib, *Assistant Librarian*
- Kirsten Hutchison, MA
- Thelma Smalley

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- Joanna Staley, BSc, MSc
- Shirley Stephens*
- Nigel Straw, BSc, PhD, FRES
- Christine Tilbury, BSc
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- Samantha Broadmeadow, BSc, MSc
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- Peter Crow, BSc
- Dave Durrant, BA
- Kirsten Foot, EngD, MSc, BSc
- Tony Hutchings, MSc
- Fiona Kennedy, BSc, PhD
- Elizabeth Luttrell, BSc *(also with Woodland Ecology Branch)*
- Anthea McIntyre, BSc
- Tom Nisbet, BSc, PhD
- Rona Pitman, BSc, PhD
- Ernest Ward, BSc, MSc, CChem, MRSC
- Christine Whitfield*
- Matthew Wilkinson BSc, MSc

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- Anthony Jeeves
- Susan Kirk
- Carol Lishman*
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- Joan Rose
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- Grace MacAskill
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- Ralph Harmer, BSc, PhD
- Andrea Kiewitt, BSc, MSc
- Richard Jinks, BSc, PhD
- Gary Kerr, BSc, MICFor, PhD
- Liz O'Brien, BSc, PhD
- Matt Parratt, BSc
- Ian Tubby, BSc
- Malcolm Robertson, BSc
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- Timothy Knight, BSc
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- Lyn Pearce
- Wayne Blackburn, BSc, *Head of Section*
- Lynn Connolly*
- Tom Connolly, BSc, PhD
- Alec Gaw, BSc*
- Alvin Milner, BSc, PhD
- Lynn Rooney*

*Denotes part-time.

KEY: ■ Alice Holt ■ Northern Research Station ● Ae, Midlands and Wales ▲ Edinburgh ■ Field Stations

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- Joan Cottrell, BSc, PhD
- Ned Cundall, BSc, PhD
- Ian Forrest, BSc, PhD
- Laura Forrest, BSc, PhD
- Allan John, BSc, PhD
- Steve Lee, BSc, PhD, MICFor
- Margaret O'Donnell*
- Rob Sykes
- Helen Tabberner, BSc

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- Helen Armstrong, BSc, PhD
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- Jonathan Clare, BSc, MSc
- Jonathan Humphrey, BSc, PhD
- Margaret Plews *(also with Technical Support Unit North)*
- Duncan Ray, BSc
- Brenda Mayle, MSc, *Head of Section*
- Andy Brunt
- Mark Ferryman
- Robin Gill, BSc, MSc, PhD
- Elizabeth Luttrell, BSc *(also with Environmental Research Branch)*
- Roger Trout, BA, PhD

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- Derry Neil
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- Joyce Rammell
- Colin Saunders
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- Mansel Jones
- Martin Lipscombe
- Paul Webster

Wales
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- Rab Beck
- Graham Bull
- Christine Brown
- Justin Gilbert, BSc
- Shona Macintosh
- Esther Whitton

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- James Nicholl
- John Strachan

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- David Anderson
- John Armstrong
- David Clark
- Graeme Crozier
- Colin Gordon
- Hamish Howell
- Nelson Innes
- Gavin Mackie
- Steven Osborne, BSc
- Alan Purves
- Steven Sloan

Inver
- Nick Evans
- Bill Rayner

Cairnbaan
- Dave Tracy, BSc, *Head of Station*
- Pauline Simson, BSc
- Elma Wilson, BSc
- James Wilson

Kielder and Mabie
- Dave Watterson, *Head of Stations*

Kielder
- Terry Gray
- Mike Ryan
- Len Thornton

Mabie
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- James Duff
- Willie Kelly
- Joanne McGregor*
- Hazel MacLean
- Harry Watson
- James White

*Denotes part-time.

KEY: ■ **Alice Holt** ■ **Northern Research Station** ● **Ae, Midlands and Wales** ▲ **Edinburgh** ■ **Field Stations**

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- Gillian Bowden
- Alison Cowie
- Andrew Kennedy
- Fraser McBirnie
- Stuart McBirnie
- Hugh MacKay, BSc
- Colin Smart
- Linda Tedford

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- Alexander Bowran
- Calum Murray
- Duncan Williams

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- Jamie Awdry
- Bob Bellis
- Tony Bright
- John Budd
- Steve Coventry
- Lorelie Haydon
- Vicky Lawrence
- Tony Martin
- Ralph Nickerson
- Doug Nisbet
- Jim Page
- Bill Page
- Sue Bellis

Alice Holt Workshop
- John Davey
- Mike Johnston

Exeter
- Dave Rogers, *Head of Station*
- Alan Ockendon
- Dave Parker
- Anthony Reeves

Fineshade and Thetford
- Dave West, *Head of Stations*
- Elizabeth Richardson

Thetford
- John Lakey
- Paul Turner
- Alistair Whybrow
- Steven Whall

Shobdon
- Nick Fielding, *Head of Station*
- Nigel Connor
- Brian Hanwell, BSc
- Jason Jones
- John Price
- Sharon O'Hare*
- Richard Nicoll

Talybont
- Chris Jones, BSc, *Head of Station*
- Lyn Ackroyd*
- Justin Chappell
- Dai Evans
- Carl Foster
- Richard Keddle
- Tony Price
- Rachel Sparks
- Ken Williams
- Colin Clayton

Wykeham
- Davey Kerr, *Head of Station*
- Ian Blair
- Lee Cooper
- Alex Hill
- Patricia Jackson*
- William Riddick

PhD students linked with Forest Research

Helen Billiald (Sussex University)
Anna Brown (Imperial College)
Lauren Crawford (Imperial College)
Hannah Drewitt (University of Durham)
Sharon Flint (Manchester Metropolitan University)
Caroline Hacker (Imperial College)
Joe Hope (University of Sterling)
Jack Johnston (Colraine University)
Amanda Lloyd (Newcastle University)
Tanya Ogilvy (Edinburgh University)
Vini Pereira (Imperial College)
Louise Timms (Imperial College)
Alessandra Timarco (Reading University)
Elena Vanguelova (Reading University)
Liz Young (University of Portsmouth)

Postdoctoral associate

Mathieu Paoletti (Imperial College)

Research associate

Steve Petty, PhD

*Denotes part-time.

KEY: ■ Alice Holt ■ Northern Research Station ● Ae, Midlands and Wales ▲ Edinburgh ■ Field Stations

Accounts for the year ended 31 March 2002

1. Financial management, planning and investment.
2. Experimental and practical advice for land reclamation [Tony Hutchings].
3. Inspecting pollens to be used in controlled pollination work as part of the Sitka spruce breeding strategy.
4. Stacked produce awaiting collection at rideside.

FOREWORD

1. Status

Forest Research became an Executive Agency of the Forestry Commission with effect from 1 April 1997. It undertakes the major part of the Commission's research and development programmes as well as providing survey, monitoring and scientific services.

Forest Research remains part of the Forestry Commission, which is a cross border Government Department responsible for forestry throughout Great Britain. The relationship between Forest Research, the Forestry Commissioners and Forestry Ministers is described in the Framework Document published February 1997.

Prior to April 1997, Forest Research was managed as a Division of the Forestry Commission and its assets and financial transactions were included in the departmental accounts presented in the Forestry Commission Annual Report and Accounts.

From 1 April 1997, the Agency assumed ownership of and responsibility for the assets and liabilities appropriate to the research activity which were included in the Forestry Commission Statement of Assets and Liabilities as at 31 March 1997. It also assumed ownership of the building assets it occupies, which were previously owned and managed on behalf of the Forestry Commission by the Forest Enterprise agency, with appropriate intra-departmental charges made, and recorded on the Forest Enterprise balance sheet as at 31 March 1997.

Two organisational reviews took place during 2001 and 2002 that impact of The Agency's status and operational arrangements.

In line with normal arrangements for agencies, Forest Research underwent a Quinquennial Review, stage one of which was completed in January 2002, while between May 2001 and August 2002 and interdepartmental group carried out a review of the Forestry Commission. This reviewed the devolution arrangements for delivering sustainable forestry policies in England, Scotland and Wales and the UK's international forestry commitments.

On conclusion of stage one of the Forest Research Quinquennial Review Forestry Ministers decided that the Agency should retain its executive agency status for a further five years. The devolution review concluded that Forest Research should continue as a GB-wide agency of the Forestry Commission but new arrangements should be set up, with an enhanced role for the devolved administrations through the National Offices in England, Scotland and Wales in determining research priorities and specifying programmes.

The stage two report of the Agency's Quinquennial Review, which addresses the issues on implementing the outcomes of the stage one review and the devolution review, has been submitted to Ministers for consideration.

Under the Framework Document, Forest Research is funded from the sale of its services to both the Forestry Commission and external customers. Any annual surplus or deficit is counted in the Forestry Commission's net funding requirement.

Forest Research has been designated a GB entity. For Resource Accounting purposes Forest Research is within the departmental boundary. Its accounts are one of a number of separate accounts produced and audited by the Commission and are consolidated into the overall Forestry Commission England/GB accounts.

2. Aims and Objectives

The aims of Forest Research are set out in the Framework Document. They are to provide:

- a capability to conduct research and development, surveys and related services relevant to the forest industry;
- authoritative advice to support the development and implementation of the Government's forestry policy.

The objectives of Forest Research are listed on page 5 in the Annual Report.

3. Review of Activities

This is Forest Research's fifth year of operation as an Agency. Forest Research produced a net operating surplus of £569,000 on its Income and Expenditure Account, excluding the notional cost of capital. A comparison of income and expenditure with the previous year's results shows that:

- staff costs increased by £140,000 (2%)
- other management costs increased by £59,000 (3%)
- materials and service costs reduced by £147,000 (5%)
- income from external customers increased by £142,000 (13%).

The net surplus for the year after cost of capital of £556,000 was £13,000.

After adjusting the total surplus for items not involving the movement of cash and for capital expenditure and income, the net cash surplus transferred to the Forestry Commission was £856,000.

4. Financial Objective

Forest Research's financial objective set out in the Framework Document is to recover the full economic costs, including cost of capital, of its operations from the sale of services to customers.

5. Post Balance Sheet Events

There are no post balance sheet events other than the outcome of the Forestry Devolution Review noted at paragraph 1.

6. Supplier Payment Policy

Forest Research observes the principles of The Late Payment of Commercial Debts (Interest) Act 1998. Unless otherwise stated in the contract, we aim to pay within 30 days from the receipt of goods and services, or the presentation of a valid invoice, whichever is the later. An analysis for 2001–02 indicates that 99.2% of payments to suppliers, including those made using the Government Procurement Card, were paid within the due date. Arrangements for handling complaints on payment performance are notified to suppliers on orders.

7. Employment Policies

Forest Research is committed to the principle of equality of opportunity for employment and advancement for all eligible people on the basis of their ability, qualifications and fitness for the work. Forest Research has systems to ensure that all permanent appointments are made on the basis of fair and open competition and in accordance with the guidance laid down by the Civil Service Commissioners. Further information on the employment of persons with disabilities, the provision of information to, and consultation with, employees, and the promotion of equal opportunities is available on request.

8. Management

The Ministers who had responsibility for the Commission during the year were:

Rt. Hon. Nick Brown MP	*Minister of Agriculture, Fisheries and Food* *Until 7 June 2001*
Rt. Hon. Margaret Beckett MP	*Secretary of State for the Department for the Environment, Food and Rural Affairs* *From 8 June 2001*
Elliot Morley MP	*Parliamentary Secretary (Commons) for the Department for the Environment, Food and Rural Affairs*

Members of the Management Board of Forest Research during the year were:

Jim Dewar	*Chief Executive*
Peter Freer-Smith	*Chief Research Officer* *(Acting Chief Executive from 2 June 2002)*
Ken Charles	*Personnel and Administration Officer*
Tony Cornwell	*Head of Finance and Planning*

The Chief Executive is appointed following public advertising of the post.

9. Auditors

These accounts are prepared in accordance with a direction given by the Treasury in pursuance of Section 5(1) of the Exchequer and Audit Departments Act 1921. They are audited by the Comptroller and Auditor General.

P. Freer-Smith
Acting Chief Executive and Agency Accounting Officer
14 November 2002

STATEMENT OF FORESTRY COMMISSION'S AND CHIEF EXECUTIVE'S RESPONSIBILITIES

Under Section 5(2) of the Government Resources and Accounts Act 2000 the Treasury has directed the Forestry Commission to prepare a statement of accounts for Forest Research for each financial year in the form and on the basis set out in the accounts direction. The accounts are prepared on an accruals basis and must give a true and fair view of the Forest Research state of affairs at the year end and of its income and expenditure and cash flows for the financial year.

In preparing the accounts the Forestry Commission is required to:

- observe the accounts direction, including the relevant accounting and disclosure requirements, and apply suitable accounting policies on a consistent basis;
- make judgements and estimates on a reasonable basis;
- state whether applicable accounting standards have been followed, and disclose and explain any material departures in the financial statements;
- prepare the financial statements on the going concern basis, unless it is inappropriate to assume that Forest Research will continue in operation.

The Director General of the Forestry Commission, as departmental Accounting Officer, has designated the Chief Executive of Forest Research as the Accounting Officer for the Agency. His relevant responsibilities as Accounting Officer, including his responsibility for the propriety and regularity of the public finances and for the keeping of proper records, are set out in the Accounting Officers' Memorandum, issued by the Treasury and published in *Government accounting* (The Stationery Office).

STATEMENT ON INTERNAL CONTROL

As Acting Accounting Officer I have responsibility for maintaining a sound system of internal control that supports the achievement of Agency policies, aims and objectives, set by the Agency's Ministers, while safeguarding the public funds and assets for which I am personally responsible, in accordance with the responsibilities assigned to me. Control of certain activities is carried out by the Forestry Commission on the Agency's behalf, and in respect of those areas I place reliance on the Forestry Commission's Statement of Internal Control.

The system of internal control is designed to manage rather than eliminate the risk of failure to achieve policies, aims and objectives: it can therefore only provide reasonable and not absolute assurance of effectiveness.

The system of internal control is based on an ongoing process designed to identify the principal risks to the achievement of Agency policies, aims and objectives, to evaluate the nature and extent of those risks and to manage them efficiently, effectively and economically. By March 2002 I had put in place the procedures necessary to implement Treasury guidance and these will operate fully in the coming year.

We have agreed and promulgated a risk management policy. Working with responsible managers, we have developed a risk register for the principal risks to the achievement of Agency policy, aims and objectives. These identify the risks, the adequacy of the controls and any corrective action required. This has been endorsed by the Agency's Management Board. A series of Financial Awareness Seminars has been introduced to be attended by representatives of all grades of staff throughout the organisation during the coming year.

The Management Board meets monthly to consider the plans and strategic direction of the Agency. The Management Board receives regular reports from managers on the steps they are taking to manage risks in their areas of responsibility including progress on key projects. The risk management policy ensures that the Board includes risk management within its remit and formally tasks it with its review. There will be a full risk and control assessment before reporting on the year ending 31 March 2003.

The Agency has an Audit Committee, which reviews matters concerning risk and internal control within the Agency. The effectiveness of risk management and control across the Forestry Commission and its Agencies is also monitored by the Forestry Commission Audit Committee. The work of the internal and external auditors is currently reported annually to the full Board of Forestry Commissioners; in future this will be expanded to cover the full business of the Forestry Commission Audit Committee.

In addition to the actions mentioned above, in the coming year we will:

- implement the financial awareness seminars which introduce the concept of risk management;
- maintain the Agency risk register and review the planned actions;
- submit a report on the Agency's internal control activities to the Principal Accounting Officer.

The Forestry Commission has an Internal Audit Unit, which operates to standards defined in the Government Internal Audit manual. They submit regular reports, which include the Head of Internal Audit's independent opinion on the adequacy and effectiveness of the Agency's system of internal control together with recommendations for improvement.

My review of the effectiveness of the system of internal control is informed by the work of the internal auditors and the executive managers within the Agency who have responsibility for the development and maintenance of the internal control framework, and comments made by the external auditors in their management letters and other reports.

P. Freer-Smith
Acting Chief Executive and Agency Accounting Officer
14 November 2002

THE CERTIFICATE OF THE COMPTROLLER AND AUDITOR GENERAL TO THE HOUSE OF COMMONS

I certify that I have audited the financial statements on pages 113 to 123 under the Government Resources and Accounts Act 2000. These financial statements have been prepared under the historical cost convention as modified by the revaluation of certain fixed assets and the accounting policies set out on pages 116 to 117.

Respective responsibilities of the Agency, the Chief Executive and Auditor

As described on page 109, the Agency and Chief Executive are responsible for the preparation of the financial statements in accordance with the Government Resources and Accounts Act 2000 and Treasury directions made thereunder and for ensuring the regularity of financial transactions. The Agency and Chief Executive are also responsible for the preparation of the other contents of the Annual Report. My responsibilities as independent auditor are established by statute and guided by the Auditing Practices Board and the auditing profession's ethical guidance.

I report my opinion as to whether the financial statements give a true and fair view and are properly prepared in accordance with the Government Resources and Accounts Act 2000 and Treasury directions made thereunder, and whether in all material respects the expenditure and income have been applied to the purposes intended by Parliament and the financial transactions conform to the authorities which govern them. I also report if in my opinion the Foreword is not consistent with the financial statements, if the Agency has not kept proper accounting records or if I have not received all the information and explanations I require for my audit.

I read the other information contained in the Annual Report, and consider whether it is consistent with the audited financial statements. I consider the implications for my certificate if I become aware of any apparent misstatements or material inconsistencies with the financial statements.

I review whether the statement on page 110 reflects the Agency's compliance with Treasury's guidance 'Corporate governance: statement on the system of internal control'. I report if it does not meet the requirements specified by the Treasury or if the statement is misleading or inconsistent with other information I am aware of from my audit of the financial statements.

Basis of audit opinion

I conducted my audit in accordance with United Kingdom Auditing Standards issued by the Auditing Practices Board. An audit includes examination on a test basis of evidence relevant to the amounts, disclosures and regularity of financial transactions included in the financial statements. It also includes an assessment of the significant estimates and judgements made by the Agency and Chief Executive in the preparation of the financial statements and of whether the accounting policies are appropriate to the Agency's circumstances, consistently applied and adequately disclosed.

I planned and performed my audit so as to obtain all the information and explanations which I considered necessary in order to provide me with sufficient evidence to give reasonable assurance that the financial statements are free from material misstatement whether caused by error or by fraud or other irregularity and that in all material respects the expenditure and income have been applied to the purposes intended by Parliament and the financial transactions conform to the authorities that govern them. In forming my opinion I have also evaluated the overall adequacy of the presentation of information in the financial statements.

Opinion

In my opinion:

- the financial statements give a true and fair view of the state of affairs of Forest Research at 31 March 2002 and of the surplus, total recognised gains and losses and cash flows for the year then ended and have been properly prepared in accordance with the Government Resources and Accounts Act 2000 and directions made thereunder by Treasury; and
- in all material respects the expenditure and income have been applied to the purposes intended by Parliament and the financial transactions conform to the authorities which govern them.

I have no observations to make on these financial statements.

John Bourn
Comptroller and Auditor General
19 December 2002

National Audit Office
197 Buckingham Palace Road
Victoria
London SW1W 9SP

INCOME AND EXPENDITURE ACCOUNT for the year ended 31 March 2002

	Notes	2002 £000	2001 £000
Income			
Income from research, development and survey services			
Forestry Commission customers	2	**11,153**	11,254
Non-Forestry Commission customers		**1,258**	1,116
Total income		**12,411**	12,370
Expenditure			
Staff costs	3	**7,317**	7,177
Other management costs	4 & 5	**1,885**	1,826
Materials and services	5	**2,640**	2,787
Total expenditure		**11,842**	11,790
Net operating surplus/(deficit)		**569**	580
Notional cost of capital	7	**(556)**	(519)
Net surplus/(deficit) for the year		**13**	61
Transferred to General Fund		**13**	61

STATEMENT OF TOTAL RECOGNISED GAINS AND LOSSES for the year ended 31 March 2002

	2002 £000	2001 £000
Net surplus/(deficit) for the year	**13**	61
Revaluation surplus/(loss) for the year	**1,280**	19
Total recognised gains/(losses)	**1,293**	80

The notes on pages 116 to 123 form part of these accounts.

BALANCE SHEET for the year ended 31 March 2002

	Notes	31 March 2002 £000	31 March 2001 £000
Fixed assets			
Tangible fixed assets	6	**9,768**	8,393
Current assets			
Stocks	8	**259**	31
Debtors	9	**471**	604
Cash at banks and in hand		**1**	1
		731	636
Current liabilities			
Creditors – amounts falling due within one year	10	**742**	261
Net current assets		**(11)**	375
Total assets less current liabilities		**9,757**	8,768
Taxpayers Equity			
General Fund	11	**5,869**	6,160
Revaluation Reserve	12	**3,888**	2,608
Total Taxpayers Equity		**9,757**	8,768

P. Freer-Smith
Acting Chief Executive and Agency Accounting Officer
14 November 2002

The notes on pages 116 to 123 form part of these accounts.

CASH FLOW STATEMENT for the year ended 31 March 2002

	Notes	2002 £000	2001 £000
Reconciliation of net surplus to net cash flow from operating activities			
Net surplus for the year		**13**	61
Notional cost of capital	7	**556**	519
Depreciation	4 & 6	**405**	396
Decrease/(-)Increase in stocks		**(228)**	79
Decrease/(-)Increase in debtors		**133**	(115)
Increase/(-)Decrease in creditors		**481**	9
Net cash inflow from operating activities		**1,360**	949
Capital expenditure			
Payments to acquire tangible fixed assets		**(513)**	(587)
Non-cash inter-country transfers		**9**	
Total net cash inflow		**856**	362
Financing			
Cash surplus transferred to Forestry Commission		**856**	362
Reconciliation of net cash flow to movement in net funds			
Net funds at 1 April 2001		**1**	1
Net funds at 31 March 2002		**1**	1

The notes on pages 116 to 123 form part of these accounts.

NOTES TO THE ACCOUNTS

NOTE 1. Accounting Policies

1.1 Form of Accounts

In accordance with Section 5(2) of the Government Resources and Accounts Act 2000, the accounts are drawn up in a format agreed and approved by Treasury. They are prepared under the historical cost convention modified by the inclusion of the valuation of assets. Without limiting the information given, the accounts meet the requirements of the Companies Acts and of the Financial Reporting Standards where relevant.

1.2 Accounting for Fixed Assets

Where the Agency is the principal beneficial user of assets of the Forestry Commission estate they are treated as a fixed asset of the Agency although legal ownership is vested in the Forestry Ministers.

The normal threshold for the capitalisation of assets is £1,500, but all IT equipment costing £250 or more is capitalised as a pooled asset, the amount involved being material.

1.3 Valuation of Assets

Land and buildings were subject to a triennial evaluation as at 31 March 2002 by professionally qualified staff employed by the Forestry Commission. Research and office equipment is revalued every three years using prevailing current prices for replacement items. Between revaluations, tangible fixed asset values are updated annually using a general price index.

All revaluation surpluses and deficits are taken to the Revaluation Reserve.

1.4 Depreciation

Depreciation is provided on all tangible fixed assets – except land – at rates calculated to write off the valuation, less estimated residual value, of each asset evenly over its expected useful life.

Freehold buildings – 20 to 80 years

Research and office equipment – 4 to 20 years

1.5 Stocks

Consumable materials and supplies are valued at current replacement cost.

Work in progress on long-term projects is valued at the cost of staff time and other direct costs plus attributable overheads based on the normal level of activity.

1.6 Research and Development

As a provider of research services, all income and expenditure on research and development is written off to the Income and Expenditure Account.

1.7 Corporation Tax

Forest Research is not subject to corporation tax.

1.8 Provision for Bad and Doubtful Debts

Specific provisions for bad and doubtful debts are set aside on the basis of a review of individual debts at the end of the year.

1.9 Foreign Currencies

Transactions in foreign currencies are recorded at the rate ruling at the time of the transaction. Exchange differences are taken to the Income and Expenditure Account.

NOTE 2. Income from Forestry Commission and Forest Enterprise

The Agency undertakes a significant proportion of the Forestry Commission's overall annual research programme in the form of specifically commissioned projects to deliver agreed outputs. A separate annual charge is agreed for each project based on full cost recovery. These charges amounted to £9.5 million. Costs established in one year are used to determine project charges for future years. The Agency also provides research and survey services for Forest Enterprise and other parts of the Forestry Commission on a full cost recovery basis.

Total income from Forestry Commission customers consisted of:

	2002	2001
	£000	£000
Reconciliation of net surplus to net cash flow from operating activities		
Research, development and other services to:		
Forestry Commission	**10,096**	10,145
Forest Enterprise	**1,057**	1,109
	11,153	11,254

NOTE 3. Staff Costs and Numbers

3.1 Employee costs during the year amounted to:

	2002	2001
	£000	£000
Wages and Salaries	**5,999**	5,820
Social Security Costs	**424**	431
Employer's Superannuation Costs	**894**	926
	7,317	7,177

Until 30 November 2001 the Agency's staff were covered by the Forestry Commission Pension Scheme which was a defined benefit pension scheme. Employer's superannuation contributions, calculated as percentage of pensionable pay, were paid to the Forestry Commission Pension Scheme and included in the Income and Expenditure Account. The employer's contribution rates were set at 15% to 22% according to grade, as determined by the Government Actuary. Actual payments were met by the Forestry Commission and reflected in its annual accounts.

From 1 December 2001 the Forestry Commission Pension Scheme was subsumed into the Principal Civil Service Pension Scheme (PCSPS) which is also a defined benefit pension scheme. Employer's superannuation contributions, calculated as percentages of pensionable pay, are paid to the PCSPS and included in the Income and Expenditure Account. The employer's contribution rates are set at 12% to 18.5%, according to salary band. Actual payments are met by the PCSPS.

3.2 The total remuneration, excluding pension contributions, of the Chief Executive, the highest paid member of the Management Board, was £63,328 (2000/01: £60,195). The Chief Executive is an ordinary member of the Pension Scheme.

3.3 The range of salaries of Management Board members, excluding the Chief Executive, is shown below. Management Board members are senior staff and are ordinary members of the Pension Scheme.

	2002	2001
Management Board Members	**Number**	Number
£35,000–£39,999	2	2
£45,000–£49,999		1
£50,000–£54,999	1	

Pension benefits are provided through the Principal Civil Service Pension Scheme. The scheme provides benefits on a 'final salary' basis at a normal retirement age of 60. Benefits accrue at the rate of 1/80th of pensionable salary for each year of service. In addition a lump sum equivalent to 3 years' pension is payable on retirement. Members pay contributions of 1.5% of pensionable earnings for the provision of widows and childrens benefits. Pensions increase in line with the Retail Price Index. On death, pensions are payable to the surviving spouse at a rate of half the member's pension. On death in service, the scheme pays a lump sum benefit of twice pensionable pay and also provides a service enhancement on computing the spouse's pension. The enhancement depends on length of service and cannot exceed 10 years. Medical retirement is possible in the event of serious ill-health. In this case, pensions are brought into payment immediately without actuarial reduction and with service enhanced as for widow(er) pensions.

Disclosures relating to members of the Management Board have been restricted in accordance with the Data Protection Act 1998.

3.4 The average number of employees (full-time equivalents) during the year was 280 (2001:277).

3.5 Benefits in kind are provided under the following schemes:

(i) Advances of Salary for House Purchase

(ii) Advances of Salary for Purchase of Season Tickets and Bicycles

(iii) Car Provision for Employees Scheme.

Each scheme is subject to conditions and financial limits.

The Advances of Salary for House Purchase scheme had 10 loans with an outstanding balance of £2,500 or more to individual members of staff at 31 March 2002. The total value of these loans was £79,251.46

NOTE 4. Other Management Costs

Other management costs are stated after charging:

	2002	2001
	£000	£000
	Number	Number
Exchange Rate Losses on EC Contracts	–	2
Auditors' Remuneration	22	19
Depreciation of Fixed Assets	405	396
Travel and Subsistence	464	399
Staff Transfer Expenses	59	60
Training	120	114
Building Maintenance	382	367
Utilities	230	227
Computer Supplies	101	109

NOTE 5. Charges from the Forestry Commission

Included within Other Management Costs and Materials and Services are charges from the Forestry Commission and Forest Enterprise amounting in total to £1,118,597 (2001: £1,210,743).

Charges are made to Forest Research from the Forestry Commission and Forest Enterprise, as appropriate, for assistance with field experiments, hire of machinery and equipment and for personnel, business management, financial and other support services at Silvan House, Edinburgh.

NOTE 6. Fixed Assets

	Freehold Land and Buildings £000	Machinery and Equipment £000	Total £000
Valuation:			
At 1 April 2001	7,443	4,532	11,975
Additions	12	501	513
Disposals and transfers	(16)		(16)
Revaluation adjustment	1,211		1,211
At 31 March 2002	**8,650**	**5,033**	**13,683**
Depreciation:			
At 1 April 2001	269	3,313	3,582
Provided in year	134	271	405
Disposals and transfers	(3)		(3)
Revaluation adjustment	(69)		(69)
At 31 March 2002	**331**	**3,584**	**3,915**
Net book value:			
At 31 March 2002	8,319	1,449	9,768
At 31 March 2001	7,174	1,219	8,393

Fixed assets were revalued as at 31 March 2002 in accordance with accounting policies. The valuation includes the two principal research stations: Alice Holt Lodge near Farnham in Surrey and the Northern Research Station, Roslin near Edinburgh, with net book values of £5.5 million and £2.2 million respectively at 31 March 2002.

NOTE 7. Cost of Capital

Notional cost of capital based on 6% of average total assets less current liabilities employed in 2001/02 amounted to £ 555,751.

NOTE 8. Stocks

	2002	2001
	£000	£000
Research Work in Progress	**259**	31
	259	31

NOTE 9. Debtors

	2002	2001
	£000	£000
Amounts falling due within one year		
Trade debtors	**368**	446
Other debtors	**30**	31
Prepayments	**2**	54
	400	531
Amounts falling due after one year – house purchase loans	**71**	73
	471	604

NOTE 10. Creditors: amounts falling due within one year

	2002	2001
	£000	£000
Payments received on account	**280**	48
Trade creditors	**454**	211
Other creditors including taxation and social security costs	**8**	2
	742	261

NOTE 11. General Fund

	2002	2001
	£000	£000
Balance brought forward	6,160	5,920
Prior year adjustment		21
Balance as adjusted	6,160	5,941
Movement in year		
Net surplus for year	13	61
Transfer of fixed assets from/(-) to other Forestry Bodies	(13)	1
Cash surplus transferred to Forestry Fund	(856)	(362)
Non-cash inter-country transfers	9	
Notional cost of capital	556	519
Balance carried forward	**5,869**	6,160

NOTE 12. Revaluation Reserve

	2002	2001
	£000	£000
Balance brought forward	2,608	2,589
Revaluation surplus for the year ended 31 March 2002		
Land and Buildings	1,280	101
Machinery and Equipment		(82)
Balance carried forward	**3,888**	2,608

NOTE 13. Contingent Liabilities

There were no contingent liabilities at 31 March 2002 for damages caused to other persons' property or for compensation for personal injury to employees.

NOTE 14. Related Party Transactions

During the year, Forest Research has had a significant number of material transactions with the Forestry Commission and Forest Enterprise Agency who are regarded as related parties. In addition, Forest Research has had various material transactions with other Government Departments and other central Government bodies. Most of these transactions have been with the Department of Trade and Industry and the Department for Environment, Food and Rural Affairs.

NOTE 15. Financial Performance Measures

The target to recover full resource costs, including capital, from internal and external customers was achieved. The Agency achieved an operating surplus of £568,471 which, after allowing for the cost of capital (£555,750), represented a cost recovery of 100% (2001: 101%).

ACCOUNTS DIRECTION GIVEN BY THE TREASURY IN ACCORDANCE WITH SECTION 7(2) OF THE GOVERNMENT RESOURCES AND ACCOUNTS ACT 2000

1. This direction applies to The Forestry Commission Research Agency.
2. The Forestry Commission Research Agency shall prepare accounts for the year ended 31 March 2002 in compliance with the accounting principles and disclosure requirements of the edition of the *Resource accounting manual* issued by H M Treasury which is in force for 2001–02.
3. The Accounts shall be prepared so as to give a true and fair view of the income and expenditure, total recognised gains and losses and cash flows of the Agency for the financial year and of the state of affairs as at 31 March 2002.
4. Compliance with the requirements of the *Resource accounting manual* will, in all but exceptional circumstances, be necessary for the accounts to give a true and fair view. If, in these exceptional circumstances, compliance with the requirements of the *Resource accounting manual* is inconsistent with the requirement to give a true and fair view, the requirements of the *Resource accounting manual* should be departed from only to the extent necessary to give a true and fair view. In such cases, informed and unbiased judgement should be used to devise an appropriate alternative treatment which should be consistent both with the economic characteristics of the circumstances concerned and the spirit of the *Resource accounting manual*. Any material departure from the *Resource accounting manual* should be discussed in the first instance with the Treasury.
5. This direction replaces any previous direction issued to the Agency.

David Loweth
Head of the Central Accountancy Team, Her Majesty's Treasury
Dated 26 February 2002

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